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Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project Murrumbidgee River System evaluation report 2014-17

Commonwealth Environmental Water Office Long-Term Intervention Monitoring project Murrumbidgee River system Selected Area evaluation report, 2014-17. December 2017

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Executive Summary

The Murrumbidgee River Long-Term Intervention Monitoring (LTIM) project is a collaborative project between Charles Sturt University, NSW Office of Environment and Heritage, Department of Primary Industries - Fisheries and the University of New South Wales (Centre for Ecosystem Science). Funding from the Commonwealth Environmental Water Office supports monitoring of the hydrological and ecological outcomes of watering actions in the river and wetlands of the Murrumbidgee for a five-year period. This report documents findings from the first three years of the LTIM project, from 2014 to 2017.

The LTIM project focuses monitoring activities through the mid and lower Murrumbidgee River and floodplain, which is referred to in this report as the Murrumbidgee Selected Area. In this report the outcomes of Commonwealth environmental watering actions are evaluated in two sections: Riverine outcomes and Wetland outcomes. The riverine sections focus on monitoring activities undertaken through a 545km stretch of River between Wagga Wagga and Carrathool, in 2016-17 additional evaluation of water quality was undertaken within the Murrumbidgee River between Carrathool and Balranald in response to Commonwealth Environmental watering actions aimed at mitigating hypoxic black water risk. The wetland section evaluates outcomes of Commonwealth environmental watering actions across three zones: the mid-Murrumbidgee which is a series of lagoons bordering the Murrumbidgee River between Narrandera and Carrathool; and the Nimmie-Caira and Redbank zones through the Lower Murrumbidgee floodplain (Lowbidgee).

In 2016-17 the Commonwealth environmental water holder delivered 241,465 ML of environmental water as part of 13 watering actions targeting the main river channel, key floodplain and wetland habitats, and anabranches and creek lines through the Murrumbidgee. Environmental watering actions commenced in winter of 2016, when water was delivered to areas of the Lowbidgee floodplain to support floodplain habitat for the threatened southern bell frog and other floodplain dependant species. In early spring, widespread rainfall throughout the catchment produced significant unregulated river rises and extensive floodplain inundation through the mid-Murrumbidgee and Lowbidgee floodplains. All Commonwealth and State environmental watering actions were halted during this period, with environmental watering actions commencing during the flood recession in order to manage the risk of hypoxic blackwater by managing the rate of flood recession. In addition to these in-channel flows, the Commonwealth Environmental Water Holder, in collaboration with NSW Office of Environment and Heritage, undertook five watering actions to support water bird breeding in the Lowbidgee floodplain which was initially triggered by unregulated floodplain inundation, but required additional watering to ensure that chicks survived to fledging.

Riverine responses

Following the large unregulated flow that occurred in September 2016, Commonwealth environmental water was delivered into the Murrumbidgee River, targeting the recession of the flow as it passed reaches downstream of Wagga Wagga, Gogeldrie Weir, and downstream of Maude Weir from late October 2016 to early January 2017. This use of environmental water sought to mitigate hypoxic blackwater conditions that developed because of overbank flows returning to the river. The effectiveness of this watering action for reducing hypoxic blackwater was evaluated, and conservative estimates demonstrate that dissolved oxygen concentrations began to increase 18 days earlier with the delivery of environmental flows than would have been the case if no environmental water had been delivered.

The delivery of Commonwealth environmental water both within the main channel and to floodplain wetlands, along with water transfers and other water deliveries to support consumptive uses, created a series of small pulses in the river between late spring and autumn. The outcomes of these pulses on fish spawning, microinvertebrates, nutrients, productivity and water quality was monitored through spring and summer in the main river channel between Narrandera and Carrathool.

We expected pulsed environmental flows would inundate dry sediment in the main channel, boosting nutrient concentrations, rates of metabolism and microinvertebrate production and providing additional food for larval fish. Overall, the large unregulated flow caused a temporary peak in nutrient concentrations, which then declined as the flood receded. Water quality also changed in response to the unregulated flow event, causing a temporary decline in dissolved oxygen and an increase in conductivity. The addition of environmental water on the recession of the unregulated flow contributed to an earlier recovery of dissolved oxygen concentrations (i.e. increase in) downstream of Maude in the Lower Murrumbidgee

River. No pulses in metabolism (primary production or respiration) appeared to be linked with the pulsing of environmental water, although the analytical models necessary to better evaluate these outcomes are not yet available.

We predicted that spawning of flow-cued species such as golden perch and silver perch would result from in-channel water level rises (freshes) and bank full events, and that base flows and above would provide suitable conditions for spawning to occur in opportunistic (e.g. carp gudgeon) and equilibrium species (i.e. non flow-cued species such as Murray cod). Monitoring of fish spawning identified eggs and larval fish from seven native species (Australian smelt, carp gudgeon, flat-headed gudgeon, golden perch, Murray cod, Murray-Darling rainbowfish and silver perch) within in the monitored reaches, demonstrating that environmental conditions were appropriate to support spawning of these species.

Riverine monitoring indicator	Key riverine outcomes	Implications for future riverine water actions
Riverine water quality	Nutrient, carbon and chlorophyll-a concentrations were consistent with prior records for the Murrumbidgee despite widespread floodplain inundation. Nutrient concentrations remain low in the river and it is hypothesised that this trend is due to limited lateral connectivity and high discharge in some reaches.	Broad-scale wetland reconnections and periods of low flow are necessary to promote resources for river food webs. Future planning of watering actions that allow for wetland reconnections either via managed return flows or by generating peaks in river height may assist with the mobilisation of carbon and nutrients from the floodplain to the river.
Dissolved oxygen	The delivery of Commonwealth environmental water in 2016-17 Improved initial recovery timing by 18 days; improved nominal DO recovery timing by 5 days	The risk of hypoxic black water events occurring can be reduced by increasing the frequency of floodplain inundation which supports the mobilisation of carbon and nutrients and reduced the rates of litter accumulation.
Stream metabolism	Rates of metabolism are low compared with other river systems monitored under the LTIM program. There was a negative relationship between discharge and metabolism at Narrandera reach, but not Carrathool reach where discharge volumes are lower.	Rates of metabolism in the Murrumbidgee River may have been reduced by the loss of nutrients and energy that were historically provided to the river during natural wetland reconnections and periods of low flow in the main river channel. However significant overbank flows in the Murrumbidgee in 2016-17 did not lead to an overall increases in metabolism within the monitored reaches. In the Murrumbidgee the relationship between flow and metabolism is weak, possibly because spring and summer discharge volumes are high within the monitored reaches and opportunities for wetland reconnections are limited.

Riverine microinvertebrates	Microinvertebrate densities exceeded levels needed to support larval fish during October in the Carathool Zone but did not match the peak in abundance of larval cod species and Australian smelt in November and carp gudgeon in December. Microinvertebrate densities in Narrandera zone were low, possibly due to high and more stable water levels.	River levels in the Narrandera zone were at least one metre higher than in the Carrathool zone and there was less variability in river height. It appears that the higher river level in the Narrandera zone may impact development of a productive and diverse microinvertebrate community. In contrast the Carrathool zone with lower more variable river levels, produced peaks in microinvertebrate densities
Riverine and larval fish	The probability of silver perch and golden perch spawning occurred at distinct water temperatures although was largely independent of river levels. The outcomes of 2016-17 indicate that spawning of small and large-bodied native fish species occurs during years of overbank flooding in the Murrumbidgee River. It is likely that the expected benefits of such a high water year and the associated productivity boost to the system were not realised in the riverine fish results due to the negative effect of low dissolved oxygen concentrations observed in the Carrathool zone.	This monitoring project is restricted to the Narrandera and Carrathool zones of the Murrumbidgee River and does not include assessment of spawning further downstream, in areas which may be affected by reduced discharge levels. In other river systems, and in absence of irrigation flows that appear to provide suitable in-channel hydrodynamic diversity, targeted environmental flows have been linked to spawning in flow-cued species such as golden and silver perch. Understanding the critical in-channel hydraulic thresholds for spawning in golden perch and silver perch within the Murrumbidgee River and then examining whether these thresholds are met in other parts of the Murrumbidgee River (particularly downstream) would be useful for extrapolating the results of the current monitoring program to other locations.

Wetlands

During 2016-17 there was extensive inundation due to unregulated flows across the Lowbidgee floodplain with a total area of almost 200,000 ha of the landscape inundated at least once during the water year. Commonwealth environmental water both increased inundation extent and extended duration of inundation in the wetland habitats of Nimmie-Caira to South Yanga inundating a cumulative area of 4,998 ha and habitats of Western Lakes inundating 1,024 ha. In the waterbird breeding sites of the Nimmie-Caira and north and south Redbank, Commonwealth and NSW environmental water actions maintained water levels and inundation extents prolonging inundation durations for at least another month.

In 2016-17 there were 11 Commonwealth environmental watering actions targeting floodplain wetlands. Seven of these events targeted wetlands within the LTIM monitoring area and are evaluated in this report. The primary objective of the seven watering actions was the support of waterbirds which established breeding colonies through the Lowbidgee floodplain following the unregulated event. These watering events include Nimmie-Caira to South Yanga winter event; Redbank (Yanga National Park) waterbird breeding support; North Redbank waterbird breeding support; and four Nimmie-Caira waterbird breeding support actions targeting separate colony sites (Telephone Bank, Eulimbah Swamp, Nap Nap Swamp and Kieeta Lake). A primary objective across the Murrumbidgee Selected Area is to "support the habitat requirements of waterbirds", with individual watering actions focused on either maintaining habitat for waterbirds or supporting breeding outcomes. While the primary objective of watering actions in 2016-17 was to support waterbird breeding, these events also created conditions suitable for other native floodplain taxa, including microinvertebrates, fish, frogs, freshwater turtles and floodplain vegetation.

Wetlands that received Commonwealth environmental water supported species of conservation significance including the threatened Australasian bittern (*Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) endangered) and vulnerable blue-billed duck, freckled duck and magpie goose (*NSW Threatened Species Conservation Act 1995* (TCS Act)), and species listed on international migratory agreements (JAMBA, CAMBA and ROKAMBA) including marsh sandpiper and sharp-tailed sandpiper. Commonwealth environmental water also contributed to successful breeding outcomes for 14 species of non-colonial waterbirds and 19 species of colonial waterbirds in wetlands across the Lowbidgee floodplain. By extending the duration and depth of inundation in each colony site and providing foraging habitat in each colony and neighbouring wetlands, Commonwealth environmental water supported successful fledging of colonial-nesting waterbirds at six colony sites in the Lowbidgee floodplain.

In 2016-17 pre-watering of key southern bell frog habitats was undertaken in autumn 2016 (*Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake*)) with the objective to "maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC Act vulnerable)". Frogs, wetland fish and freshwater turtles also benefited from the Commonwealth environmental watering actions targeting waterbirds which had the secondary objective of "supporting habitat for wetland vertebrates".

Six frog species were recorded in 2016-17, including large numbers of southern bell frogs (EPBC Act vulnerable) at Nap Nap swamp which received water as part of the *Nimmie-Caira to South Yanga* (*Nimmie Creek to Yanga Lake*) watering action. Three species of freshwater turtles (broad shelled turtles, eastern long necked turtle and Macquarie turtles, small numbers of hatchling Macquarie turtles) were recorded at wetlands that received Commonwealth environmental water.

Eight native and five exotic fish species were recorded during 2016-17. This included juvenile silver perch (EPBC Act endangered) and flathead gudgeon collected at Yarradda Lagoon for the first time since monitoring began in 2014, thus demonstrating the value of repeat watering actions to improve refuge habitat for native fish, frogs and turtles.

Vegetation communities also benefited from Commonwealth environmental actions undertaken with the primary objective of supporting waterbird breeding, but had the secondary objectives of "maintaining and improving the condition of wetland vegetation". Commonwealth environmental water extended the depth and duration of wetland inundation at a number of sites in the Lowbidgee floodplain, allowing for the establishment and growth of complex aquatic plant communities. Because vegetation communities can take a long time to establish, we considered the responses of aquatic vegetation communities in the context of the past three years of Commonwealth environmental watering actions. In mid-Murrumbidgee wetlands that did not receive environmental water over the past 3 years, but filled during the unregulated spring flow in 2016, there was a far lower diversity of water dependent species and higher abundance of exotic weed species, compared to the wetlands that received Commonwealth environmental water in 2014-15 and 2015-16. There were also notable increases in the number of water-dependent species at Yarradda Lagoon in the Mid-Murrumbidgee with the reestablishment of key water dependant species including spiny mudgrass (*Pseudoraphis spinescens*), tall spike rush (*Eleocharis sphacelata)*, and fringe lily (*Nymphoides crenata*) following Commonwealth environmental watering actions in 2014-15 and 2015-16.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Wetland hydrology	During 2016-2017 there was extensive inundation across the Lowbidgee floodplain due to unregulated flows, with a total annual area of almost 200,000 ha of the landscape inundated. Commonwealth environmental water increased inundation in the wetland habitats of Nimmie-Caira to South Yanga inundating a cumulative area of 4,998 ha and habitats of Western Lakes inundating 1,024 ha.	The use of environmental water to compliment unregulated flows can maximise ecological outcomes and should continue to be a priority action in years with moderate and high water availability.
Wetland water quality	Water quality in wetland sites that received Commonwealth environmental water to support active waterbird colonies remained within expected ranges during the delivery of environmental water.	If environmental watering seeks to maintain a community of native fish within key refuge sites over winter periods, environmental flow managers should consider possible late-summer or autumn top up flows to maintain water quality until temperatures decline.
Wetland microinvertebrates	As in previous years, high densities of microinvertebrates were observed at wetland monitoring sites throughout spring and summer, dominated by copepods with cladocerans and ostracods present.	Responses of microinvertebrates to inundation were consistent across years suggesting the current regime of wetting and drying is maintaining the egg bank and high levels of productivity. The densities and species composition over time would provide a plentiful food supply to filter-feeding waterbirds, native fish and other biota.
Vegetation diversity	Wetlands that have not received Commonwealth environmental since in the years between 2014 and 2017 continued to be dominated by terrestrial species even after inundation with unregulated flows and had higher percentages of river red gum seedlings, indicating encroachment, while wetlands that had received commonwealth environmental water at least once over the past 3 years contained higher percentages of water dependent species and lower percentages of river red gums.	The majority of monitored wetlands have received Commonwealth environmental water at least once over the past 3 years and vegetation communities remain in very good condition. This is consistent with predictions that restoring a more natural inundation frequency through Commonwealth environmental watering will support the establishment and persistence of water dependent species to a far greater extent than unregulated flows alone.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Wetland fish	Nine native and four exotic fish species were captured in 2016-17 Evidence of recruitment and survival was identified for three native species, carp gudgeon, Australian smelt and bony herring.	Species richness remains stable through the 12 monitored wetlands. In regulated systems, where dry phases can fall outside their historical intensity or frequency, the maintenance of fish communities through floodplain wetlands is largely provided by persistent waterbodies that support populations during dry phases and allow them to recolonise wetlands during inundation. Key refuges habitats are typically large, deep waterbodies that can hold water for extended periods and have high connectivity with other seasonally inundated and ephemeral wetlands in the surrounding areas. In the Murrumbidgee key refuge habitats include annually flooded wetlands (e.g. Yarradda Lagoon) and permanent creek systems (e.g. Telephone Creek and Wagourah Lagoon). Maintaining adequate water levels in key off-river refuge wetlands, including Wagourah Lagoon and Telephone Creek should be a priority under all water availability scenarios.
Frogs and turtles	Six frog and three turtle species were recorded in 2016-17 which is the same as previous years. Very significant numbers of southern bell frogs were recorded at Nap Nap Swamp (over 300 individuals recorded in March 2017) suggesting successful recruitment occurred within and around this wetland. Frog and tadpole abundance has declined at Yarradda Lagoon over the past 3 years	The management of frog and turtle populations through the Murrumbidgee floodplain wetlands requires a mix of long-term watering strategies to maintain key refuge habitats during dry years, and the provision of spring flows to support breeding. With respect to southern bell frog breeding, large scale inundation is critical and watering actions that target larger continuous sections of the floodplain (such as the Nimmie-Caria flood ways to Yanga National Park) are likely to be more successful in supporting frog populations than smaller disconnected flows spread over a larger area. As is the case for floodplain fish, the maintenance of key refuges in particular Telephone Creek, Wagourah Lagoon and associated creek lines through the Nimmie-Caria and Redbank systems may be critical to the long-term persistence of frog and turtle populations While natural reconnections have benefits for water quality and other aquatic taxa, tadpole abundance have declined at Yarradda Lagoon following natural reconnection probably due to colonisation of the wetland by introduced fish.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Waterbird diversity	Total waterbird diversity was higher in wetlands inundated by Commonwealth environmental water and other sources of inundation including natural flooding, compared to sites not inundated from 2014-17. In addition a high number of non-colonial waterbird species were observed breeding in the Murrumbidgee in 2016-17 (14 species) compared to the previous two water years (2014-15 (4 species) and 2015-16 (8 species).	Future delivery of Commonwealth environmental water should aim to deliver flows to provide seasonal habitat for waterbirds in spring (August-November) and where possible, maximise wetland inundation duration into summer and a slow rate of recession into autumn months. This approach will provide a diverse range of wetland habitats for a high diversity of waterbird species including migratory shorebird species. As done successfully in 2014-15 and 2015-16, environmental water should be used to extend duration of inundation and maintain adequate water depths in any active colonial waterbird sites to support breeding events through to completion (minimum of three to four months from egg laying plus post-fledgling care for most species). To increase opportunities for colonial waterbird breeding, Commonwealth environmental water should be used to inundate known colony sites and key foraging grounds for >two months (August-September) before the commencement of the core breeding season.
Waterbird breeding	Commonwealth environmental water supported an estimated 53,150 waterbird nests in the Nimmie-Caria, 11,645 in Redbank, and 810 in the mid-Murrumbidgee Reproductive success of straw necked ibis was measured at two locations. Reproductive rates for straw-necked ibis (number of eggs laid that became fledged juvenile birds) were 59% at the Eulimbah Swamp colony and 40% at the Tori Lignum Swamp ibis colony	Colonial-nesting waterbirds and non-colonial waterbird species require widespread inundation to maximise opportunities to breed and for recruitment of their young. Historically adjoining habitats to the main colony sites in the Nimmie-Caira and Redbank systems would have been inundated during wet years creating large areas of suitable foraging and nesting habitat. To increase opportunities for colonial waterbird breeding, Commonwealth environmental water could also be used to inundate known colony sites and key foraging grounds for >two months (August-September) before the commencement of the core breeding season. If colonial waterbird breeding is detected in the Murrumbidgee and/or neighbouring catchments Commonwealth environmental water should be used to maintain inundation of foraging and breeding habitats to promote the survival of young birds. This was done successfully in 2016-17, where environmental water was used to extend duration of inundation and maintain adequate water depths in active colonial waterbird sites to support breeding events through to completion. Following colonial waterbird breeding events in the Lowbidgee floodplain and neighbouring wetlands (i.e. the Lower Lachlan and mid-Murray) Commonwealth environmental water should be prioritised for delivery to key foraging areas in months and the water year following large breeding events to promote the survival of first year birds which in turn will contribute to the maintenance of waterbird diversity and abundance across the MDB.

1 Introduction

The Commonwealth Environmental Water Holder (CEWH) is responsible under the *Water Act 2007* (Commonwealth) for managing Commonwealth environmental water holdings to protect and restore the environmental assets of the Murray-Darling Basin (MDB). The Basin Plan (2012) further requires that the holdings must be managed in a way that is consistent with the Basin Plan's Environmental Watering Plan. The *Water Act 2007* and the Basin Plan also impose obligations to report on the contribution of Commonwealth environmental water to the environmental objectives of the Basin Plan. Monitoring and evaluation are critical to effectively and efficiently use Commonwealth environmental water, supporting the CEWH's reporting obligations in addition to demonstrating overall effectiveness at meeting conservation objectives.

The Long-Term Intervention Monitoring Project (LTIM Project) is the primary framework by which the Commonwealth Environmental Water Office (CEWO) monitors and evaluates the ecological outcomes of Commonwealth environmental watering and its objectives. The LTIM Project is implemented at seven selected areas over a five year period from 2014-15 to 2018-19 to deliver five high-level outcomes (in order of priority):

- Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan
- Evaluate the ecological outcomes of Commonwealth environmental watering at each of the seven selected areas
- Infer ecological outcomes of Commonwealth environmental watering in areas of the MDB not monitored
- Support the adaptive management of Commonwealth environmental water
- Monitor the ecological response to Commonwealth environmental watering at each of the seven selected areas.

This evaluation report describes the ecological outcomes of environmental watering actions in the Murrumbidgee selected area undertaken in 2014-15 to 2016-17, the first three years of the five year LTIM Project. More details of results and analyses for each monitoring indicator are presented in technical appendices that follow this evaluation report. This report draws on information presented in the **Murrumbidgee Monitoring and Evaluation Plan (M&EP)**(Wassens, Jenkins et al. 2014).

2 Murrumbidgee River system selected area and zones

The Murrumbidgee Catchment in southern NSW, is one of the largest catchments (81,527 km^2) in the MDB (Kingsford and Thomas 2004). Wetlands make up over 4% (370,000 ha) of the catchment, with over 1000 wetlands identified (Murray 2008). Nationally important wetlands, including the mid-Murrumbidgee and Lowbidgee floodplain, cover over 208,000 ha (2.5% of the catchment area). For the purposes of the assessment of environmental water requirements and identification of monitoring zones, three key areas are identified for the Murrumbidgee (Gawne, Brooks et al. 2013). Each area is identified by the MDBA as a "*key environmental asset within the Basin*" and "*important site for the determination of the environmental water requirements of the Basin*" (Murray-Darling Basin Authority 2012). They are:

- The Lower Murrumbidgee River (in-channel flows)
- The mid-Murrumbidgee River wetlands and
- The Lower Murrumbidgee (Lowbidgee) floodplain

Monitoring zones represent areas with common ecological and hydrological attributes. We identified separate zones for riverine and wetland habitats across the Murrumbidgee Selected Area. In most cases, we aimed to align zones with existing classifications by the MDBA and NSW Office of Environment and Heritage (NSW OEH). In order to align closely with established management units across the Murrumbidgee Selected Area, we have taken a broad scale approach to the selection of zones, focusing on large scale differences in hydrology, vegetation and faunal communities. It is noted that our zones cover large areas, and, in the case of wetland zones, there remains considerable heterogeneity within as well as between zones. As a result, higher levels of replicate monitoring locations are required in some zones to enable statistical evaluation of ecological outcomes.

Riverine zones

The Murrumbidgee River is over 1600 km long, with the LTIM Project Selected Area covering the lowland section (approximately 786 km)(Wassens, Jenkins et al. 2014). In the Murrumbidgee River we have identified three zones that have a degree of hydrological uniformity that can be accurately estimated using the existing gauge network. The zone classification also takes into account key inflows (tributaries) and outflows (distributaries and irrigation canals) (Figure 2-1).

- **Narrandera reach (187.3 km)** – Includes major irrigation off-takes, also key populations of Murray cod.
- **Carrathool reach (358.0 km)** – Downstream of Tom Bullen storage and major irrigation off-takes, reduced influence of irrigation flows, principle target for in-channel Commonwealth environmental watering actions, partly affected by hypoxic blackwater in 2010-11.
- **Balranald reach (241.4 km)** – Aligns with the Lowbidgee floodplain, impacted by hypoxic black water in 2010-11 resulting in reduced abundance of large-bodied native fish.

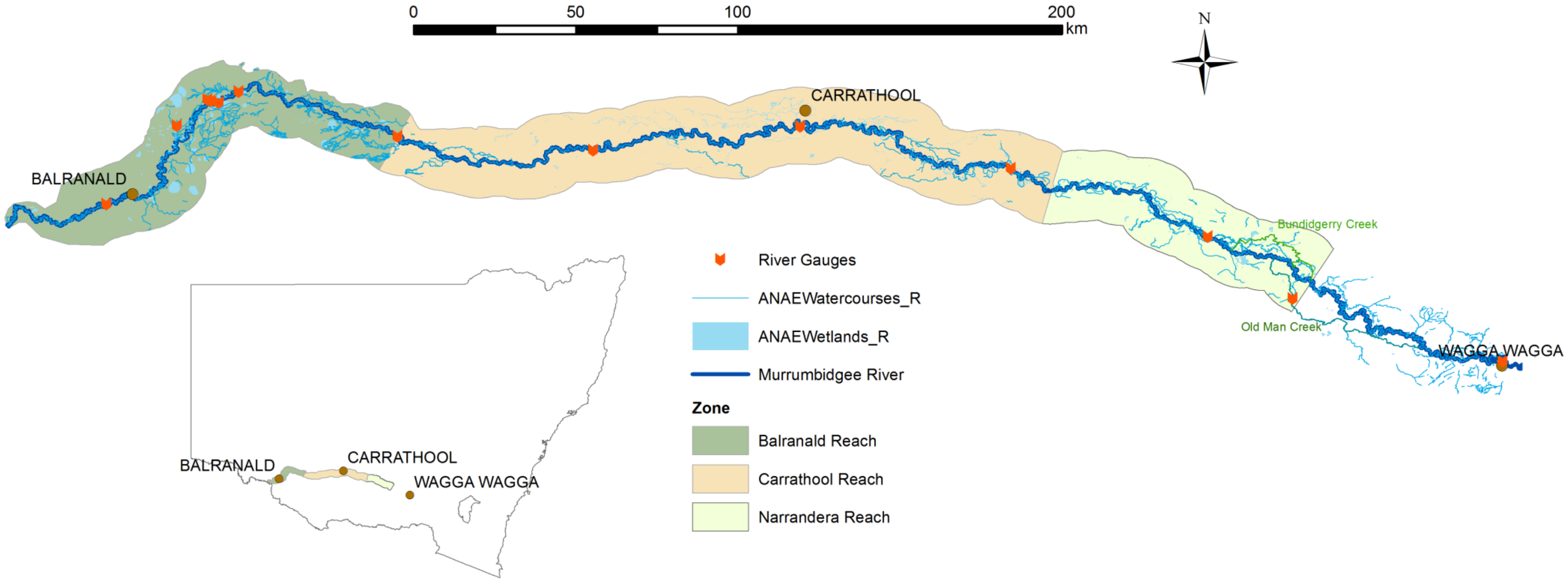


Figure 2-1 Distribution of riverine zones in the Murrumbidgee Selected Area.

Wetland zones

Identification of zones across floodplain habitat is more complex than in riverine systems, due to the diversity of aquatic habitats, complexity of hydrological regimes (spatiotemporal variability of flows), diversity of vegetation types and presence of flow control structures (water management units). Ultimately we opted for very broad zones, dominant vegetation type, faunal communities and expected ecological responses. These align with the management units identified by NSW OEH and are recognised by the MDBA and CEWO. Zones were classified for the two key wetland regions: the mid-Murrumbidgee wetlands (Murray 2008) and the Lower Murrumbidgee (Lowbidgee) floodplain (Murrumbidgee Catchment Management Authority 2009). See Table 4.1 for a list of key wetlands in each zone.

These regions are split into six broad zones (Figure 2-2):

- **mid-Murrumbidgee wetlands (82,800 ha)** – River red gum forest interspersed with paleochannels and oxbow lagoons
- **Pimpara–Waugorah (55,451 ha)** – Mosaic of creek lines, paleochannels and wetlands, with River red gum and black box mostly north of the Murrumbidgee River
- **Redbank (92,504 ha)** – Mosaic of river red gum forest and woodland, spike rush wetlands - divided into two management subzones (north and south Redbank)
- **Nimmie-Caira (98,138 ha)** – Mosaic of creek lines, paleochannels, open wetlands and lakes dominated by lignum and lignum-black box communities
- **Fiddlers-Uara (75,285 ha)** – Paleochannels and creek lines bordered by black box
- **The Western Lakes (3,459 ha)** – Open quaternary lakes with inactive lunettes west of the Lowbidgee floodplain

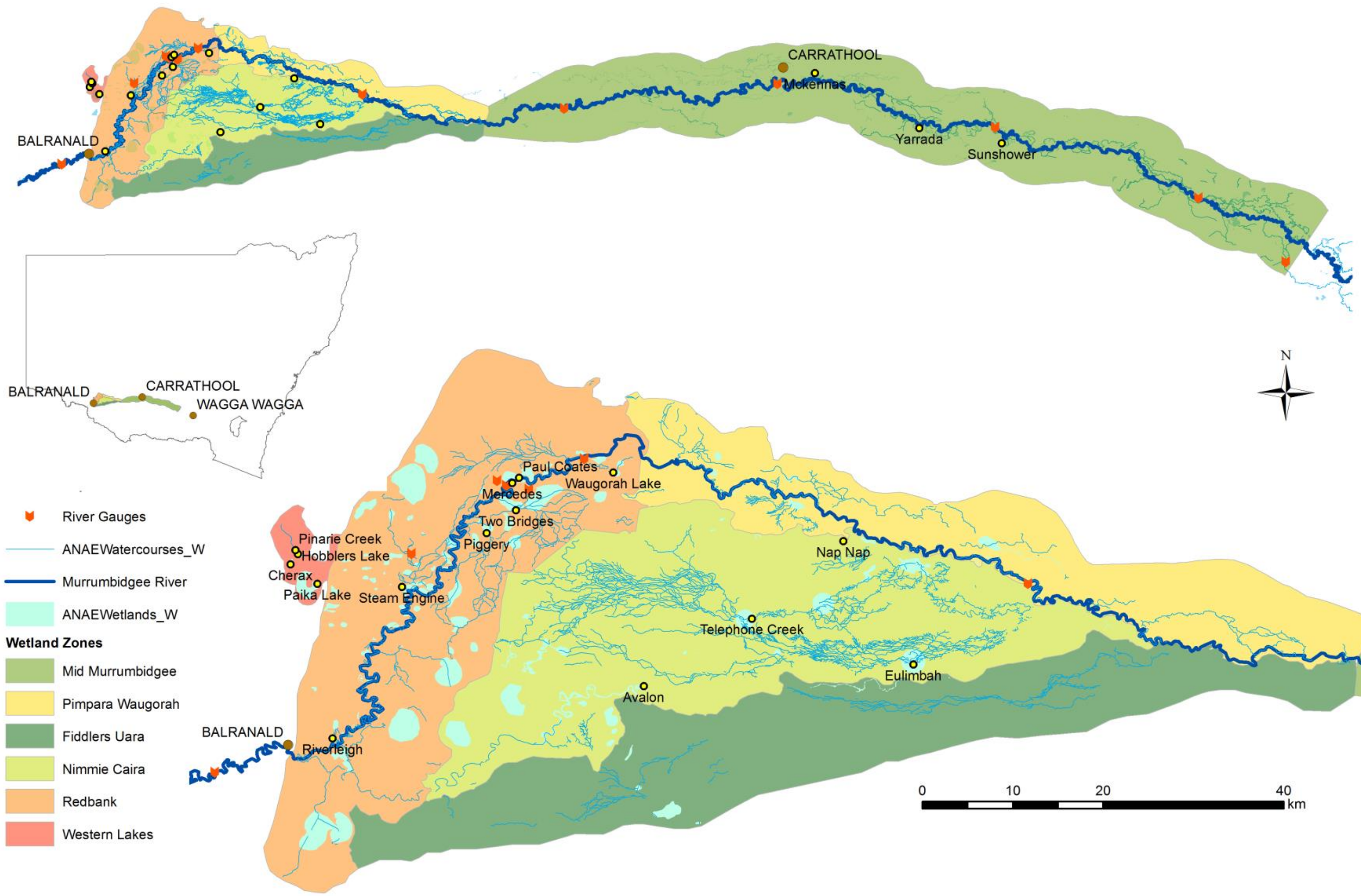


Figure 2-2 Distribution of wetland zones in the Murrumbidgee Selected Area and locations of key wetlands.

3 Environmental water delivered in 2016-17, context and expected outcomes

3.1 Climate and watering context

Flows within the Murrumbidgee River have undergone significant long-term changes since the construction of large headwater dams and in-channel weirs which allow the river flows to be regulated and diverted to meet agricultural and consumptive needs. In particular, the timing of high flow periods has shifted from winter to spring to meet irrigation demands and there have been significant reductions in the frequency of minor and moderate flow pulses (Frazier, Page et al. 2005, Frazier and Page 2006). Between 2000 and 2010 a significant drought event coupled with increasing consumptive water demand exacerbated the effects of river regulation (Dijk, Beck et al. 2013) leading to significant declines in the condition of floodplain vegetation (Wen, Ling et al. 2009). Large-scale flooding occurred in 2010 and 2011 which was followed by moderate water availability between 2012 and mid-2016. In 2016-17 there was above average rainfall in the catchment contributing to increasing tributary inflows and unregulated river flows which inundated significant areas of wetland through the mid-Murrumbidgee and Lowbidgee floodplains between September and November 2016.

3.2 2016-17 Watering Actions

Environmental watering actions are determined by a combination of catchment and climate conditions, the environmental demand and the volume of water holdings. In 2016-17 the Commonwealth environmental water holder delivered **241,465 ML** of environmental water as part of 13 watering actions targeting key floodplain and wetland habitats, anabranches and creek lines floodplain through the Murrumbidgee and two in-channel actions: Murrumbidgee River Fresh (flood recession and DO management) and Lower Murrumbidgee Autumn Fish pulse (Table 3-1).

Murrumbidgee River Fresh: Flood recession and dissolved oxygen management

As in 2014-15 and 2015-16 the priority watering actions for the 2016-17 water year was the reconnection of the mid-Murrumbidgee wetlands. However, widespread rain during September-November 2016 resulted in high unregulated flows in the Murrumbidgee River which inundated wetlands through the mid-Murrumbidgee zone, including the four monitoring sites, without the need for additional Commonwealth environmental water. As the unregulated flow peak receded, the risk of poor water quality associated with hypoxic black water in the Murrumbidgee River increased and declining dissolved oxygen levels were reported in the lower reaches of the Murrumbidgee River. In response to these conditions, a flow of Commonwealth, NSW OEH and The Living Murray environmental water was delivered from late October 2016 to early January 2017. The principle objective of this flow was to:

- manage the flood recession
- slow the rate of return of water from the floodplain which contained high concentrations of dissolved organic carbon, and
- to maintain a steady in channel dilution flow until dissolved oxygen levels had risen to safe levels for native fish and other aquatic animals.

Commonwealth environmental water was also delivered to significant wetland habitats through the lower Murrumbidgee floodplain (Lowbidgee). Commonwealth environmental water was delivered to sections of the Nimmie-Caria and Redbank zones in the Lowbidgee floodplain in August 2016, with the objective of supporting habitat for the southern bell frog and creating foraging habitats for waterbirds (Figure 3-1). The delivery of Commonwealth environmental water to the Lowbidgee floodplain was paused in early September due to high volumes of water entering the floodplain as unregulated flows recommencing in late November and December 2016 after flood waters had receded. Following the peak of unregulated flows the main priority for Commonwealth environmental watering actions were to maintain water levels in wetlands where additional flows were needed to support the successful breeding, fledging and recruitment of waterbird species across multiple wetlands through the Lowbidgee floodplain. Multiple waterbird breeding events were supported by Commonwealth environmental watering through the Lowbidgee floodplain from November 2016 through to March 2017 (seeTable 3-1).

Additional Commonwealth watering actions were undertaken in areas outside of the long-term intervention monitoring program target area, these included providing flow pulses through the Yanco-Billabong- Forest Creek system to improve water quality and support waterbird breeding in Wanganella Swamp, actions to reconnect the Junction wetlands and provide fish passage in the lower reaches of the Murrumbidgee (see Table 3.1)

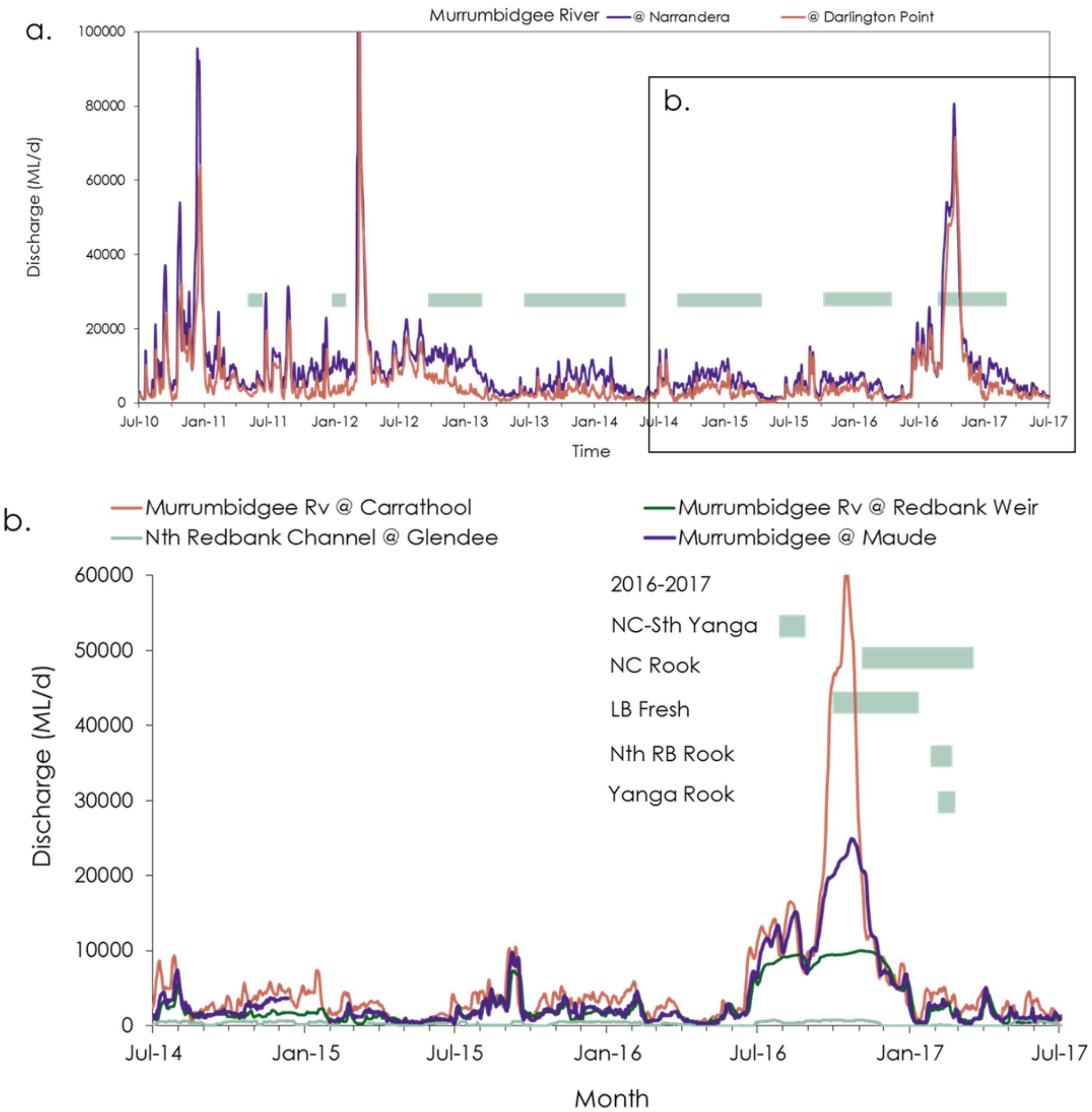


Figure 3-1 a. Mean daily discharge in the Murrumbidgee River at Narrandera and Darlington Point between 1 July 2010 to 30 June 2016. The 2012 peaked at 200,000 ML. Horizontal green bars show Commonwealth and NSW environmental water actions in 2011-12, 2012-13, 2013-14, 2014-15 and 2015-2016. b. Mean daily discharge in the Murrumbidgee River at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glendee in relation to the timing of environmental water delivery water actions (horizontal green bars) during survey period (1 July 2016 to 30 June 2017).

Table 3-1 Summary of Commonwealth environmental watering actions and expected watering outcomes. Adapted from (Commonwealth of Australia 2016). Expected outcomes that are evaluated in this report are shown in **bold**. Table continues over page.

Action	Dates (start/end)	Expected outcomes (primary and secondary as at delivery)	Related report sections
10052-02 Murrumbidgee River Fresh: Flood recession and dissolved oxygen management	Start: 28/10/2016 End: 05/01/2017	This action was expected to: - provide in-channel refuge habitat and in-channel movement opportunities for native fish from areas of low dissolved oxygen levels in the lower reaches to refuge habitat upstream; - support the movement of native fish and other aquatic animals from the floodplain to the river channel, thereby minimising or preventing stranding of these animals on the floodplain; - **improve water quality** - reduce bank slumping of saturated banks. Note: while expected outcomes of this flow were not specifically related to fish spawning or habitat quality, this flow coincided with the LTIM fish spawning and monitoring period and therefore the outcomes of this event are also considered in the context of native fish spawning	4.2 River water quality 4.3 Stream metabolism 4.4 Riverine Microinvertebrates 4.5 Riverine and larval fish 4.6 Hypoxic blackwater in the Lower Murrumbidgee River, 2016
10052-05 Nimmie-Caira: Eulimbah waterbird breeding support	Start: 28/11/2016 End: 03/03/2017	Primary: - **Maintain rookery water levels to support successful breeding, fledging and recruitment of waterbird species.** - **Provide foraging habitat to prevent reduction in food sources due to drying.** Secondary benefits include: - **Improving water quality** - **Maintaining and improving the condition of wetland vegetation** - **Supporting the habitat requirements of native fish and other aquatic animals.**	5.1 Wetland hydrology 5.2 Wetland water quality 5.3 Wetland microinvertebrates 5.4 Vegetation diversity 5.5 Frogs and turtles 5.6 Wetland fish 5.7 Waterbird diversity 5.8 Waterbird breeding
10052-06 Nimmie-Caira: Telephone Bank waterbird breeding support	Start: 24/11/2016 End: 20/03/2017		
10052-11 Nimmie-Caira: Nap Nap waterbird breeding support	Start: 03/01/2017 End: 07/01/2017		

Table 3.1 (continued)

Action	Dates (start/end)	Expected outcomes (primary and secondary as at delivery)	Related report sections
10052-12 Nimmie-Caira: Is-Y-Coed (Kieeta and Kia Lakes) Lake pelican breeding support	Start: 10/02/2017 End: 20/03/2017	Primary: - Maintain water levels to support the successful breeding, fledging and recruitment of pelicans. Secondary: - Improve water quality - Maintain and improve wetland vegetation condition in Kia Swamp - Provision of foraging habitat - Supporting habitat requirements of native fish and other aquatic animals.	5.8 Waterbird breeding
10034-09 Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga	Start: 04/08/2016 End: 03/09/2016	- **Maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC Act vulnerable).**	5.1 Wetland hydrology 5.2 Wetland water quality 5.3 Wetland microinvertebrates 5.4 Vegetation diversity 5.5 Frogs and turtles 5.6 Wetland fish 5.7 Waterbird diversity
10052-08 Yanga National Park: waterbird breeding support	Start: 29/01/2017 End: 13/02/2017	**Primary:** - **Maintain rookery water levels to support successful breeding, fledging and recruitment of waterbird species.** **Secondary:** - **Improving water quality** - **Maintaining and improving the condition of wetland vegetation** - **Supporting the habitat requirements of native fish and other aquatic animals.**	5.1 Wetland hydrology 5.2 Wetland water quality 5.3 Wetland microinvertebrates 5.4 Vegetation diversity 5.5 Frogs and turtles 5.6 Wetland fish 5.7 Waterbird diversity 5.8 Waterbird breeding
10052-09 North Redbank: waterbird breeding support	Start: 27/01/2017 End: 13/02/2017	Primary: - **Maintain rookery water levels in Tori Lignum Swamp to support successful breeding, fledging and recruitment of waterbird species.** Secondary: - Improving water quality - Maintaining and improving the condition of wetland vegetation Supporting the habitat requirements of native fish and other aquatic animals.	5.8 Waterbird breeding
10052-13 Fresh flow Lower Murrumbidgee River: Autumn fish pulse	Start: 01/04/2017 End: 25/04/2017	- Contribute in-stream flows to provide movement and recruitment opportunities for native fish and to support hydrological connectivity, biotic and nutrient dispersal, riparian vegetation and water quality. Specifically targets movement into the Murrumbidgee River from the Murray system, including members of the large Darling River perch cohort, and to/from the Lowbidgee floodplain lake system.	Not evaluated – action occurred outside of LTIM monitoring periods

Table 3.1 (continued)

Action	Dates (start/end)	Expected outcomes (primary and secondary as at delivery)	Related report sections
10052-03 Yanco-Billabong-Forest Creek system: Wanganella Swamp waterbird breeding support	Start: 21/11/2016 End: 04/01/2017	Primary: - Maintain water levels in Wanganella Swamp to support successful breeding, fledging and recruitment of waterbird species. Secondary: - Improving water quality - Maintaining and improving the condition of wetland vegetation Supporting the habitat requirements of native fish and other aquatic animals.	Not evaluated – not within LTIM Survey areas
10034-08 Junction Wetlands: no take	Start: 07/07/2016 End: 31/08/2017	Primary: - Target wetland and floodplain vegetation to avoid further damage at Junction Wetlands. Secondary: Provision of habitat for a range of waterbird, native fish and frog species.	Not evaluated – not within LTIM Survey areas
Western Lakes (10052-07 regulated water component) (10034-10 supplementary water component)	Start: 04/05/2017 End: 30/06/2017 Start: 07/11/2016 End: 19/12/2016	- Provide habitat for waterbirds, and native wetland dependent fauna improve the condition of aquatic, riparian and wetland vegetation.	Not evaluated – not within LTIM Survey areas
10052-10 Toogimbie IPA Wetlands	Start: 04/03/2017 End: 30/06/2017	Improve wetland health and resilience by building on improvements to vegetation condition from natural flooding and environmental water delivery; and provision of habitat for wetland dependent fauna (fish, frogs, turtles, waterbirds) including the Southern bell frog (EPBC vulnerable).	Not evaluated – not within LTIM Survey areas

Table 3-2 Summary of environmental water usage from Commonwealth and state sources in 2016-17. (Drawn from Watering Action Acquittal Report Murrumbidgee 2016-17 (Commonwealth of Australia 2016)).

Events	CEW Delivered Volume (ML)	NSW Delivered Volume (ML)	Net usage (ML)
Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga	15,507	0	15,507
Murrumbidgee River Fresh: Flood recession and dissolved oxygen management	150,978 TLM 85,000	134,861	370,839
Nimmie-Caira Rookery maintenance (3 actions) -Eulimbah waterbird breeding support -Telephone Bank waterbird breeding support -Nap Nap waterbird breeding support	8375	3923	12,298
North Redbank: waterbird breeding support	844	1496	2790
Yanga National Park: waterbird breeding support	2,155	0	2,155
Nimmie-Caira: Is-Y-Coed (Kieeta and Kia Lakes) pelican breeding support	5,000	4,903	9,903
Fresh flow Lower Murrumbidgee River: Autumn fish pulse	47,548	1039	48,587
Yanco-Billabong- Forest Creek system: Wanganella Swamp waterbird breeding support	5000	800	5,800
Junction Wetlands: no take	0	0	0
Western Lakes (10052-07 regulated water component) (10034-10 supplementary water component)	5060	13300	18,360
Toogimbie IPA Wetlands	998	0	998

4 Riverine responses to Commonwealth environmental water

Plate 4-1 Murrumbidgee River at Hay on 20 October 2016

4.1 Summary of river monitoring activities 2016-17

Riverine monitoring is undertaken at three sites spread across each of the two ecological zones – Narrandera and Carrathool (Figure 2-1). Surveys are conducted fortnightly from October to December each year for water quality, nutrients and carbon, microinvertebrates and larval fish. Stream metabolism is monitored at one site in both the Carrathool (October – April) and Narrandera (October – January) zones concurrent with the larval fish monitoring. There were two Commonwealth environmental watering actions undertaken in the Murrumbidgee River that specifically targeted in channel outcomes (see Table 3.1). Firstly, the Murrumbidgee River Fresh: flood recession and dissolved oxygen management event, which is evaluated against its primary objectives to improve water quality and manage hypoxic black water (see section 4.6 Hypoxic blackwater in the Lower Murrumbidgee River, 2016) and (2) *Fresh flow Lower Murrumbidgee River:* Autumn fish pulse which fell outside of the LTIM monitoring period and is not considered further in our evaluation. In addition multiple Commonwealth environmental watering actions targeting wetlands in the Lowbidgee floodplain (see Table 3.1) influenced the hydrology of the river in the mid- reaches, and coincided with evaluation of fish spawning, microinvertebrates, water quality and stream metabolism responses.

Table 4-1 LTIM monitoring sites in each zone and associated monitoring activities in the Murrumbidgee Selected area (see Figure 2-1).

Site Name	Zone	ANAE classification	Stream metabolism	Nutrients carbon	Microinvertebrate	Larval fish C1	Larval Fish SA	Fish community (C1)
Yarradda (River)	Carrathool	Permanent transitional zone streams		X	X	X	X	X
McKennas (River)		Permanent lowland streams	X	X	X	X	X	X
Bringagee				X	X	X	X	X
Birdcage								X
Gundaline claybar								X
Gundaline US								X
Rudds Point								X
Toganmain DS								X
Toganmain HS								X
Toganmain US								X
Wyreema								
The Dairy	Narrandera	Permanent lowland streams		X	X		X	
Euroley Bridge				X	X		X	
Narrandera			X	X	X		X	

US = upstream, DS = downstream, River = distinguishes site from comparable Wetland site with the same name see Table 5-1, C1 = Category 1 LTIM standard methods, C3 = Category 3 LTIM standard methods).

4.2 River water quality

During 2016-17 there were two Commonwealth environmental water deliveries that affected river flows. The Murrumbidgee flood recession and dissolved oxygen management flow (net use of 370,839ML) was initially targeted at Wagga in late October 2016 (125,070 ML), then Gogelderie in mid-November (56,978 ML) and downstream in Maude between November and early January 2017 (188,791 ML) tracking the flood recession as it passed downstream. The outcomes of this event respect to dissolved oxygen management downstream of Maude are discussed in section (4.6 Hypoxic blackwater in the Lower Murrumbidgee River, 2016;

Table 3-2). The autumn river fish pulse (49GL) was delivered to the Balranald Reach during April 2017, although the timing and location of this delivery fell outside the scope of Murrumbidgee Selected Area monitoring (

Table 3-2). In addition, Commonwealth environmental water was delivered via the main channel to support waterbird outcomes in the Lowbidgee floodplain (total of 46.5 GL) during multiple smaller-volume water uses between November 2016 and June 2017. In this section we describe the ranges of water quality observed in the Murrumbidgee River during 2016-17 and compare these findings against prior observations and published water quality guidelines (ANZECC 2000).

Summary of watering actions and outcomes

<table>
<tr><th>MEP and 2016-17 Acquittal Report Expected outcomes</th><th>Watering Action (s) in 2016-17</th><th>Evaluation questions</th><th>Measured outcomes</th><th>Was the expected outcome achieved</th></tr>
<tr><td rowspan="3">Support primary productivity, nutrient and carbon cycling, biotic dispersal and movement;

Provide refuge habitat from adverse water quality events.</td><td rowspan="3">Murrumbidgee flood recession and dissolved oxygen management flow

Commonwealth water also influenced hydrology due to transit of water for downstream river and floodplain assets resulting in the presence of channel freshes throughout the monitoring period</td><td>Physicochemical variables remain within range tolerated by aquatic species</td><td>Physicochemical parameters consistent with prior records and within water quality criteria</td><td>Yes</td></tr>
<tr><td>Nutrient, carbon and chlorophyll-a concentrations within range tolerated by aquatic species</td><td>Nutrient, carbon and chlorophyll-a concentrations consistent with prior records and/or within water quality criteria</td><td>Yes</td></tr>
<tr><td>Nutrient concentrations sufficient to support ecosystem functions</td><td>Not known if production in the Murrumbidgee River is resource-supply limited.</td><td>NA</td></tr>
</table>

Main findings from the River Water Quality monitoring program

- Physicochemical parameters were generally within the expected range of water quality for the Murrumbidgee River and do not reveal any adverse conditions under the observed range of flows within the monitored zone.
- Dissolved oxygen fell to potentially harmful (low; <4 mg L^{-1}) levels in the Carrathool reach during October 2016. This occurred in response to a large, natural overbank flood event and is not attributed to the use of environmental water.
- Conductivity increased in the Carrathool reach during the flood, but values were well below the ANZECC (2000) trigger guideline of 2.2 mS cm^{-1} and largely within the range of previously observed values.
- Nutrient concentrations increased during and after the flood, eliciting a pulse of chlorophyll-a in the Carrathool reach Zone once the floodwaters subsided.
- Nutrient concentrations exceeded both previously recorded data for the Murrumbidgee Catchment and the ANZECC (2000) trigger thresholds.

Discussion, recommendations and adaptive management

Data from the 2016-17 water year documents the role of overbank flows that engage large areas of floodplain and carry floodplain-derived nutrients and energy back to the river channel. Water quality during 2016-17 exceeded both previous records and the ANZECC (2000) water quality guidelines for water nutrient data, dissolved oxygen and electrical conductivity. For the observable period of monitoring we attributed these water quality changes to the natural overbank flow event and not to any environmental water deliveries. Nutrient concentrations were substantially higher in 2016-17 than 2015-16 and 2016-17, in particular highly bioavailable ammonia (NH3), oxidised nitrogen (NOx) and reactive phosphorus (FRP). DOC also increased, reaching 14 mgL^{-1} in the Carrathool reach, approximately four times greater than the median background concentration of 3.59 mgL-1, and coinciding with the lowest recorded dissolved oxygen (~3 mg L^{-1}). It isn't known if dissolved oxygen was lower earlier in the event. However, this sample was collected close to the flood peak, and that the lowest oxygen during blackwater events is roughly coincident with the flood peak (section 6.2). Moreover, further downstream at Maude dissolved oxygen concentrations did not fall below 3 mg L^{-1} and persistent hypoxia upstream of Maude is unlikely. The 4-fold increase in DOC is dwarfed by associated increases in available nitrogen and phosphorus, which are 67 and 27 times the background median concentration, respectively. When compared with the 2014-15 and 2015-16 monitoring data, years when the floodplain did not connect with the river, the 2016-17 results show the contribution of overbank flows to in-channel nutrient concentrations.

Like other streams in the MDB, median concentrations of nutrients in the Murrumbidgee River are slightly lower than other floodplain rivers across the world (Grace 2016). Production in the Murrumbidgee River is potentially limited by the supply of carbon and nutrients that would naturally be provided during lateral reconnection events, particularly phosphorus (Vink, Bormans et al. 2005). Although environmental water cannot be used to inundate large floodplain areas, any substantial return flows, from either high freshes inundating riparian areas or flushing flows using infrastructure-assisted deliveries, could have a disproportionately large impact on nutrient availability in this low-nutrient system (Wolfenden, Wassens et al. 2017). Target thresholds of concentrations needed to drive these processes are still being investigated.

4.3 Stream metabolism

Stream metabolism is a measure of the amount of carbon-based energy produced and consumed by river food webs. It provides an ecosystem-level estimate rates of gross primary production (GPP) by algae and aquatic plants as well as rates of heterotrophic respiration (i.e. carbon consumption, ER) by all respiring organisms, particularly microorganisms. During 2014-15 and 2015-16 there were no monitored Commonwealth environmental watering actions specifically targeting in-channel metabolism, although the monitoring program thus far provides an important benchmark for evaluating the potential contribution of environmental water. During 2016-17 there were two environmental water use actions that had the potential to affect in-stream metabolism. However, both of these actions fell either outside the monitored reaches of the Murrumbidgee or outside the period those reaches were monitored for stream metabolism (

Table 3-2). Environmental water also contributed additional flows to the river channel while being delivered to support waterbird outcomes in the Yanga and Nimmie-Caira wetland monitoring zones. We investigated the relationship between stream metabolism and river flows during 2014-15, 2015-16 and 2016-17. We discuss these findings with regard to future deliveries of Commonwealth environmental water.

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions	Measured outcomes	Was the expected outcome achieved
Murrumbidgee flood recession and dissolved oxygen management flow Commonwealth water also influenced hydrology due to transit of water for downstream river and floodplain assets resulting in the presence of channel freshes throughout the monitoring period	What did CEW contribute to patterns and rates of decomposition? What did CEW contribute to patterns and rates of primary productivity?	Commonwealth water influenced hydrology both through direct watering actions and due to transit of water for floodplain assets resulting in the presence of channel freshes throughout the monitoring period.	Rates of metabolism low compared with other river systems monitored under the LTIM program. Negative relationship between flow and metabolism at Narrandera but not Carrathool.	Unknown

Main findings from the River Water Quality monitoring program

- Rates of metabolism in the Murrumbidgee River appear consistently low compared with other studies
- Preliminary findings show weak relationships between metabolism (GPP and ER) with both flow and temperature
- No evidence of increased metabolism resulting from overbank flooding in September 2016-17, inconsistent with water quality results

Discussion, recommendations and adaptive management

Overall rates of metabolism in the Murrumbidgee remain slightly lower than other published data for the Murray-Darling Basin and previous studies from the Murrumbidgee (Vink, Bormans et al. 2005). As noted by Wassens, Thiem et al. (2015), the discrepancy with the findings by Vink, Bormans et al. (2005) may be explained by differences in methodology (Song, Dodds et al. 2016). However, Vink, Bormans et al. (2005) speculated that rates of metabolism in the Murrumbidgee River have been reduced by the loss of nutrients and energy that were historically provided to the river during natural overbank flood events. If metabolism in the Murrumbidgee River is limited by these resources, then environmental flows that re-engage lateral and longitudinal connections, flushing nutrients and energy from adjacent floodplain soils into the river, are expected to boost river productivity.

We therefore expected an increase in both GPP and ER in response to the overbank flooding in 2016-17, especially considering the lengthy lag in elevated nutrients and carbon (Section 4.2) that might be expected to stimulate production. This prediction is partly supported by an increase in water column chlorophyll-a, suggesting increased phytoplankton production coincided with the recession of the flood (see sections 4.2 River water quality). However, no increase in rates of GPP are apparent in the 2016-17 metabolism data. Instead, rates of metabolism remained relatively consistent between the two monitored zones despite the overall difference in nutrient and carbon concentrations, both of which were higher in the Carrathool zone at the time of monitoring. Peak discharges in 2016-17 appeared to increase both nutrient concentration and availability (section 4.2), but did not appear to correspond with any measurable change in productivity. At this stage in the LTIM program the models required to fully test these predictions aren't yet available.

During 2015-16 there was an overall increase in GPP and decline in ER at the Narrandera monitoring site that shifted net ecosystem metabolism toward net primary production, but no changes were recorded in the Carrathool monitoring site. This pattern coincided with lower river flows and higher chlorophyll-a, than for other monitoring years in the Narrandera Zone. Overall, flow regulation is thought to favour increased primary production and that increased lateral carbon inputs should drive the system towards net heterotrophy (P:R <1; (Robertson, Bacon et al. 2001). While this shift in production did occur during 2016-17, it appears to have been because of lower GPP rather than increased respiration. During 2016-17 there was also a net decline in metabolism also only at the Narrandera site. Multiple years of data are required to derive relationships between metabolism and hydrology, at this stage while there are some trends suggesting a possible link between metabolism and hydrology, the full five years of monitoring data is required to develop statistically robust models on which recommendations could be based.

4.4 Riverine Microinvertebrates

Microinvertebrates are a food source for a wide range of fauna including larval and adult fish and as such play a key role in floodplain river food webs (King 2004). Microinvertebrates depend on appropriate river flows to flourish, with deliveries of environmental water playing a key role in generating these flows in regulated rivers. During 2014-15, 2015-16 and 2016-17 Commonwealth environmental water was not directly targeting in-channel watering outcomes to support this critical food source for larval fish in the Narrandera and Carathool reach during the monitoring period (Table 3-1). However, in 2016-17 the Murrumbidgee flood recession and dissolved oxygen management flow (370,839ML) was delivered to the Balranald reach and is likely to have contributed to small water levels rises in the hydrology in the Narrandera and Carrathool reach during transit. In addition, the transfer of Commonwealth environmental water to wetland and floodplain habitats in all three years contributed to water level rises in the Murrumbidgee River during our six fortnightly trips to monitor benthic and pelagic microinvertebrates from mid-spring to early summer, coinciding with the sampling of larval fish. We predicted an increase in productivity on sampling trips that follow inundation of previously dry sediment along the channel, in benches and backwaters, coinciding with warm temperatures. To support the growth and survival of larval fish, a peak in microinvertebrate density should coincide with peaks in larval fish abundance.

Summary of watering actions and outcomes

MEP and 2016-17 Acquittal Report Expected outcomes	Watering Action (s) in 2016-17	Evaluation questions	Measured outcomes	Was the expected outcome achieved
Provide flows, including restoring natural flow events that are affected by river regulation and/or extraction, to support habitat, food sources and breeding requirements of waterbirds, native fish and other vertebrates.	Murrumbidgee flood recession and dissolved oxygen management flow Commonwealth water also influenced hydrology due to transit of water for downstream river and floodplain assets resulting in the presence of channel freshes throughout the monitoring period	What did Commonwealth environmental water contribute to breeding and recruitment of riverine native fish by supporting prey?	Microinvertebrate densities exceeded levels needed to support larval fish during October in the Carathool Zone but did not match the peak in abundance of larval cod species and Australian smelt in November and carp gudgeon in December. *Macrothricidae* favoured prey of Murray cod was present in reduced numbers, compared to years 1 and 2. Microinvertebrate densities in Narrandera zone low, possibly due to high and more stable water level.	No

Main findings from the riverine microinvertebrate monitoring program

- Microinvertebrate densities were lower in 2016-17 compared to previous years (2014-15 and 2015-16).
- The lower densities observed during the unregulated flows could be due to a combination of high flows flushing individuals downstream, dilution of the densities due to the large volume of water, mortality due to low dissolved oxygen levels and reduced productivity due to lower temperatures.
- Despite the lower densities of microinvertebrates overall in 2016-17, we predict the flooding will stimulate increased productivity in future seasons, due to the increase in nutrients observed in the river associated with overbank flooding.

- In the Narrandera zone in all years, microinvertebrate densities were mostly well below 100-1000 individuals per litre. Water levels in the Narrandera zone are higher and more stable than the Carrathool zone.

Discussion, recommendations and adaptive management

Data from the 2016-17 water year documents the role of unregulated overbank flows that connected the river with large areas of floodplain. Interestingly, we did not observe high peak densities of microinvertebrates in response to 2016-17 unregulated overbank flows when compared to those observed in benthic habitats in the Carathool zone during in-channel flows during 2014-15 and 2015-16. This is likely due to high water levels on the recession of the flood, fast flow and cool temperatures in 2016-17 flushing microinvertebrates and reducing productivity. Nevertheless, we expect that when the peak of the unregulated flows receded, microinvertebrate productivity in the river channel would be high given the boost in nutrient concentrations observed in 2016-17 compared with the two previous years (see section 4.3). In particular highly bioavailable ammonia (NH3), oxidised nitrogen (NOx), reactive phosphorus (FRP) and DOC were high during the unregulated flow peak and these are most likely to stimulate primary and secondary production.

In previous years microinvertebrate productivity peaked on the recession of peak flows during spring and early summer, whilst densities were lowest at high water levels. Similarly, densities were low throughout 2016-17 when water levels were high due to the unregulated flows. There appears to be a threshold river level below which higher densities of microinvertebrate are observed and analysis of this threshold will be undertaken drawing on the five year data set for LTIM. A similar pattern of density was also observed during monitoring of sites in the Carrathool zone and at a site closer to Wagga in 2012-13 (Wassens, Jenkins et al. 2014).

In 2016-17, the highest densities in the benthic habitat in the Carathool zone were observed in October (trips 1 and 2) when sampling occurred on the floodplain, because the river channel site could not be accessed during the high flow event. These densities were comparative to the lower densities observed in 2014-15 and 2015-16 and did not match peaks in larval fish densities observed in 2016-17 (refer section: 4.5). In contrast, the peak in benthic microinvertebrate densities in 2015-16 coincided with peaks in Australian smelt and cod species captured in light traps. However peak numbers of cod species and perch captured in drift nets occurred two weeks earlier in late October, suggesting peak densities of larval fish and microinvertebrates were offset. This mismatch in timing between peaks was more apparent in 2014-15 when larval fish numbers peaked in early to mid-November well before the peak in microinvertebrate densities in early to mid-December.

River levels in the Narrandera zone were at least one metre higher than in the Carrathool zone and there was less variability in river height. It appears that the higher river level in the Narrandera zone may impact development of a productive and diverse microinvertebrate community. In contrast in the Carrathool zone with lower more variable river levels, pronounced peaks in microinvertebrate densities were recorded in both 2014-15 and 2015-16. This is likely due to drying and then rewetting of edge sediments stimulating nutrient release that then supports peak densities of microinvertebrates.

Before, during and after monitoring as river levels rise, peak and fall would help unravel if these aspects of hydrology are driving the patterns observed in microinvertebrate community dynamics. For example, in 2016-17 if monitoring had continued through summer 2017 we might have observed a strong response to the pulse in nutrients in the river from the flood. If this is the case, then environmental water deliveries could aim to produce a peak in river flows at the appropriate time for microinvertebrates to pulse when larval fish are also abundant. The differences in productivity between the Narrandera (high flow) and Carrathool zones (lower more variable flows) could be teased out by replicated monitoring in other locations. Flow manipulations in high flow areas to reduce flow and increase variability with before, during and after monitoring could also shed light on this important process.

4.5 Riverine and larval fish

Flow plays a critical role in the early life-cycle of native fish, with the duration, magnitude and timing of flows strongly influencing adult spawning and the subsequent survival and growth of larvae. During 2016-17, the principle in channel watering action undertaken using Commonwealth environmental water was the Murrumbidgee flood recession and dissolved oxygen management flow, which targeted lower reaches of the Murrumbidgee but also influenced the hydrology in the mid-Murrumbidgee. In addition the transfer of water to floodplain habitats as part of the waterbird breeding support actions resulted in the presence of Commonwealth environmental water during in-channel monitoring activities. The autumn fish pulse, delivered to the Lower Murrumbidgee River during April 2017, fell outside the period and location of larval fish monitoring (Table 3-1). While none of these watering actions were undertaken with an objective of triggering native fish spawning, we evaluated native fish in-channel spawning during periods of Commonwealth environmental water delivery. Specifically, we predicted that spawning of flow-cued species such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) would result from in-channel freshes and bankfull events, and that base flows and above would provide suitable conditions for spawning to occur in opportunistic and equilibrium species (i.e. non flow-cued species). Larval fish and eggs were sampled fortnightly at three sites in each of two hydrological zones in the Murrumbidgee River from October to December 2016. During the 2016-17 watering year the hydrology of the Murrumbidgee River was characterised by high overbank flows resulting from substantial unregulated inflows. Predictive relationships were developed for flow-cued spawning responses to abiotic drivers (hydrology and water temperature), with a view towards providing watering targets to maximise reproductive opportunities in future years.

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation question	Measured outcomes	Was the expected outcome achieved
Murrumbidgee flood recession and dissolved oxygen management flow Commonwealth water also influenced hydrology due to transit of water for downstream river and floodplain assets resulting in the presence of channel freshes throughout the monitoring period.	No expected outcomes specifically related to native fish spawning.	Were hydrological conditions sufficient to support spawning outcomes in native fish species?	The probability of silver perch and golden perch spawning occurred at distinct water temperatures although was largely independent of river levels. Environmental conditions were appropriate for spawning to occur for native fish species, including a number of equilibrium and opportunistic species	Yes

Main findings from River Fish monitoring program

- At least seven native fish species (Australian smelt *Retropinna semoni*, carp gudgeon *Hypseleotris* spp., flat-headed gudgeon *Philypnodon grandiceps*, golden perch, Murray cod *Maccullochella peelii*, Murray-Darling rainbowfish *Melanotaenia fluviatilis*, and silver perch *Bidyanus bidyanus*) and three alien species (common carp *Cyprinus carpio*, Eastern gambusia *Gambusia holbrooki* and redfin perch *Perca fluviatilis*) spawned in the Murrumbidgee River in 2016-17.

- Larval fish catches were dominated by Australian smelt, common carp and cod larvae. Based on egg captures, multiple spawning events occurred for both golden perch and silver perch, although only in the Narrandera zone. Neither species was recorded spawning in the Carrathool zone nor were any larvae captured in either zone.

- Predictive relationships are under development for flow-cued spawners (golden perch and silver perch) and will be strengthened in future years of monitoring. These indicate little association between spawning and hydrology metrics. Both species exhibit temperature dependent spawning, with golden perch generally spawning earlier (October-November) than silver perch (December).

Discussion, recommendations and adaptive management

Commonwealth environmental water was not specifically delivered to support native fish spawning outcomes during 2016-17. Long-term watering plans for the Murrumbidgee River (Commonwealth of Australia 2016) forecast the need to deliver environmental flows to support habitat and food sources and promote increased movement, recruitment and survival of native fish and other aquatic biota in future water years. Under the observed flows in 2016-17 we identified spawning of seven native and three alien fish species across the two monitored hydrological zones. Predictive relationships were further developed for flow-cued spawning species golden perch and silver perch. In the case of golden perch, we hypothesised that the observed relationships presented here indicate that appropriate in-channel hydraulic conditions are available throughout much of the watering season to trigger a spawning response.

We did not observe spawning in either golden perch or silver perch in the Carrathool zone in 2016-17. It is possible that the low dissolved oxygen values observed resulted in either spawning failure or reduced survival of eggs and larvae. It is currently unknown whether the spawning observed in golden perch and silver perch in the Narrandera zone in 2016-17 or in both zones in previous years is translating to recruitment in either of these species.

For the third continuous year we did not capture any juvenile golden perch within the selected area during annual community sampling in the Carrathool zone in March 2016. One juvenile silver perch was captured within the selected area in 2015, although none were captured in 2016 or 2017. While stocking of golden perch does occur within the region, recent evidence suggests that stocking only contributes 14% to golden perch populations in the Narrandera zone (Forbes, Watts et al. 2016). Further, stocking of silver perch does not occur within the Murrumbidgee River. We can therefore assume that the adult population contributing to spawning in both species is comprised of wild adults that presumably were spawned and recruited locally given the number of impassable barriers within the system. Subsequently, recruitment must therefore be occurring within the Murrumbidgee River to support adult populations of both species, although the drivers of recruitment, as well as key locations supporting juveniles, remain unknown and represent an important knowledge gap that requires further investigation.

The outcomes of 2016-17 indicate that spawning of small and large-bodied native fish species occurs during years of overbank flooding in the Murrumbidgee River. It is likely that the expected benefits of such a high water year and the associated productivity boost to the system were not realised in the riverine fish results due to the negative effect of low dissolved oxygen concentrations observed in the Carrathool zone. It is important to note that this monitoring project is restricted to the Narrandera and Carrathool zones of the Murrumbidgee River for spawning responses, and does not include assessment of spawning further downstream, in areas which may be affected by reduced discharge levels. In other river systems, and in absence of irrigation flows that appear to provide suitable in-channel hydrodynamic diversity, targeted environmental flows have been linked to spawning in flow-cued species such as golden and silver perch. Understanding the critical in-channel hydraulic thresholds for spawning in golden perch and silver perch within the Murrumbidgee River and then examining whether these thresholds are met in other parts of the Murrumbidgee River (particularly downstream) would be useful for extrapolating the results of the current monitoring program to other locations.

4.6 Hypoxic blackwater in the Lower Murrumbidgee River, 2016

Hypoxia can occur in rivers of the Murray-Darling Basin when increased carbon availability combined with warming water accelerates microbial oxygen consumption to a rate that exceeds aeration through passive diffusion and photosynthesis (Kerr, Baldwin et al. 2013). Hypoxia often coincides with high carbon concentrations, called "hypoxic blackwater" that can result when overbank flood events that inundate areas of floodplain where substantial amounts of red gum leaf litter have accumulated. In unregulated systems the natural hydrology of floodplains creates frequent overbank flow events that regulates leaf litter accumulation, with hypoxic blackwater arising from a reduction in overbank flood frequency in regulated systems (Whitworth, Baldwin et al. 2013).

Between September-December 2016 there was an unregulated overbank flood event that reconnected the Murrumbidgee River with large areas of floodplain. Hypoxic conditions developed as a result of increased carbon inputs associated the return of this water to the river downstream of Maude Weir. The Murrumbidgee flood recession and dissolved oxygen management flow (net usage of 370,839ML;

Table 3-2) was undertaken using a combination of Commonwealth environmental water, NSW Environmental water allowance (EWA) and The Living Murray (TLM) environmental water to mitigate the impacts of the hypoxic event.

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions	Measured outcomes	Was the expected outcome achieved
Murrumbidgee flood recession and dissolved oxygen management flow	improve water quality	What did CEW contribute to the recovery of dissolved oxygen concentrations in the lower Murrumbidgee River?	Improved initial recovery timing by 18 days; improved nominal DO recovery timing by 5 days	Yes
	reduce bank slumping of saturated banks.	Not evaluated	NA	NA
	minimising or preventing stranding of these animals on the floodplain	Not evaluated	NA	NA
	support the movement of native fish and other aquatic animals from the floodplain to the river channel, thereby	Not evaluated	NA	NA

Main findings from the hypoxic blackwater monitoring program

- Dissolved oxygen concentration began recovering 18 days earlier with environmental flows than without.
- Dissolved oxygen concentration recovered to within the nominal range (>4mg L^{-1}) 5 days sooner with environmental flows than without
- Recovery coincided with DOC concentrations <12 mg L^{-1}

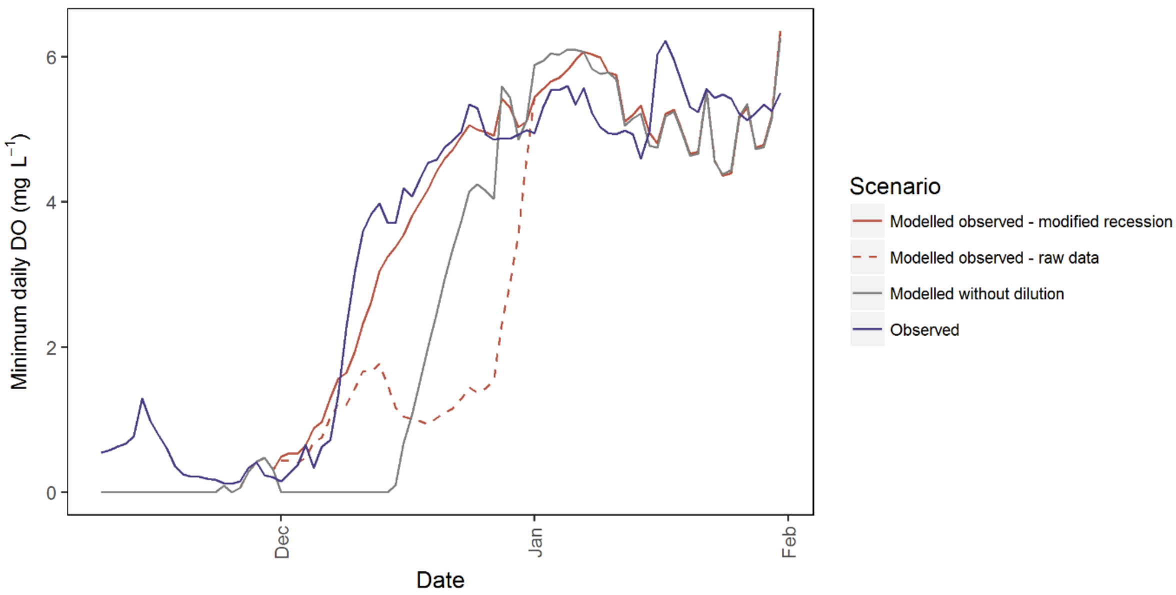


Figure 4-1: Blackwater intervention tool model results. Data show the observed minimum daily DO at Balranald, modelled observed DO with and without a decline in dilution flow volume, and modelled DO in the absence of environmental water.

Discussion, recommendations and adaptive management

This study shows a tangible benefit from the delivery of environmental water for the purpose of mitigating a large hypoxic blackwater event, accelerating a return to nominal water quality conditions in the lower Murrumbidgee River. The without-environmental water counterfactual presents a best-case outcome for the use of environmental water as the actual volumes passing Maude Weir may not have been reduced to the baseline end-of-system targets so soon on the recession of the flood. However, we also note that in this example the contribution of environmental water is only evaluated downstream of Redbank Weir. This delivery of environmental water will have diluted other return flows en route and contributed to an earlier recovery of DO concentrations at both Maude and Redbank Weirs. In this way, the contribution of the environmental flows are additive. However, with the available information this outcome cannot be evaluated for reaches upstream of Maude.

The return to normal DOC dilution (in the Murrumbidgee, DOC<=~3-5 mg L^{-1}) at the end of a flood recession is the most important aspect of recovery. DO in waterways is broadly considered to be acceptable at values > 4mgL^{-1}, harmful at 2-4mgL^{-1} and potentially lethal at values <2mgL^{-1} (Gehrke 1988) and though tolerances vary among species (King, Tonkin et al. 2012, Small, Kopf et al. 2014) we have adopted these benchmark values to rate the recovery of normal water quality conditions. In this case, DO appears to recover once DOC concentration falls to, or is diluted to below 12.5-15 mg L^{-1}. This concentration threshold will vary depending on temperature and reaeration, both of which vary in time and space and with discharge, so the results may not be universally applicable and each event should be individually assessed. This threshold provides a dilution target for similar actions in the future. However, until a more detailed empirical model, that accurately predicts DO outcomes across multiple events, is available, flow timing and volume should be managed for individual actions and be based on information available at the time.

5 Wetland responses to Commonwealth environmental water

Plate 5-1 Sampling fish and tadpoles at Mckennas Lagoon (mid-Murrumbidgee wetlands) September 2016

Summary of wetland monitoring activities 2016-17

Wetland monitoring is undertaken at 12 wetlands spread across three ecological zones in the Murrumbidgee Selected Area – the mid-Murrumbidgee, Nimmie-Caira and Redbank zones (Table 5-1, Figure 5-1). Wetland surveys are conducted four times per year in September, November, January and March and target water quality, nutrients and carbon, microinvertebrates, wetland vegetation, wetland fish, tadpoles, frogs, turtles, and waterbirds. Additional funding was made available to monitor key waterbird colonies in the Nimmie-Caria and Redbank zones where waterbirds began breeding in response to natural flooding and were later supported by the delivery of environmental water. Intensive monitoring of waterbird breeding, survival and recruitment success for major ibis colonies commenced in November 2016 and was completed in mid-March 2017. Additional monitoring breeding (number of nests) and recruitment (number of young) of heron, egret and cormorant colonies was done from October 2016 through to April 2017.

Table 5-1 Summary of monitoring activities and locations across three wetland zones in the Murrumbidgee floodplain (see Figure 5-1). D indicates that the site was dry throughout entire year and no samples for that indicator could be collected.

Site Name		Zone	ANAE classification	Nutrients , carbon, chl a	Microinvertebrate	Vegetation Diversity	Wetland Fish community	Frogs and turtles	Waterbird Diversity	Waterbird breeding (1)	Waterbird breeding (3)
Gooragool Lagoon	GOO	mid-Murrumbidgee	Permanent floodplain wetland	X	X	X	X	X	X		X
McKennas Lagoon	MCK		Intermittent river red gum floodplain swamp	X	X	X	X	X	X		
Sunshower Lagoon	SUN		Intermittent river red gum floodplain swamp	X	X	X	X	X	X		
Yarradda Lagoon	YAR		Intermittent river red gum floodplain swamp	X	X	X	X	X	X		X
Avalon Swamp	AVA	Nimmie-Caira	Temporary floodplain lakes	X	X	X	X	X	X		
Eulimbah Swamp	EUL		Temporary floodplain wetland	X	X	X	X	X	X	X	X
Nap Nap Swamp	NAP		Intermittent river red gum floodplain swamp	X	X	X	X	X	X		X
Telephone Creek	TEL		Permanent floodplain wetland	X	X	X	X	X	X		X
Mercedes Swamp	MER	Redbank	Intermittent river red gum floodplain swamp	X	X	X	X	X	X		
Piggery Lake	PIG		Permanent floodplain tall emergent marshes	X	X	X	X	X	X		X
Two Bridges Swamp	TBR		Intermittent river red gum floodplain swamp	X	X	X	X	X	X		X
Waugorah Lagoon	WAG		Permanent floodplain wetland	X	X	X	X	X	X		X

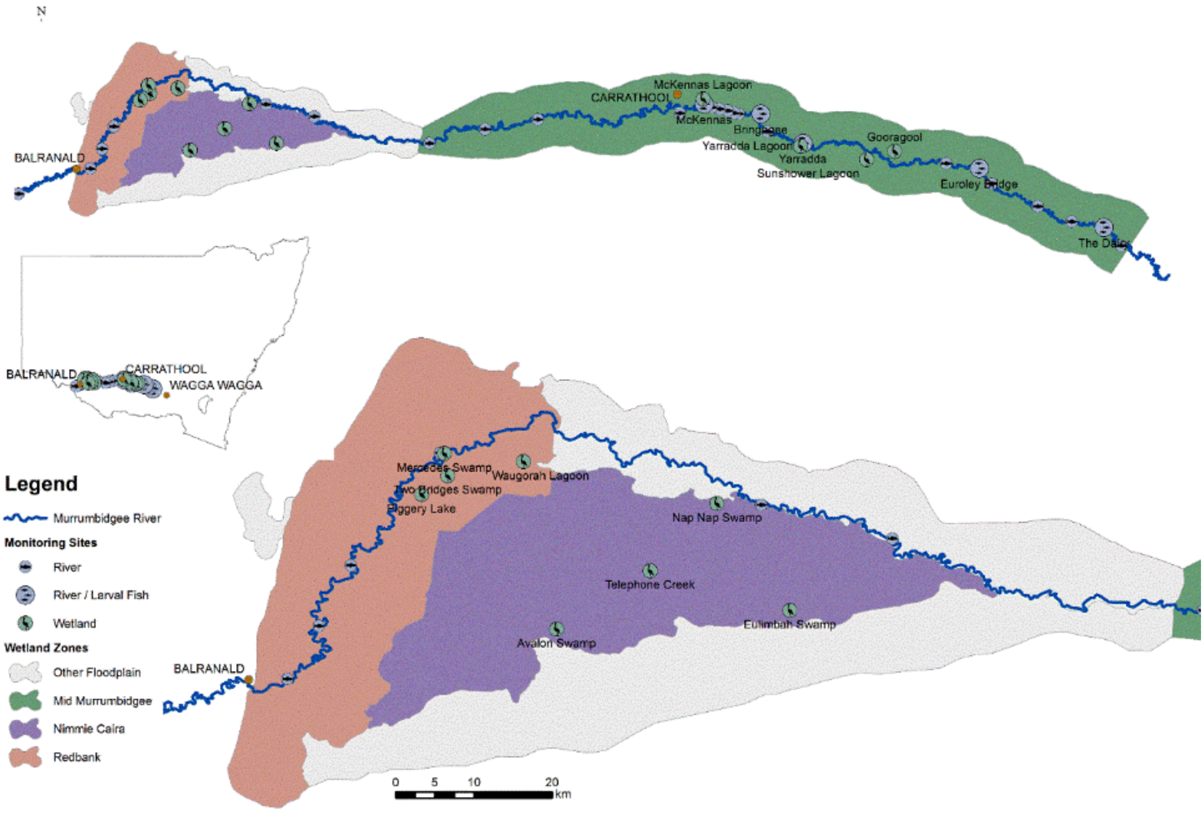


Figure 5-1 Distribution of wetland zones and key monitoring locations in the Murrumbidgee Selected Area

5.1 Wetland hydrology

Wetland hydrology indicators include inundation extent, water depth and volume. Inundation extent is estimated from inundation maps derived from the classification of Landsat satellite imagery. Water depth is measured in surveyed wetlands using depth loggers which can then be converted to wetland volume for use in ecological models.

The broad objective across the Murrumbidgee Selected Area is to "inundate wetland and refuge habitats", with individual watering actions focused on either maintaining inundation extents (water levels), increasing inundation extent or allowing flood recession. The intention is to re-instate a more natural inundation regime to support wetland vegetation and fauna life cycles, and more broadly ecosystem function. Most Commonwealth environmental watering actions during 2014-15, 2015-16 and 2016-2017 had wetland inundation targets. For this 2016-17 water year Commonwealth environmental water was delivered to maintain water levels in waterbird rookeries throughout the Lowbidgee after waterbird breeding began during the large natural flood in spring (October-November 2016). Commonwealth environmental water was also delivered to increase inundation extent in wetland and refuge habitats for lateral connectivity. Fresh and bankfull flows were delivered along the Murrumbidgee River and to the Lowbidgee floodplain to manage the flood recession of the natural event.

The inundation outcomes of environmental water actions across the Murrumbidgee Selected Area were assessed against the evaluation question "What did CEW contribute to inundation extents?" to determine if the expected outcomes were achieved in terms of maintaining, increasing or decreasing extents. The measured inundation outcomes are summarised as the total cumulative area of the floodplain inundated by the water action. Even though the unregulated flood was not a managed flow the inundation outcome of these flows was included because it was an important part of the 2016-17 inundation regime and influenced the water actions throughout the year.

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions	Measured outcomes	Was the expected outcome achieved
Nimmie-Caira to South Yanga Hypoxic water management Western Lakes Nimmie-Caira rookery maintenance North Redbank rookery maintenance Yanga rookery maintenance	Inundation of wetland rookery and refuge habitat in specified wetlands locations.	What did CEW contribute to inundation extents?	80,205 ha inundated	Yes

Main findings from the wetland hydrology monitoring program

- During 2016-2017 there was extensive inundation across the Lowbidgee floodplain due to unregulated flows, with a total annual area of almost 200,000 ha of the landscape inundated at least once during the water year (Figure 5-2 and Figure 5-3).
- Commonwealth water increased inundation in the wetland habitats of Nimmie-Caira to South Yanga inundating a cumulative area of 4,998 ha and habitats of Western Lakes inundating 1,024 ha.
- In the rookery sites of Nimmie-Caira, North Redbank, and Yanga National Park; Commonwealth and NSW environmental water actions maintained water levels and inundation extents prolonging inundation durations to allow sufficient time for waterbirds to complete breeding.

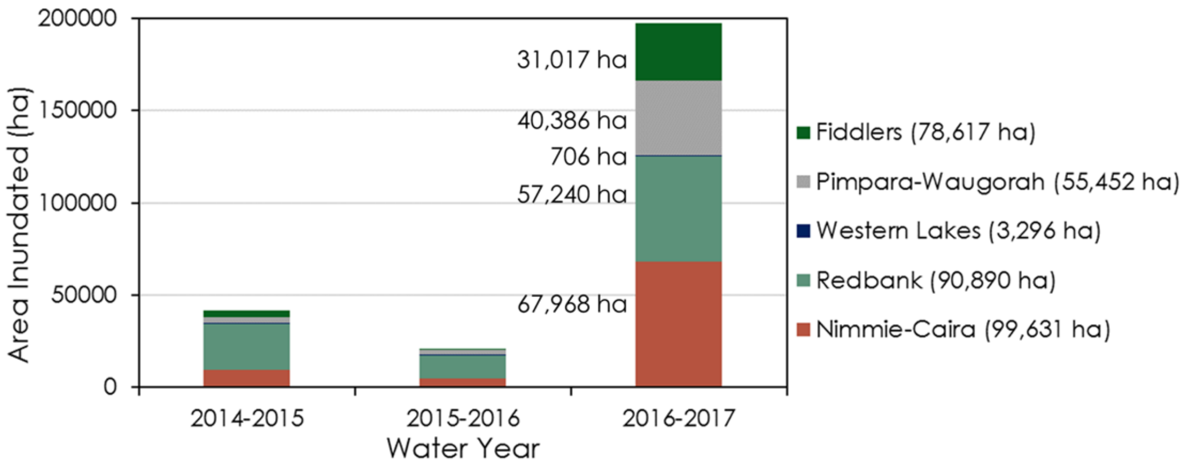


Figure 5-2 Annual cumulative total area (ha) of the floodplain inundated for the Lowbidgee floodplain and wetland zones for the 2014-2015, 2015-2016 and 2016-2017 water years.

Plate 5-2 Piggery Lake September 2016

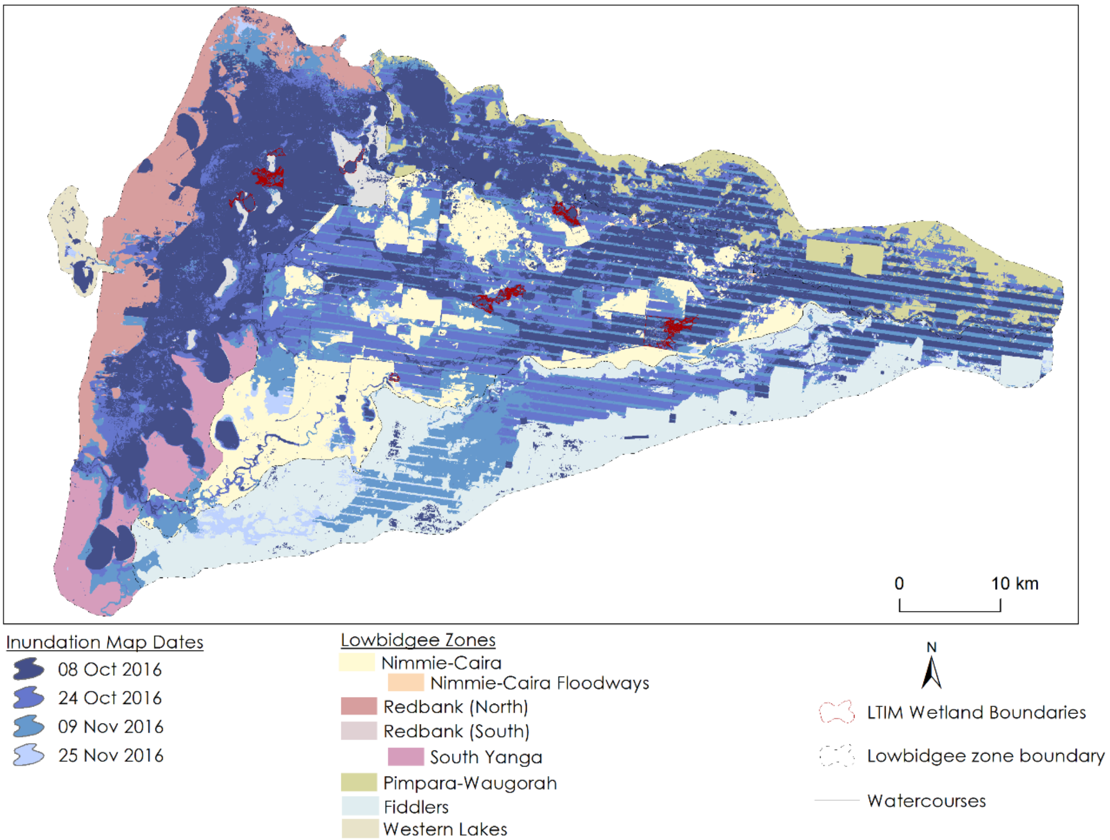


Figure 5-3 Inundation progression across the Lowbidgee floodplain during October and November 2016. Inundation maps are classified from Landsat satellite images and display inundation expansion from the top map date (earliest) to the bottom map date (latest). The striping effect is as a result of the missing data in the Landsat ETM+7 image dates (this data were used because regular cloud cover during the period obscured flooding in the Landsat 8 image dates).

Discussion, recommendations and adaptive management

Commonwealth environmental water was delivered to wetlands through the Nimmie-Caira and Redbank to “inundate wetland and refuge habitat” in the Murrumbidgee Catchment. The results of wetland hydrology inundation monitoring during the delivery of Commonwealth environmental water actions show clear evidence that these watering actions contributed inundation outcomes across the Lowbidgee floodplain. These inundation outcomes include maintaining inundation extents to stabilise water levels in waterbird breeding rookery sites of Nimmie-Caira and Redbank and increasing inundation extents in targeted core wetlands from Nimmie-Caira to South Yanga and in the Western Lakes.

5.2 Wetland water quality

In 2016-17 Commonwealth environmental watering focused on maintaining waterbird breeding events, initiated by widespread unregulated overbank flooding, and improving water quality in the river. Water quality was monitored as part of the quarterly wetland surveys in the Nimmie-Caira (Nap Nap, Eulimbah and Telephone Creek) and Redbank zone (Two Bridges and Piggery Lake) which included wetlands that supported waterbird breeding. Additional water quality monitoring was done as part of the waterbird breeding monitoring of large ibis colony sites (see Section 5.9). In wetlands, the quality of physical habitat for aquatic species can be affected by water quality (here defined as the physicochemical environment and concentrations of dissolved nutrients and carbon). Water quality outcomes in 2016-17 have no defined evaluation questions but serve as an important covariate that can explain patterns observed for other components of the Murrumbidgee LTIM program (Wassens, Jenkins et al. 2014). Here, we describe the patterns of water quality across the three wetland zones in 2016-17. We also evaluated the effectiveness of environmental flow deliveries in their support of waterbird habitat by comparing observed ranges of 1) physicochemical parameters and 2) concentrations of carbon, nutrients and chlorophyll-a against previously collected data and against other wetlands in the Murrumbidgee catchment. We evaluated the outcomes of Commonwealth environmental water against the following criteria:

- What did Commonwealth environmental water contribute to wetland water quality?

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support Nimmie-Caira: Nap Nap waterbird breeding support North Redbank: Tori Lignum Swamp waterbird breeding support	Support the habitat requirements of waterbirds	What did Commonwealth environmental water contribute to wetland water quality?	Water quality in wetland sites that received Commonwealth environmental water which supported active waterbird colonies remained within expected ranges during the delivery of environmental water.	Yes

Main findings from the Wetland Water Quality monitoring program

- Overall, water quality in the sampled wetlands remained within the expected ranges with some exceptions caused by the later stages of drying that fell outside the period of active nesting.
- For LTIM monitoring sites that received environmental water as part of waterbird breeding support (Two Bridges, Nap Nap, and Eulimbah swamps) water quality remained within expected ranges and adverse conditions were not detected.
- Water quality issues at Tori Lignum Swamp leading to botulism and subsequent waterbird deaths.

Discussion, recommendations and adaptive management

Commonwealth environmental water was delivered to wetlands through the Redbank and Nimmie-Caria wetland zones in order to "support the habitat requirements of waterbirds" in the Murrumbidgee Selected Area. Environmental water delivered to support waterbirds extended the period of inundation across sites in the Nimmie-Caira and Redbank zones, delaying the onset of poorer water quality conditions that often develop when climatic conditions become hot and wetland water levels decline. Wetland monitoring in 2016-17 at the 12 long-term monitoring sites did not identify any occasions where water quality is thought to have impacted on waterbirds, except for a brief drying event at Eulimbah Swamp in late November 2016. Additional water quality monitoring was carried out at waterbird rookery sites at Tori Lignum Swamp which identified low dissolved oxygen levels, the implications of which are discussed in Section 5.9.

5.3 Wetland microinvertebrates

Microinvertebrates are a food source for a wide range of fauna including larval and adult fish (King 2004), tadpoles and filter-feeding waterbirds (Horváth, Vad et al. 2013) and as such play a key role in floodplain river food webs. In 2016-17 Commonwealth environmental watering focused on maintaining waterbird breeding events, initiated by widespread unregulated overbank flooding, and improving water quality in the river. In both 2014-15 and 2015-16, Commonwealth environmental water was delivered to wetlands in order to improve water quality and to support the feeding habitat and breeding requirements of native vegetation, waterbirds, fish and other vertebrates (turtles, frogs).

Inundation of wetlands stimulates emergence and reproduction of microinvertebrates, often resulting in an abundant food supply. In 2016-17 environmental watering occurred in the Nimmie-Caira system, the Redbank and mid-Murrumbidgee wetlands. We monitored benthic and pelagic microinvertebrate communities in wetlands and three river comparison sites coinciding with the wetland fish and tadpole monitoring from September 2016 to March 2017.

Microinvertebrate outcomes in 2016-17 have no defined evaluation questions but serve as an important covariate that can explain patterns observed for other components of the Murrumbidgee LTIM program (Wassens, Jenkins et al. 2014). Here, we describe the patterns of microinvertebrate productivity and diversity across the three wetland zones in 2016-17. We also evaluated the effectiveness of environmental flow deliveries in their support of waterbird habitat by comparing observed ranges of 1) microinvertebrate taxa and 2) densities and composition of microinvertebrates against previously collected data in the Murrumbidgee catchment.

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support Nimmie-Caira: Nap Nap waterbird breeding support	Improve aquatic habitat, water quality and riparian vegetation Support the habitat and breeding requirements of native vegetation, waterbirds and fish	What did Commonwealth environmental water contribute to wetland productivity nutrients and carbon fluxes, primary productivity (CHL a) and secondary productivity (Microinvertebrates)?	High densities of microinvertebrates observed throughout spring and summer, dominated by copepods with cladocerans and ostracods present	Yes

Main findings from the Wetland Water Quality monitoring program

- High densities of microinvertebrates (500-1000 /L) were recorded following inundation of monitored wetlands with Commonwealth environmental water in 2016-17, 2015-16, and 2014-15.
- Densities were higher in the mid-Murrumbidgee (Yarradda Lagoon) and Nimmie-Caira wetlands than in the Redbank wetlands in both years.
- In all watering years, densities of microinvertebrates fell by March in all zones.
- In all watering years, copepods dominated wetland assemblages, with cladocerans and lower densities of ostracods also present.
- Responses of microinvertebrates to inundation were consistent across years suggesting the current regime of wetting and drying is maintaining the egg bank and high levels of productivity.

Discussion, recommendations and adaptive management

In 2016-17, 2015-16 and 2014-15, Commonwealth environmental water was delivered to wetlands in order to improve water quality and to support the feeding habitat and breeding requirements of native vegetation, waterbirds, fish and other vertebrates (turtles, frogs). The current water regime is yielding productive feeding habitats for filter-feeding waterbirds, fish, larval fish and tadpoles in terms of microinvertebrate densities. Based on information from fisheries research, microinvertebrate densities between 100-1000 /L support larval fish and adult fish that predate on microinvertebrates (King 2004). Required microinvertebrate densities for waterbirds and tadpoles are not known.

The fall in microinvertebrate densities in March is likely due to falling temperatures, depletion of nutrients as inundation extends, possibly increased predation pressure as water levels fall and declining water quality as wetlands dry.

Based on research in the MDB for microinvertebrates, frequent (annual for wetlands with this historical frequency) inundation of wetlands with some drawdown over winter yields the most productive sites for microinvertebrates. Inundation needs to be long enough for biota to complete life cycles and for microinvertebrates at least 3-5 months. It is important that the drying phase is also adequate to allow terrestrial decomposition processes to replenish soil nutrients, but the exact length is not known.

Restoring the natural wetting and drying regimes to floodplain wetlands, and maintaining a mosaic of inundation frequencies will continue to provide suitable conditions for microinvertebrates.

5.4 Vegetation diversity

The wetlands included in this monitoring program represent a diversity of vegetation community types: Lignum and Lignum-Black Box through the Nimmie-Caira; fringing river red gum wetlands in the mid-Murrumbidgee; and river red gum-spike rush communities through the Redbank zones. Due to unregulated flows creating very wet conditions during 2016-17 all of the 12 monitored wetlands filled in spring 2016, with McKenna's and Sunshower Lagoons, in the mid-Murrumbidgee zone, filling completely for the first time since 2011-12.

In 2016-17 Commonwealth environmental watering was primarily focused on maintaining waterbird breeding events and improving water quality in the river. However, watering undertaken across the floodplain had the secondary objective to "*Maintaining and improving the condition of wetland vegetation*" and these actions were monitored in three wetlands in the Nimmie-Caira (Nap Nap Swamp, Eulimbah Swamp and Telephone Creek) and two in the Redbank zone (Two Bridges Swamp and Piggery Lake).

The persistence of wetland plant communities can also be influenced by the length of time between wet periods. Long dry periods can allow the establishment of longer lived terrestrial species, and facilitate river red gum (*Eucalyptus camaldulensis*) encroachment into wetlands. Environmental watering actions that target plant communities seek to reinstate the natural hydrological regime to maintain aquatic species.

Plate 5-3 Cycle of vegetation community at Piggery Lake from November 2014 to January 2017.

November 2014 (Inundated 1 month)

January 2016 (dry)

January 2017 (inundated 5 months)

In order to determine the extent to which the Commonwealth environmental watering actions achieved their objectives with respect to riparian, floodplain and native vegetation to "*Maintaining and improving the condition of wetland vegetation*" we considered three key aspects of the plant community response 1) species diversity (number of species), in particular the diversity of water dependent species, 2) the community diversity which is a measure of the number of unique plant communities (groups of species) that formed following environmental water, and 3) the relative abundance of water dependant plant species following environmental water when compared to dry sites.

Unlike previous years where Commonwealth and NSW state environmental water were the only source of water for floodplain wetlands, there was extensive unregulated flows that inundated floodplain wetlands in 2016-17. In addition to inundating the regularly watered sites, higher river flows reconnected two wetlands that had not received water since 2011. This allowed for a comparison between wetland plant communities that had received environmental water in 2014-15 and 2015-16 as well as reconnecting during high river flows in 2016-17 and those that were only inundated in 2016-17. We evaluated the outcomes of Commonwealth environmental water against the following criteria:

Did Commonwealth environmental water contribute to vegetation species diversity?

Did Commonwealth environmental water contribute to vegetation community diversity?

Did environmental watering influence the types of species present in wetlands?

Summary of watering actions and outcomes

Monitored Watering Action (s) in 2016-17	2016-17 Acquittal Report Expected outcomes	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support Nimmie-Caira: Nap Nap waterbird breeding support	Maintaining and improving the condition of wetland vegetation	Did Commonwealth environmental water contribute to vegetation species diversity?	Vegetation species richness is a reflection of the number of species present in each of the monitored vegetation communities. Significant relationships between number of water dependent species and soil moisture and water depth. Cumulative species richness is increasing at a faster rate at wetlands receiving environmental water.	Yes
		Did Commonwealth environmental water contribute to vegetation community diversity?	Vegetation community diversity reflects district vegetation community types recognised under the LTIM Ecosystem diversity classification. In 2016-17 environmental watering targeted three of the four vegetation communities monitored as part of this program: Lignum, Lignum-black box and Tall emergent aquatic communities.	Yes
		Did environmental watering influence the types of species present in wetlands?	51 native water-dependant species were recorded since September 2014. There are significant differences in the composition of understory plant communities at wetlands receiving environmental water compared with wetlands inundated only during un-regulated flows and not receiving environmental water (see table 5.2). With the more frequently watered sites supporting higher diversity and higher cover of native aquatic species.	Yes

Main findings from the vegetation diversity monitoring program

Wetlands in the mid-Murrumbidgee that did not receive environmental water in either 2014-15 or 2015-16 (Sunshower and McKennas Lagoons) were dominated by a mix of native and exotic terrestrial species, with a low diversity of aquatic species, while sites that have been regularly watered were dominated by native species with a mix of aquatic and terrestrial species (Table 5-2, Plate 5-4).

Overall 224 species (160 native and 64 exotic) have been recorded since September 2014, with 51 aquatic species recorded.

Overall species richness did not change significantly over time, when considered across all the monitoring sites, but there have been notable increases in the number of aquatic species at individual wetlands. For example, repeat environmental watering of Yarradda Lagoon in 2014-15 and 2015-16 has supported the reestablishment of key aquatic species including spiny mudgrass (*Pseudoraphis spinescens*), tall spike rush (*Eleocharis sphacelata)*, and fringe lily (*Nymphoides crenata*).

Table 5-2 Species that contribute to vegetation communities at wetlands in the mid-Murrumbidgee receiving environmental water in (2014-15, 2015-16) and non-target reconnection in 2016-17 (wet for 3 years) and wetlands only inundated in 2016-17 during high river flows (wet for 1 year).

Species that occur in higher abundance at wetlands that received environmental water in 2014-15 and 2015-16	**Species that occur in higher abundance at wetlands that did not receive environmental water**
Common spike rush (*Eleocharis acuta*)	Spear Thistle (*Cirsium vulgare*) *
spiny mudgrass *(Pseudoraphis spinescens)*	tufted-burr daisy (Calotis scapigera)
Common sneeze weed (*Centipeda cunninghamii*)	small crumbweed (Dysphania pumilio)
creeping knotweed (*Prsicaria prostrata*)	wireweed * (Polygonum aviculare)
lesser joyweed (*Alternanthera denticulata*)	Exotic annual grass*

* Indicates introduced species,

Plate 5-4 Vegetation response in Gooragool Lagoon, mid-Murrumbidgee (September 2016).

Discussion, recommendations and adaptive management

In 2016-17 most wetland inundation occurred as a result of unregulated inflows, with Commonwealth environmental watering actions extending the inundation duration at wetlands in the Nimmie-Caria with the primary objective of supporting waterbird breeding, and a secondary objective of "*Maintaining and improving the condition of wetland vegetation*". The vegetation communities recorded in 2016-17 were typical of what would be expected during a very wet year, with high percent cover of open water and deeper water contributing to lower diversity and percent cover of terrestrial species, and a small increase in the diversity of aquatic species.

In the mid-Murrumbidgee wetlands, the diversity of aquatic species continues to increase at Yarradda and Gooragool Lagoons which received environmental water in 2014-15 and 2015-16 and filled during unregulated flows in 2016-17. In the Lowbidgee floodplain, the wetlands monitored as part of this program have received regular inundation over several years and the aquatic vegetation communities are in good condition, with high proportion of native species. In these wetlands, the observed changes in species richness and community composition reflect annual variability in wet-dry transitions, consistent with Commonwealth environmental water objective of maintaining wetland vegetation. Each of the wetlands considered here support a distinct vegetation community that has been shaped by the wetlands geomorphology and long-term hydrological patterns. To maximise outcomes of aquatic plant species, watering actions should aim to match, to the greatest extent practical, the historic long-term watering regime, including the maintenance of drying phases where appropriate for the individual wetland. Watering actions that result in a complete fill of the wetland and inundate the fringing vegetation communities are also likely to support a greater diversity of native species then those that target the main body of the wetland only, because they support the growth of annual native species that establish as the water levels decline.

5.5 Frogs and turtles

Environmental watering actions can be used to maintain amphibious vertebrate populations via two key mechanisms: providing persistent refuge habitat that supports frog and turtle populations during periods of low water availability, and through the provision of shallow temporary standing water that provides breeding habitat and supports tadpole growth and survival. In 2016-17 pre-watering of key southern bell frog habitats was undertaken in winter 2016 (*Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake*)) with the objective to "Maintain wetland and floodplain vegetation condition and provide suitable habitat for a range of waterbird, native fish and frog species, including southern bell frog (EPBC Act vulnerable)". This watering action was paused in early spring due to widespread rainfall that led to natural inundation across the mid-Murrumbidgee and Lower-Murrumbidgee floodplain. As water from the natural inundation receded, a series of environmental watering actions focused on supporting waterbird breeding in the Nimmie-Caria and Redbank systems were undertaken (Monitored actions included: Nimmie-Caira: Eulimbah waterbird breeding support, Nimmie-Caira: Telephone Bank waterbird breeding support, Nimmie-Caira: Nap Nap waterbird breeding support and Yanga National Park: waterbird support), which had the secondary objective of "supporting the habitat requirements of native fish and other aquatic animals". These four watering actions extended the duration of inundation at four monitoring sites (Eulimbah, Telephone and Nap Nap in the Nimmie-Caria and Two Bridges in the Redbank system). In the mid-Murrumbidgee all four monitored wetlands connected during natural periods of high river flows, while the Murrumbidgee River Fresh targeted reaches from Wagga Wagga downstream and included the objective of supporting movement of native fish and other aquatic animals from the floodplain to the river. In addition, two of these sites (Yarradda Lagoon and Gooragool Lagoon) benefited from environmental watering in 2014-15 and 2015-16, and Yarradda Lagoon was still partly full when it reconnected during unregulated flows in September 2016. McKenna's Lagoon received a partial fill during the Murrumbidgee River Fresh while Sunshower Lagoon had previously received a partial fill in 2015-16. Detailed evaluation outcomes of each watering action are in the appendices of this report. This report section summarises key outcomes for frogs and tadpoles and turtle with respect to three key evaluation criteria:

What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?

What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?

What did Commonwealth environmental water contribute to the maintenance of refuge habitats?

Summary of watering actions and outcomes

Expected outcomes	Related watering actions	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Supporting habitat for wetland vertebrates Maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC Act vulnerable)	Yanga National Park: waterbird support Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga Nimmie-Caira: Nap Nap waterbird breeding support	What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?	Six frog and three turtle species were recorded in 2016-17, including the vulnerable (EPBC Act) southern bell frog. Which is the same as previous years.	Yes
		What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?	Breeding activity for all six frog species known to occur across the monitoring sites was recorded in response to Commonwealth environmental water. Very high abundances of southern bell frogs at Nap Nap swamp suggesting that successful recruitment took place within and around this wetland in 2016-17. Hatchling turtles of two species (eastern long-neck and Macquarie turtle) were recorded in the Redbank system	Yes
		What did Commonwealth environmental water contribute to the maintenance of refuge habitats?	Three species of freshwater turtles recorded are now present at Yarradda lagoon which received Commonwealth water in 2014-15 and 2015-16. Telephone Creek and Wagourah Lagoon continue to act as important refuge for turtles and frogs	Yes

Main findings from frog and turtle monitoring program

Watering actions in the Nimmie-Caira targeting Nap Nap Swamp in association with unregulated flows and a second environmental watering action targeting waterbirds, supported breeding by southern bell frogs with over 300 individuals recorded in March 2017.

Breeding activity for all six frog species known to occur across the monitoring sites was recorded at wetlands receiving Commonwealth environmental water.

Three turtle species were recorded, the eastern long-necked turtle, broad shell turtle and Macquarie turtle. Hatchlings of eastern long-neck and Macquarie turtle were recorded in the Redbank system.

Discussion, recommendations and adaptive management

Above average rainfall in 2016-17 resulted in considerable unregulated inundation of floodplain wetlands through the mid-Murrumbidgee and Lowbidgee floodplains, and the responses of frogs and turtles to environmental watering needs to be considered in the context of these unregulated flows as well as past environmental watering actions. With the exception of the Nimmie-Caira to South Yanga action which had specific objectives for frogs, the majority of actions undertake in 2016-17 had a primary objective of supporting bird breeding and the secondary objective of supporting habitat requirements of native fish and other aquatic animals. Overall, Commonwealth environmental watering were successful in supporting habitat for frogs and turtles and this is reflected in the breeding activity of key floodplain species. In addition previous watering actions aimed at maintaining refuge habitats in 2015-16 and to support southern bell frog populations in the Nimmie-Caira (Nap Nap Swamp) are likely to have contributed to notable positive outcomes for southern bell frogs at this site in 2016-17. Our ability to detect a response for frogs, tadpoles and turtles may have been lower in 2016-17 because we were unable to access wetlands sites through spring due to flooding and the availability of additional floodplain habitats allowed individuals to disperse away from the long-term monitoring sites into newly created habitats. High levels of predation by nesting waterbirds may have further reduced frog populations at these sites in 2016-17 compared to previous years.

The maintenance of refuge habitats, mainly Yarradda, Telephone Creek and Wagourah Lagoon, remains an important management objective and contribute to positive outcomes for frogs and turtle populations. The maintenance of refuges is particularly important for broad shell turtles which are restricted to these sites. Very positive outcomes for the southern bell frog in the Nimmie-Caira demonstrate the value of supporting key populations through the maintenance of a few key areas of persistent aquatic habitats. However, the maintenance of refuges alone is not sufficient to support populations in the long-term; the inundation of temporary, less frequently inundated sections of these wetlands, particularly actions that create large areas of shallow temporary water, are critical to successful recruitment and breeding. For example, in years of high water available undertaking large, whole of floodway watering actions through Nimmie-Caira and Redbank may be preferable to under taking multiple smaller actions throughout the Murrumbidgee because they are more likely to allow for thresholds linked to frog and water bird breeding to be met.

Plate 5-5 Inland Banjo frog (*Limnodynastes interioris*) (January 2017).

5.6 Wetland fish

Native fish communities in the Murrumbidgee catchment are severely degraded, exhibiting declines in abundance, distribution and species richness (Gilligan 2005). In particular small-bodied floodplain species such as the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis agassizii*) were historically abundant throughout Murrumbidgee River wetland habitats (Anderson 1915, Cadwallader 1977) but are now considered locally extinct from the mid and lower Murrumbidgee (Gilligan 2005). River regulation has significantly contributed to native fish declines in the Murrumbidgee Catchment. Reductions in the frequency and duration of small-medium natural flow events prevent regular connections between the river and off-channel habitats (Arthington and Pusey 2003).

Five watering actions delivered during 2016-17 were monitored as part of the LTIM project that have objectives relating to native fish communities in wetlands. The first of these was delivered to the Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake), seeking to maintain wetland aquatic communities, including wetland fish. This action inundated several wetlands of the Nimmie-Caira and Redbank zones in August and the early part of September 2016, but was paused and later cancelled due to widespread rainfall in September and October. After the subsequent unregulated, overbank flow event that inundated all 12 LTIM wetlands, environmental water was delivered to the Nimmie-Caria and Redbank systems to support nesting waterbirds that began breeding in response to the unregulated flows. While multiple watering actions were undertaken across the Lowbidgee floodplain, LTIM monitoring sites where this water was delivered include Eulimbah swamp, Telephone Bank, Nap Nap swamp and Yanga National Park. These deliveries also sought to “support habitat requirements of native fish”. Here, we evaluate the environmental watering actions targeting wetland fish communities under two overarching criteria:

What did Commonwealth environmental water contribute to native fish populations and native fish diversity?

What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?

Summary of watering actions and outcomes

<table>
<tr><th>Watering Action (s) in 2016-17</th><th>MEP and 2016-17 Acquittal Report Expected outcomes</th><th>Evaluation questions</th><th>Measured outcomes</th><th>Was the expected outcome achieved</th></tr>
<tr><td rowspan="2">Yanga National Park: waterbird support

Nimmie-Caira: Eulimbah waterbird breeding support

Nimmie-Caira: Telephone Bank waterbird breeding support

Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga

Nap Nap waterbird breeding support</td><td rowspan="2">Supporting habitat for wetland vertebrates

Maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC Act vulnerable)</td><td>What did Commonwealth environmental water contribute to native fish populations and native fish diversity?</td><td>Seven native and four exotic species were captured in 2016-17.
Silver perch juveniles and flathead gudgeon were collected at Yarradda Lagoon increasing the overall number of native species collected from six in 2014-15 to eight.</td><td>Yes</td></tr>
<tr><td>What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?</td><td>Evidence of recruitment and survival was identified in three native species, carp gudgeon, Australian smelt and bony herring.</td><td>Yes</td></tr>
</table>

Main findings from wetland fish monitoring program

- Eight native and five exotic species were captured across 12 LTIM surveyed wetland sites that contained water between September 2016 and March 2017.
- Silver perch juveniles and flathead gudgeon were collected Yarradda Lagoon for the first time since monitoring began.
- As in previous years exotic fish species were widespread, with gambusia, common carp, goldfish and oriental weatherloach the most commonly recorded exotic species.
- Increased fish survival was recorded at wetlands where environmental water has maintained persistent refuges between water years (Yarradda Lagoon and Waugorah Lagoon).
- Changes in the size structure of wetland fish populations identified a second cohort of native fish at wetlands that received follow-up environmental watering to maintain waterbird breeding.

Discussion, recommendations and adaptive management

Five watering actions that had outcomes targeting wetland fish communities were monitored in 2016-17. These included deliveries to support waterbird breeding in the Nimmie-Caira and Yanga monitoring zones (Table 3-1). These actions were successful in prolonging the period of fish occupation in target wetlands, allowing the development of more mature fish. By providing ongoing habitat for fish survival in wetlands these environmental watering actions achieved their stated objectives in providing support for breeding waterbirds that rely on fish as a food resource. However, we note that overall wetland fish communities remain in poor condition and are dominated by highly abundant opportunistic generalist species with floodplain specialist species, those that still survive in parts of the Murrumbidgee Catchment (such as Murray hardyhead), generally absent from wetland data. None of the species previously recorded by LTIM appear to have been lost from wetland survey data and we continue to see increased use of wetlands in the mid-Murrumbidgee by larger-bodied native fish (golden and silver perch). The ongoing use of wetlands by these species suggests the successive years of environmental watering is maintaining existing populations. The unregulated overbank event in 2016-17 presents opportunities for broad-scale fish movements and depending on the hydrology of wetlands in subsequent years it is possible that some populations may return over successive years as a result of this high flow.

In general, common widespread fish species are spawning, growing and recruiting most often in wetland habitats. At least two separate spawning events by native species were identified in 2016-17, one earlier in the season and one later, varying among zones and species. In contrast, the catch of carp was dominated by juveniles that were spawned during the early stages of the unregulated event, with the population consistently ageing across the monitoring year, demonstrating that environmental watering actions did not have a large impact on carp reproduction.

5.7 Waterbird diversity

Commonwealth environmental water was delivered to wetlands in the Redbank and Nimmie-Caria wetland zones as part of seven watering actions in 2016-17: Nimmie-Caira to South Yanga winter event; Redbank (Yanga National Park) waterbird breeding support; North Redbank waterbird breeding support; and four Nimmie-Caira waterbird breeding support actions targeting separate colony sites (Telephone Bank, Eulimbah Swamp, Nap Nap Swamp and Kieeta Lake). The broad objective across the Murrumbidgee Selected Area is to "support the habitat requirements of waterbirds", with individual watering actions focused on either maintaining habitat for waterbirds or supporting breeding outcomes.

We assessed the responses of waterbird diversity and abundance to environmental watering actions across the Murrumbidgee Selected Area against four key evaluation questions to determine the extent to which the expected outcomes were achieved.

What did Commonwealth environmental water contribute to waterbird species diversity?

What did Commonwealth environmental water contribute to waterbird species of conservation significance?

What did Commonwealth environmental water contribute to waterbird abundance?

What did Commonwealth environmental water contribute to non-colonial waterbird breeding?

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Nimmie-Caira to South Yanga Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support Nimmie-Caira: Nap Nap swamp waterbird breeding support Nimmie-Caira: Kieeta Lake pelican breeding support Yanga National Park: waterbird breeding support North Redbank: Tori Lignum waterbird breeding support	Support the habitat requirements of waterbirds	What did Commonwealth environmental water contribute to waterbird species diversity?	Total waterbird diversity was higher in wetlands inundated by Commonwealth environmental water and other sources of inundation including natural flooding, compared to sites not inundated from 2014-17.	Yes
		What did Commonwealth environmental water contribute to waterbird abundance?	Total waterbird abundance was higher in wetlands inundated by Commonwealth environmental water and other sources of inundation including natural flooding, compared to sites not inundated from 2014-17.	Yes
		What did Commonwealth environmental water contribute to waterbird species of conservation significance?	Conservation significant species recorded include the nationally endangered Australasian bittern (EPBC Act), migratory shorebird species (JAMBA, CAMBA and ROKAMBA, and the NSW listed (TSC Act) blue-billed duck, freckled duck and magpie goose. Breeding by JAMBA listed Eastern great egrets was also recorded at wetlands inundated with Commonwealth environmental water	Yes
		What did Commonwealth environmental water contribute to non-colonial waterbird breeding?	Overall, a high number of non-colonial waterbird species were observed breeding in the Murrumbidgee in 2016-17 (14 species) compared to the previous two water years (2014-15 (4 species) and 2015-16 (8 species) at wetlands inundated with Commonwealth environmental water.	Yes

Main findings from waterbird monitoring program

- Waterbird species diversity and total waterbird abundance was greater in monitored wetlands from 2014-17 that were inundated by Commonwealth environmental water and other sources of inundation compared to sites that were dry.
- Wetlands that received Commonwealth environmental water supported species of conservation significance including the endangered Australasian bittern *Botaurus poiciloptilus* (EPBC Act) and vulnerable blue-billed duck *Oxyura australis*, freckled duck *Stictonetta naevosa* and magpie goose *Anseranas semipalmata* (NSW TSC Act 1995), and species listed on international migratory agreements including marsh sandpiper *Tringa stagnatilis* and sharp-tailed sandpiper *Calidris acuminata* (JAMBA, CAMBA and ROKAMBA).
- Commonwealth environmental water delivered in 2016-17 contributed to breeding in 14 species of non-colonial waterbirds in wetlands across the Murrumbidgee Selected Area (note that the contribution of Commonwealth environmental water to colonial waterbird breeding is assessed in more detail in Section 5.9 Waterbird Breeding).

Discussion, recommendations and adaptive management

Commonwealth environmental water was delivered to wetlands through the Redbank and Nimmie-Caria wetland zones in order to "support the habitat requirements of waterbirds" in the Murrumbidgee Selected Area. The results of the quarterly LTIM wetland surveys and complementary NSW OEH monitoring indicated that delivery of Commonwealth environmental water contributed to waterbird outcomes across the Murrumbidgee Selected Area by supporting increased waterbird diversity and abundance, and breeding activity in non-colonial species. Environmental water created wetland habitat for at least 60 species of waterbirds, including threatened species and species listed under international migratory bird agreements (Table 6-19).

Several approaches to environmental water management can be taken to maximise outcomes for waterbird populations, though the options available to environmental water managers will vary according to the water availability scenario for a given water year. The timing of flows, total wetland area inundated and types of habitat inundated are important factors influencing the total number and type of waterbird species. The Lowbidgee Floodplain is regionally significant for waterbird populations and has been identified as a key site that can be actively managed to contribute to the recovery of waterbird populations across the MDB (Murray-Darling Basin Authority 2014). To achieve this objective, we recommend future management of Commonwealth environmental water in the Murrumbidgee Selected Area consider the following:

- The provision of wetland habitat in spring and summer to meet the water requirements of a whole range of waterbird species including migratory species, and non-colonial and colonial waterbird breeding species. Timing the delivery of flows in late winter-early spring allows birds to access foraging habitat and build condition prior to them pairing up and establishing nests for their broods later in spring and summer months. The delivery of Commonwealth and NSW environmental water over late winter 2016 inundated a range of wetland habitats over a large area effectively priming the system prior to natural flooding in spring 2016. It is possible to undertake this landscape-scale watering approach in the Lowbidgee floodplain in median to wet years to maximise waterbird responses in spring, particularly if unregulated flood event happens following these large environmental watering events.
- Using environmental water to maintain inundated habitat into summer and autumn can enhance feeding and breeding opportunities for waterbirds. Where flows target active colony sites, this can also provide outcomes for non-target species using the same habitats, enhancing waterbird diversity and abundance outcomes across the Murrumbidgee Selected Area. This added benefit was observed during the 2016-17 water year where environmental water was delivered to maintain inundation at six active colony sites from November 2016 to March 2017 to support successful breeding (see Section 5.9 Waterbird Breeding). These watering actions also enhanced waterbird diversity across the Murrumbidgee Selected Area and provided breeding opportunities for non-colonial waterbird species.

- In the months and years following large natural flood events in the Murrumbidgee Selected Area and neighbouring catchments, Commonwealth environmental water should be prioritised for delivery to key waterbird foraging areas to promote the survival of waterbirds and contribute to the maintenance of waterbird diversity and increased abundance of waterbirds across the MDB.

5.8 Waterbird breeding

Commonwealth environmental water was delivered to wetlands in the Redbank and Nimmie-Caria wetland zones as part of seven watering actions in 2016-17: Nimmie-Caira to South Yanga winter event; Redbank (Yanga National Park) waterbird breeding support; North Redbank waterbird breeding support; and four Nimmie-Caira waterbird breeding support actions targeting separate colony sites (Telephone Bank, Eulimbah Swamp, Nap Nap Swamp and Kieeta Lake). The broad objective across the Murrumbidgee Selected Area was to "support the habitat requirements of waterbirds', with individual watering actions focused on maintaining breeding and feeding habitat to support breeding outcomes.

The responses of colonial waterbird species, including ibis, spoonbills, pelicans, egrets and herons to environmental watering actions across the Murrumbidgee Selected Area were assessed against two key evaluation questions to determine the extent to which the expected outcomes were achieved.

What did Commonwealth environmental water contribute to colonial waterbird breeding?

What did Commonwealth environmental water contribute to waterbird fledging and survival?

Summary of watering actions and outcomes

Watering Action (s) in 2016-17	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions	Measured outcomes	Was the objective achieved
Nimmie-Caira to South Yanga Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support Nimmie-Caira: Nap Nap swamp waterbird breeding support Nimmie-Caira: Kieeta Lake pelican breeding support Yanga National Park: waterbird breeding support and North Redbank: waterbird breeding support	Maintain rookery water levels to support successful breeding, fledging and recruitment of waterbird species. Provide foraging habitat to prevent reduction in food sources due to drying.	What did Commonwealth environmental water contribute to colonial waterbird breeding?	Commonwealth environmental water supported breeding by 19 species of colonial waterbirds (and at least 14 non-colonial waterbirds) which is a substantial increase from 2014-15 and 2015-16 Commonwealth environmental water supported at least 3 large ibis colonies (Straw-necked and White ibis) and tree-nesting egrets, herons and cormorants as well as a large pelican breeding colony	Yes
		What did Commonwealth environmental water contribute to waterbird fledging and survival?	Commonwealth environmental water increased reproductive success rates of colonial nesting water birds at Eulimbah Swamp Kieeta Lake pelican colony supported the completion of a large Australian pelican colony (estimated 6,000 nests).	Yes

Main findings from waterbird monitoring program

Commonwealth environmental water delivered in 2016-17 contributed to breeding in 19 species of colonial waterbirds (and at least 14 non-colonial waterbird species) in wetlands across the Murrumbidgee Selected Area (the contribution of Commonwealth environmental water to non-colonial waterbird diversity, abundance and breeding activity is assessed in more detail in Section 5.8 Waterbird Diversity).

Commonwealth environmental water was used to support six large colony sites in the Lowbidgee floodplain by extending the duration and depth of inundation in each colony site and providing foraging habitat in each colony and neighbouring wetlands.

We predicted that maintenance of water levels and increased flow rates in colony sites using Commonwealth environmental water would support successful fledging of colonial waterbird chicks and this was supported by our 2016-17 monitoring results. Overall reproductive success rates for straw-necked ibis (number of eggs laid that became fledged juvenile birds) were Eulimbah Swamp colony (59.44%) and Tori Lignum Swamp ibis colony (39.74%)

Active colony sites that received Commonwealth environmental water supported species of conservation significance including the Eastern great egret listed on the international migratory bird bilateral agreement JAMBA.

Discussion, recommendations and adaptive management

Commonwealth environmental water was delivered to wetlands through the Redbank and Nimmie-Caria wetland zones in order to "support the habitat requirements of waterbirds" in the Murrumbidgee Selected Area. The results of the Category 1 waterbird breeding led by UNSW and complementary Category 3 monitoring led by NSW OEH monitoring demonstrated that the delivery of Commonwealth environmental water in 2016-17 contributed to the success of waterbird breeding outcomes across the Lower Murrumbidgee (Lowbidgee) Floodplain. In particular at Eulimbah swamp where Commonwealth water supported successful fledging following the initial abandonment of nests which occurred following a levee breach. The the delivery of Commonwealth environmental water also provided newly inundated foraging habitat adjacent to the colony that was exploited by juvenile ibis and spoonbills and may have improved water quality within the rookery sites.

The Lowbidgee Floodplain is regionally significant for waterbird populations and has been identified as a key site that can be actively managed to contribute to the recovery of waterbird populations across the MDB (Murray-Darling Basin Authority 2014). Many of the colony sites that were active in 2016-17 and in previous water years have been reliant on management interventions to maintain water levels in each colony and surrounding foraging habitats.

Several approaches can be taken to maximise outcomes from colonial waterbird breeding events, with the options available to environmental water managers varying according to the water availability scenario for a given water year. Key hydrological variables that contribute to successful major colonial waterbird breeding events include: large-scale inundation to initiate breeding, sufficient water depths and flow movement for the duration of breeding, and the provision of foraging habitat before, during and after breeding events.

To support the recovery of waterbird populations across the MDB, we recommend future management of Commonwealth environmental water in the Murrumbidgee Selected Area consider the following:

Large colonial waterbird breeding events in the Murrumbidgee and elsewhere in the MDB have been associated with large natural floods. Protecting these events from extraction and extending the duration of unregulated flows can provide breeding opportunities for many waterbird species. These large flood events play a central role in maintaining diversity and abundance of waterbirds across the MDB.

Future planning of Commonwealth environmental water use in the Murrumbidgee Selected Area should also consider inundating habitats known to historically support colonially-nesting waterbirds which have since been degraded. This includes lignum shrubland in the Nimmie-Caira zone for example Suicide Swamp and Pollen Creek, and river red gum sites in south Yanga National Park (Redbank zone) for example River Smythes swamp which have not supported breeding for more than a decade.

Inundation also needs to encompass foraging grounds adjoining key colony sites to support successful breeding. It is likely that the early watering event in August 2016 acted to prime the system prior to the natural widespread flooding. This pattern of inundation with large environmental inundation occurring prior to widespread unregulated flooding was seen in 2010 when large ibis, and egret and heron colonies were active from October 2010-April 2011 (Brandis, Ryall et al. 2011, Spencer, Thomas et al. 2011).

Monitoring data collected from the Eulimbah colony, Nimmie-Caira, in 2010-11 (Brandis, Ryall et al. 2011) and again in the 2016-17 season demonstrated that water depth is a key driver of reproductive success for ibis and spoonbill species. Adequate water depths are critical as they not only provide suitable nesting habitat (inundated vegetation) but when sufficiently deep enough prevent predation by ground-based predators (e.g. pigs, foxes, cats).

It is important that the duration of inundation covers the full breeding period including the trampling and establishment of nesting, through to fledging of young. The extended delivery of flows after the completion of breeding provide opportunities for young birds to build up body condition prior to leaving the breeding area. Extending flows into late summer and early autumn also provides further opportunities for breeding by other colonial and non-colonial waterbird species, as observed in the Eulimbah and Telephone colonies in the 2016-17 water year.

Delivering environmental water to create feeding habitat after the completion of breeding (in the same water year and following water years) within the Lowbidgee floodplain and in neighbouring catchments will also promote the survival of first-year birds.

It is likely that ongoing movement of water through the colony site is important for managing water quality issues including eutrophication and avian diseases, such as botulism. Observations of dead or dying birds were made in late stages of the Eulimbah colony and throughout all surveys at Tori Lignum Swamp, with testing of dead birds indicating that botulism was most likely impacting these sites. Future management of large breeding events should consider monitoring key variables that will assist in managing the risk of avian botulism to improve outcomes for waterbird populations.

6 Technical Appendices

6.1 Riverine water quality

Prepared by Dr Ben Wolfenden (CSU) and Dr Yoshi Kobayashi (NSW OEH)

Introduction

During 2016-17 there were two principle environmental water use actions that affected flows in the Murrumbidgee River. The Murrumbidgee flood recession and dissolved oxygen management flow was initially targeted at Wagga in late October 2016, then Gogelderie in mid-November and further downstream in Maude between November and early January 2017 (188,791 ML) moving downstream with the flood recession. The outcomes of this event with respect to dissolved oxygen management down stream of Maude are discussed in section (4.6 Hypoxic blackwater in the Lower Murrumbidgee River, 2016; Table 3-1). The autumn river fish pulse (49GL) was delivered to the Balranald Reach during April 2017, although the timing and location of this delivery fell outside the scope of Murrumbidgee Selected Area monitoring. In addition, Commonwealth environmental water passed down the Murrumbidgee River channel while being delivered to floodplain wetlands in support of waterbird breeding between November 2016 and June 2017 (Table 3-1).

Between June and December 2016, the Murrumbidgee River experienced high unregulated river flows that created overbank flooding, reconnecting the river with floodplain wetland habitats along the length of the regulated Murrumbidgee River. We expected these flows to have a strong influence on water quality in 2016-17, with the recession and aftermath of these flows falling within the monitoring period. We compared observed ranges of 1) physicochemical parameters and 2) concentrations of carbon, nutrients and chlorophyll-a between the Narrandera and Carrathool Zones and with data collected in the Murrumbidgee River before 2014. Where applicable we also present these findings with respect published water quality guidelines (ANZECC 2000). The utility of environmental watering that enables return flows is discussed.

Methods

River water quality was monitored six times in each of 2014-15, 2015-16 and 2016-17 between October and December. Sampling coincided with larval fish and microinvertebrate monitoring (sections 6.4 and 6.5 respectively). Measurements of physicochemical parameters (electrical conductivity (EC, mS cm^{-1}), turbidity (NTU) and pH and dissolved oxygen (mg L^{-1})) were taken at three randomly-chosen locations at each site using a calibrated water quality meter (Horiba U-52G). Note that dissolved oxygen was monitored continuously at Narrandera and Carrathool (see Section 6.2). Duplicate water samples were also collected and later analysed for dissolved organic carbon (DOC, mg L^{-1}), chlorophyll-a (CHLA, mg L^{-1}), filterable reactive phosphorus (FRP, µg L^{-1}) and oxidised nitrogen (NOX, µg L^{-1}) (Wassens, Thiem et al. 2015).

Data analysis

To test for differences between river zones and water years, data were analysed using a linear mixed effects model with repeated measures. Zone (n=2) and water year (n=3) were treated as fixed factors. The error for the test included a random intercept plus a random intercept for sites nested within zones. To investigate within-year differences across time, the full model was used despite being less parsimonious than a reduced model. Normality of residuals were checked using quantile-quantile plots of residuals and data were log(x+1) transformed where necessary. We present the F-tests from the lmer results (type II Wald F-tests with Kenward-Roger degrees of freedom approximation). Post-hoc tests (Tukey's HSD) were used to further isolate significant terms (invariable the interaction between Water Year, Zone and Trip#). Results were considered significant at P<0.05. Linear mixed effect models were produced using the lme4 package in R (Bates, Maechler et al. 2015). Four turbidity measurements were not recorded due to equipment malfunction. Where this occurred these data points were excluded. No unbalanced or empty levels were included in analyses. Indicative ranges of expected values are calculated as the 50th (median), 5th and 95th percentiles from river observations in previous years. ANZECC water quality guidelines (ANZECC 2000) are also indicated (Table 6-1).

Table 6-1 ANZECC (2000) water quality trigger guidelines and median, 5th and 95th percentile data compared against water quality measurements taken during the 2014-15 and 2015-16 river monitoring. The number of samples (*n*) is the number of datapoints collected prior to 2014 from which the median was calculated.*ANZECC trigger guidelines for lowland rivers in south-east Australia.

Indicator	NOx $\mu g\ L^{-1}$	FRP $\mu g\ L^{-1}$	Chl-a $\mu g\ L^{-1}$	DOC $mg\ L^{-1}$	Cond. $mS\ cm^{-1}$	pH	Turbidity NTU	DO $mg\ L^{-1}$
ANZECC (2000) trigger*	500	50	5	NA	2.2	6.5-8	6-50	(90-110%)
Median (5th-95th)	79.9 (3.80-217.49)	4.40 (2.51-8.58)	9.6 (3.9-19.9)	3.59 (2.16-10.69)	0.095 (0.064-0.179)	7.61 (7.21-8.19)	39.4 (15.79-76.65)	9.61 (7.64-0.86)
No. of samples (*n*)	39	39	43	43	48	48	47	48

Results

Physicochemical measurements varied significantly among zones, water years and trips as indicated by significant high-order interaction terms (Figure 6-1 and Table 6-2). There was little variation among replicate sites within zones (spaced across ~100km reach) for each sample occasion, therefore relatively small effect sizes are likely to be significant overall. Data for 2016-17 differed from previous years, with higher conductivity across both zones and lower dissolved oxygen, again varying among sample occasions but significantly different for first three sample occasions. The lowest dissolved oxygen was recorded for the Carrathool Zone on 10 October 2016 at approximately 3 mg L^{-1} (Figure 6-1), and at approximately 35% saturation this is well below the ANZECC (2000) trigger threshold (Table 6-1). The flood passed the Narrandera Zone approximately 10 days before the Carrathool Zone and it is possible that lower dissolved oxygen could have also occurred through the Narrandera reach prior to sampling. pH was also slightly lower across both zones in 2016-17 and turbidity significantly higher than previous years on two sample occasions in the Narrandera Zone (Figure 6-1).

Water column nutrients show a much stronger response to the flood pulse, with values for DOC and available nutrients exceeding both the 95th percentile data for previous records for the Murrumbidgee and the ANZECC (2000) trigger thresholds (Figure 6-2). DOC results were somewhat less stark than for the available nutrients, significantly higher on the first sample occasion in the Narrandera Zone and the first two in the Carrathool Zone. FRP was significantly more concentrated during 2016-17 in both reaches, and remained significantly higher until the last two sample occasions. Oxidised nitrate/nitrite and ammonia followed a similar trend, although NO_x increased initially in the Carrathool Zone, peaking in November (Figure 6-2).

Chlorophyll-a results show less chlorophyll-a in the Narrandera Zone than previously recorded (Figure 6-2). Similarly, results from the Carrathool Zone show less chlorophyll-a initially, however there was a peak in chlorophyll-a following the recession of the flood that was not seen in the Narrandera Zone.

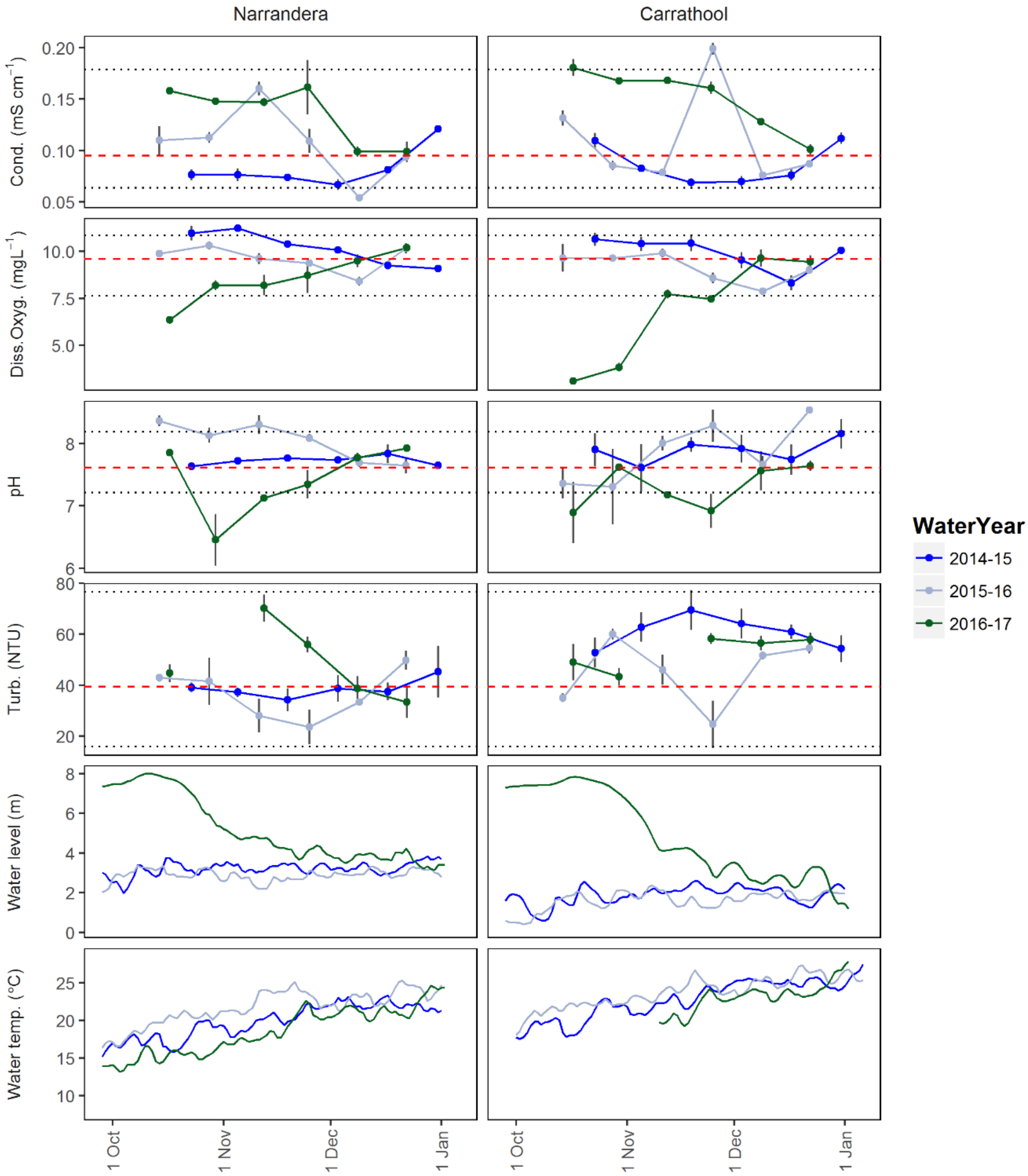


Figure 6-1 Mean ± standard error for physicochemical parameters (turbidity, pH, dissolved oxygen and conductivity) measured on six occasions between October and December during 2014-15, 2015-16 and 2016-17. Data are the mean of three sites ± standard error of the mean. Mean daily water level is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature was taken from the gauge data for Narrandera. The Carrathool temperature data is collected by the LTIM metabolism monitoring program which was delayed in 2016-17 due to flooding. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

Table 6-2 LMER results for water quality data collected for the Narrandera and Carrathool Zones for the 2014-15, 2015-16 and 2016-17 water years. The highest-order significant term is shaded for each measured variable. Significance levels are *p<0.05, **p<0.01, ***p<0.001

Term	1	2	3	4	5	6	7	Model
	WaterYear(WY)	**Zone(Zo)**	**TripNo(TN)**	**WY*Zo**	**WY*TN**	**Zp*TN**	**WY*Zo*TN**	**R^2(m)**
df	*2*	*1*	*5*	*2*	*10*	*5*	*10*	
NH3	696.769***	0.134	110.610***	23.535***	63.598***	3.346**	4.195***	0.96
NOx	193.056***	78.474***	7.198***	8.368***	10.3698***	1.735	8.537***	0.87
FRP	2665.731***	88.858***	129.409***	166.647***	72.684***	29.839***	22.143***	0.99
Chl-a	32.386***	3.35	2.034	16.619***	5.114***	2.768*	5.248***	0.66
DOC	164.353***	92.036***	38.605***	31.163	60.704***	12.614***	13.752***	0.93
Cond.	374.218***	8.948*	58.888***	5.549**	50.667***	24.844***	22.461***	0.94
pH	21.149***	0.637	1.748	2.266	2.095*	2.9378*	2.951**	0.53
DO	323.123***	82.790***	32.688***	57.561***	93.377***	21.459***	19.866***	0.96
df (Turb)	*2*	*1*	*3*	*2*	*6*	*3*	*6*	
Turb.	13.798***	10.599*	1.378	5.025*	9.903***	4.619**	2.941*	0.662

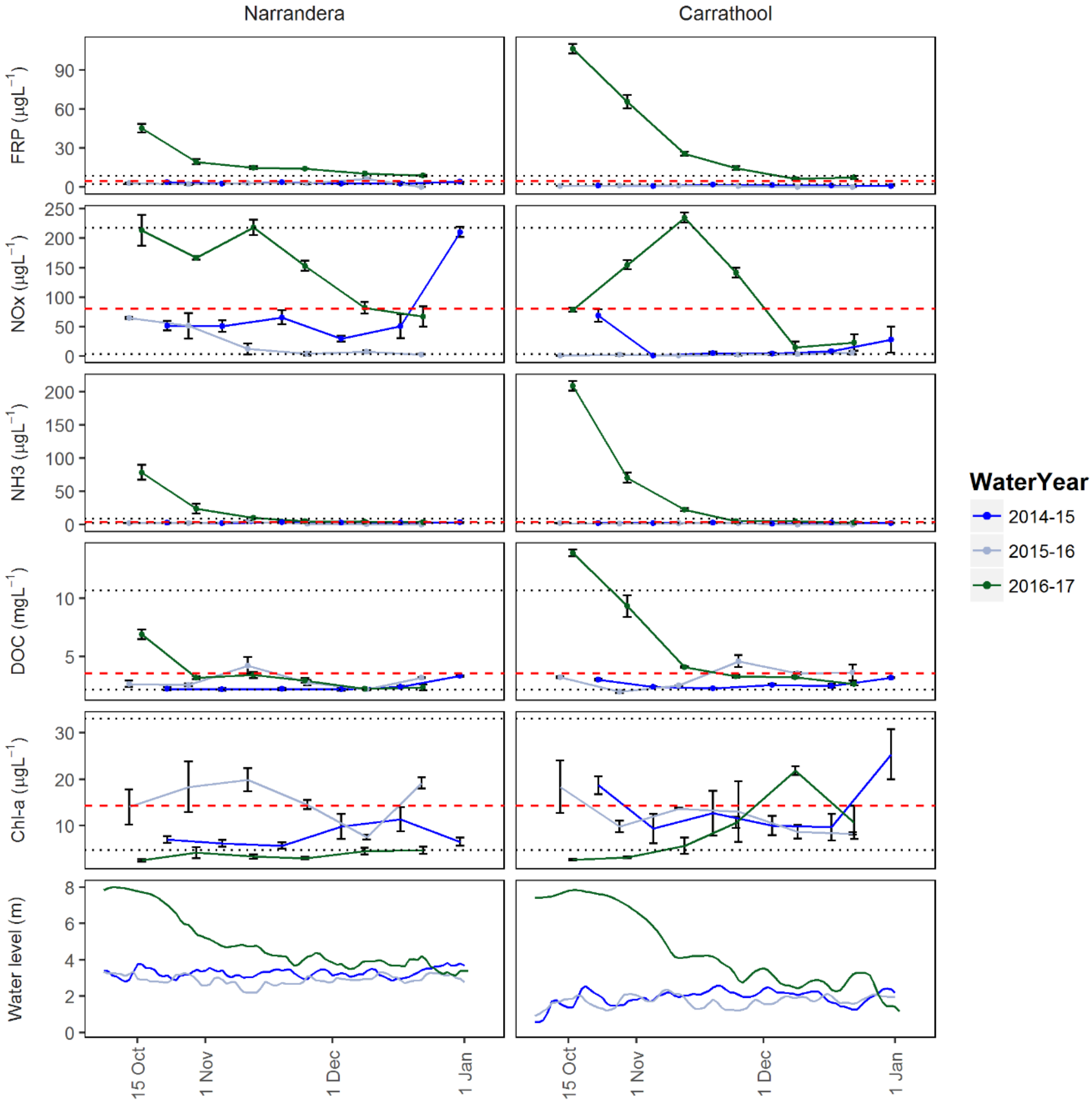


Figure 6-2 Concentrations of bioavailable nutrients (filterable reactive phosphorus – FRP; oxidised nitrate/nitrite – NO_x; and ammonia – NH_3), dissolved organic carbon (DOC) and chlorophyll-a (Chl-a) in water samples collected on six occasions between October and December during each of 2014-15, 2015-16 and 2016-17. Data are the mean of three sites ± standard error of the mean. Mean daily water level is sourced from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

Discussion

Can Commonwealth environmental water be used to support the cycling of nutrients and carbon in the Murrumbidgee River?

Overbank inundation that flows across large areas of floodplain carries floodplain-derived nutrients and energy that augment in-channel processes (Puckridge, Sheldon et al. 1998). Nutrient concentrations in 2016-17, in particular, highly bioavailable ammonia (NH_3), oxidised nitrogen (NO_x) and reactive phosphorus (FRP), increased compared with the two previous years, demonstrating the flood pulse as it occurs in the Murrumbidgee River. DOC also increased in 2016-17, reaching 14 mgL^{-1} in the Carrathool reach, approximately four times greater than the median background concentration of 3.59 mgL^{-1}. However, this response is dwarfed by proportional increases in available nitrogen and phosphorus, which were 67 and 27 times, respectively. The Murrumbidgee Catchment contains many fringing wetlands, riparian zones and flood-runners that can be connected to the river by natural events, triggering aquatic processes at the water-sediment interface and within the water-column (Baldwin and Mitchell 2000, Knowles, Iles et al. 2012) and transporting nutrients into the river channel with water returning to the river. The nutrient results suggest these processes were not activated during the monitoring period in either 2014-15 or 2015-16, but were in 2016-17.

Large areas of floodplain in the Murrumbidgee catchment are developed for agriculture (Kingsford and Thomas 2004). Agricultural activities that augment available nutrients in soils can be an important source of nutrients (e.g. Brodie and Mitchell 2005). However, river red gum leaves also rapidly leach highly bioavailable orthophosphate upon inundation (Baldwin 1999). Wolfenden, Wassens et al. (2017) reported floodplain phosphate concentrations were considerably higher in a largely uncropped floodplain than the adjacent Murrumbidgee River. Although it seems likely that leachates from floodplain red gum leaves are a key source of nutrients during high flows, we cannot discriminate among potential sources of nutrients delivered to the Murrumbidgee River during the 2016 overbank flows.

Like other streams in the MDB, the Murrumbidgee River contains lower median concentrations of nutrients compared to other floodplain rivers across the world (Grace 2016). Moreover, there is speculation that production in the Murrumbidgee River is limited by the supply of carbon and nutrients that would naturally be provided during lateral reconnection events, particularly phosphorus (Vink, Bormans et al. 2005). The 2016-17 monitoring data therefore sets an important benchmark for the potential role of overbank environmental water use actions to augment in-channel functions. Environmental flows cannot be used to inundate large floodplain areas, but any substantial return flows, from either high freshes inundating riparian areas or flushing flows using infrastructure-assisted deliveries, could have a disproportionately large impact on nutrient availabilities in this low-nutrient system. Target thresholds of concentrations needed to drive these processes are still being investigated.

6.2 Hypoxic blackwater mitigation

Prepared by Ben Wolfenden (CSU)

Introduction

Hypoxic blackwater occurs when increased bioavailable dissolved organic carbon accelerates microbial respiration to a rate that exceeds that of passive reaeration (Whitworth and Baldwin 2016). These events occur intermittently in the Murray and Murrumbidgee Rivers, typically following natural overbank flood events that connect the mainstem with infrequently inundated forested floodplain areas, liberating carbon from floodplain soils and leaf litter (King, Tonkin et al. 2012, Whitworth, Baldwin et al. 2012, McCarthy, Zukowski et al. 2014). The tolerances of many species of aquatic animals to low oxygen stress remains largely unknown (McMaster and Bond 2008, Small, Kopf et al. 2014) but is often defined as dissolved oxygen (DO) concentrations that have the potential to harm (DO concentration <4 mg/L) or kill (DO concentration <2 mg/L) aquatic fauna (Gehrke and Fielder 1988).

Widespread flooding in the southern MDB during late winter and early spring 2016 triggered a hypoxic blackwater event in the Murrumbidgee River downstream of Hay. Commonwealth environmental water was delivered to mitigate the impacts of persistent hypoxia, seeking to:

- provide in-channel refuge habitat and in-channel movement opportunities for native fish from areas of low dissolved oxygen levels in the lower reaches to refuge habitat upstream;
- support the movement of native fish and other aquatic animals from the floodplain to the river channel, thereby minimising or preventing stranding of these animals on the floodplain;
- improve water quality

In this section, we present the findings of water quality monitoring before, during and after the event. Specifically, we sought to evaluate the contribution of environmental watering to the recovery of dissolved oxygen concentrations between Redbank and Balranald Weirs. We expected dilution would lead to an earlier recovery of DO.

Methods

Dissolved oxygen (DO), flow and temperature data, measured continuously at the Downstream Maude Weir (410040), Downstream Redbank Weir (410041) and Downstream Balranald Weir (410130) gauge stations, were downloaded from the NSW Water Info website (http://waterinfo.nsw.gov.au/). Spot measurements of DO and dissolved organic carbon (DOC) were collected from river and wetland sites in mid-October 2016 to provide a snapshot of wetland and river conditions at the peak of the event and to validate the results from the gauge stations (Table 6-3). Dissolved oxygen was measured using a handheld ProOdo luminescent dissolved oxygen meter (YSI). Dissolved organic carbon was sampled following methods described in Section 6.1. Additional DO and DOC data were used from the river and wetland monitoring programs where necessary (Sections 6.1 and 6.7).

Data analysis

To evaluate the contribution of environmental water to mitigating the hypoxic event we compared observed DO concentrations against potential DO concentrations in the absence of environmental water (see also Whitworth and Baldwin 2013). A time series of DO concentration was modelled using the Blackwater Intervention Tool (BIT; Kerr et al. 2013), with observed flow, temperature and water quality conditions as input parameters and mixing DOC concentration and minimum daily DO at Balranald as the outputs. First, a model was created using the parameters observed during the observed high flow event. This model was then rerun without the dilution volume added by environmental water. Parameters for dilution flows were approximated by the volume and conditions at Redbank Weir and return flows by the observed conditions in adjacent wetlands. Return flow DOC concentration was assumed to be 23 mg L^{-1} (the average of wetland water samples collected during early October and December) for the entire event. The return flow volume for each day was calculated by subtracting the mean daily discharge at Redbank Weir from Balranald Weir after taking into account three days travel time between the two stations. At Redbank Weir, discharges above ~10,000 MLd^{-1} force water out of the channel and onto on the surrounding floodplain, therefore calculations were limited to dates after the flow had begun to recede at Redbank.

Results

Hydrology

At Balranald, the natural high flow event began during June 2016, with river discharge remaining above 7,000 ML d^{-1} until mid-October. River height peaked at 31,583 MLd^{-1} on 11 November 2016, falling to 6,000 ML d^{-1} by the end of December (Figure 6-3). A lower, more diffuse and variable peak was recorded at Maude Weir. The hydrograph at Balranald appeared unaffected by the variable discharge at Maude (Figure 6-3). A combination of Commonwealth, NSW and The Living Murray environmental water was delivered from Maude Weir between 27 November 2016 and 5 January 2017 totalling 188.79 GL (Figure 6-4).

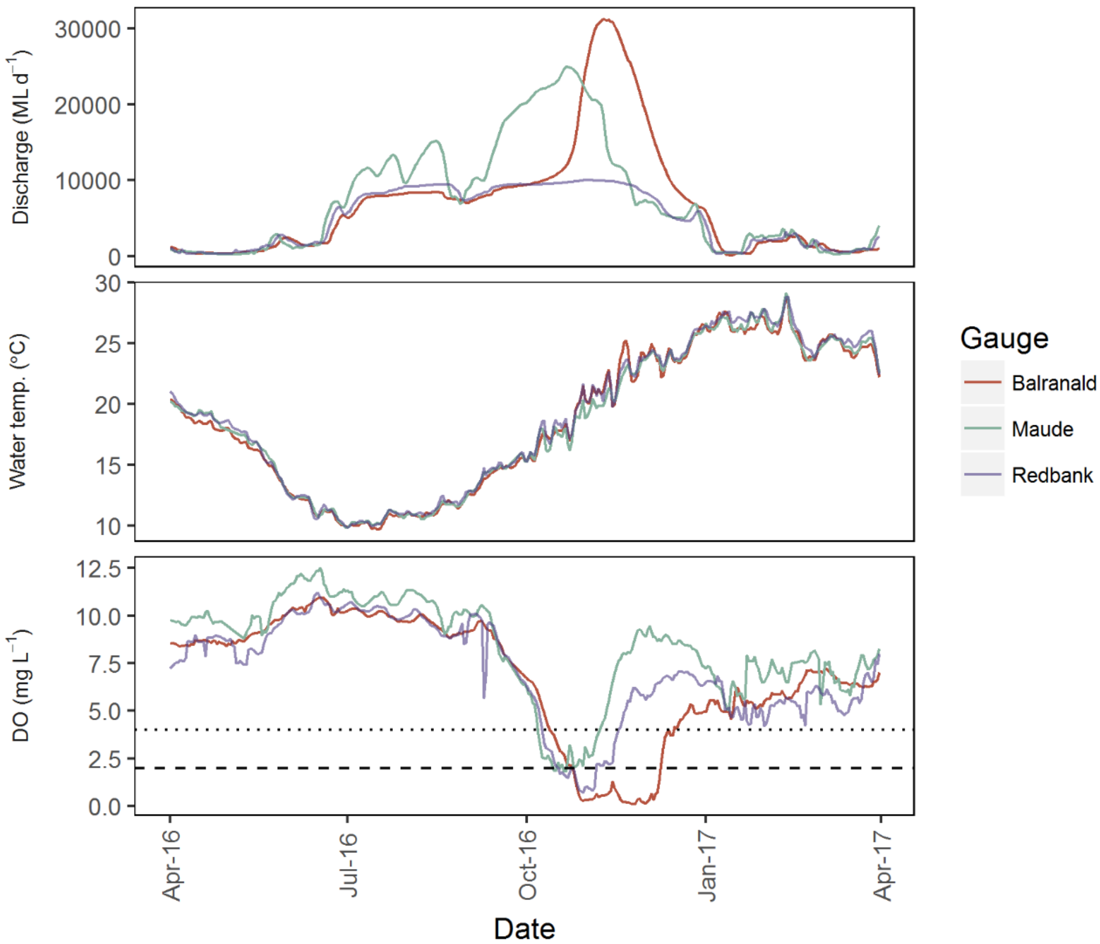


Figure 6-3: Discharge, water temperature and dissolved oxygen recorded at Maude, Redbank and Balranald weirs between April 2016 and April 2017. The critical oxygen thresholds of 4 and 2 mg L^{-1} are indicated by dotted and dashed lines. Data from NSW Water Info.

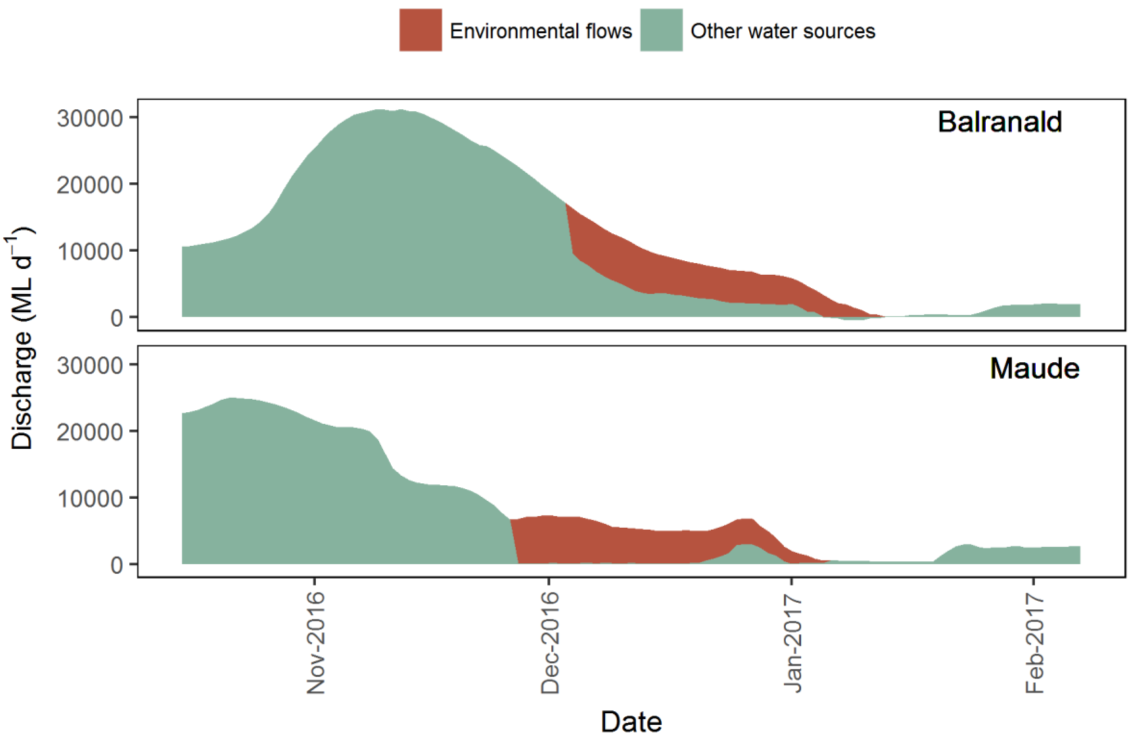


Figure 6-4: River discharge for the Maude and Balranald gauges between October 2016 and February 2017. Environmental water is differentiated from other water sources.

Onset and recovery of hypoxia

Dissolved oxygen began declining across all sites in the Lowbidgee River (Maude, Redbank and Balranald Weirs) during the rising limb of the flood on ~15 September (Figure 6-3). Concentrations remained above 2 mg L-1 at Maude, but fell below this threshold at Redbank and Balranald in October 2016, recovering (DO>4mg L-1) at Redbank by early November and Balranald by mid-December. Murrumbidgee River sites further upstream also recorded low dissolved oxygen concentrations, with spot measurements <3mg/L as far upstream as Carrathool (10 October 2016; Table 6-3). Sites closer to Darlington Point recorded values of 3.9 and 4 mg/L and remained within the normal range in the Narrandera reach. With the limited data available for upstream locations, it does not appear that persistent hypoxia (i.e. <2mg/L) occurred above the gauge at Maude, however, values less than 4mg/L persisted for the period 7 October to 7 November. Carbon concentrations (normally between 3 and 5mg/L in the Murrumbidgee River; Wassens et al. 2016), showed a small increase at sites around Narrandera and were more concentrated at sites around Hay, and Carrathool (Table 6-3). Lowbidgee River sites, and associated drainage channels (Monkem Creek, Uara Creek and Yanga Creek) all had DOC concentrations of 17-20 mg/L (Table 6-4). The flood did not appear to affect wetland DO or DOC concentrations. DOC is typically very high in the North Redbank system and lower in south Redbank (Table 6-4).

Table 6-3 Observed dissolved oxygen and dissolved organic carbon concentrations for the Murrumbidgee River, October 2016.

Zone	Site	Date	DO (mg/L)	DOC (mg/L)
Mid-Murrumbidgee	Gooragool	13/9/16	6.47	10.65
Narrandera Reach	Dairy Reserve	18/10/16	6.51	6.2
	Euroley Bridge	20/10/16	6.18	6.88
	Narrandera	19/10/16	7.21	7.65
Carrathool Reach	McKennas River	10/10/16	2.92	13.35
	McKennas River	24/10/16	3.50	10
	Yarradda River	12/10/16	3.17	14.0
	Bringagee	11/10/16	3.18	14.3
	Hay	20/10/16	3.56	14.7
Lowbidgee	Maude	18/10/16	2.56	16.5
	Maude	10/12/16	8.86	3.55
	Maude	2/2/17	9.14	3.98
	Downstream RBW	19/10/16	2.9	17.8
	Balranald Bridge	19/10/16	2.84	18
	Balranald Bridge	12/12/16	5.95	9.6
	Balranald Bridge	1/2/17	6.75	3.7

Table 6-4 Observed dissolved oxygen and dissolved organic carbon concentrations for the Murrumbidgee Wetlands, October 2016.

Zone	Site	Date	DO (mg/L)	DOC (mg/L)
Carrathool Reach	Gooragool	13/9/16	6.47	10.65
	Gooragool	20/10/16	0.98	10.5
	Sunshower	13/9/16	7.15	11.85
	McKennas	14/9/16	4.53	12.2
	Yarradda	14/9/16	7.02	11.6
	Yarradda	20/10/16	3.67	11.1
South Redbank	Waugorah	18/10/16	4.57	16.8
	Two Bridges	19/10/16	2.35	16.8
	Piggery	19/10/16	4.64	16.8
	Shaws	18/10/16	NA	17.5
	Mercedes	19/10/16	4.17	17.6
North Redbank	Steam Engine	20/10/16	NA	28.8
	Riverleigh	19/10/16	NA	30.3
	Narwie	19/10/16	4.80	30.3
Nimmie-Caira	Monkem Creek	20/10/16	3.56	20.8
	Yanga Creek	20/10/16	2.70	20.8
	Eulimbah	18/10/16	0.35	21.5
	Uara Creek	20/10/16	2.61	21.7
	Avalon Swamp	18/10/16	0.32	22.1

Environmental flow modelling scenarios

The BIT models predict mixing DOC concentrations that are similar to the two available data points collected at Balranald on 12 December 2016 and 2 February 2017. Predicted DOC concentration increased in mid-December, coinciding with a decrease in discharge at Redbank Weir (Figure 6-5). In the absence of accounted environmental flows this concentration could have reverted back towards 20 mg L^{-1} (Figure 6-5). The calculation also predicted return flows ceased at the end of December, with DOC returning to the baseline concentration of ~3.6 mg L^{-1} (Figure 6-5).

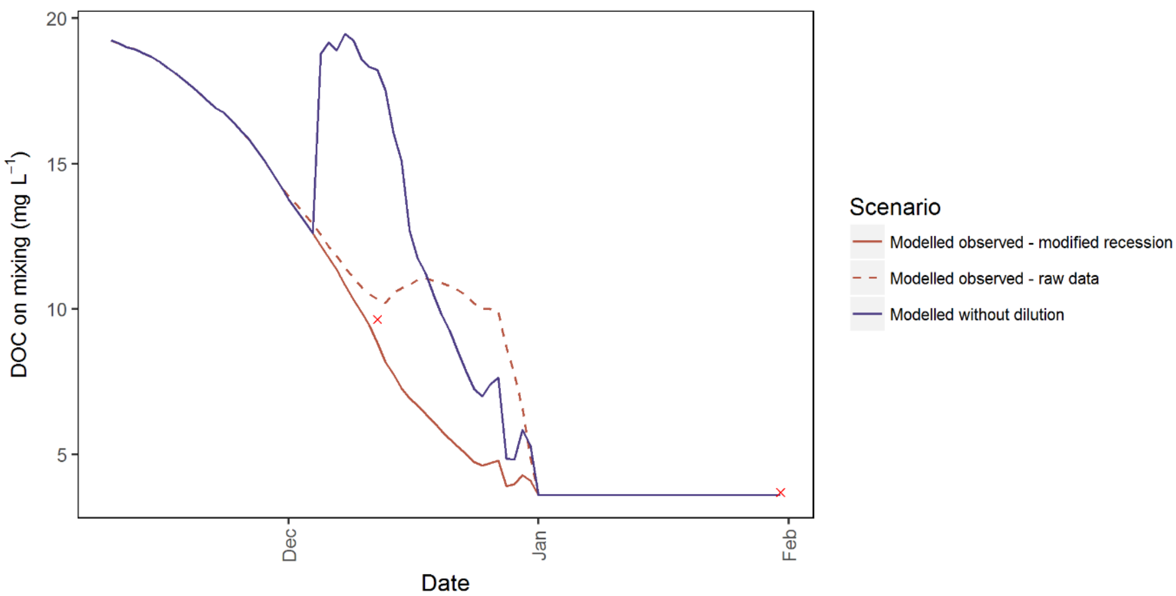


Figure 6-5: Mixing DOC concentrations based on flow hydrology and measured DOC in dilution and return flows water. The red ‘x’ shows DOC concentrations on two sample dates at Balranald Bridge.

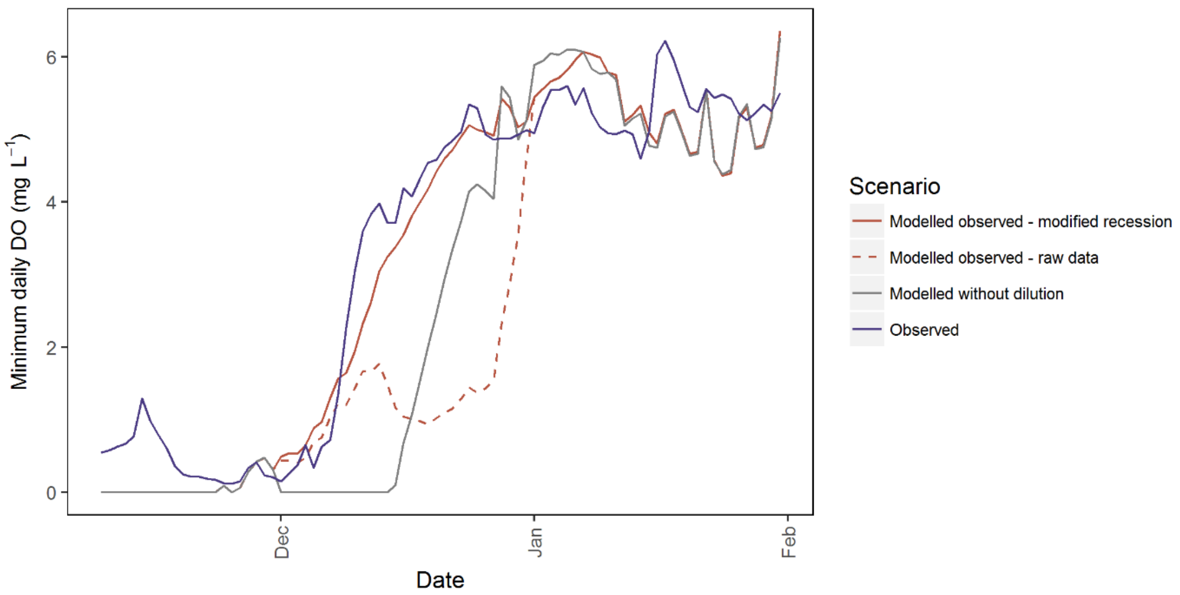


Figure 6-6: Blackwater intervention tool model results. Data show the observed minimum daily DO at Balranald, modelled observed DO with and without a decline in dilution flow volume, and modelled DO in the absence of environmental water.

Modelling predicted a similar timing for the initial recovery of DO at Balranald across the observed and two dilution models (Figure 6-6). However, the raw data model predicted a worsening of conditions in mid-December, coinciding with a slight decline in flow at the Redbank Gauge that consequently increased the volume of return flow and increased DOC concentration because this artefact was not observed at Balranald (Figure 6-6). Rerunning the model with the slump in discharge removed from the dilution volume predicted DO concentrations that better fit the observed data. Removing the volume of environmental water delivered delayed the initial recovery by 18 days and delayed the return to normal DO concentrations by six days (Table 6-5). Dissolved Organic Carbon mixing results suggest recovery was initiated once the diluted DOC concentration fell to below 12.5 mg L^{-1}.

Table 6-5 Summary of dissolved oxygen change points in the observed and modelled data. Initial recovery dates were those dates where oxygen began to rise and did not subsequently fall below the initial value.

Model Scenario	Recovery initiated	DOC at *t*	Date exceed 2mg L^{-1}	DOC at *t*	Date exceed 4 mg L^{-1}	DOC at *t*
Observed data	2-Dec-2016	-	9-Dec-2016	-	16-Dec-2016	-
Modelled raw data	28-Nov-2016	15.09	28-Dec-2016	8.69	30-Dec-2016	6.59
Modelled raw (modified recession)	28-Nov-2016	15.09	11-Dec-2016	9.44	18-Dec-2016	6.04
Modelled without dilution	16-Dec-2016	12.69	19-Dec-2016	10.49	24-Dec-2016	7.25
Difference (With-Without)	18	-	8	-	5	-

Discussion

What did Commonwealth environmental water contribute to water quality?

This study shows a tangible benefit from the delivery of environmental water for the purpose of mitigating a large hypoxic blackwater event, accelerating a return to nominal water quality conditions in the lower Murrumbidgee River. Although the initial modelling found inconsistencies between predicted and observed values, a reasonable approximation of the observed DO dynamics was possible with a relatively small change to the dilution hydrograph (Pokhrel and Gupta 2011). Because of the multiple inputs and 'smoothing' of variability in the hydrograph as flows pass downstream, it may not be sensible to use the raw discharge data at Redbank Weir to estimate dilution discharge at Balranald. Moreover, overall discharge rates were ~6,000 ML d^{-1} greater at Balranald, suggesting significant inputs from either the Lachlan Catchment or the Nimmie-Caira system, potentially providing both additional carbon and dilution sources. This highlights the need for more detailed information about the hydrology of wetland return flows to improve the forecasting and management of events.

The subsequent without-environmental water counterfactual presents a best-case outcome for the use of environmental water as the actual volumes passing Maude Weir may not have been reduced to the baseline end-of-system targets so soon on the recession of the flood. However, we also note that in this example the contribution of environmental water is only evaluated downstream of Maude Weir. This delivery of environmental water is also expected to have diluted other return flows en-route and therefore contributed to an earlier recovery of DO at both Maude and Redbank Weirs. In this way, the contribution of the environmental flows are additive. However, with the available information this outcome cannot be evaluated.

Factors contributing to the recovery of dissolved oxygen on the recession of the 2016-17 flood

The rapid recovery of dissolved oxygen reported here contrasts with that seen during the much larger 2012 flood event reported by Whitworth and Baldwin (2013) when DO took approximately three weeks to recover. Although these differences can be explained by the smaller size and higher temperature during the 2016 event, there are several critical drivers that affected both the rate of recovery and the BIT's capacity to predict DO concentration.

The return to normal DOC dilution (in the Murrumbidgee, DOC<=~3-5 mg L^{-1}) at the end of a flood recession is the most important aspect of recovery. In this case, DO appears to recover once DOC concentration falls to, or is diluted to below 12.5-15 mg L^{-1}. This concentration threshold will vary depending on temperature and reaeration, both of which vary in time and space and with discharge, so the results may not be universally applicable and each event should be individually assessed. For example, (Whitworth, Baldwin et al. 2013) reported a recovery coincident with higher DOC concentrations than reported here, although in their study recovery occurred at lower temperatures.

Another important factor driving DO recovery rates is the consumption of labile carbon and nutrients from the pool of dissolved organic matter that is being transported downstream. DOC is often used as a surrogate for available carbon, however, the portion of DOC that is bioavailable is less than the total leached DOC (O'connell, Baldwin et al. 2000, Baldwin and Valo 2015). Given enough time, the pool of labile DOC will reduce, with the recovery of oxygen possible under higher concentrations of DOC. The same may also be true for the availability of labile nutrients (phosphate, nitrate/nitrite, ammonia) upon which microbial respiration of DOC also depends. DOC may cease to be a sensible surrogate to predict hypoxia given a long enough timeframe.

6.3 Stream metabolism

Prepared by Dr Ben Wolfenden (CSU) and Dr Yoshi Kobayashi (NSW OEH)

Introduction

Stream metabolism is a measure of the amount of energy produced and consumed by river food webs. It estimates rates of gross primary production (GPP) by algae and aquatic plants as well as rates of heterotrophic respiration (i.e. carbon consumption; ER) by microorganisms. Metabolism is calculated using the diurnal change in dissolved oxygen arising from these two processes, but also varies with temperature, light and the availability of nutrients and carbon (Young, Matthaei et al. 2008). As the master variable controlling these drivers (Poff and Zimmerman 2010), flow exerts a controlling influence over rates of metabolism. Changes to the flow regime that affect any one of these drivers can alter the amount and quality of energy supplied to aquatic consumers (Young, Matthaei et al. 2008), with flow-on effects to food web dynamics and water quality (Marcarelli, Baxter et al. 2011). Understanding the relationship between flow and metabolism provides the means to deliver environmental flows that support basic ecosystem functions and water quality conditions at the river-scale.

During 2014-15, 2015-16 and 2016-17 there were no monitored Commonwealth environmental watering actions specifically targeting stream metabolism, although environmental flows did pass down the river channel while being delivered to river and floodplain assets further downstream. There were two larger actions during 2016-17 that targeted metabolism, one of which is evaluated in section 6.2 of this report, the other fell outside the Murrumbidgee Selected Area (Table 3-1). Long-term watering plans for the Murrumbidgee River forecast in-channel deliveries of Commonwealth environmental water to support habitat and riverine productivity for fish. It is anticipated that these flows will be delivered approximately 7 in 10 years (Commonwealth of Australia 2016). We investigated the relationship between stream metabolism and river flows during 2014-15, 2015-16 and 2016-17 and discuss these findings with regard to future deliveries of Commonwealth environmental water.

Methods

Stream metabolism was measured using the LTIM Category 1 Standard Method (Hale et al. 2014). Metabolism was surveyed at one site in both the Carrathool (October – April) and Narrandera (October – January) zones concurrent with the larval fish monitoring and as part of the Category 1 and Category 3 ecosystem metabolism monitoring. At each site, water temperature and dissolved oxygen were logged at ten minute intervals using a calibrated dissolved oxygen datalogger (Zebra Tech) attached to a float and chain secured mid-stream to a snag. Photosynthetically active light (PAR) and barometric pressure were logged at the same interval by nearby weather stations (Hobo U30). Water level and temperature data were obtained from nearby gauge stations operated by the NSW state government and can be accessed at http://waterinfo.nsw.gov.au/.

Data analysis

Daily rates of ecosystem metabolism were calculated using the BASE modelling package in the statistical-computing environment R (Grace, Giling et al. 2015) modified to incorporate improvements proposed by (Song, Dodds et al. 2016).

As in our previous work (Wassens, Spencer et al. 2016), we used linear regression with autoregressive errors to model GPP and ER using mean daily water level as a predictor. After examining the autocorrelation and partial autocorrelation functions of simple regression model, autoregressive error of a lag-1 or AR(1) was thought to be appropriate in modelling GPP and ER. Thus, we used the model in the form

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t$$

with errors

$$\varepsilon_t = \rho \varepsilon_{t-1} + \omega_t$$

where y_t is the value of GPP (mg O_2 L^{-1} d^{-1}) or ER (mg O_2 L^{-1} d^{-1}) at day t, β_0 and β_1 are regression coefficients (i.e. intercept and slope estimates), x_t is the value of mean daily water level (m d^{-1}) at day t, ε_t and $\varepsilon_{t-1}$are the errors at days t and $t-1$, ρ is the first-order autocorrelation coefficient, and ω_t ~ iid $N(0, \sigma^2)$. A Cochrane-Orcutt procedure was used to model and predict GPP and EP using AR(1) errors for each site and each water year with the significance level of 0.05 (Cochrane and Orcutt 1949). Prior to analysis, missing values were fitted with cubic spline interpolation. All statistical analyses were performed using the statistical-computing environment 'R' (R Development Core Team 2014).

Results

Summary statistics for GPP, ER and water level at the Narrandera and Carrathool sites are presented in Table 6-6. GPP and ER varied through time at both sites, with median values ranging from 0.77-1.74 and 0.79-1.53 $mgO_2\ L^{-1}\ d^{-1}$, respectively. At the Narrandera and Carrathool sites, mean and median GPP/ER ratios were > 1 during the 2015-16 water year. However, median GPP/EP ratio remained < 1 for all three water years. Both the mean and median water levels at Narrandera were higher than those at Carrathool during the three water years (Table 6-6). All flows (or water levels) were typically within-channel, not engaging floodplain or riparian areas (i.e. the proportion of bankfull remained < 1).

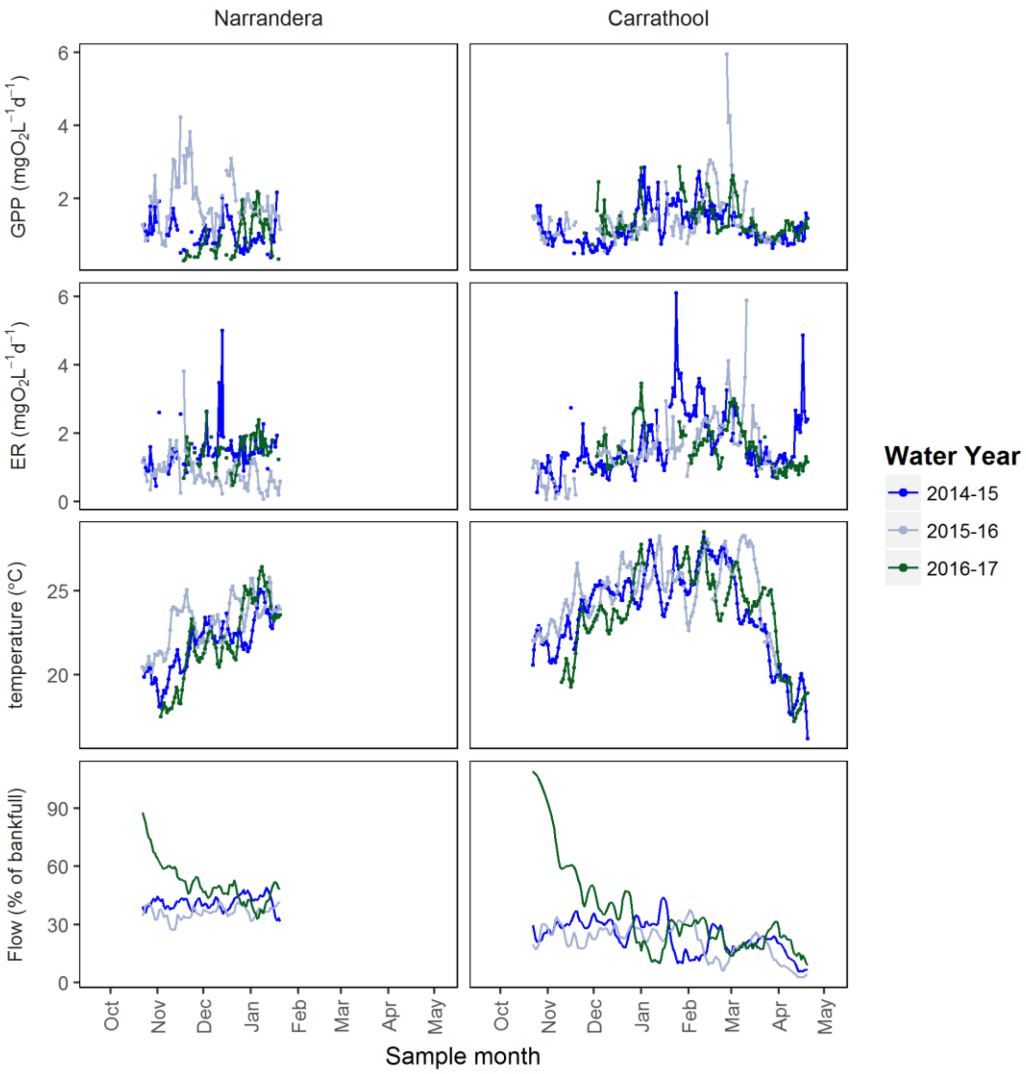


Figure 6-7 Metabolism results (GPP.mean – gross primary production; ER.mean – ecosystem respiration; PR_ratio – the ratio of GPP:ER) measured continuously at the Narrandera Cat 3 (October to January) and Carrathool Cat 1 (October to April) sites. The P:R ratio of 1 is indicated by the dotted line. Data are shown for 2014-15, 2015-16 and 2016-17 using ordinal date on the x-axis. Mean daily water temperature (wtemp) was monitored continuously.

Table 6-6 Summary statistics for stream metabolism at Narrandera and Carrathool in the Murrumbidgee River (GPP: Gross Primary Productivity; ER: Ecosystem Respiration).

	Narrandera			Carrathool		
Monitoring period	2014-15	2015-16	2016-17	2014-15	2015-16	2016-17
	23/10/2014 – 18/01/2015 (86 days)	22/10/2015 – 22/02/2016 (89 days)	02/11/2016 – 20/01/2017 (79 days)	22/10/2014 – 20/4/2015 (177 days)	22/10/2015 – 01/04/2016 (158 days)	09/11/2016 – 20/04/2017 (89 days)
Number of available observations (number of missing observations)	72 (14)	82 (7)	50 (29)	165 (12)	134 (24)	116 (23)
GPP (mg O_2 L^{-1} d^{-1}) mean (median) [range]	1.02 (0.97) [0.39-2.17]	1.89 (1.74) [0.55-4.24]	0.92 (0.77) [0.30-2.18]	1.24 (1.07) [0.49-2.85]	1.45 (1.27) [0.56-5.97]	1.40 (1.23) [0.74-2.88]
ER (mg O_2 L^{-1} d^{-1}) mean (median) [range]	1.52 (1.44) [0.46-5.00]	0.86 (0.79) [0.16-3.81]	1.48 (1.53) [0.5-2.61]	1.68 (1.38) [0.26-6.10]	1.55 (1.42) [0.07-5.89]	1.58 (1.40) [0.70-3.46]
GPP/ER ratio mean (median) [range]	0.75 (0.64) [0.20-2.92]	2.94 (2.34) [0.72-15.71]	0.62 (0.59) [0.24-1.04]	0.90 (0.72) [0.17-6.33]	1.40 (0.92) [0.26-4.54]	0.95 (0.97) [0.32-1.93]
Water level (m) mean (median) [range]	3.32 (3.37) [2.56-3.85]	2.89 (2.90) [2.19-3.32]	3.60 (3.67) [2.63-4.33]	1.64 (1.66) [0.39-3.07]	1.61 (1.69) [0.44-2.62]	1.87 (1.70) [0.64-3.54]

Table 6-7 Linear regression results comparing water level and metabolism estimates for the Narrandera and Carrathool zones in the Murrumbidgee River (GPP: Gross Primary Productivity; ER: Ecosystem Respiration).

Zone	Variable	Pseudo F	Pseudo R2
Narrandera	GPP.mean	$8.273e^{-12}$ ***	0.45
	ER.mean	0.7815	0.04
Carrathool	GPP.mean	$5.718e^{-11}$***	0.21
	ER.mean	$2.2e^{-16}$***	0.33

At Narrandera, simple linear regression analysis showed significant negative relationships between water level and GPP for all the three water years (Adjusted R^2 = 0.35, 0.15 and 0.68; P <0.0001) and ER for the 2015-16 and 2016-17 water years (Adjusted R^2 = 0.27 and 0.17; P <0.0005). At Carrathool, simple linear regression analysis showed significant negative relationships between water level and GPP for all the three water years combined (Adjusted R^2 = 0.03, 0.25 and 0.11; P <0.009) and ER for all the three water years (Adjusted R^2 = 0.29, 0.04, and 0.16; P <0.007). After adjusting the original parameter estimates using the Cochrane-Orcutt method, the predicted (forecast) values were calculated with the use of the error term and were plotted, together with the observed values at each site for each water year (Figure 6-8 and Figure 6-9).

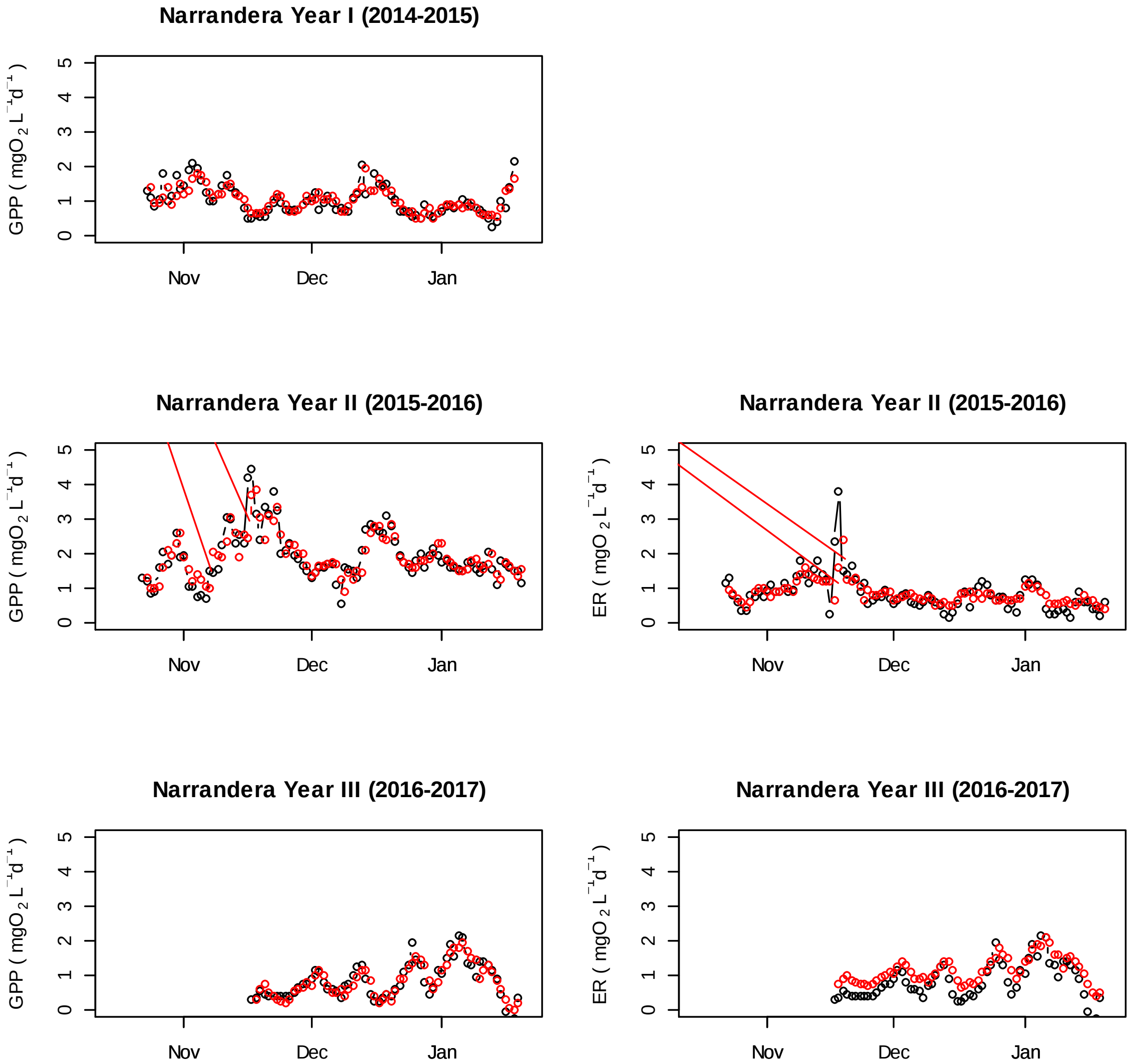


Figure 6-8 Predicted (forecast; red) and observed (black) values of gross primary productivity (GPP, mgO_2 L^{-1} d^{-1}) and ecosystem respiration (ER, mgO_2 L^{-1} d^{-1}) at the Narrandera Cat 1 site for the water years 2014-15, 2015-16 and 2016-17, based on linear regression model with autoregressive errors of a lag-1, using mean daily water level (m d^{-1}) as a predictor. For the time-series plot (upper and lower left columns), the predicted (forecast) values are shown by open red circles and the observed values are shown by open black circles.

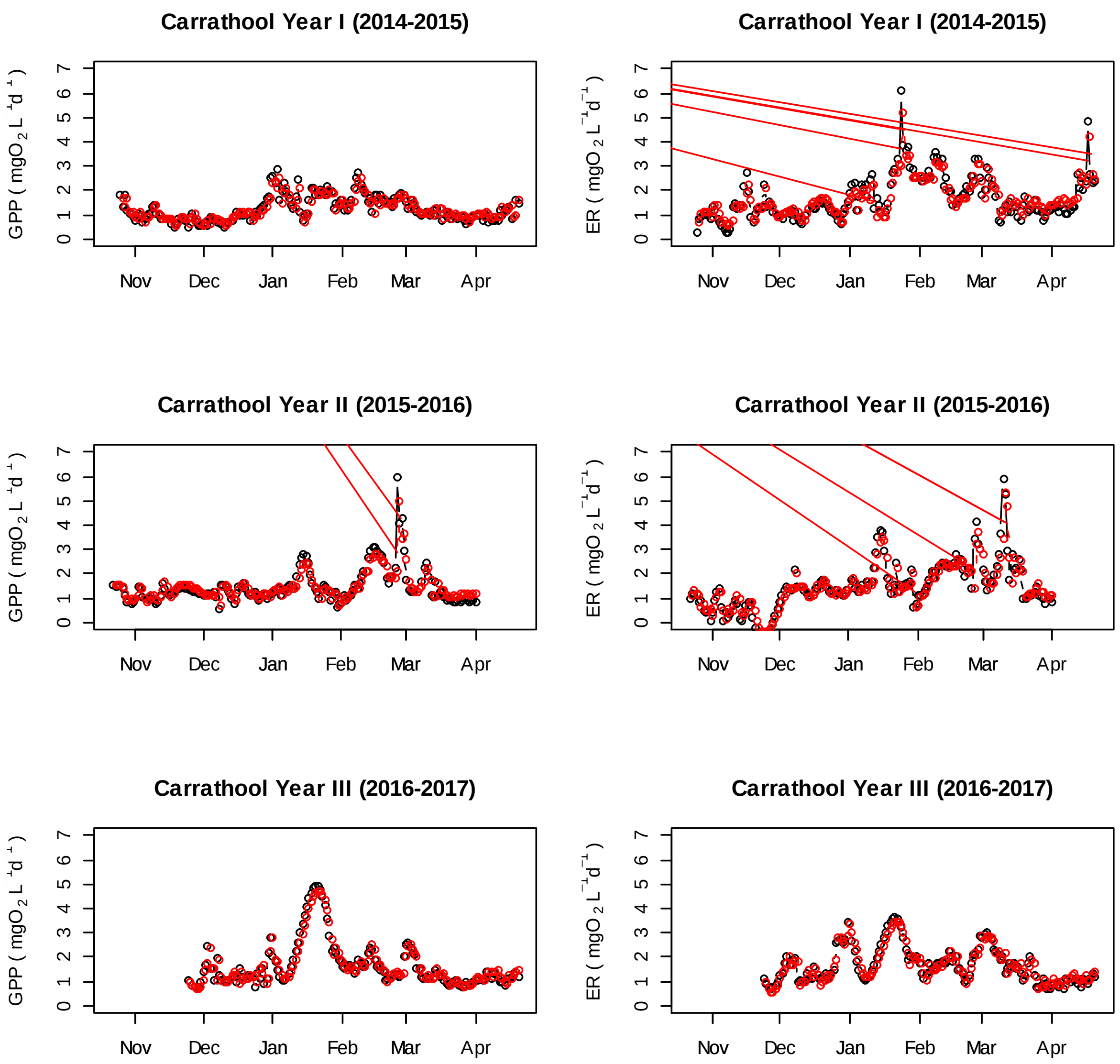


Figure 6-9 Predicted (forecast) and observed values of gross primary productivity (GPP, mgO_2 L^{-1} d^{-1}) and ecosystem respiration (ER, mgO_2 L^{-1} d^{-1}) at the Carrathool Cat 3 site for the water years 2014-15, 2015-16 and 2016-17, based on linear regression model with autoregressive errors of a lag-1, using mean daily water level (m d^{-1}) as a predictor. For the time-series plot (upper and lower left columns), the predicted (forecast) values are shown by open red circles and the observed values are shown by open black circles.

Discussion

What are the baseline rates of metabolism for environmental watering in the Murrumbidgee River?

Overall rates of metabolism in the Murrumbidgee remain slightly lower than other published data for the Murray-Darling Basin and previous studies from the Murrumbidgee (Vink, Bormans et al. 2005, Grace 2016). As noted by Wassens, Thiem et al. (2015), the discrepancy with the findings by Vink, Bormans et al. (2005) may be explained by differences in methodology (Song, Dodds et al. 2016). However, Vink, Bormans et al. (2005) speculated that rates of metabolism in the Murrumbidgee River have been reduced by the loss of nutrients and energy that were historically provided to the river during natural overbank flood events. The consistently low rates of production observed during the LTIM stream metabolism monitoring program support this prediction, although it isn't clear if production is limiting other ecological processes.

What is the relationship between flow and stream metabolism in the Murrumbidgee River?

We expected an increase in both GPP and ER in response to the overbank flooding in 2016-17, especially considering the lengthy lag in elevated nutrients and carbon (Section 4.2) that might be expected to stimulate production. This prediction is partly supported by an increase in water column chlorophyll-a, suggesting a response in phytoplankton production, that appears to coincide with the recession of the flood (see sections 4.2 River water quality). We found no evidence that the natural overbank event in 2016-17 had any influence on rates of metabolism, however, the analytical capacity to fully evaluate these outcomes is not yet available.

When considering data from across the last three years, there was an apparent overall increase in GPP and decline in ER at the Narrandera site during 2015-16 that shifted net ecosystem metabolism toward primary production. This change was supported by an increase in water column chlorophyll-a, again only observed for the Narrandera site. But during 2016-17 both chlorophyll-a and rates of metabolism both declined at the Narrandera site. As yet we are unable to explain these shifts, although apparent differences in flow height suggest a possible link with hydrology. Overall, flow regulation is thought to favour increased primary production and that increased lateral carbon inputs should drive the system towards net heterotrophy (P:R <1; (Robertson, Bunn et al. 1999). While this shift in production did occur during 2016-17, it appears to have been because of lower GPP rather than increased respiration.

Rates of metabolism varied across time at both study sites, with peak values loosely coinciding with both high and low flows. However, we found little evidence of a strong predictive relationship between flow and metabolism, particularly in the Carrathool zone. The overarching mechanisms by which flow is expected to influence metabolism are 1) wetland and riparian reconnection events that increase the supply of bioavailable nutrients and carbon that support increased rates of production and 2) high flows that scour river biofilms, resuspending nutrients previously tied up in biomass and detritus held in biofilms and by resetting biofilm community succession (Battin, Kaplan et al. 2008). Low flows also create conditions that favour higher rates of production (Humphries, King et al. 1999). The relationship between flow and metabolism is therefore unlikely to be a consistent linear trend, and we expect step-changes to rates of metabolism at thresholds where adjacent wetlands are reconnected with the river, when benthic shear stress exceeds that needed to scour the benthos, or when light saturates the water column.

Although we used linear regression with autoregressive errors of a lag-1, this approach may not always be best in accounting for the error structure associated with time-series stream metabolism data. The modelling results of this and previous studies (Wassens, Spencer et al. 2016) should be taken as a preliminary analysis of the time-series metabolism. Alternative models such as autoregressive models, moving average models or their combination should also be considered from the statistical point of view. However, such models may not necessarily be amenable to ecological interpretations of the underlying processes that regulate stream metabolism. Furthermore, there may be an as yet undefined lag in response and autocorrelation structure between flow, temperature and metabolism (Marcarelli, Baxter et al. 2011). Sources of water (i.e. local rainfall, tributary inflows or dam releases) is another important aspect that needs to be modelled to fully understand controls on metabolism in the Murrumbidgee River (Vink, Bormans et al. 2005).

6.4 Riverine microinvertebrates

Prepared by Dr Kim Jenkins (CSU), Dr Gilad Bino (UNSW), Dr Ben Wolfenden (CSU), Claire Sives (UNSW), Luke McPhan (UNSW) and Sylvia Hay (UNSW)

Microinvertebrates play a key role in floodplain river food webs, as prey to a wide range of fauna including fish (King 2004) and as important consumers of algae, bacteria and biofilms. Microinvertebrates are the critical link between stream metabolism and larval fish survival and recruitment (King 2004). As fish are gape limited, the availability of microinvertebrate prey in each size class at different times in the larval fish development is a critical factor influencing growth and survival. Density of microinvertebrates is also considered important for larval success, with densities between 100 and 1000/L reported for marine fish and densities within this range noted in hatching experiments and aquaculture for freshwater species (King 2004).

During 2016-17 there were no Commonwealth environmental watering actions specifically targeting microinvertebrates, however Commonwealth environmental water was delivered through monitored zones as part of the flood recession and dissolved oxygen management flow and river rises associated with this action coincided with microinvertebrate monitoring period. In addition small river pulses were created during the transfer of Commonwealth environmental water to the river, floodplain and wetland habitats downstream of the monitoring zones during the monitored period.

Between June and December 2016, the Murrumbidgee River experienced high unregulated river flows that created overbank flooding, reconnecting the river with floodplain wetland habitats along the length of the regulated Murrumbidgee River. Commonwealth environmental water was used to taper the flow recession, ensuring that adequate volumes were maintained to dilute nutrient rich water entering the river from the floodplain and reduce the risk of hypoxic blackwater. Microinvertebrate outcomes for 2016-17 are considered in the context of 2014-15 and 2015-16 outcomes, Commonwealth environmental water was not directly targeted at in-channel watering outcomes during 2014-15 and 2015-16 and overall river flows were lower particularly in the Carrathool zone which is less impacted by the delivery of irrigation flows.

We predicted that environmental flows in spring and summer would inundate previously dry sediments in rivers (i.e. backwaters, in-channel benches), releasing and transporting nutrients that along with rising temperatures, stimulates productivity and diversity of microinvertebrate communities. With this in mind we aimed to detect whether peaks in the density of microinvertebrates are matched to the timing of peak numbers of fish larvae.

Methods

Microinvertebrate samples were collected fortnightly from the six larval fish sampling sites along the Murrumbidgee River (three sites in each of the Carrathool and Narrandera zones) from mid spring to early summer in 2014, 2015 and 2016. In year one of the LTIM project (2014-15) sampling occurred fortnightly between 20 October 2014 and 1 January 2015. In year two (2015-16), sampling was undertaken fortnightly from 13 October until 24 December 2015. In year three sampling occurred fortnightly from 10 October until 22 December 2016. In each year there was six sampling events at each of the six sites in association with larval fish monitoring.

Benthic and pelagic samples were collected following the methods described by (Wassens, Jenkins et al. 2014). In the laboratory, benthic and pelagic microinvertebrate samples were poured into a Bogorov tray and enumerated with the aid of a dissecting microscope (Leica M125 and M165) at a magnification of 32x to 80x. We sub-sampled all samples by dividing Bogorov trays into 44 cells (1.5 x 1.3 cm) and counting and measuring individuals in every second cell (50 per cent of sample processed). Prior to counting every second cell in pelagic samples we also took a 10 per cent sub-sample (5 per cent of sample processed). This was done using a 30 mL syringe to draw a sample from a 300 mL beaker stirred on a magnetic stirrer. Rose Bengal stain was used in the field or the laboratory to highlight individuals in samples with excessive sediment present. Specimens were identified with relevant guides to species where possible (Williams 1980, Smirnov and Timms 1983, Shiel and Dickson 1995, Shiel 1995). A maximum of 30 individuals of each taxa per sample were measured for length and width.

Data analysis

Daily stream gauging data from Narrandera (WaterNSW gauge 410005) and Carrathool (gauge 410078) was used to graphically represent daily water level changes in respective hydrological zones. We analysed responses of microinvertebrates in relation to zone (i.e., Carathool or Narrandera) along with trip by fitting a linear mixed-effects model (LMM) using the lmer function in the lme4 package in R (Bates, Maechler et al. 2015; R version 3.2.1, R Core Team, 2015). Zone and trip were incorporated as an interaction term to account for different responses over time while site was a random effect in the model. Prior to analysis, all our response variables were ln(x+1) transformed to reduce skewness and stabilize error variances. We tested the effects of water flow and water level on microinvertebrate responses by incorporating an additional and separate continuous term to the linear mixed-effects model. To draw generalizations about the effects of zone and trip from the samples collected, we present model estimates of responses for ease of interpretation and inference.

Results

In all three years, densities of microinvertebrates were two orders of magnitude higher in benthic (<3000/L) than pelagic (<10/L) habitats within the Murrumbidgee River (Figure 6-10). Pelagic densities were consistently an order of magnitude below the lowest prey density threshold suggested for successful feeding by larval fish (Figure 6-10). Densities of microinvertebrates were lower in 2016-17 than in previous years, likely due to higher water levels, faster flows and lower water temperatures in 2016-17 (Figure 6-10). In the first two trips in 2016-17, pelagic densities were higher (20-30 individuals L^{-1}) than on subsequent trips (<10 individuals L^{-1}) (Figure 6-10). This was likely due to sampling taking place on the floodplain due to high water levels in the river.

Overall, densities of microinvertebrates were higher in the Carrathool than Narrandera zone (Figure 6-10). Model estimates of total microinvertebrate density indicate the higher densities in the Carathool zone compared to the Narrandera zone were not significant, but were consistent between years (Figure 6-11). The lowest densities of microinvertebrates were recorded in 2016-17 in both Carathool and Narrandera zones, but this difference was only significant in the Narrandera zone (Figure 6-11). In benthic habitats in both the Narrandera and Carathool zones, microinvertebrate densities generally increased in the latter three trips in 2014-15 and 2015-16 (Figure 6-12). In contrast, densities were lower in the latter four trips in 2016-17 (Figure 6-12). This was likely due to the sampling locations returning from the floodplain to the river channel where flows were fast and water levels high, flushing microinvertebrates away.

The lower densities observed in 2016-17 (Figure 6-10 and Figure 6-12), were reflected in a different taxa composition compared to 2014-15 and 2015-16 (Figure 6-13). In the higher flow year (2016-17) there were lower densities of key microinvertebrate taxa including; *Macrothix* sp., *Neothrix armata*, *Macrothrix spinosa* and a number of chydorids (Figure 6-13). Despite the composition differences between years, species richness did not show consistent patterns over trips across years (Figure 6-14). Species richness was slightly higher in Carrathool than Narrandera and more taxa were detected in benthic than pelagic samples (Figure 6-14).

Total microinvertebrate density showed a u-shaped relationship with both flow volume (Figure 6-15) and water level (Figure 6-16) for both benthic and pelagic habitats. There were more samples with high densities observed at low flows, than at high flows where the samples were all from the first two trips in 2016-17. The relationship with higher densities at high flows needs to be treated with caution as it was not possible to sample in the river channel due to high flows and so sampling was undertaken in slower flowing water on the adjoining floodplain. The benthic densities in Narrandera zone at the highest flows and water levels were not as high as observed in the Carathool zone (Figure 6-16).

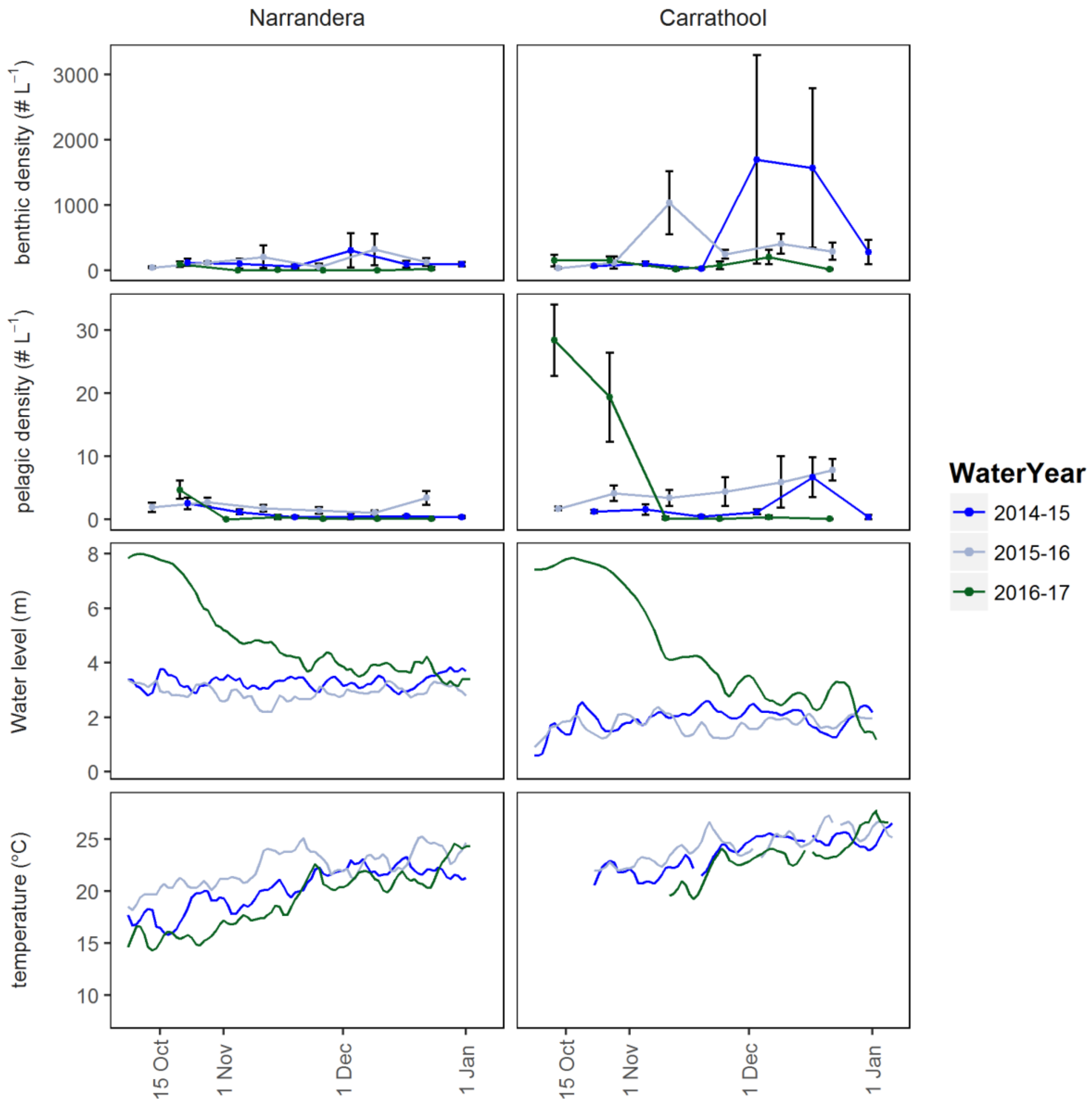


Figure 6-10 Benthic (upper row) and pelagic (second row) microinvertebrate densities (L-1) for 3 sites in the Carrathool zone (left graphs) and 3 sites in the Narrandera zone (right graphs) of the Murrumbidgee River sampled from October 2014 to January 2017. Data are plotted as scatter plots with the mean and standard errors for the three sites in each zone on each trip. Benthic and pelagic samples are presented on different scales, with benthic samples typically exhibiting densities several orders of magnitude greater than pelagic samples. Mean daily water level (third row) is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature (lower row) was taken from the gauge data for Narrandera. The Carrathool temperature data is collected by the LTIM metabolism monitoring program which was delayed in 2016-17 due to flooding. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

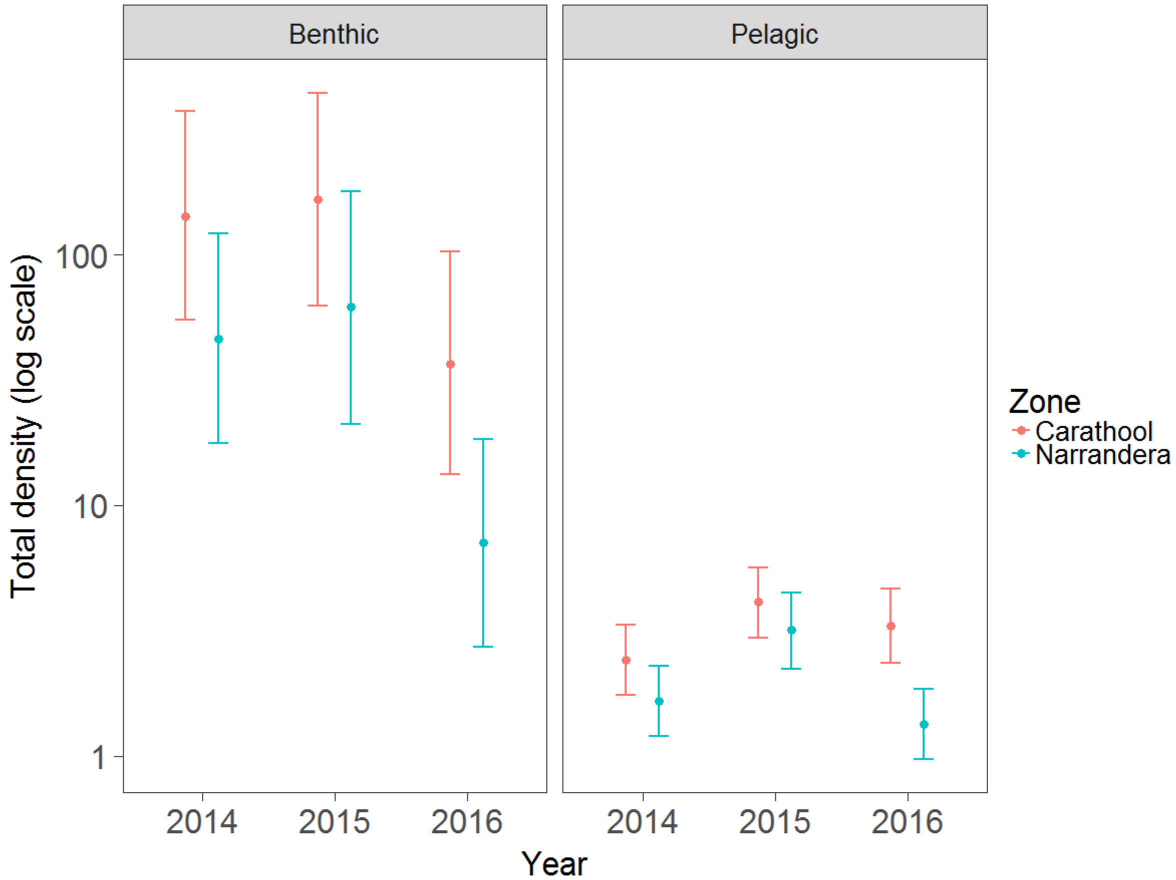


Figure 6-11 Model estimates (mean ± 95% confidence intervals) of total microinvertebrate density (log scale) for three sample occasions and three sites each from the Carrathool and Narrandera zones in both benthic (left graph) and pelagic (right graph) habitats sampled in 2014-15, 2015-16 and 2016-17.

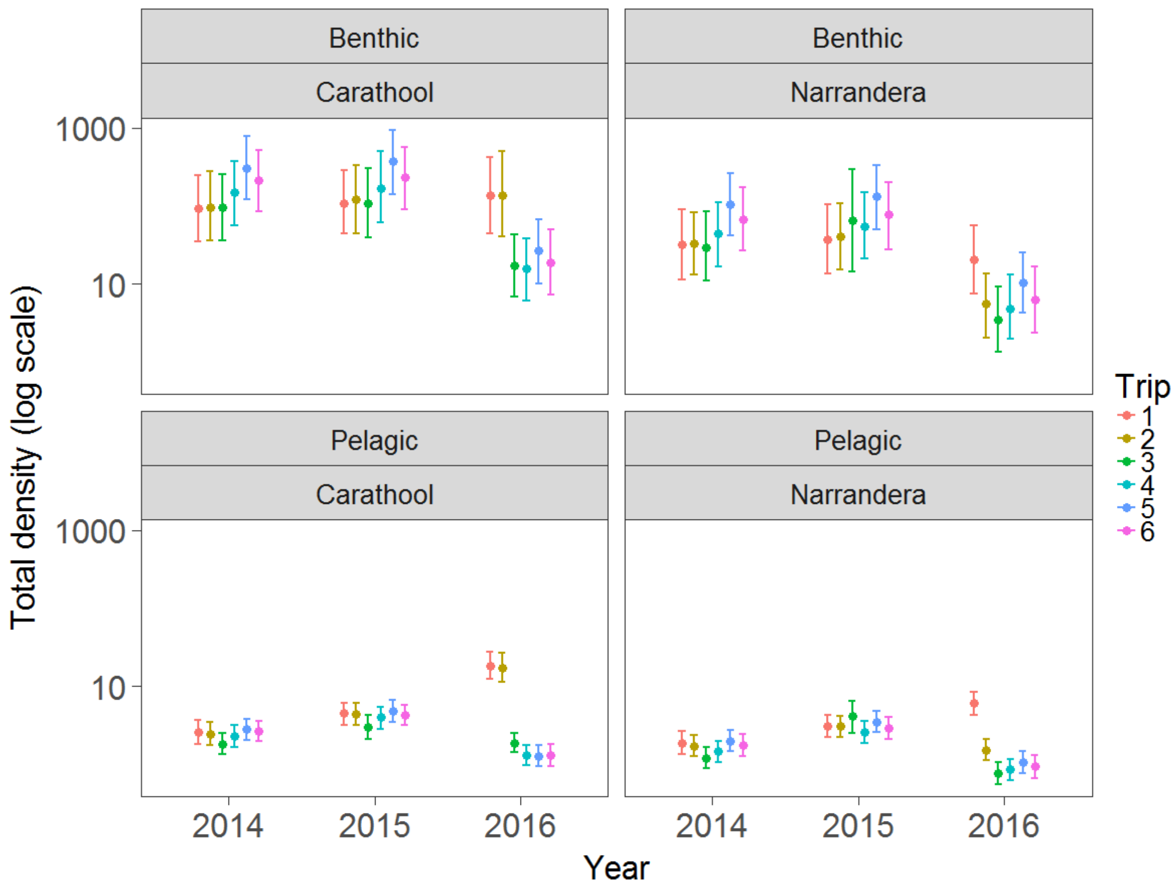


Figure 6-12 Model estimates (mean ± 95% confidence intervals) of total microinvertebrate density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic (upper graphs) and pelagic (lower graphs) habitats sampled over 6 trips in 2014-15, 2015-16 and 2016-17.

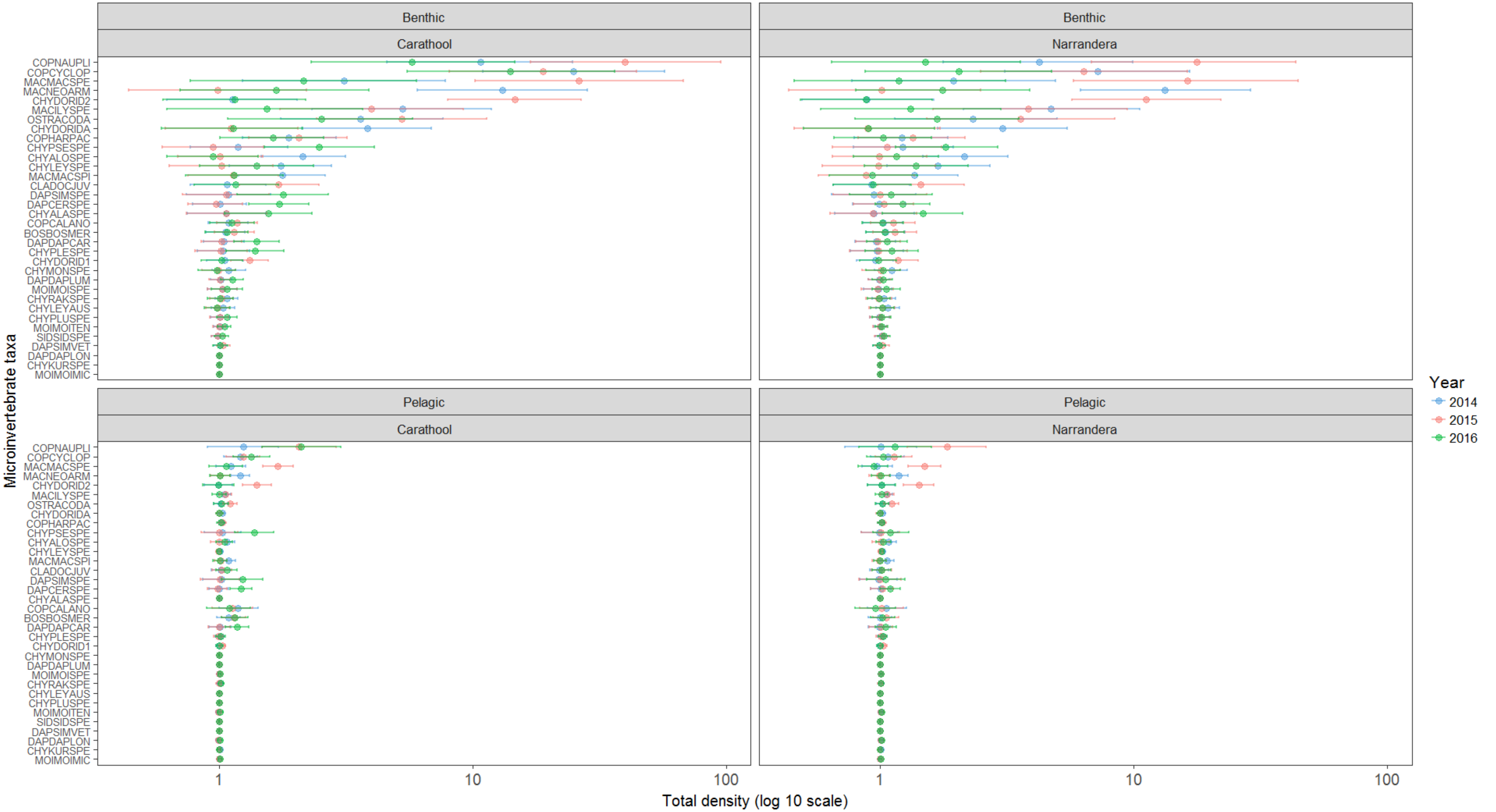


Figure 6-13 Model estimates (mean ± 95% confidence intervals) of total microinvertebrate taxa density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic (upper row) and pelagic (lower row) habitats sampled in 2014-15, 2015-16 and 2016-17.

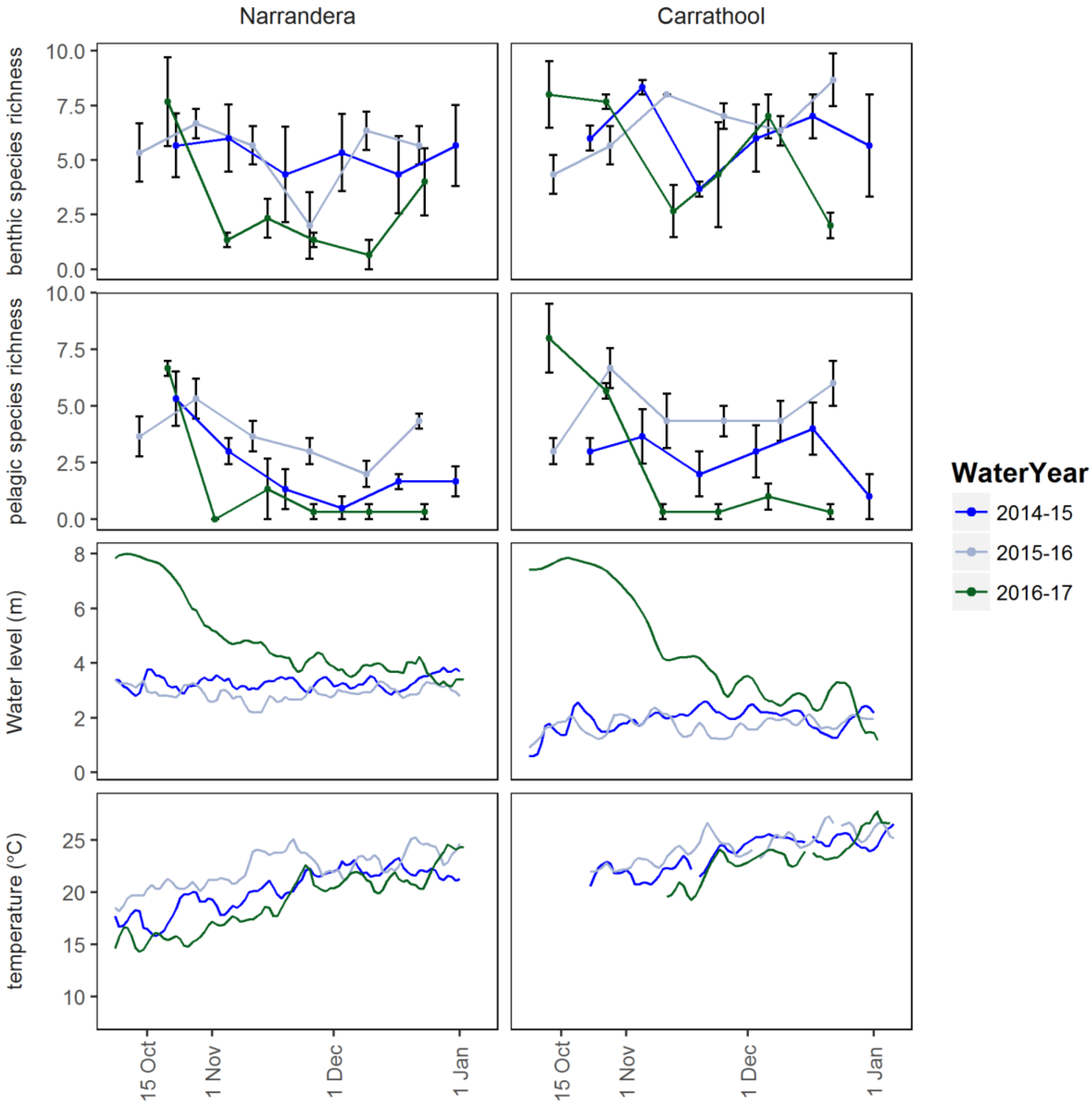


Figure 6-14 Benthic (upper row) and pelagic (second row) microinvertebrate species richness for 3 sites in the Carrathool zone (left graphs) and 3 sites in the Narrandera zone (right graphs) of the Murrumbidgee River sampled from October 2014 to January 2017. Data are plotted as scatter plots with the mean and standard errors for the three sites in each zone on each trip. Mean daily water level (third row) is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature (lower row) was taken from the gauge data for Narrandera. The Carrathool temperature data is collected by the LTIM metabolism monitoring program which was delayed in 2016-17 due to flooding. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

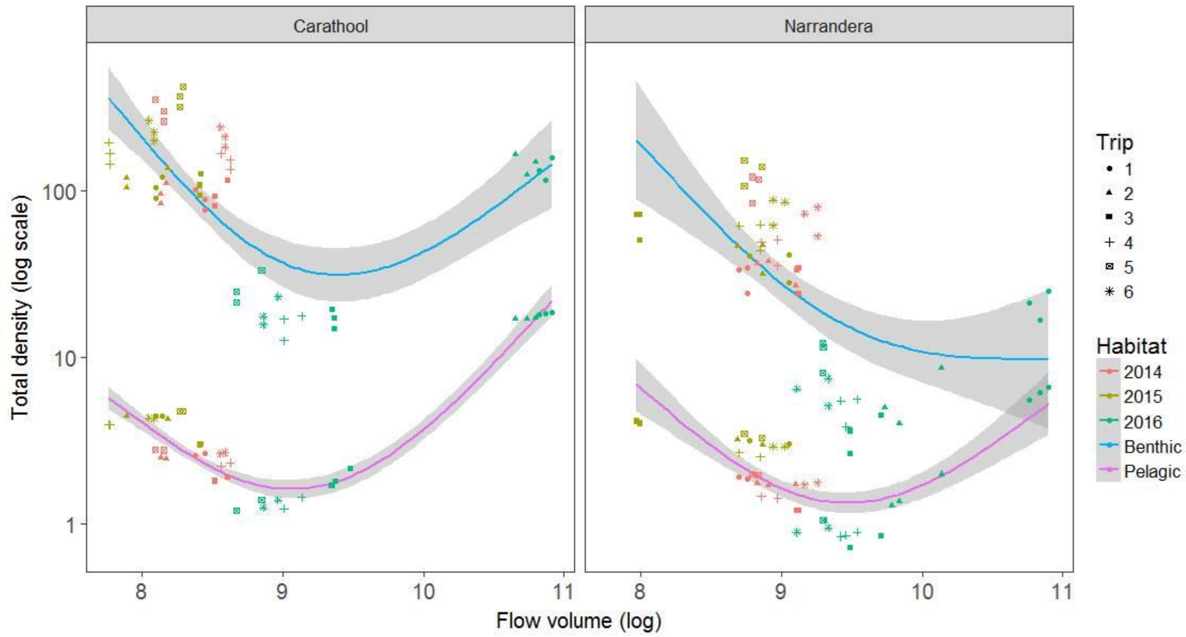


Figure 6-15 Model estimates(mean ± 95% confidence intervals) of flow volume (log scale) versus total microinvertebrate density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic and pelagic habitats sampled in 2014-15, 2015-16 and 2016-17.

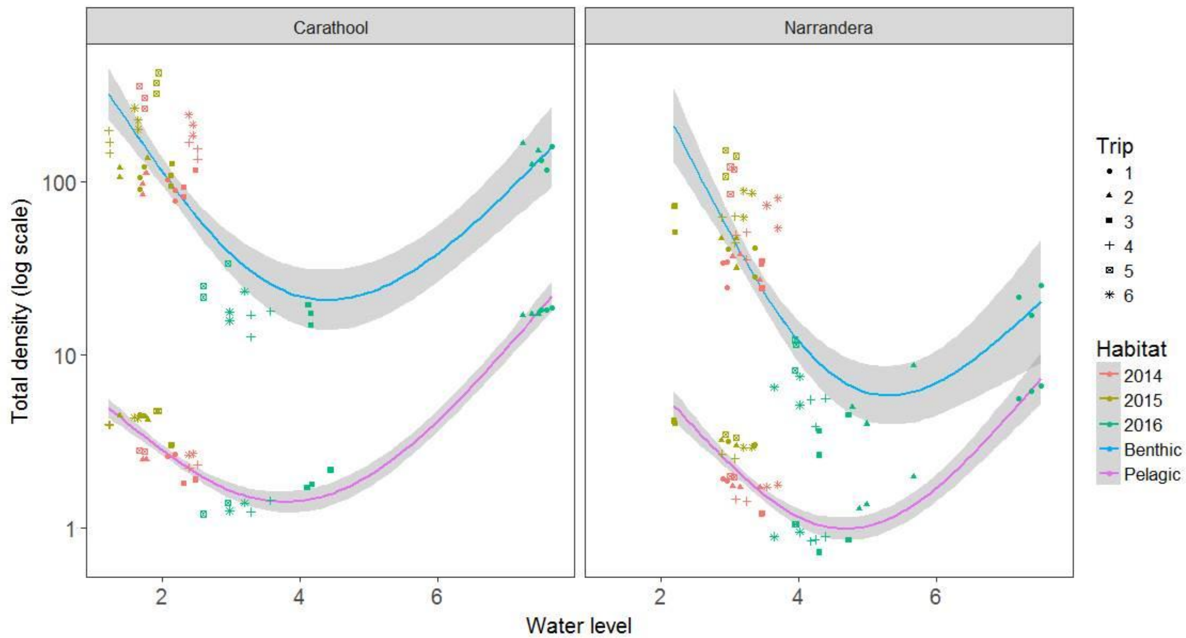


Figure 6-16 Model estimates (mean ± 95% confidence intervals) of water level versus total microinvertebrate density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic and pelagic habitats sampled in 2014-15, 2015-16 and 2016-17.

Discussion

What did Commonwealth environmental water contribute to densities of benthic and pelagic microinvertebrates as prey for larval fish?

The delivery of Commonwealth environmental water to creeks and wetlands in the mid to lower Murrumbidgee resulted in peaks in flow within the Murrumbidgee River in the Carrathool Zone and to a lesser extent in the Narrandera Zone (See Figure 6-10). Peaks in benthic microinvertebrate densities in the Carrathool Zone were recorded 7-10 days after river levels peaked as water levels were falling (Figure 6-10). In 2014-15 this occurred in mid-December for chydorids, ostracods and copepods, while in 2015-16 this occurred in mid-November. This same response was not observed in 2016-17 when higher flows and lower temperatures were observed during flood flows in the Murrumbidgee River (Figure 6-10 and Figure 6-11).

The peak in benthic microinvertebrate densities in 2015-16 coincided with peaks in Australian smelt and cod species captured in light traps (see Section 6.5). However peak numbers of cod species and perch captured in drift nets occurred two weeks earlier in late October, suggesting peak densities of larval fish and microinvertebrates were offset. This mismatch in timing between peaks was more apparent in 2014-15 when larval fish numbers peaked in early to mid-November (see 4.5 Riverine and larval fish) well before the peak in microinvertebrate densities in early to mid-December. In 2016-17, microinvertebrate densities did not peak in November when most larval fish were captured.

Overall, densities of pelagic microinvertebrates were two to three orders of magnitude lower than benthic densities throughout the three year study period. This is likely due to the fast flowing nature of the river flushing microinvertebrates from this habitat, but also because it is a nutrient poor environment compared to the productive benthic zone on the edge of the river channel.

Although not significantly different, densities of microinvertebrates were higher in the Carathool than Narrandera zone across the three years of this study (see Figure 6-11). River levels in the Narrandera zone were at least one metre higher in the Narrandera than in the Carrathool zone and there was less variability in river level (See Figure 6-10). It appears that the higher river level in the Narrandera zone may impact development of a productive and diverse microinvertebrate community. In contrast in the Carrathool zone with lower more variable river levels, pronounced peaks in microinvertebrate densities were recorded in both 2014-15 and 2015-16. This is likely due to drying and then rewetting of edge sediments stimulating nutrient release that then supports peak densities of microinvertebrates. In addition, when river levels are higher and flow faster it is likely that benthic microinvertebrates may be flushed from this habitat. However, further studies with additional zones are needed to replicate these observations. In addition, before, during and after monitoring as river levels rise, peak and fall would help unravel if these aspects of hydrology are driving the patterns observed in microinvertebrate community dynamics.

Data from the 2016-17 water year documents the role of overbank flows that connected the river with large areas of floodplain. During the first two trips in 2016-17, it was not possible to sample in the river channel due to flood levels and so samples were taken on the adjacent floodplain. At this time the highest densities of microinvertebrates were recorded for the 2016-17 year, likely due to slower flowing water and emergence of microinvertebrates on the floodplain (see Figure 6-11). Although densities of microinvertebrates were lower when sampling returned to the high flowing river sites from trip 3 (see Figure 6-12), it is likely that the increase in riverine productivity (see Section 6.3) would benefit microinvertebrate community productivity in following seasons.

6.5 Larval fish

Prepared by Jason Thiem (NSW DPI Fisheries)

Introduction

Flow plays a critical role in the early life-cycle of native fish, and the duration, magnitude and timing of flows strongly influence adult spawning and subsequent survival and growth of larvae (King, Gwinn et al. 2016). The larvae stage is the most critical and vulnerable part of a fish's life history. Larval fish survival is highly dependent on hydrology which influences habitat availability (Copp 1992), water temperature (Rolls, Growns et al. 2013), dispersal (Gilligan and Schiller 2003) and microinvertebrate abundance for first feed (King 2004). Commonwealth environmental water targeting native fish has the capacity to positively influence reproductive opportunities, enhance larval survival, and hence, increase recruitment to the wider population. Understanding the critical links between flow, fish spawning and larval fish survival can assist the management of environmental flows to support and enhance native fish populations.

Use of a specifically designed hydrograph that targets groups of fish species based on similar reproductive strategies could benefit a range of species in a given water year (Baumgartner, Conallin et al. 2014). For example, increased flows may inundate river or wetland habitat needed by small-bodied generalist species or large-bodied nesting species for reproduction, while also releasing nutrients and increasing productivity of microinvertebrates, a key prey item for the first feed of all species of native fish (Devries, Stein et al. 1998). Alternatively flow peaks may be used to trigger reproduction directly in flow-dependant species such as golden (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (King, Tonkin et al. 2009, King, Gwinn et al. 2016). This current study aimed to determine the seasonal timing of reproduction of native fish species within the Murrumbidgee Selected Area, and the biotic and abiotic factors associated with spawning and early survival of fish larvae. Spawning data collected during 2014-15 and 2015-16 (LTIM Years 1 and 2; Wassens, Thiem et al. 2015) are included for comparison. Category 1 fish community sampling data collected from the Carrathool zone only in 2015, 2016 (Wassens, Thiem et al. 2015, Wassens, Spencer et al. 2016) and

2017 are also included to add some context for the translation of spawning into young-of-year recruitment.

Between June and December 2016 the Murrumbidgee River experienced a natural overbank flood, reconnecting the river with floodplain wetland habitats along the length of the regulated Murrumbidgee River. While there were no flows specifically targeting native fish spawning, monitoring was undertaken during the transit of water as part of the Commonwealth Flood recession and dissolved oxygen management flow. In this section we sought to describe the range of fish responses observed during 2016-17, and contrasted these with previous years.

Methods

Larval fish were collected using methods described by (Wassens, Jenkins et al. 2014). Larval fish sampling was undertaken at six riverine sites, with three sites selected within each of two hydrological zones (Figure 6-17). Eight larval drift nets and ten quatrefoil light traps were set overnight at each riverine site. Equipment and methods were consistent with those described by (Hale, Stoffels et al. 2014), with the exception being that five additional larval drift nets were set at each site to adequately detect commonly encountered larvae such as Murray cod (*Maccullochella peelii*). Sampling was undertaken fortnightly from 10 October until 22 December 2016, resulting in six sampling events at each of the six sites. These data were compared with data collected from the same sites and using the same methods in the previous watering years 2014-15 and 2015-16 (Wassens, Thiem et al. 2015, Wassens, Spencer et al. 2016). Eggs were live-picked and enumerated from drift net samples in the field, and a subset of these were hatched in river water at ambient temperatures. Larvae were subsequently identified to species in the laboratory. With the exception of juvenile Murray River crayfish (*Euastacus armatus*) and freshwater yabby (*Cherax destructor*), entire samples collected from both light traps and drift nets were preserved in 90% ethanol for later laboratory identification using keys described in (Serafini and Humphries 2004).

A sub-sample of larvae hatched from live-picked eggs as well as preserved eggs, comprising both golden and silver perch, and representing all possible combinations of sites and sampling events, were submitted to the Australian Genome Research Facility (AGRF). Nucleic acid extraction and subsequent verification of species assignment was based on dual-direction sequencing following PCR amplification. Genetic assignment of golden and silver perch generally conformed to laboratory identification based on morphological characteristics, and species assignment to egg captures was scaled for each site and trip based on the ratios of hatched and identified larvae and eggs. In addition, samples were pooled at the genus level for cod (i.e. *Maccullochella* spp.) due to difficulties with species identification, as per previous studies done through short-term intervention monitoring projects (Wassens, Jenkins et al. 2013, Wassens, Jenkins et al. 2014).

Data analysis

Data were standardised to a single value per species, site, sampling event and method (i.e. total catch for each species from a site was pooled by sampling method) and are represented as catch per unit effort (CPUE; number of larvae per light trap hour or the number of larvae per cubic metre of water filtered). Juveniles and adults were excluded from analysis and reporting because the sampling effort was not consistent for adult and juveniles and numbers were too low to allow for further analysis. Daily stream gauging data from Narrandera (NSW Office of Water gauge 410005) and Carrathool (gauge 410078) was used to represent daily water level changes in respective hydrological zones as a proportion of the bankfull threshold. To determine differences in larval fish CPUE between zones (Narrandera and Carrathool) and years (2014-15, 2015-16 and 2016-17), data were analysed using a two-way fixed factor (with zone and year as factors) Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson, Gorley et al. (2008)). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, SIMPER tests were used to identify individual species contributions to average dissimilarities.

A linear mixed-effect modelling approach was undertaken to examine the (binary) probability of periodic species spawning (golden perch and silver perch) in response to abiotic factors (hydrology and temperature). Briefly, model-selection was undertaken examining a suite of standardised hydrological (proportion of bankfull height, change in proportion of bankfull height) and climatic (water temperature, change in water temperature) variables over 1, 10 and 20 day time periods for each hydrological zone during each of the sampling events within watering years. We analysed silver and golden perch occupancy in relation to water conditions by fitting a global generalized linear mixed-effects model (GLMM) using the glmer function in the lme4 package in R (Bates, Maechler et al., 2015; R version 3.2.1, R Core Team, 2015). We then employed a model averaging method to generate a summary model from subset models based on the corrected Akaike information criterion (AICc; Grueber, Nakagawa et al. (2011), using the dredge and model.avg functions in the MuMIn package (Barton 2015). We used a cutoff of 2AICc to generate the submodel set that was averaged in the summary model (Burnham and Anderson 2002). Model averaging accounts for uncertainty in model selection and provides robust parameter estimates, particularly when there is no single best model for the data and models have small differences in their fit, based on an information criterion (Grueber, Nakagawa et al. 2011).

Category 1 fish community data as per (Hale, Stoffels et al. 2014) collected from the focal zone in March 2015, 2016 and 2017 (encompassing Yarradda, Bringagee and McKennas larval sampling sites) are presented to examine whether spawning in either watering year translated into young-of-year recruitment. Specifically, length-frequency plots are presented to indicate the presence of new recruits as a proportion of the sampled population.

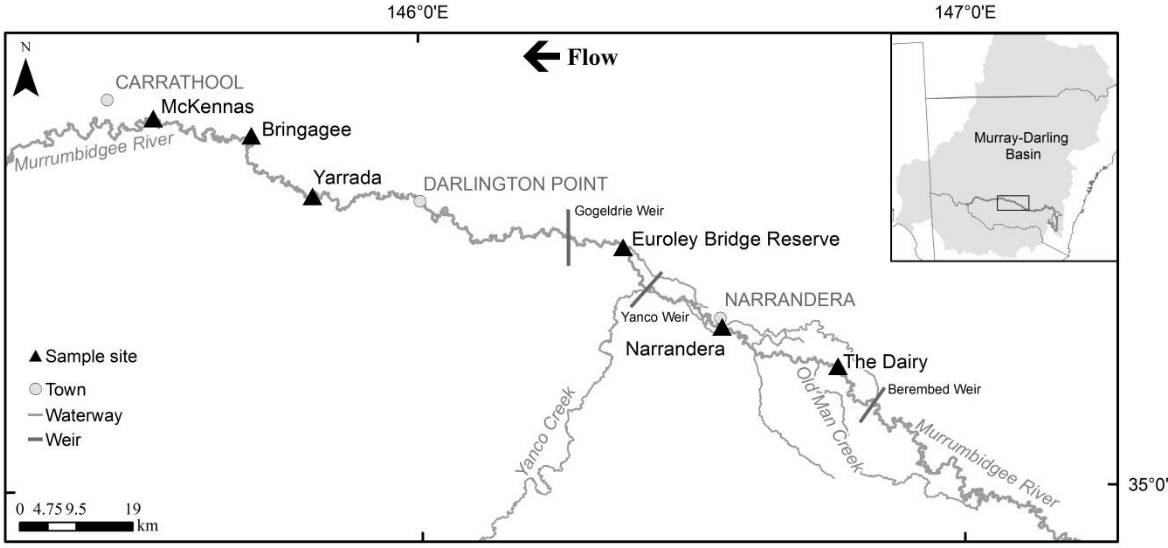


Figure 6-17 Locations of larval fish in-channel sampling sites on the Murrumbidgee River, encompassing Narrandera (The Dairy (DAI), Narrandera (NRD) and Euroley Bridge (EUB)) and Carrathool (Yarradda (YRR), Bringagee (BRI) and McKennas (MKR)) hydrological zones.

Results

A combined total of 2,882 eggs and larvae were collected during the 2016-17 sampling. At least seven native fish species (Australian smelt *Retropinna semoni*, carp gudgeon *Hypseleotris* spp., flat-headed gudgeon *Philypnodon grandiceps*, golden perch *Macquaria ambigua*, Murray cod *Maccullochella peelii*, Murray-Darling rainbowfish *Melanotaenia fluviatilis*, silver perch *Bidyanus bidyanus*) and three alien species (common carp *Cyprinus carpio,* Eastern gambusia *Gambusia holbrooki* and redfin perch *Perca fluviatilis*) spawned in the Murrumbidgee River in 2016-17 (Table 6-8). Additionally, early stage juvenile Murray River crayfish and freshwater yabby were captured in drift nets (Table 6-8). Australian smelt larvae were captured in the greatest abundance (n=680), and occurred at all sites (Table 6-8). Common carp (n=642) and cod species (*Maccullochella* spp.; n=229) were also abundant and larvae were captured at all sites. Carp gudgeon larvae were locally abundant at Yarradda (n=119). Silver perch (n=29) and golden perch (n=52) eggs were only captured in the Narrandera zone, and no larvae of either species were captured.

Catch per unit effort of larvae and eggs differed significantly among years ($Pseudo\text{-}F_{2,101}$ = 3.423, P =0.001) and between hydrological zones ($Pseudo\text{-}F_{1,101}$ = 4.998, P =0.002). There was a significant difference in the interaction between year and zone ($Pseudo\text{-}F_{2,101}$ =1.957, P =0.045). Pair-wise comparisons indicated that there were significant differences in larval CPUE were between 2014 and 2016 (t=2.000, P=0.004) as well as 2015 and 2016 (t=2.388, P<0.001), but not between 2014 and 2015 (t=0.786, P=0.653). Differences among years were primarily driven by higher CPUE of Australian smelt and common carp larvae in 2016, as well as a lower abundance of Murray cod larvae (Figure 6-8). Differences between zones were primarily driven by higher CPUE of Australian smelt, cod species and carp gudgeon in the Carrathool zone (Table 6-9).

Table 6-8 Raw (unstandardised) total captures of eggs and larvae from combined larval drift nets and light traps separated by sampling site pooled across all sampling events.

		Hydrological zone					
		Narrandera			Carrathool		
		The Dairy	Narrandera	Euroley Bridge	Yarradda	Bringagee	McKennas
Native fish species							
Australian smelt	larvae	57	15	48	380	153	27
bony herring	larvae						
carp gudgeon	larvae		1	1	119		15
cod species	larvae	35	35	49	60	19	31
flat-headed gudgeon	larvae				1	5	12
golden perch	eggs	16	36				
	larvae						
Murray-Darling rainbowfish	larvae			1			
silver perch	eggs	21	7	1			
trout cod	larvae						
unidentified	eggs	3		20	7	3	
	larvae		15	2	307	336	406
Alien fish species							
common carp	eggs						
	larvae	4	3	118	138	277	102
Eastern gambusia	larvae						4
redfin perch	larvae					4	
Other							
Murray River crayfish	juveniles	1					
freshwater yabby	juveniles			1	2	4	5

Table 6-9 Contributions of fish larvae CPUE (Catch per unit effort) to variability among years (2014, 2015 and 2016) and between hydrological zones (Narrandera and Carrathool) in the Murrumbidgee River, determined through SIMPER analysis. Note that only species contributing ≥10% (dissimilarity) to changes are included. Comparisons between 2014 and 2015 are not included as there was no significant pair-wise difference in CPUE.

Comparison	Species	Contribution to difference (%)	Greatest CPUE
2015-2016	Australian smelt	28	2016
	cod species	25	2015
	common carp	12	2016
	carp gudgeon	12	2015
	silver perch	11	2015
2014-2016	Australian smelt	28	2016
	cod species	27	2014
	common carp	13	2016
	carp gudgeon	11	2014
Carrathool-Narrandera	Australian smelt	28	Carrathool
	cod species	25	Carrathool
	carp gudgeon	15	Carrathool
	silver perch	10	Narrandera

Distinct peaks were evident in the timing of collection of larvae and eggs of most fish species in 2016-17. For example, captures of cod larvae peaked in early-mid December 2016, later than in previous years (Figure 6-18 and Figure 6-19). Australian smelt larvae were more abundant in the Carrathool zone, and catch data displayed similar bi-modal peaks to 2014-15 and 2015-16. Carp gudgeon larvae likewise were more abundant in the Carrathool zone, and captures peaked in December (Figure 6-19).

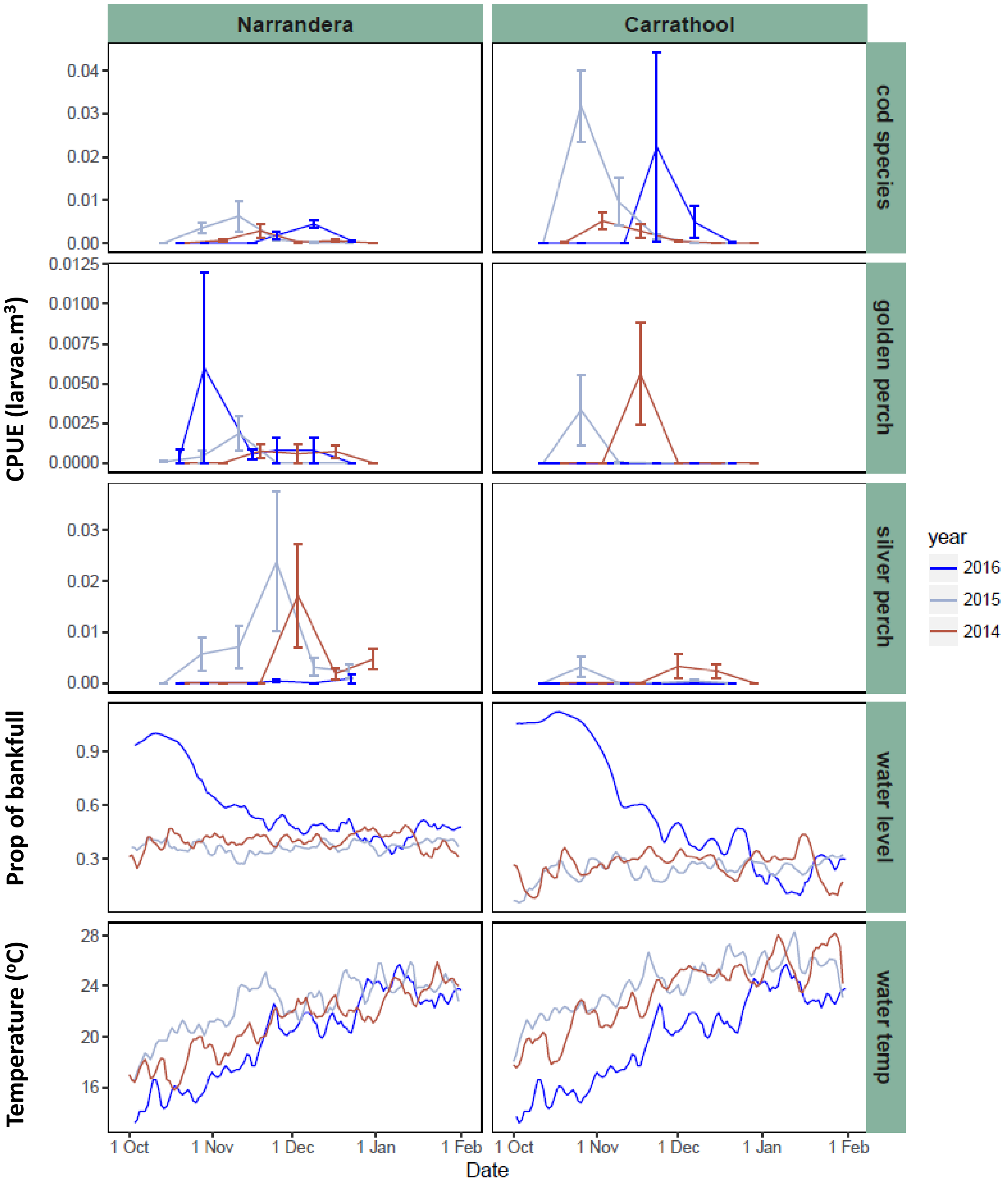


Figure 6-18 Larval drift net catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones in 2014, 2015 and 2016. The three most abundant species are represented, with captures of cod species represented by larvae, and golden and silver perch by eggs.

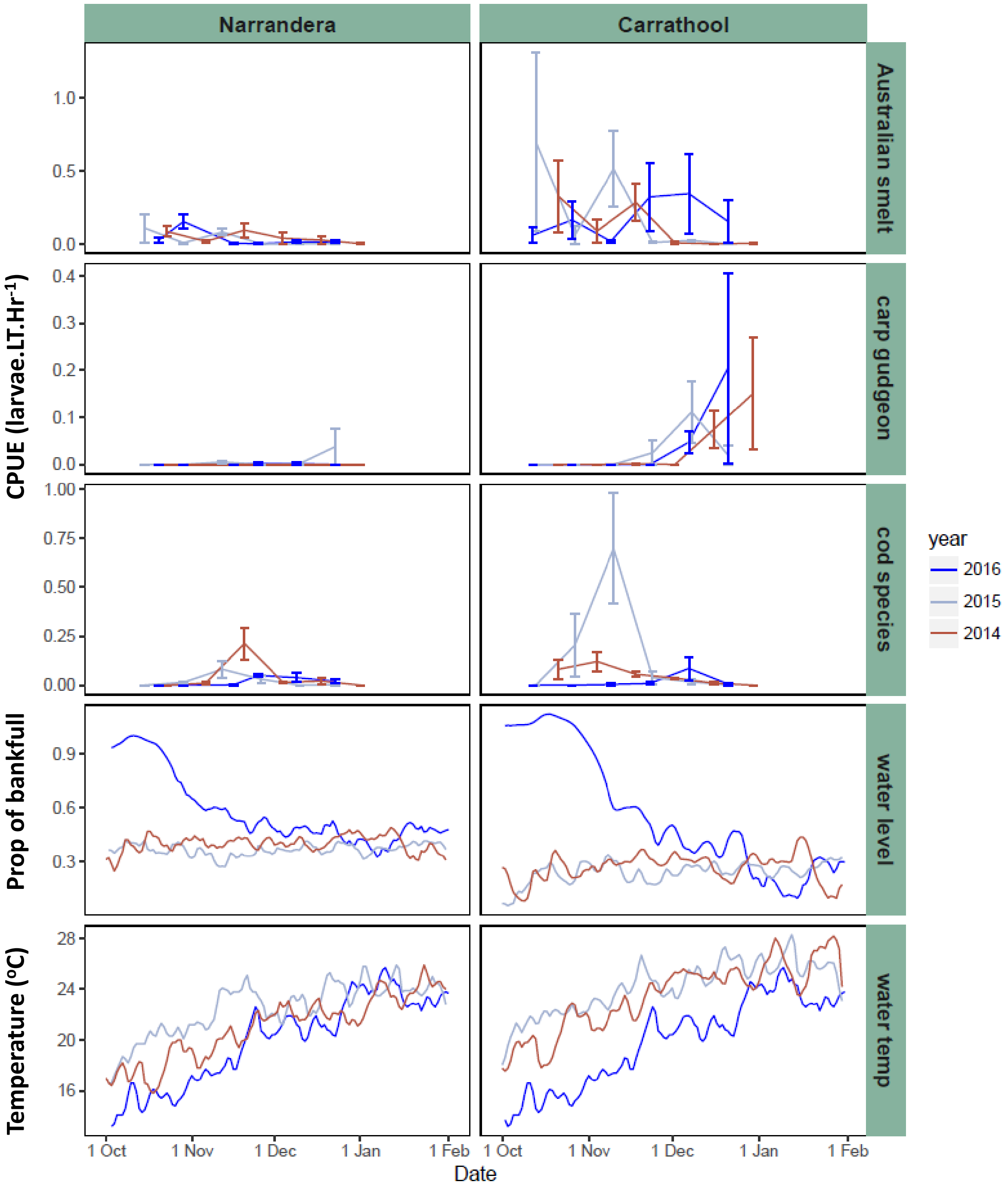


Figure 6-19 Larval light trap catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones in 2014, 2015 and 2016. Only captures of the three most abundant species larvae are represented.

Golden perch eggs were only collected from the Narrandera zone in 2016-17, and captures were highest in late October 2016 (Figure 6-18). As the probability of golden perch spawning differed significantly between zones, predictive relationships are presented separately for each zone. Golden perch exhibit an optimal spawning window between 18 and 20°C (Figure 6-20a). There is little evidence to support a relationship between the probability of spawning and standardised water levels in either zone although it should be noted that golden perch spawning data is sparse (Table 6-10; Figure 6-20a). Similarly, silver perch eggs were only collected from the Narrandera zone in 2016-17, although unlike golden perch they were generally collected later in season (December) as per previous years (Figure 6-18). Predictive relationships for silver perch are likewise presented separately for each zone given significant zone differences (Table 6-11). Predictive models indicate a strong positive relationship between the probably of silver perch spawning and water temperature (Table 6-11; Figure 6-20c), although a generally negative relationship between spawning and standardised water level (Table 6-11; Figure 6-20d).

All fish captured as eggs and/or larvae in the Carrathool zone during 2016-17 were represented in the fish community sampling undertaken in March 2017 (Table 6-12). Six additional species were captured during March surveys including bony herring, golden perch, Murray-Darling rainbowfish, silver perch, un-specked hardyhead and goldfish (Table 6-12). New recruits of the most abundant species were generally present in the river with the exception of golden perch (Figure 6-21 and Figure 6-22). There was a higher proportion of common carp and lower proportion of Murray cod new recruits in 2016-17 compared with previous years (Figure 6-22).

Table 6-10 Model-averaged parameter estimates explaining the probability of golden perch spawning in relation to water temperature (1, 10 and 20 day averages; temp), changes in water temperature over the same time period (d.temp), water level as a proportion of bankfull height (1, 10, and 20 day averages; proplev) and changes in proportion of bankfull height over the same time period (d.proplev).

Parameter	Estimate	Std. Error	Adjusted SE	z value	p
(Intercept)	-2.2996	0.4411	0.4462	5.153	<0.001
zone	1.6786	0.7804	0.7897	2.126	0.03353
d.10.proplev	-3.3739	1.8564	1.8727	1.802	0.0716
d.temp	-1.8258	0.6863	0.6936	2.632	0.00848
10.prop.lev	11.9005	7.1809	7.269	1.637	0.1016
20.prop.lev	-10.9073	8.2548	8.3106	1.312	0.18936
20.temp	-2.1584	0.9342	0.9453	2.283	0.02241
10.temp	-2.2896	0.9907	1.0026	2.284	0.02239
proplev	4.7269	6.4784	6.5214	0.725	0.46855
d.proplev	0.635	0.8037	0.8137	0.78	0.43512
d.20.proplev	1.1486	1.1125	1.1261	1.02	0.30775

Table 6-11 Model-averaged parameter estimates explaining the probability of silver perch spawning in relation to water temperature (1, 10 and 20 day averages; temp), changes in water temperature over the same time period (d.temp), water level as a proportion of bankfull height (1, 10, and 20 day averages; proplev) and changes in proportion of bankfull height over the same time period (d.proplev).

Parameter	Estimate	Std. Error	Adjusted SE	z value	p
Intercept	-1.7199	0.4876	0.4926	3.492	0.00048
zone	1.9793	0.7553	0.7629	2.595	0.00947
d.20.proplev	1.6373	1.198	1.2112	1.352	0.17646
10.temp	3.1441	1.3709	1.384	2.272	0.0231
temp	2.66	1.4677	1.4793	1.798	0.07215
20.prop.lev	-2.574	2.0818	2.1056	1.222	0.22152
20.temp	3.0106	1.2044	1.2154	2.477	0.01325
d.10.temp	0.7192	0.6932	0.6999	1.028	0.30418
d.10.proplev	-1.3143	1.2266	1.2403	1.06	0.2893
10.prop.lev	-2.2628	2.1816	2.2065	1.026	0.30512
proplev	-1.9141	1.7262	1.7466	1.096	0.27312
year2	0.1661	0.648	0.6552	0.254	0.79986
year3	-1.2154	0.8303	0.8398	1.447	0.14784
d.20.temp	-0.1274	0.7714	0.7761	0.164	0.86957
d.temp	0.1113	0.7179	0.7234	0.154	0.87767

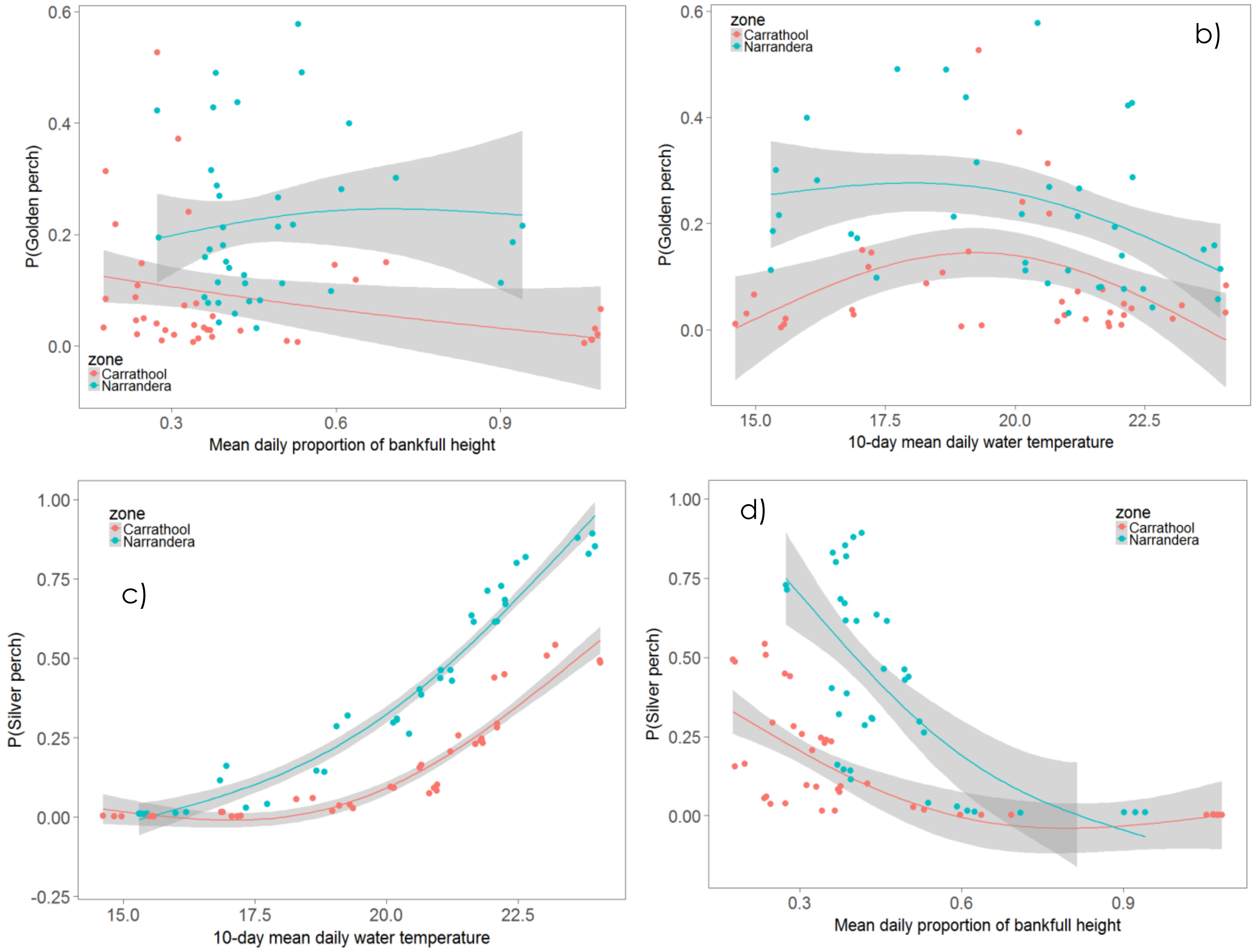


Figure 6-20 Predictive relationships generated from model-averaged parameter estimates (Table 6-10, Table 6-11) describing the spawning probably (p; y-axis) for a) golden perch in relation to water temperature (10 day mean), b) golden perch in relation to daily proportion of bankfull height, c) silver perch in relation to water temperature (10 day mean), and d) silver perch in relation to daily proportion of bankfull height. Data were collected over three watering years (2014-15, 2015-16 and 2016-17) using larval drift nets in the Murrumbidgee River and probabilities are based on the presence/absence of drifting egg captures.

Table 6-12 Summary of fish captured during Category 1 standardised sampling in 2015, 2016 and 2017 in the Murrumbidgee LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	**2015**				**2016**				**2017**			
	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**
native species												
Australian smelt	109	26		**135**	335	4		**339**	297	103		**400**
bony herring	438	2		**440**	360			**360**	170	2		**172**
carp gudgeon	9	205	18	**232**	22	704	39	**765**	13	567	40	**620**
flatheaded gudgeon				**0**				**0**		2		**2**
golden perch	39			**39**	28			**28**	37			**37**
Murray cod	126	5		**131**	155			**155**	68	1		**69**
Murray-Darling rainbowfish	162	401		**563**	131	136		**267**	86	61		**147**
silver perch	1			**1**				**0**	3			**3**
un-specked hardyhead	4	2		**6**	4			**4**	1	2		**3**
alien species												
common carp	112			**112**	63			**63**	313	1	6	**320**
eastern gambusia	8	735	1	**744**	11	493	1	**505**	6	371		**377**
goldfish	11			**11**	3			**3**	6			**6**
redfin perch				**0**				**0**	1			**1**

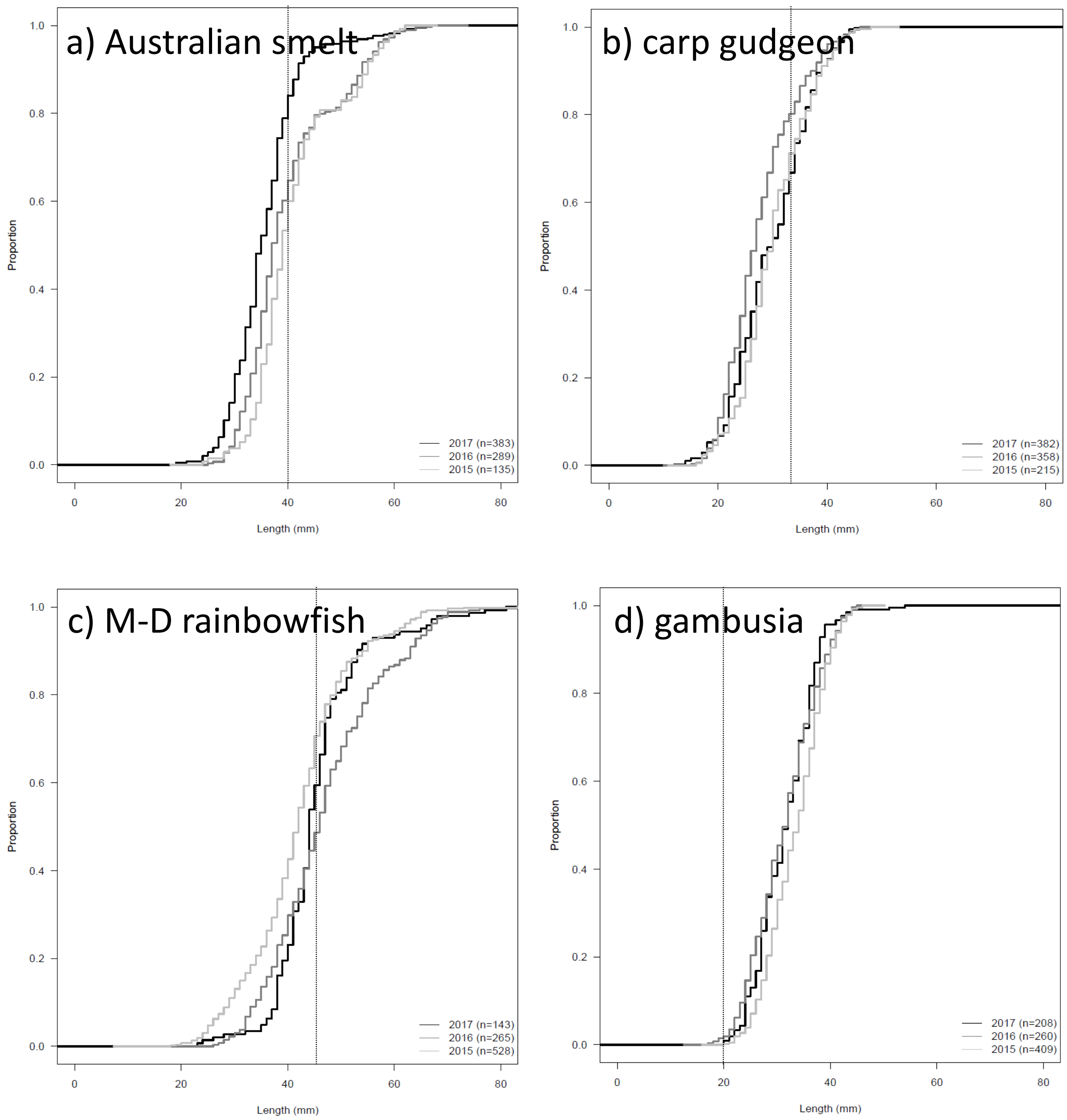


Figure 6-21 Length-frequency comparison among years (2015, 2016 and 2017) of the four most abundant small-bodied fish species captured during Category 1 fish community sampling in the Murrumbidgee River. The dashed line indicates approximate size at sexual maturity.

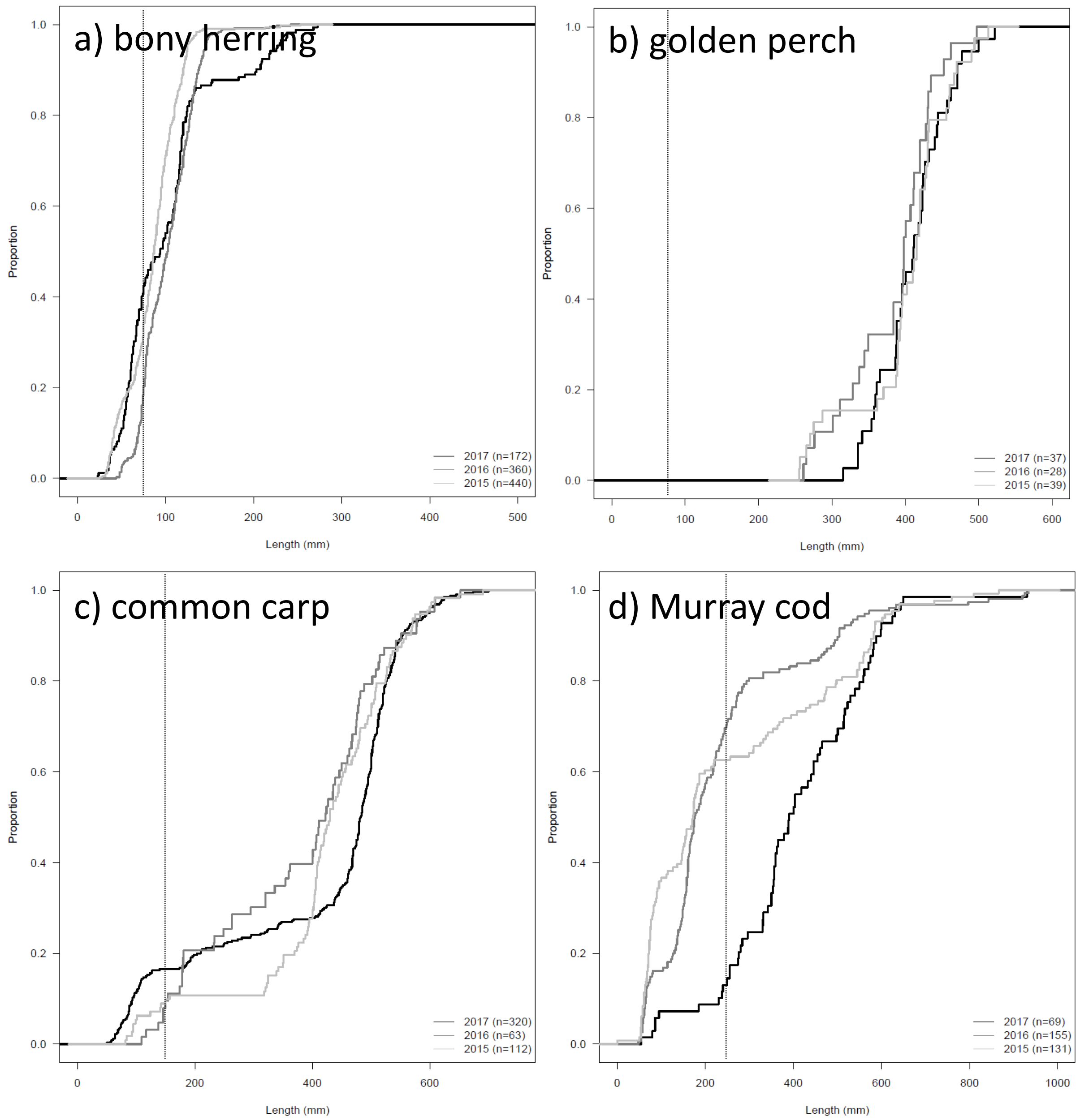


Figure 6-22 Length-frequency comparison among years (2015, 2016 and 2017) of the four most abundant medium-large bodied fish species captured during Category 1 fish community sampling in the Murrumbidgee River. The dashed line indicates approximate size at one-year of age.

Discussion

What did Commonwealth environmental water contribute to native fish reproduction?

Data from the 2016-17 water year documents riverine fish responses to overbank flooding in the Murrumbidgee River. Commonwealth environmental water was not specifically delivered to support native fish spawning outcomes during 2016-17, however significant volumes of Commonwealth environmental water were present in the Murrumbidgee River as part of the hypoxic black water and flood recession flow. Under the observed flows in 2016-17 we identified spawning of seven native and three alien fish species across the two monitored hydrological zones. Predictive relationships were further developed for flow-cued spawning species golden perch and silver perch, with the latter representing an excellent candidate to trial in-channel flow delivery to improve spawning outcomes in future years. In the case of golden perch, the observed relationships presented here indicate that appropriate in-channel hydraulic conditions to trigger a spawning response are available within the mid-Murrumbidgee river channel throughout much of the watering season.

We did not observe spawning in either golden perch or silver perch in the Carrathool zone in 2016-17, nor detect any evidence of recruitment. Further, Murray cod young-of-year (YOY) proportional abundance was reduced compared with previous years. Conversely, common carp YOY proportional abundance was the highest observed to date. The positive response exhibited by common carp is unsurprising as previous positive responses by common carp to flooding in other parts of the MDB have been well documented (e.g. Bice, Gehrig et al. (2014)). A number of behavioural and physiological traits, including a wide range of environmental tolerances, ability to rapidly colonise habitats and high reproductive output, enable common carp to dominate freshwater fish communities in the MDB (Koehn 2004). In comparison, a number of native species such as Murray cod and golden perch are particularly susceptible to poor water quality. For example, the observed concentrations of dissolved oxygen in the Carrathool zone of the Murrumbidgee River during 2016-17 were close to the levels required to induce mortality in a number of large-bodied native species (Small, Kopf et al. 2014). Small, Kopf et al. (2014) predicted that mortality in juvenile Murray cod would begin at dissolved oxygen concentrations of 3.1 mg L^{-1}.

The mechanisms contributing to our failure to detect spawning in golden perch and silver perch in the Carrathool zone in 2016-17, as well as the poor YOY recruitment response exhibited by Murray cod, remain unknown.

It is currently unknown whether the spawning observed in golden perch and silver perch in the Narrandera zone in 2016-17 or in both zones in previous years is translating to recruitment in either of these species. For the third continuous year we did not capture any juvenile golden perch within the selected area during annual community sampling in March. One juvenile silver perch was captured within the selected area in 2015, although none were captured in 2016 or 2017. While stocking of golden perch does occur within the region, recent evidence suggests that stocking only contributes 14% to golden perch populations in the Narrandera zone (Forbes, Watts et al. 2016). Further, stocking of silver perch does not occur within the Murrumbidgee River. We can therefore assume that the adult population contributing to spawning in both species is comprised of wild adults that presumably were spawned and recruited locally given the number of impassable barriers within the system. Subsequently, recruitment must therefore be occurring within the Murrumbidgee River to support adult populations of both species, although the drivers of recruitment, as well as key locations supporting juveniles, remain unknown and represent an important knowledge gap that requires further investigation.

We predicted that in-channel freshes would promote spawning in golden perch and silver perch. However, model predictions based on three years of monitoring in the Murrumbidgee selected area indicate optimal temperatures for spawning in these species, but there is little evidence to support the prediction of an increasing probability of spawning with increasing river levels for either species. This result is not consistent with the recent findings of (King, Gwinn et al. 2016) whereby spawning intensity increased with increasing flows in the Murray River. It is worthwhile noting that spawning in both species has occurred independently of any discernible river level rise and at stable bankfull summer irrigation flows in the Murray River e.g. (Gilligan and Schiller 2003, King, Crook et al. 2005, Koster, Dawson et al. 2014). Further, the data input for the current models reflect only the small period of time for which sampling was undertaken and the associated abiotic conditions during that time. Additionally, data are somewhat biased by the high-water levels that occurred in 2016-17 and the absence of spawning (in the Carrathool zone). The evidence presented to date does not refute a spawning response of either species to in-channel freshes. Rather, the concept of river level rises *per se* as a flow-cued spawning trigger may be too prescriptive. For example, the broad definition of in-channel freshes is generally met all summer in the Murrumbidgee and mid-Murray rivers as a result of irrigation releases. Therefore, the appropriate hydraulic conditions may be present for a protracted period rather than a defined, discrete event such as a rise. In the absence of these high irrigation flows, it may be that a delivered 'rise' is required to meet the threshold requirement of appropriate in-channel hydraulics (i.e. in-channel freshes). Further, golden perch have been observed to exhibit substantial flexibility in both spawning and recruitment responses (Mallen-Cooper and Stuart 2003, Balcombe, Arthington et al. 2006, Balcombe and Arthington 2009). We anticipate that the continued monitoring of flow-cued spawning responses will strengthen the predictive relationships within the Murrumbidgee selected area and facilitate transferable information to other un-monitored sections of the Murrumbidgee River.

6.6 Wetland hydrology

Prepared by Rachael F. Thomas (NSW OEH), Jessica Heath (NSW OEH) and Andrew Hall (CSU)

Introduction

Commonwealth environmental water was delivered to wetlands through the mid-Murrumbidgee, Redbank, and Nimmie-Caria to "*inundate wetland and refuge habitats*" in the Murrumbidgee Catchment. Floodplain wetlands in the Murrumbidgee Selected Area have been identified as being part of the managed floodplain which could be actively managed with water recovered for the environment to improve lateral connectivity (Murray-Darling Basin Authority 2014).

Flooding is the most influential driver of floodplain wetland ecosystems (Bunn and Arthington 2002). Floodplain wetlands in semi-arid regions are governed by variable flow regimes which produce diverse inundation patterns over large areas and time scales (Thomas, Kingsford et al. 2015). Aspects of the flood pulse with ecological significance include the inundation magnitude (extent), duration, timing, inter-flood dry interval and frequency of pulses (Walker, Sheldon et al. 1995). These inundation regime components are known to be important for vegetation (Roberts and Marston 2011) and waterbird breeding (Kingsford and Auld 2005) in floodplain wetlands. For these reasons, targeted wetland inundation is the primary focus for environmental water managers.

Inundation extent is a useful indicator of environmental watering outcomes in floodplain wetlands where flooding from river flows varies widely in space and over time (Thomas, Kingsford et al. 2015). Extent provides a measure of the inundated area of the floodplain and an inundation map shows the distribution of the area across the landscape at a point in time. A time series of inundation maps enables us to measure the inundation regime components of a wetland area including how long has the area been inundated (duration) and how many times has the area been inundated after drying out (frequency).

In 2016-2017, the fifth year since large flows and flooding in 2011-2012, Commonwealth environmental water was delivered to wetlands of the Murrumbidgee Selected Area

(Figure 6-23). Commonwealth environmental water actions to the Lowbidgee occurred throughout the year starting in August 2016 but which was halted once the natural flood began. A fresh and bankfull flow was delivered to the Lowbidgee to manage the flood recession over November and December. Further actions targeted maintaining water levels in waterbird rookery sites in Nimmie-Caira, Redbank and Yanga. Western Lakes were also targeted for environmental delivery by the Commonwealth and NSW. All water actions had inundation objectives for targeted wetland assets which ranged from increasing inundation extents in core wetland and refuge habitats, maintaining inundation extents to increase periods of inundation duration, and slowing wetland discharge of low dissolved oxygen water back into the river during flood recession.

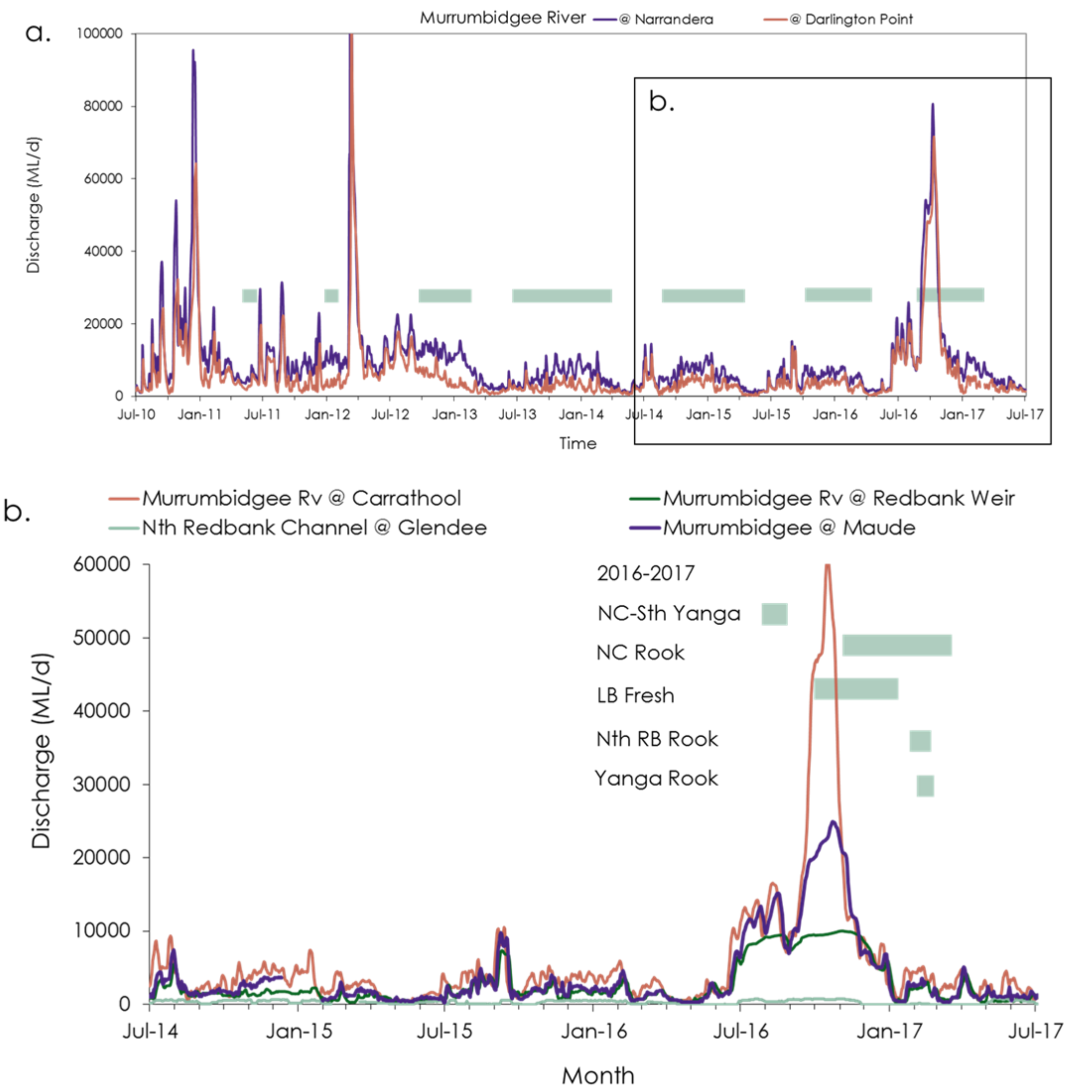


Figure 6-23 a. Mean daily discharge in the Murrumbidgee River at Narranderra and Darlington Point between 1 July 2010 to 30 June 2016. The 2012 peaked at 200,000 ML. Horizontal green bars show Commonwealth and NSW environmental water actions in 2011-12, 2012-13, 2013-14, 2014-15 and 2015-2016. b. Mean daily discharge in the Murrumbidgee River at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glendee in relation to the timing of environmental water delivery water actions (horizontal green bars) during survey period (1 July 2016 to 30 June 2017).

Methods

To map floodplain wetland inundation, we used Landsat satellite images from both the Landsat 8 and Landsat ETM+ 7 sensors. During the 2016-2017 water year there was often extensive cloud cover obscuring flooding in the Lowbidgee wetlands and so we used Landsat ETM+ 7 imagery which has missing data in the eastern portion of imagery (Wulder, Ortlepp et al. 2008). Images were automatically downloaded by NSW OEH from the USGS (United States Geological Survey's Earth Explorer website (http://earthexplorer.usgs.gov) as 30m pixel orthorectified images. NSW OEH processed these images to standardised surface reflectance (Flood, Danaher et al. 2013). Each Landsat scene location was designated by the satellite path (p) and row (r) (e.g. the Lowbidgee is located on scene p094r084). We used as many available image observations as possible from July 2016 to June 2017.

From each satellite image observation OEH automatically generates a water index (Fisher, Flood et al. 2016) and the NDVI vegetation index and we use these indices to classify inundation as open water, water mixed with vegetation, and dense cover vegetation that is inundated (Thomas, Kingsford et al. 2015). For each map inundated pixels were allocated a value of one (1). This method has been previously used to monitor inundation extents in the Lowbidgee floodplain (Spencer, Thomas et al. 2011, Thomas and Cox 2012, Thomas, Cox et al. 2013, Thomas and Heath 2014). For observation dates affected by some cloud we reclassify areas of cloud shadow that were incorrectly detected as water using a cloud mask, initially automated (Goodwin, Collett et al. 2013) but manually edited at the wetland site scale. One image observation at the peak of the natural flood had cloud obscuring parts of the Lowbidgee floodplain and so inundation extents from the individual map were not used however it was included in the total cumulative estimates of inundation area because it showed important aspects of the flood progression. Inundation maps classified from Landsat 7+ETM satellite imagery were affected by the missing data and displayed the characteristic striping in parts of the maps. For the Lowbidgee this affected the eastern portion of the floodplain.

Data analysis

We used inundation map observations and inundation event maps to estimate inundation extents. An inundation map observation provided a snapshot of inundation extent and its distribution at a point in time. To summarise the inundation outcome of a water action or inundation pulse we created inundation event maps. An inundation event map provided the total cumulative area of floodplain inundated during the time period of a flow pulse or water action period. To create inundation event maps, we allocated inundation maps to a water action by selecting the observation dates that occurred after the start of the water action as it progressed and/or contracted. We used a spatial overlay to count the number of times a pixel was inundated and then all counts greater than zero were recoded to a new value of one to create a map of the cumulative area of the floodplain inundated by the water action or flow pulse.

Flows in the Lowbidgee are managed to inundate specific wetlands which may be long distances from each other and often the existing agricultural infrastructure is used to move water across the floodplain. This means that for one water action the location of the inundation outcome may be spatially distributed. For this reason, we tabulated inundated areas within the delineated Lowbidgee Water Management Areas (WMA) (Thomas, Heath et al. 2014) which are nested within the Murrumbidgee Selected Area zones. The WMAs compartmentalise the floodplain into units based on the characteristics of the ecosystem (wetland vegetation), hydrology (flow paths) and infrastructure (structures). Discrete wetlands are located within the broader WMAs. To estimate the inundation outcome extent, we sum the inundated areas across each relevant Water Management Area.

For the LTIM surveyed wetlands where discrete wetland boundaries had been previously delineated (Wassens et al. 2016) we tabulated the inundated areas for each inundation map and water action. For this year's reporting we also delineated the maximum extent of other wetlands targeted with environmental water (Tarwillie Swamp and Kieeta Lake), by visually digitising boundaries from digital high resolution photography and an inundation frequency map, and then tabulated inundated areas. We then estimated the percentage area inundated and plotted them over time. From the plots of the percentage area inundated we estimated the inundation duration within the year for each discrete wetland.

We also provide an overview of the total area of Lowbidgee floodplain inundated during the 2014-2015, 2015-2016 and 2016-2017 water years. These inundation extents represent the cumulative area of the floodplain inundated at least once in the water year.

Results

Annual Outcomes Lowbidgee Floodplain

During 2016-2017 there was extensive inundation across the Lowbidgee floodplain with a total annual area of almost 200,000 ha of the landscape inundated at least once during the water year (Figure 6-24 and Figure 6-25). The last extensive flooding in the Lowbidgee occurred four and half years ago, in 2012 when about 170,000 ha of the floodplain was inundated after high flows peaked in March 2012 (Figure 6-23). Compared to the last two years, the 2016-2017 inundation extents were 5 to 9 times more extensive due to the large inundated areas of the Nimmie-Caira, Redbank and Fiddlers zones floodplain (Figure 6-24 and Figure 6-25). This was due to the large natural flood that occurred during the spring months of October and November 2016 when the inundated area peaked at about 150,000 ha in early November 2016 (Figure 6-26).

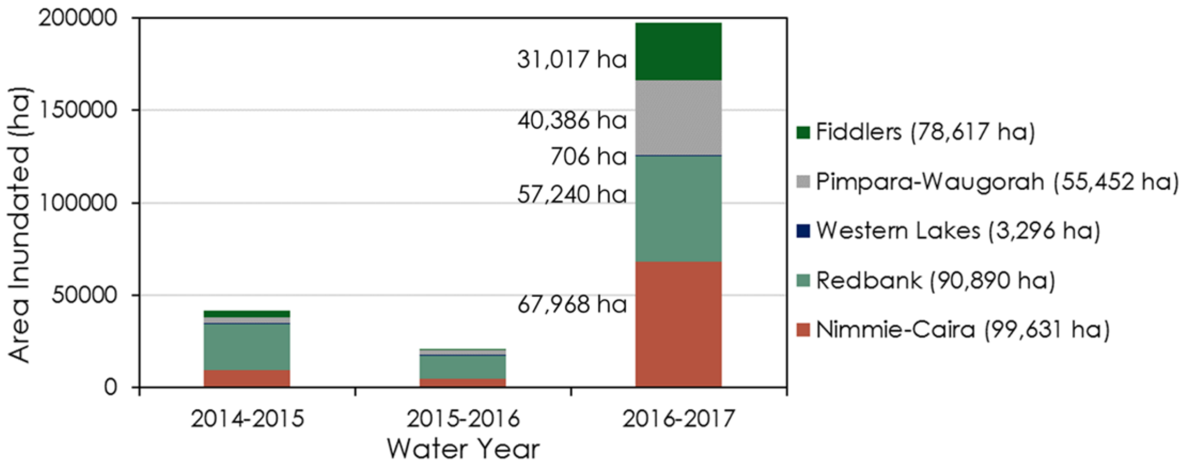


Figure 6-24 Annual cumulative total area (ha) of the floodplain inundated for the Lowbidgee floodplain and wetland zones for the 2014-2015, 2015-2016 and 2016-2017 water years.

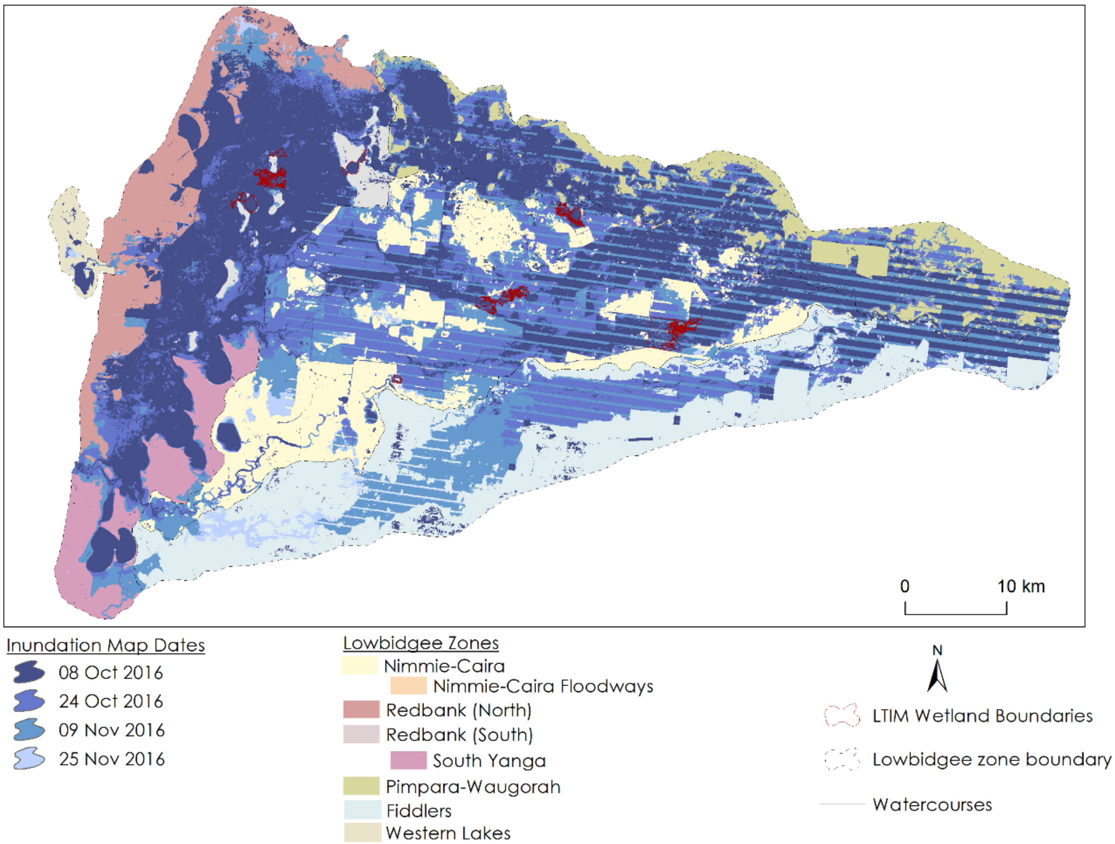


Figure 6-25 Inundation progression across the Lowbidgee floodplain during October and November 2016. Inundation maps are classified from Landsat satellite images and display inundation expansion from the top map date (earliest) to the bottom map date (latest). The striping effect is as a result of the missing data in the Landsat ETM+7 image dates (this data were used because regular cloud cover during the period obscured flooding in the Landsat 8 image dates).

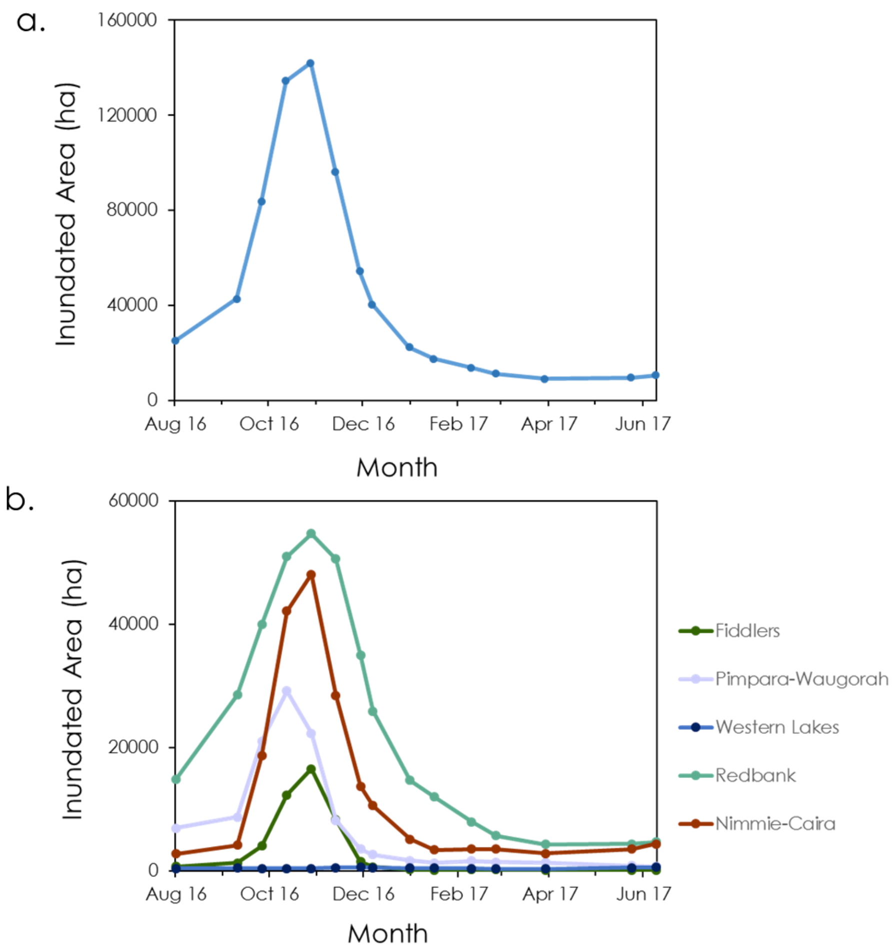


Figure 6-26 Inundated areas over time during 2016-2017 for a. the Lowbidgee floodplain and b. the Lowbidgee zones

Lowbidgee surveyed wetlands

Inundation patterns in the surveyed wetlands of the Lowbidgee revealed the wetting and drying cycle over the last three surveyed water years (2014-2015, 2015-2016, and 2016-2017) (Figure 6-27.) This pattern of wetting and drying aligned with water depth observations over the survey period (Figure 6-28). Even though extensive overbank flooding did not occur across the entire Lowbidgee floodplain in the previous two years (see Figure 6-24) all surveyed wetlands were inundated at least twice in the last three years (Figure 6-28).

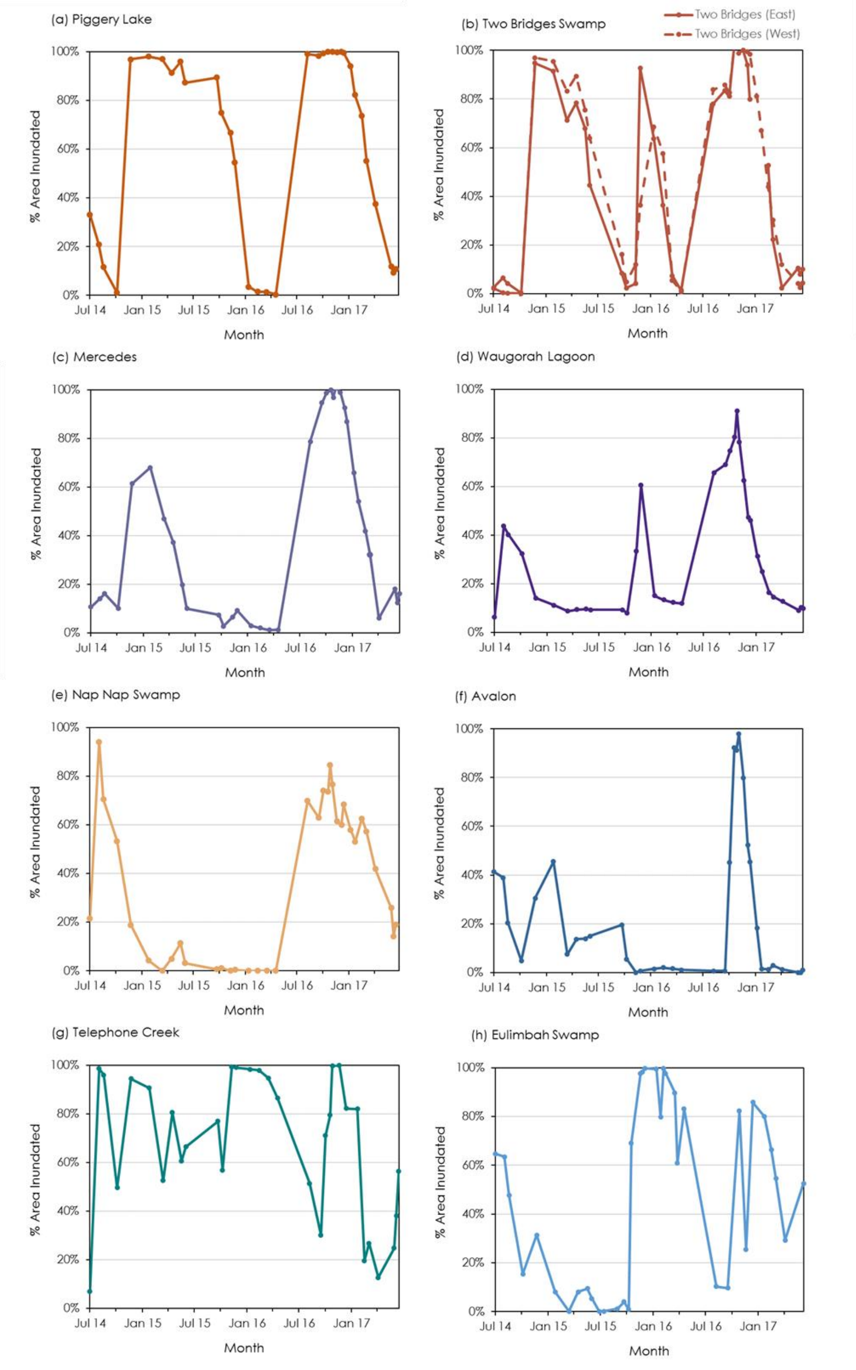


Figure 6-27 Percentage area inundated for surveyed wetlands in the Redbank zone: a. Piggery Lake, b. Two Bridges Swamp, c. Mercedes Swamp, d. Waugorah Lagoon; and in the Nimmie-Caira zone: e. Nap Nap Swamp, f. Avalon Swamp, Telephone Creek and Eulimbah Swamp during three water years 2014-2015, 2015-2016 and 2016-2017

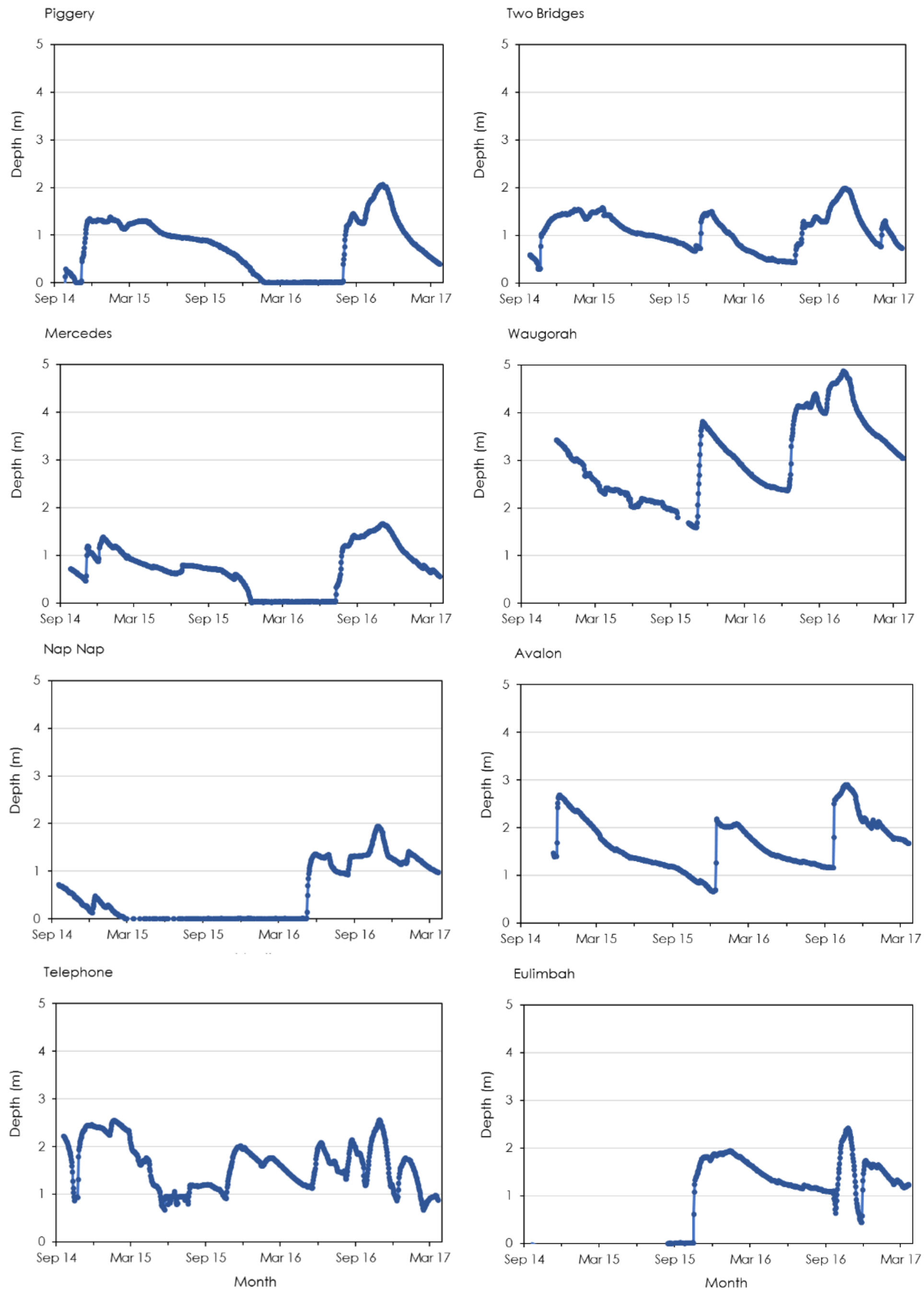


Figure 6-28 Water depth for surveyed wetlands in the Redbank zone: a. Piggery Lake, b. Two Bridges Swamp, c. Mercedes Swamp, d. Waugorah Lagoon; and in the Nimmie-Caira zone: e. Nap Nap Swamp, f. Avalon Swamp, Telephone Creek and Eulimbah Swamp during three water years 2014-2015, 2015-2016 and 2016-2017.

During the 2016-2017 water year the surveyed wetlands were inundated for a range of duration periods. In the Redbank zone at least 90% of Piggery Lake was inundated for five and a half months (mid-August to the end of January), about 80% of Two Bridges was also inundated for five and a half months over the same period whereas 80% of Mercedes Swamp was inundated for four months to mid-December (Figure 6-27 and Figure 6-29). Only 60% of Waugorah Lagoon was inundated for three and a half months. In the Nimmie-Caira zone at least 60% of Nap Nap Swamp was inundated for five and a half months between mid-August and the end of January whereas Avalon Swamp was almost fully inundated but for only one month (October) and then dried over the summer months. About 80% of Telephone Creek was inundated for almost four months and 60% of Eulimbah Swamp was inundated for two months from mid-December to mid-February (Figure 6-27 and Figure 6-28).

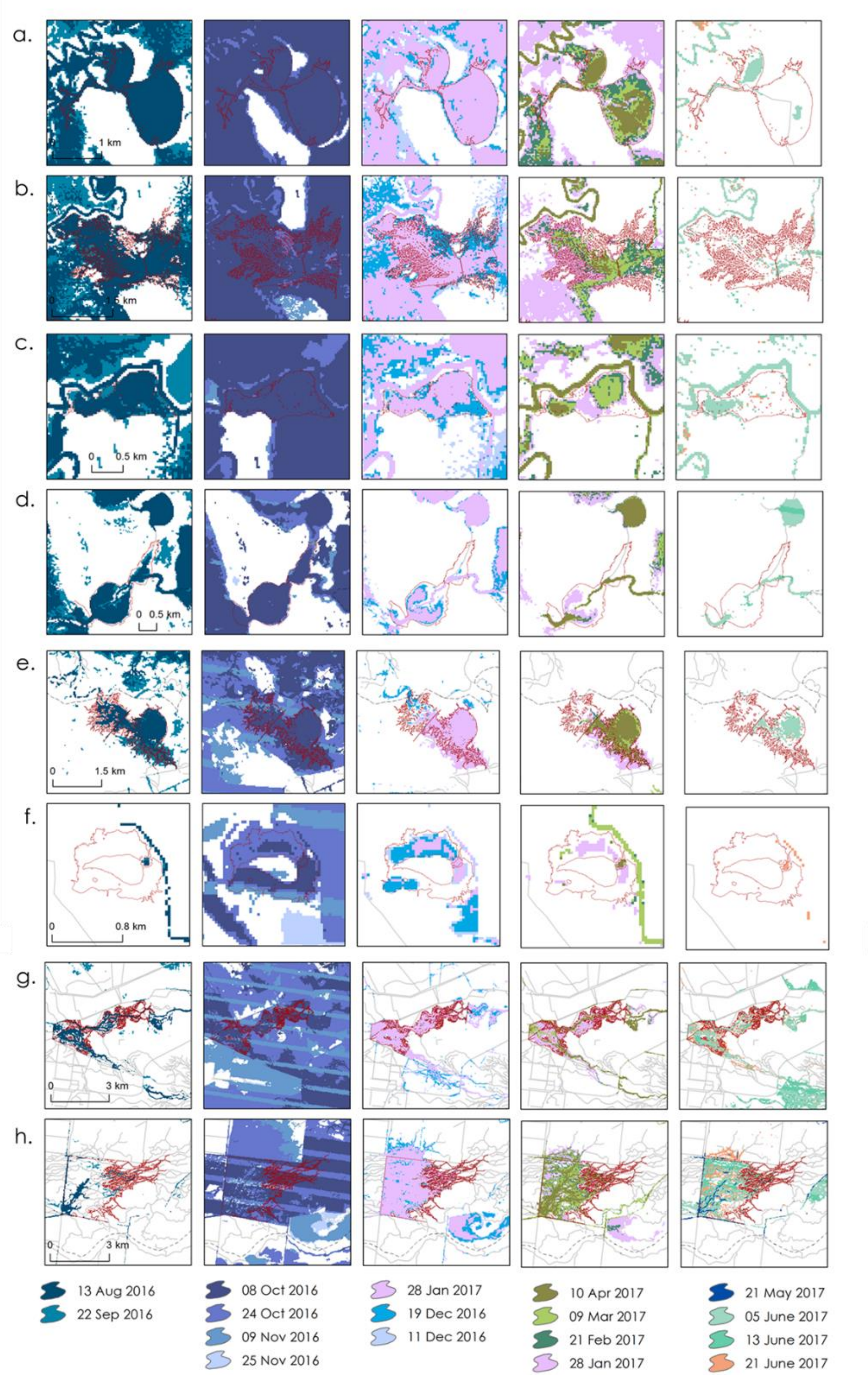


Figure 6-29 Inundation progression during 2016-2017 within the surveyed wetlands of the Redbank zone: a. Piggery Lake, b. Two Bridges Swamp, c. Mercedes Swamp, d. Waugorah Lagoon; and of the Nimmie-Caira Zone: e. Nap Nap Swamp, f. Avalon Swamp, Telephone Creek and Eulimbah Swamp

Mid-Murrumbidgee surveyed wetlands

Inundation patterns in the surveyed wetlands of the Mid-Murrumbidgee revealed that only Yarradda Lagoon was significantly inundated between 2014 and 2016 as indicated by the measures of percentage area inundated and water depth (Figure 6-30). Inundation in 2015-2016 was because of an environmental water action whereas inundation in 2016-2017 largely occurred during the natural flood which was extensive in the surrounding river red gum forests at the peak flood in September 2016 (Figure 6-31). Each lagoon was inundated to 100% of its area for about a month from late September to late October 2016 which then contracted to 50% of its area for McKenna's and Sunshower within the next month (Figure 6-30 and Figure 6-31). At least 50% of Yarradda Lagoon was inundated for 6 months and at least 30% was retained for the entire water year (Figure 6-30 and Figure 6-31).

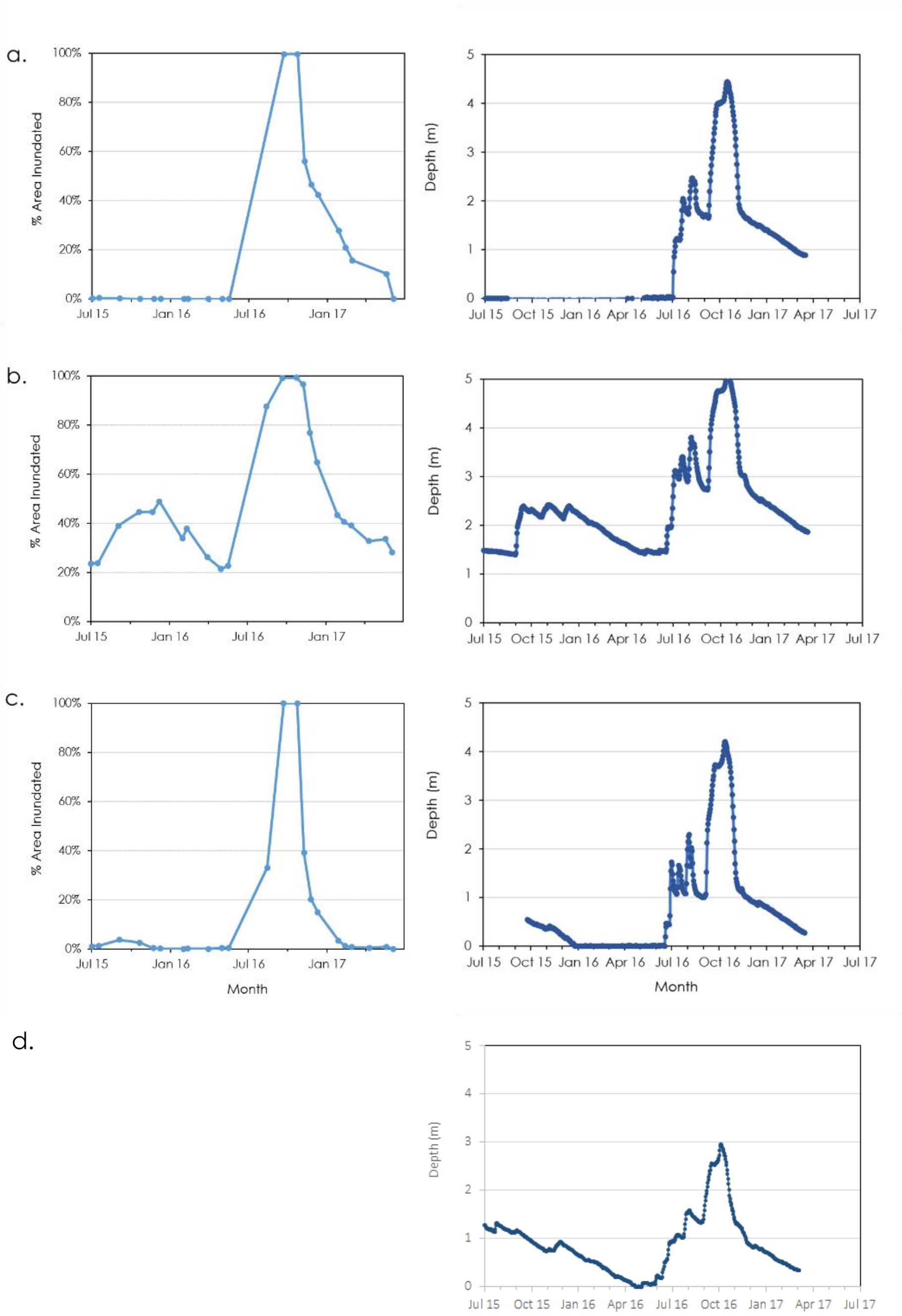


Figure 6-30 Percentage area inundated since July 2015 (left) and water depth (right) for mid-Murrumbidgee lagoons a. McKenna's Lagoon, b. Yarradda Lagoon, c. Sunshower Lagoon and d. Gorragool Lagoon. Note that % area inundated data for Gooroagool Lagoon is not available to 2016-17 because of cloud cover.

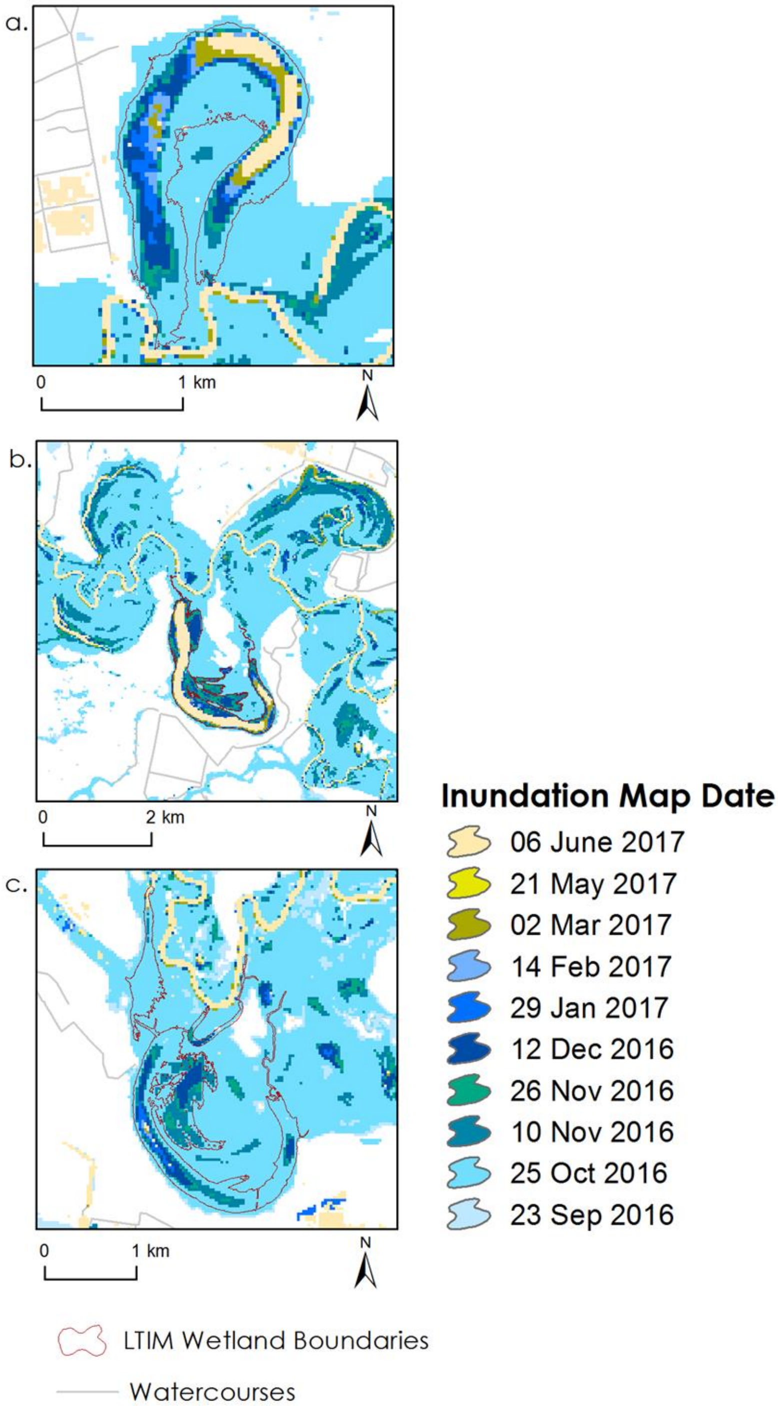


Figure 6-31 Inundation progression for the mid-Murrumbidgee lagoons a. McKenna's Lagoon, b. Yarradda Lagoon and c. Sunshower Lagoon showing contraction from 23 September to 6 June 2017.

What did Commonwealth environmental water contribute to wetland inundation?

Commonwealth environmental water contributed to expanding inundation extents maintaining inundation extents across wetland rookery and refuge habitat, and allowing for inundation recession (Table 6-13).

Table 6-13 Measured inundation outcome (total cumulative hectares of target wetland inundated) during the specified water action period.

Flow Event/ Watering Action in 2016/17	Start -End Date	NSW Water Use (ML)	CEW Water Use (ML)	Total Water Use (ML)	Measured Outcomes (ha)
Nimmie-Caira to South Yanga	4/08/16-3/09/16	0	15,507	15,507	4,998
Natural flood	October-November	-	-	-	194,076
Murrumbidgee River Fresh: Flood recession and dissolved oxygen management	29/10/2016-5/01/2017	134,861	150,978 TLM 85,000	370,839	58,602
Nimmie-Caira waterbird breeding support (4 actions)	24/11/2016-20/03/2017 Eulimbah 28/11/16-3/3/17; Telephone Bank 24/11/16-20/3/17; Nap Nap 3/1/17-7/1/17; Is-Y-Coed 10/2/17-20/3/17	8,826 3923 4903	13,375	22,201	2,817
North Redbank: waterbird breeding support	27/01/2017-13/02/2017	1496	844	2790	318
Yanga National Park: waterbird breeding support	29/01/2017-7/02/2017	0	2,155	2,155	1,808
Western Lakes	7/11/2016-19/12/2016 4/05/2017-30/06/2017	- 13,300	5,060	5,060 13,300	1,162 1,024#

inundation progression continued in July 2017 – inundation mapping was not completed at the time of writing this report but satellite observations indicate that the inundation outcome will be a larger extent than reported here.

Nimmie-Caira to South Yanga

Commonwealth environmental water contributed to inundating a cumulative total of 4,998 ha of the Lowbidgee floodplain across the Nimmie-Caira floodways into Nap Nap Swamp and Waugorah Creek in the north and into Monkem Creek in the south-west (Table 6-13 and Figure 6-32). Flows reached Tala Lake which had been previously filled. Inundation was distributed in other parts of the Lowbidgee floodplain during the time of this water action but was not attributed to the environmental flow water action (Figure 6-32).

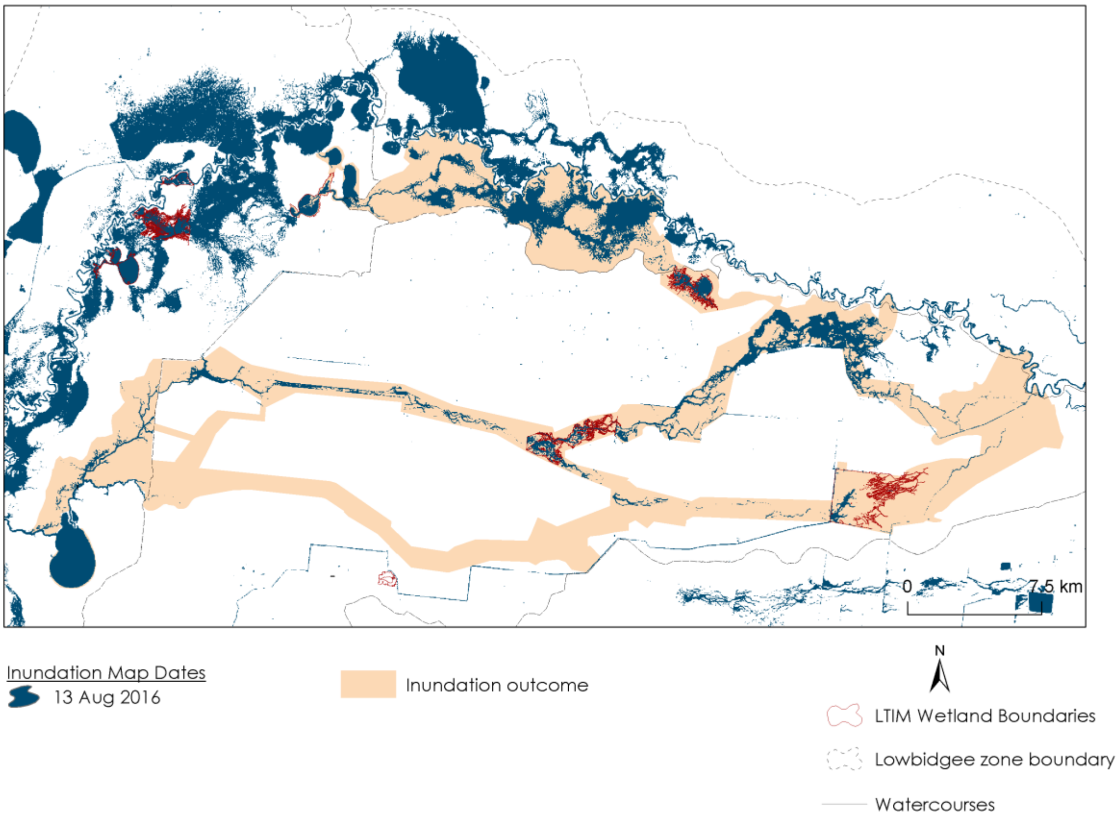


Figure 6-32 Inundation outcome for the Nimmie-Caira to South Yanga water action showing estimated inundation extent from the one inundation map date (13 August 2016).

Murrumbidgee River Fresh – flood recession and dissolved oxygen management

Both Commonwealth and NSW environmental water was used to manage the flood recession by maintaining bankfull flows to slow wetland discharge of low dissolved oxygen water back into the river channel. Inundation contraction occurred from mid-December 2016 with a cumulative total of 58,602 ha of the floodplain inundated across all Lowbidgee zones during the flood recession period (Table 6-13 and Figure 6-33).

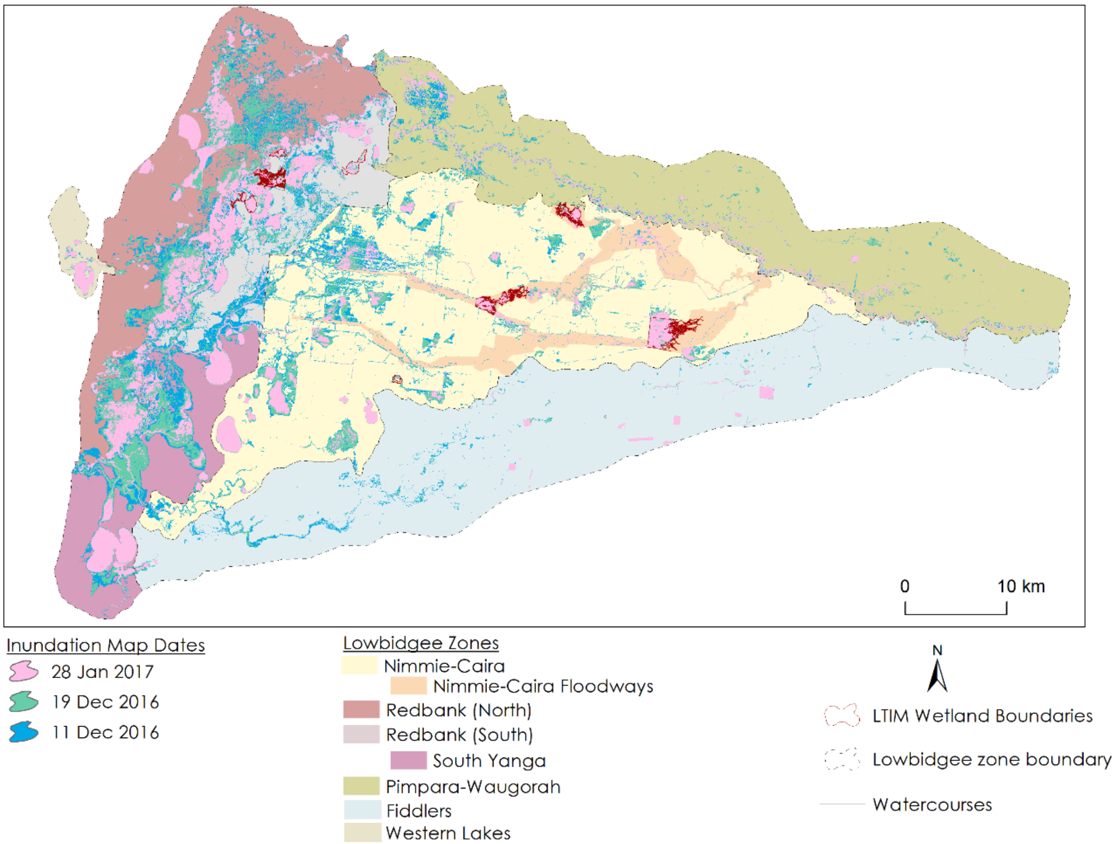


Figure 6-33 Inundation progression during the period of the Murrumbidgee River fresh water action showing the flood recession from 11 December 2016 to 28 January 2017

Western Lakes

Commonwealth environmental water contributed to inundating a cumulative total of 1,162 ha of the Western Lakes including the flow path to the Western Lakes, Narwie red gum forest and Yarrawal wetlands (Table 6-13, Figure 6-34 and Figure 6-35). After inundation contracted in the Western Lakes wetlands over the summer months NSW environmental water was delivered over May-June 2017 inundating a cumulative total of 1,1143 ha to the end of June 2016 (Table 6-13, Figure 6-34 and Figure 6-35).

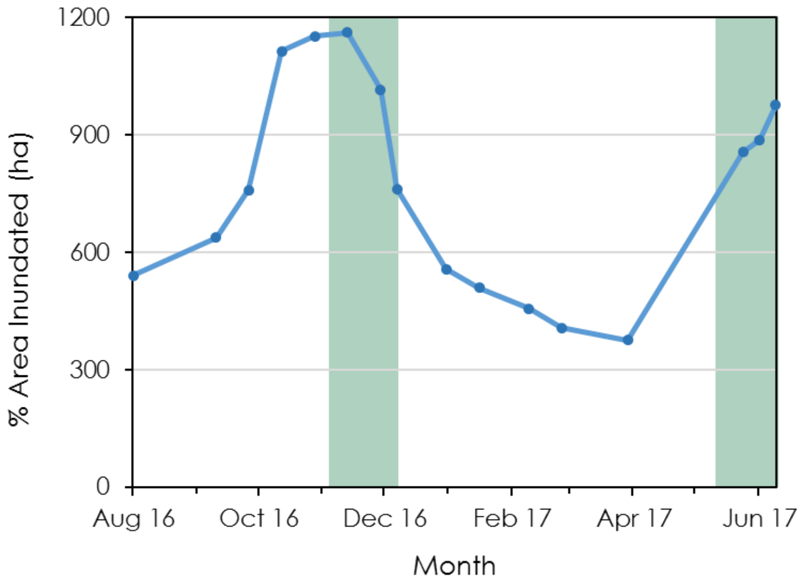


Figure 6-34 Inundated area (ha) for all wetlands of the Western Lakes and associated flow path during the two Western lakes water actions (CEW-Nov-Dec 2016; NSW AEW-May-June 2017) (green bars) (see Table 6-13)

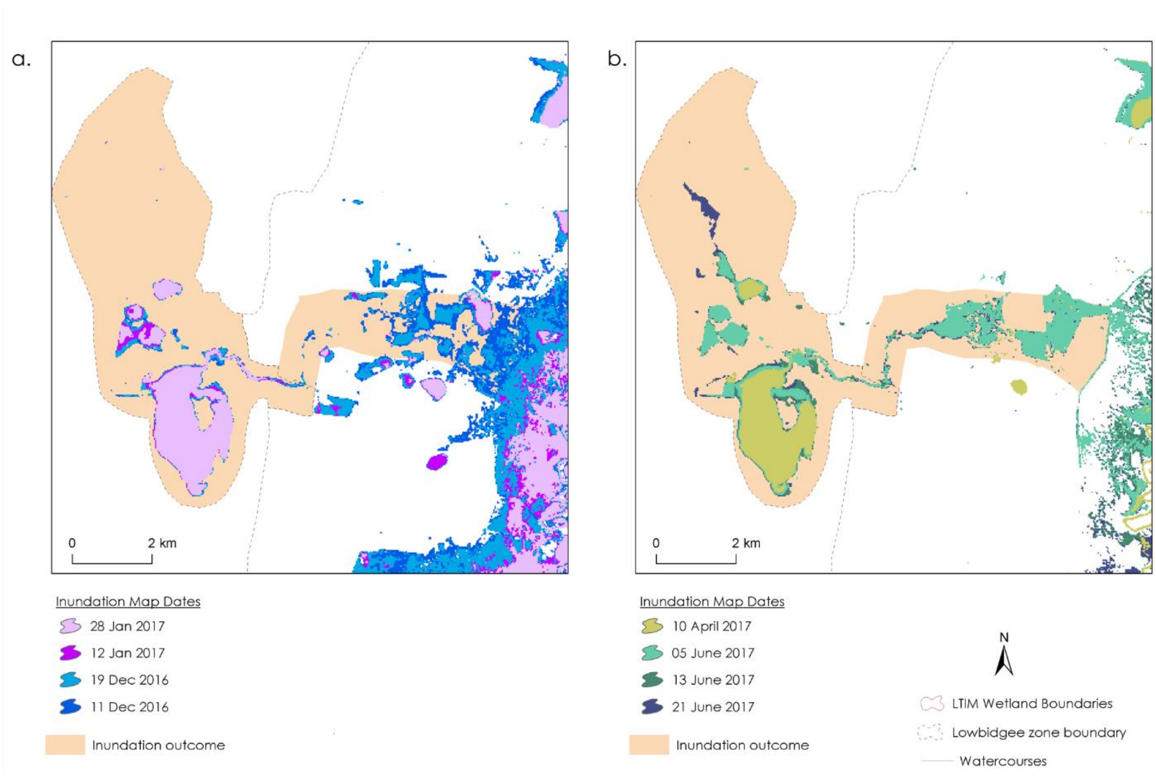


Figure 6-35 Western Lakes inundation progression during water actions a. CEW November-December 2016) showing inundation contraction from 11 December to 28 January 2017 and b. NSW AEW May-June 2017 showing inundation expansion from 10 April to 21 June 2017.

Nimmie-Caira Waterbird Breeding Support

Commonwealth environmental water contributed to inundating a cumulative total of 2,817 ha in the Nimmie-Caira rookery sites: Eulimbah Swamp (818 ha), Telephone Creek 430 ha), Nap Nap Swamp (292 ha), and Kieeta Lake (1,277 ha) (Table 6-13). Eulimbah Swamp was filled to just over 80% capacity during the natural flood in early November but then there was significant flood recession to 20% by 25 November (Figure 6-36 and Figure 6-37). This rapid contraction instigated the environmental water action to Eulimbah from 28/11/2016 to 3/3/2017 (Table 6-13). By mid-December Eulimbah filled to over 80% capacity and remained so until the end of January (1.5 months) (Figure 6-36 and Figure 6-37).

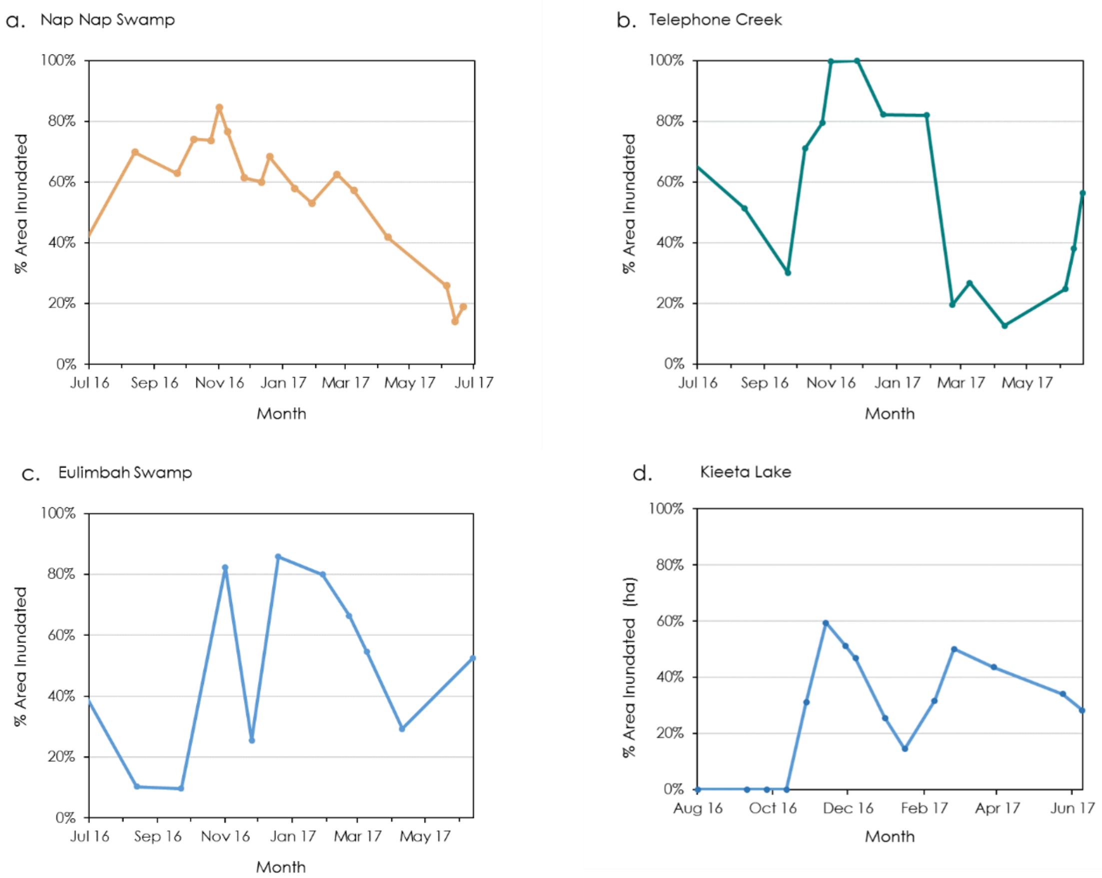


Figure 6-36 Percentage area inundated for targeted waterbird rookery sites during the Nimmie-Caira waterbird breeding support water actions (see Table 6-13).

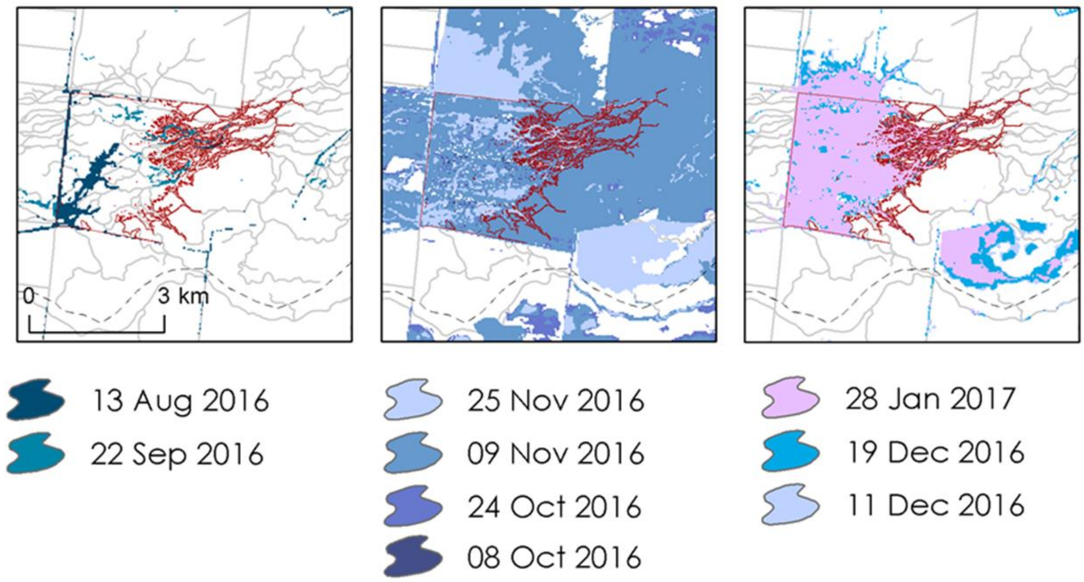


Figure 6-37 Inundation progression for Eulimbah Swamp showing inundation expansion from September to October 2017 and then significant contraction from early to late November 2016.

In Telephone Creek, the environment water action increased water levels after the natural flood event (Figure 6-28) even though there was a 20% contraction in inundated areas to 80% between 11 and 19 of December 2016 (Figure 6-36). Just over 80% of the inundated area was retained to the end of January, after which there was rapid decline in inundation area with 20% of Telephone Creek remaining inundated in February (Figure 6-36 and Figure 6-38) which is also reflected in the water depth measures (Figure 6-28).

By early mid-December the inundated areas in Nap Nap Swamp continued to contract as water depth levels began to fall (Figure 6-28 and Figure 6-36). After the natural flood in November inundation in Kieeta Lake contracted from 60% to 18% of its area. During this time a waterbird breeding event commenced and the environmental water action increased inundation extents back to 50% by mid-April (Figure 6-38)

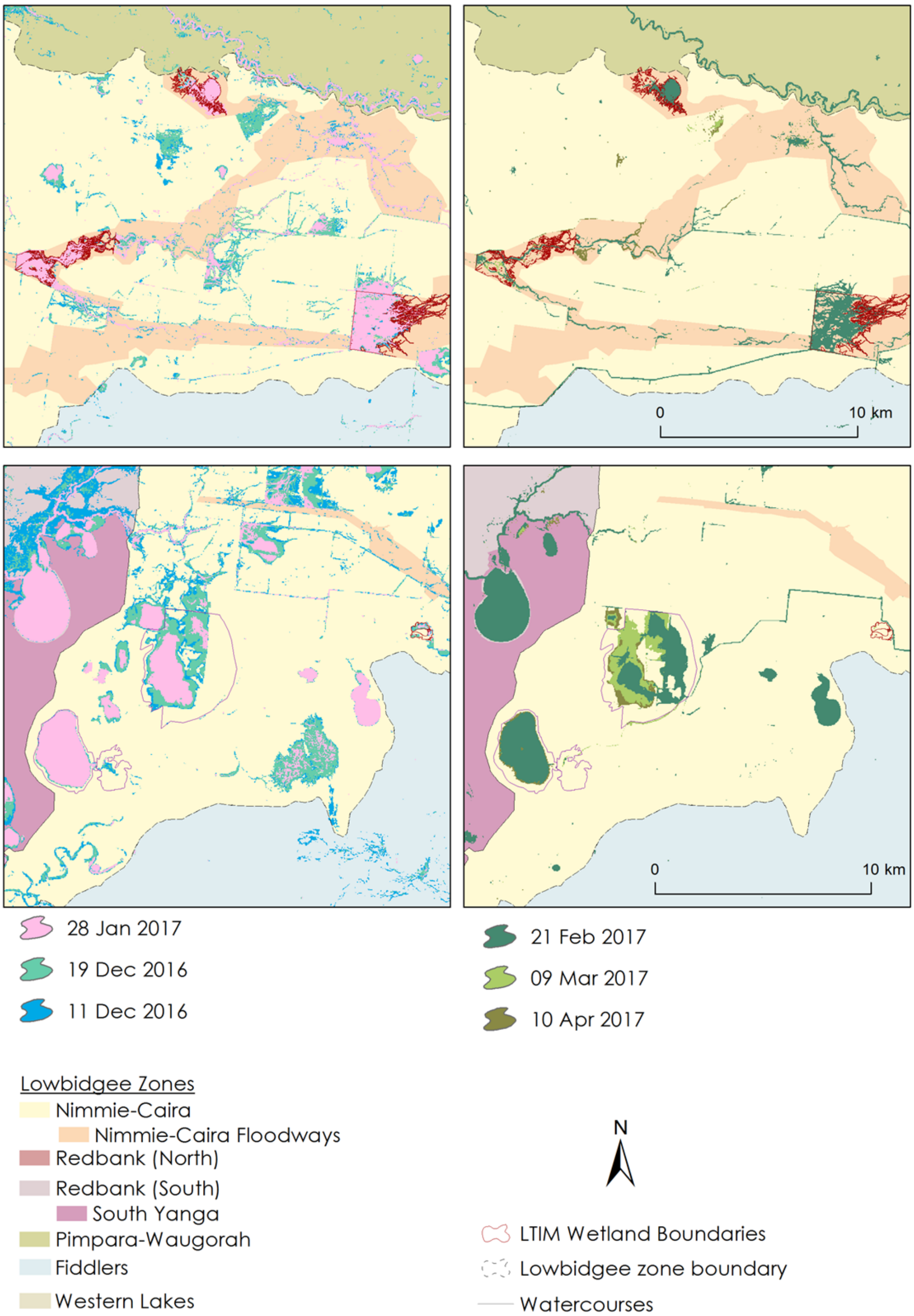


Figure 6-38 Inundation progression for the Nimmie-Caira waterbird breeding support water actions showing inundation contraction (left) from January to April 2017 in. Nap Nap Swamp, Telephone Bank, and Eulimbah Swamps (top), and then the inundation expansion in Kieeta Lake (bottom).

Yanga Waterbird Breeding Support

During the natural flood at least 90% of Tarwillie Swamp was inundated for two months between early October and mid-January 2017 (Figure 6-39 and Figure 6-40). By late January this contracted to 85% inundated. Combined Commonwealth and NSW environmental water maintained inundated extent to about 75% up until late February indicating that water levels were well maintained since the natural flood. By early March 50% of Tarwillie Swamp remained inundated contracting to 20% by mid-April 2017. Overall at least 50% of Tarwillie Swamp was inundated for about six and a half months.

Two Bridges Swamp is located on a major flow path and so 50% of it was inundated for eight months between July 2016 and March 2017 and supported colonial waterbird breeding (see Section 6.12). Whilst other wetlands in Yanga were not specific targets for environmental water delivery they were inundated during the natural flood. More than 50% of Piggery Lake was inundated for eight months during the same periods whilst 50% of Mercedes Swamp was inundated for seven months until the end of February (Figure 6-39 and Figure 6-40).

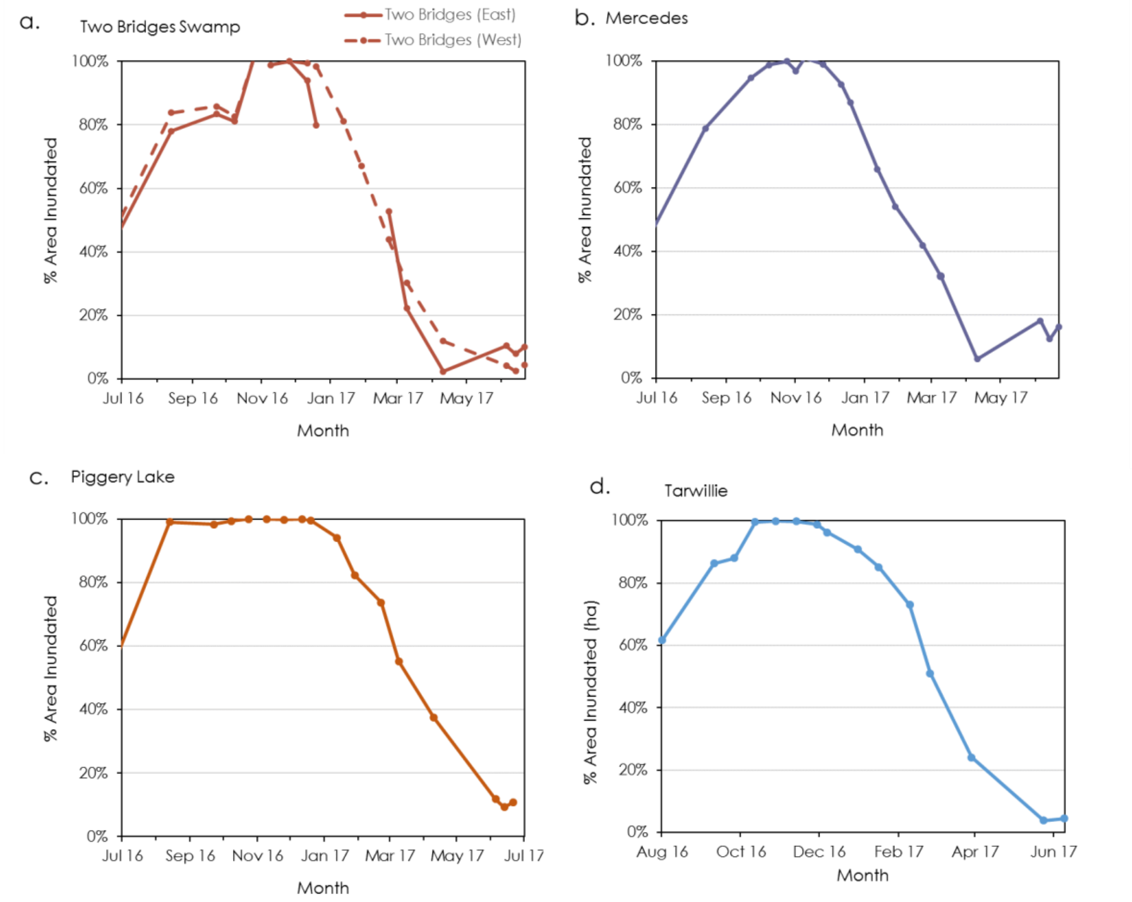


Figure 6-39 Percentage area inundated for targeted waterbird rookery sites during the Yanga waterbird breeding support water action (see Table 6-13)

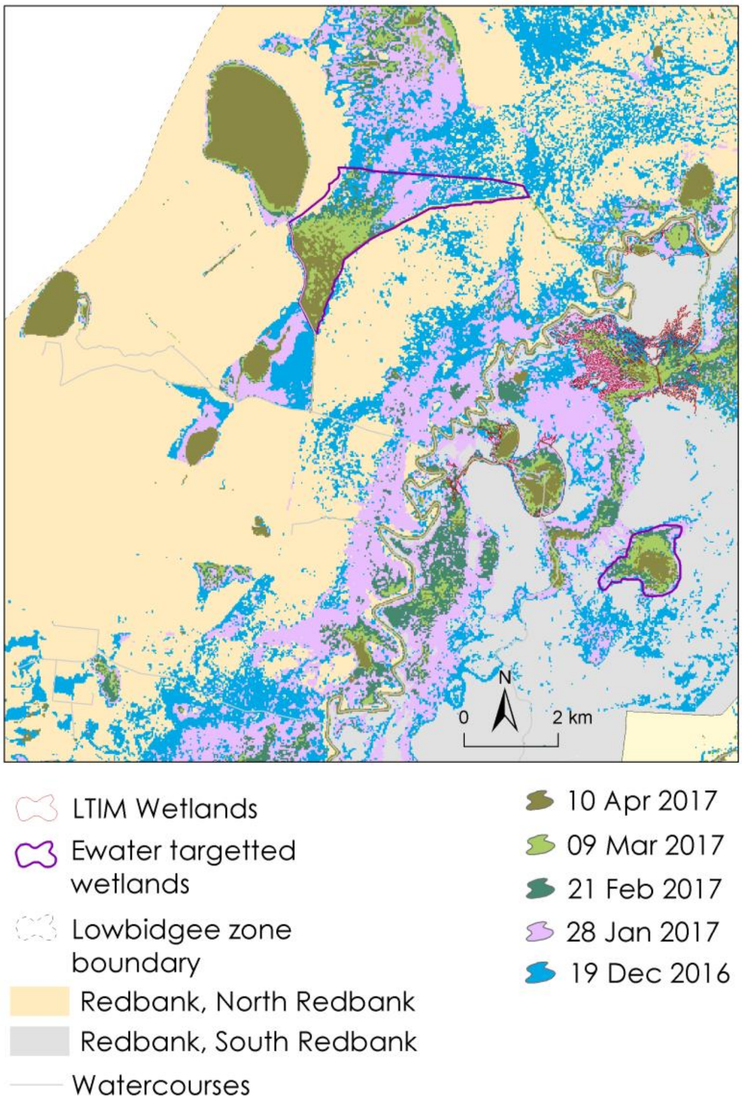


Figure 6-40 Inundation progression for the Yanga Rookery (Tarwillie Swamp) and North Redbank (Tori Lignum Swamp) waterbird breeding support water actions from January to April 2017.

North Redbank Waterbird Breeding Support

More than 80% of Tori Lignum Swamp was inundated for four months between mid-August and mid-December during which time waterbirds began to breed (Figure 6-41). Water levels dropped and inundation extent contracted to about 50% (Figure 6-40) and so an environmental water action was delivered which maintained an inundation extent of 50% of Tori Lignum Swamp for the month of February 2017 to support the breeding colonial waterbirds (see 6.12 Waterbird Breeding).

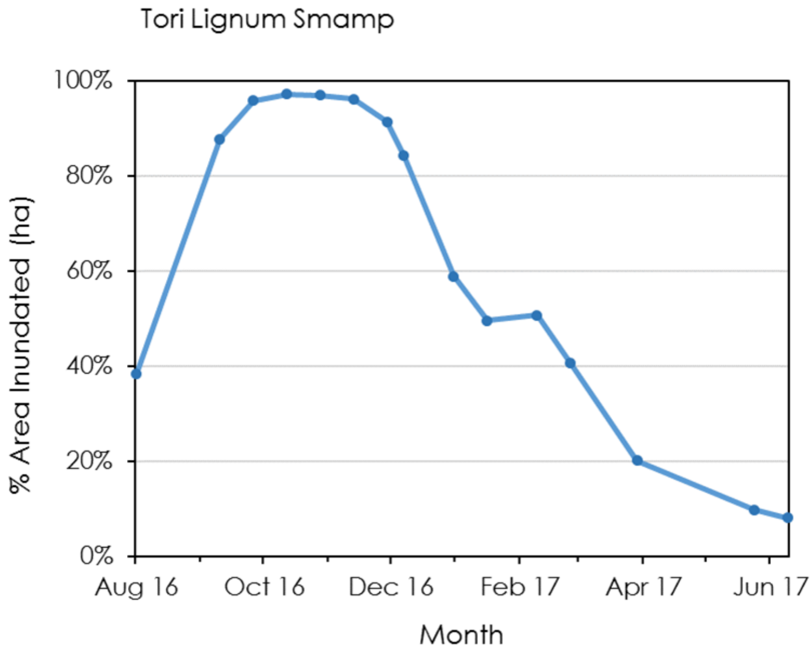


Figure 6-41 Percentage area inundated for targeted waterbird rookery sites during the North Redbank waterbird breeding support water action (see Table 6-13).

Discussion

What did Commonwealth environmental water contribute to inundated area?

Commonwealth environmental water was delivered to wetlands through the Nimmie-Caria and Redbank to "inundate wetland and refuge habitat" in the Murrumbidgee Catchment. All Commonwealth water actions achieved the expected inundation outcomes for targeted wetland assets. These inundation outcomes ranged from increasing inundation extents in core wetland and refuge habitats, maintaining inundation extents to increase periods of inundation duration, and managing flood recession. The 2016-2017 total inundated area of the Lowbidgee floodplain was nine times larger than the total inundated area in 2015-2016. This large extent was due to extensive natural flooding that occurred during spring 2016. The main contribution of

Commonwealth environmental water actions in 2016-2017 was to maintain water levels and inundation extent in waterbird colony sites.

Increased inundation extents were achieved in the core wetlands through the floodways of the Nimmie-Caira, including Nap Nap Swamp, Waugorah Creek and Lagoon through to Tala Lake via the Monkem Creek system. This increased extent occurred prior to the natural flood that began in spring 2016 and enabled increasing lateral connectivity between wetland habitats throughout the region. Increased inundation extents were also achieved in the wetlands of Western Lakes during November and December 2016 for the provision of habitat and to improve wetland vegetation condition. Combined Commonwealth and NSW environmental water increased inundation extents in the Eulimbah Swamp rookery site after water levels suddenly dropped and inundation extents rapidly contracted during a waterbird breeding event (see 6.12 Waterbird Breeding).

Maintaining inundation duration is critical for the completion of the life history stages of flora and fauna. Commonwealth environmental water combined with NSW water was successfully used to maintain the water levels, or inundation extent, in four rookery sites in the Nimmie-Caira, one in Yanga and one in North Redbank. After the natural flood water levels dropped and inundation extents contracted whilst waterbird breeding events were progressing. Combined Commonwealth and NSW environmental water enabled the prolonged inundation duration of more than 50% of these wetland sites for at least another month. Whilst many other wetland sites were not targeted for environmental water delivery their extended inundation duration (up to eight months) would be important for the provision of foraging habitat for breeding waterbirds in adjacent wetland rookery sites. This highlights the importance of having a mosaic of wet and dry habitats closely available to fauna so they can complete their lifecycles. Environmental water actions also contributed to providing a more natural wetting and drying cycle for wetland vegetation over the longer term.

6.7 Wetland water quality

Prepared by Dr Ben Wolfenden (CSU) and Dr Yoshi Kobayashi (NSW OEH)

Introduction

While multiple watering actions were undertaken in the Murrumbidgee, during 2016-17, Commonwealth environmental water that influenced the 12 LTIM-monitored wetlands was largely targeted to support waterbirds breeding as a primary objective. In wetlands, the quality of physical habitat for aquatic species can be affected by water quality (here defined as the physicochemical environment and concentrations of dissolved nutrients and carbon). Water quality is naturally variable over time, reflecting changes in air temperature, discharge, patterns of wetting and drying, salinisation and aquatic photosynthesis. Biota found in ephemeral wetlands tolerate a degree of variability in physicochemical conditions (Poff, Allan et al. 1997), however, exceeding tolerance limits can cause sub-lethal impacts (i.e. impaired growth or reproduction) or mortality (Heugens, Hendriks et al. 2001, Bunn and Arthington 2002). Extreme weather and/or hydrology can lead to poor water quality in wetlands. While these extremes are part of the expected pattern for hydrologically variable ephemeral wetlands, changes to the frequency, timing and duration of wetland inundation in regulated systems can increase the likelihood of poor water quality with flow-on effects to aquatic biota and the associated food chains (Mazumder, Johansen et al. 2012) if this occurs at the wrong time of year. In most cases, appropriately timed environmental water deliveries can be used to off-set the negative impacts of drying or extreme climate, allowing affected biota to complete their lifecycles and further recruitment potential.

During September-November 2016-17 all 12 Murrumbidgee wetlands monitored under LTIM were inundated by a large unregulated overbank flow event. Environmental water was subsequently delivered to support waterbird breeding at colony sites in the Nimmie-Caira wetland zone (EulimbahSwamp, Telephone Bank, Nap Nap Swamp) and Redbank wetland zone (Two Bridges Swamp and Tori Lignum Swamp). We evaluated the effectiveness of environmental flow deliveries by comparing observed ranges of 1) physicochemical parameters and 2) concentrations of carbon, nutrients and chlorophyll-a against previously collected data and against other wetlands in the Murrumbidgee Catchment.

2016-17 environmental watering actions that influenced the hydrological regime of wetland sites monitored under LTIM were:

- Nimmie-Caira: Eulimbah waterbird breeding support (Eulimbah Swamp)
- Nimmie-Caira: Telephone Bank waterbird breeding support (Telephone Creek)
- Nimmie-Caira: Nap Nap waterbird breeding support (Nap Nap Summer)
- Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) (Nap Nap autumn)
- Yanga National Park: waterbird support (Two Bridges Swamp)

Water quality was also measured at Tori Lignum Swamp and these results are discussed in section 6.12.

Methods

Wetland water quality is monitored across all twelve wetland sites, four times per year (September, November, January and March), beginning in September 2014 and most recently sampled in March 2016. However, interference to sensors and contamination by benthic sediments means measurements are not collected where there is less than 10 cm of surface water. Sampling included measurements of physicochemical parameters (temperature (°C), electrical conductivity (EC, µS/cm), turbidity (NTU), pH and dissolved oxygen (mg/L)) at three randomly-chosen locations at each site using a calibrated water quality meter (Horiba U-52G). To capture the range of diurnal variability, dissolved oxygen was measured at ten minute intervals at each wetland over twelve hours using a dissolved oxygen data logger (D-Opto, Zebra Tech). Duplicate water samples were also collected and later analysed for dissolved organic carbon (DOC), chlorophyll-a, total nitrogen (TN) and total phosphorus (TP).

Results

Physicochemical measurements collected from wetland sites in 2016-17 show some departure from the previous data, but remained largely consistent with data collected during previous years. Conductivity was higher than the 95th percentile of previous records in the mid-Murrumbidgee zone during March 2017 (Table 6-14). This high mean value is due to Sunshower Lagoon which reached 1.58 $mScm^{-1}$ while the wetland had dried to ~2% of its full volume. Maximum dissolved oxygen was also much higher at Sunshower Lagoon on this occasion, but also at Piggery Lake in the Redbank Zone (with DO exceeding the calibrated range of the instruments).

Measured carbon, nutrient and chlorophyll-a concentrations also typically fell within the nominal range in 2016-17 (Figure 6-43). In the mid-Murrumbidgee zone chlorophyll-a was lower than previous results during the peak of the flood, with levels below the detectable limit across all sites. Chlorophyll-a increased across time thereafter. Also in the mid-Murrumbidgee, DOC ranged above the 95th percentile for previous records during March 2017, reaching concentrations of 250 mg L^{-1} at Sunshower Lagoon and 60 mg L^{-1} at McKennas Lagoon, again during the latter stages of drying.

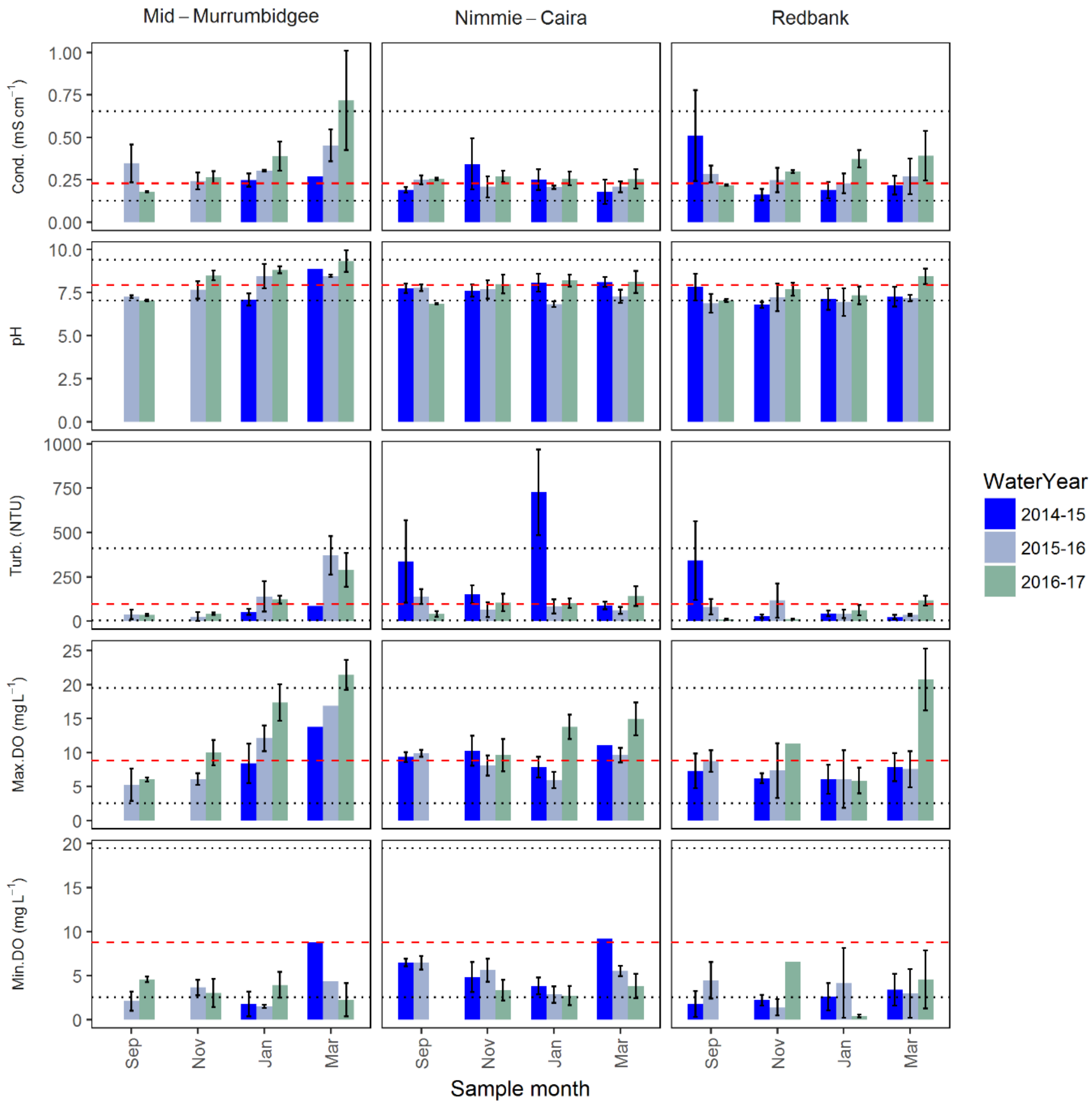


Figure 6-42 Mean ± standard error for physicochemical parameters (turbidity, pH, dissolved oxygen and conductivity) measured on four occasions between September and March during each of 2014-15, 2015-16 and 2016-17. Samples are collected across four sites within each of three monitored zones. Data are the mean of all sites wet on that sample occasion ± standard error of the mean. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

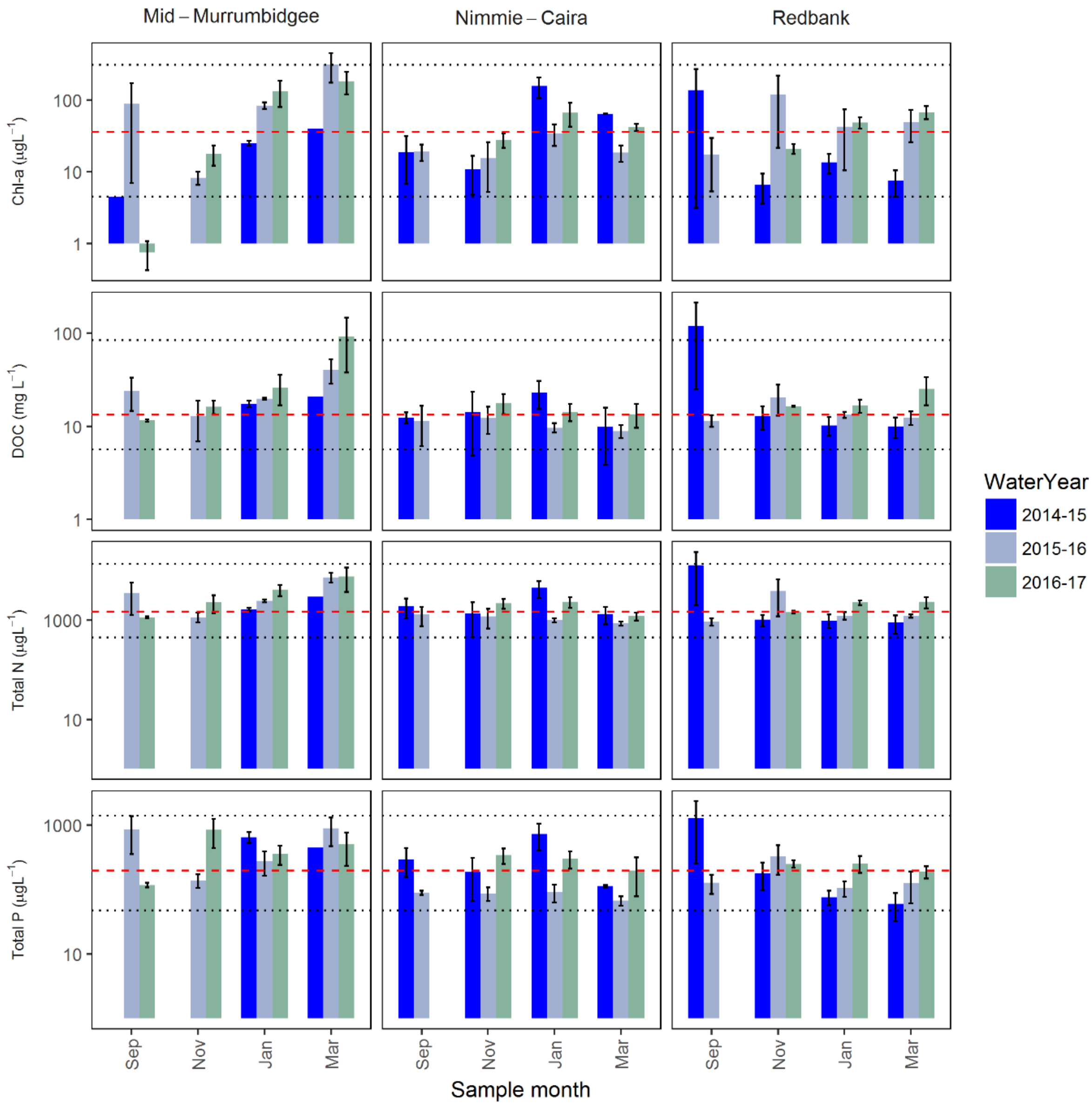


Figure 6-43 Mean ± standard error for dissolved organic carbon (DOC), total nitrogen (Total N), total phosphorous (Total P) and chlorophyll-a (Chl-a) measured on four occasions between September and March during each of 2014-15, 2015-16 and 2016-17. Samples are collected across four sites within each of three monitored zones. Data are the mean of all sites wet on that sample occasion ± standard error of the mean. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

Table 6-14 Median, 5th and 95th percentile and number of samples for water quality measurements collected across all wetlands in the Murrumbidgee catchment prior to 2014.

Indicator	TN mg L^{-1}	TP mg L^{-1}	Chl-a µg L^{-1}	DOC mg L^{-1}	Cond. mS cm^{-1}	pH	Turb. NTU	DO mg L^{-1}
Median (5th – 95th)	1483.5 (444-13719)	196.8 (47-1388)	35.6 (4.5-306.2)	13.4 (5.9-83.8)	0.229 (0.126-0.655)	7.93 (7.05-9.41)	94.8 (3.0-409.5)	8.79 (2.55-19.48)
# samples	70	70	62	103	365	356	355	329

Discussion

What did Commonwealth environmental water contribute to suitable water quality conditions?

In the Murrumbidgee Catchment, poor water quality is typically associated with increasing conductivity, turbidity and pH, and with declining dissolved oxygen. It is not immediately clear how important climate (i.e. season) versus wetland fill volume is as a driver for poor water quality in wetlands. However, we anticipate water quality conditions to deteriorate as temperatures increase and wetland volumes decline. The watering actions seeking to support waterbird habitat in 2016-17 focussed on floodplain areas that had been previously inundated by flooding and were at risk of drying, potentially affecting waterbird breeding success. Overall, the water quality conditions observed during 2016-17 only exceeded past records at the end of the season (March 2017), and only in the mid-Murrumbidgee wetlands where environmental water was not delivered. This indicates that water quality remained within the normal range at wetlands receiving Commonwealth environmental water. However, we note that because of levees breached during the flood, water levels at Eulimbah Swamp fell to <25% of the maximum fill level and this may have led to a temporary decline in water quality (see Section 6.12) before environmental water was returned to the system in late November 2016.

6.8 Wetland microinvertebrates

Prepared by Dr Kim Jenkins (CSU), Dr Ben Wolfenden (CSU), Dr Gilad Bino (UNSW), Claire Sives (UNSW), Sylvia Hay (UNSW) and Luke McPhan (UNSW)

Introduction

Microinvertebrates play a key role in floodplain river food webs, as prey to a wide range of fauna including larval and adult fish (King 2004), tadpoles and filter-feeding waterbirds. Microinvertebrate communities comprise a diverse array of taxa and life histories. Within the microinvertebrates, microcrustacea can dominate biomass and are a principle source of food for native larval fish in the Murrumbidgee.

We evaluated the effectiveness of environmental flow deliveries by comparing observed ranges of 1) benthic and pelagic microinvertebrate communities in wetlands and three river comparison sites and 2) densities of microinvertebrates against previously collected data within the Murrumbidgee and elsewhere. Sampling coincided with the wetland fish and tadpole monitoring in September to March in each water year.

Watering actions that are expected to have influenced the microinvertebrate communities at monitored wetland sites are:

- Nimmie-Caira: Eulimbah waterbird breeding support (Eulimbah Swamp)
- Nimmie-Caira: Telephone Bank waterbird breeding support (Telephone Creek)
- Nimmie-Caira: Nap Nap waterbird breeding support (Nap Nap Summer)
- Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) (Nap Nap autumn)
- Yanga National Park: waterbird support (Two Bridges Swamp)

Methods

Wetland microinvertebrates were sampled four times per year (September, November, January and March), beginning in September 2014 and most recently sampled in March 2017. Sampling was conducted across all twelve wetland sites (Section 4.1) on each occasion. Microinvertebrate samples were not collected when there was less than 10cm of surface water. Benthic and pelagic samples were collected following the methods described by Wassens, Jenkins et al. (2014). Laboratory methods follow those reported in the riverine microinvertebrate section.

Data analysis

We analysed responses of microinvertebrates in relation to wetland zones (i.e., Mid-Murrumbidgee, Nimmie-Caira or Redbank) along with trip by fitting a linear mixed-effects model (LMM) using the lmer function in the lme4 package in R (Bates, Maechler et al., 2015; R version 3.2.1, R Core Team, 2015). Zone and trip were incorporated as an interaction term to account for different responses over time while site was a random effect in the model. Prior to analysis, all our response variables were ln(x+1) transformed to reduce skewness and stabilize error variances. To draw generalizations about the effects of zone and trip from the samples collected, we present model estimates of responses for ease of interpretation and inference.

Results

What did Commonwealth environmental water contribute to wetland secondary productivity (microinvertebrates)?

The widespread unregulated flooding and inundation of wetlands in the mid-Murrumbidgee, Nimmie-Caira and Redbank zones with Commonwealth and NSW environmental water contributed to high levels of secondary productivity with densities of microinvertebrates between 500-1000/L throughout spring and summer (Figure 6-44). Densities of microinvertebrates were higher in benthic than pelagic habitats and although wetland pelagic densities were less than 500 /L (100-400/L), they were considerably higher than pelagic densities in riverine habitats (< 100/L, See Section 6.4).

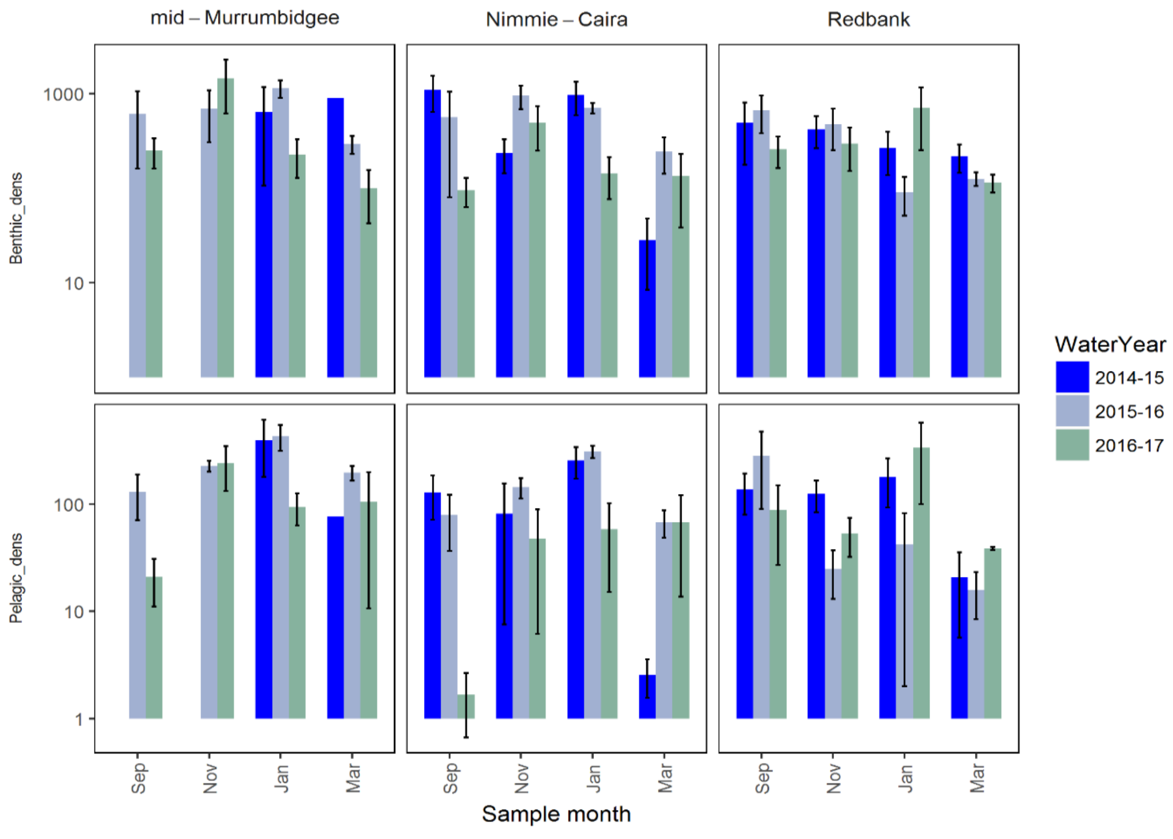


Figure 6-44 Mean densities of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) , 2015-16 (light blue) and 2016-17 (green). Errors are standard errors. In September and November 2014-15 wetlands in the mid-Murrumbidgee were dry and not available to sample.

There were no significant differences between zones or years in densities of benthic or pelagic microinvertebrates (Figure 6-45). However, benthic densities were relatively higher in the Nimmie-Caira and Redbank zones than the mid-Murrumbidgee. In pelagic habitats, lower densities were observed in the Redbank zone than the other two zones (Figure 6-45).

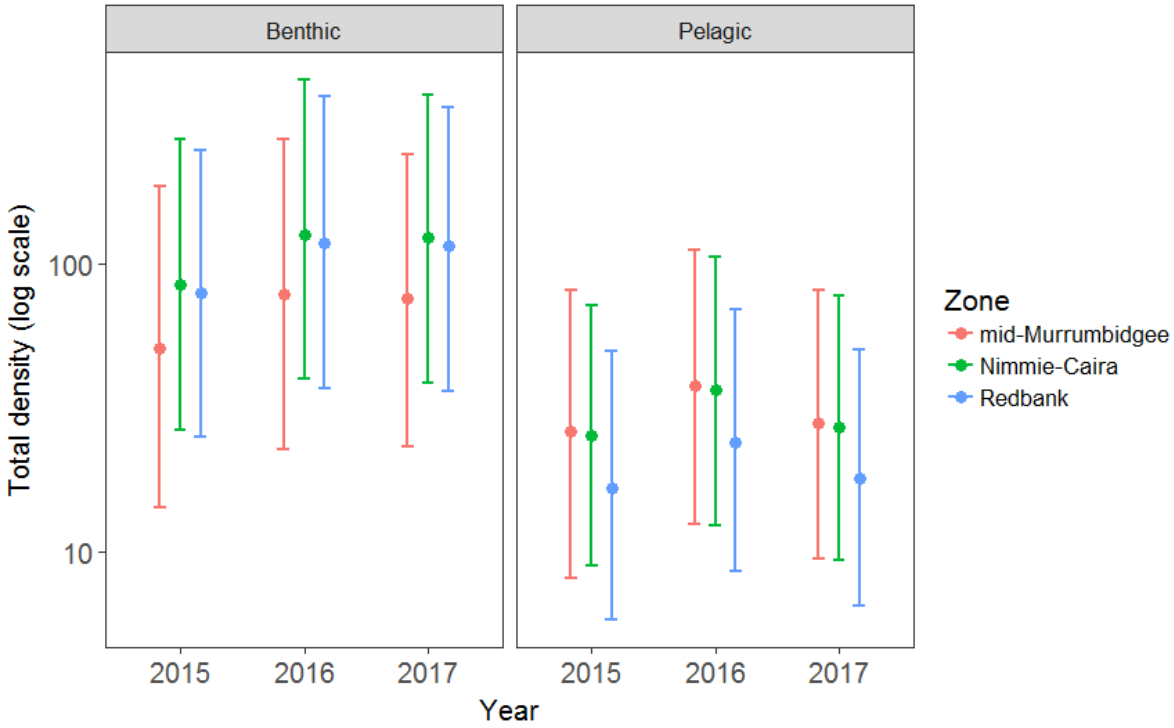


Figure 6-45 Model estimates (mean ± 95% confidence intervals) of total microinvertebrate density (log scale) in four sites each from the mid-Murrumbidgee, Nimmie-Caira and Redbank zones in both benthic (left graph) and pelagic (right graph) habitats sampled in 2014-15, 2015-16 and 2016-17.

There were no significant differences between years or among trips nested within year in densities of microinvertebrates (Figure 6-46). Nevertheless, densities tended to be lowest in all wetlands in March and highest in January (Figure 6-46).

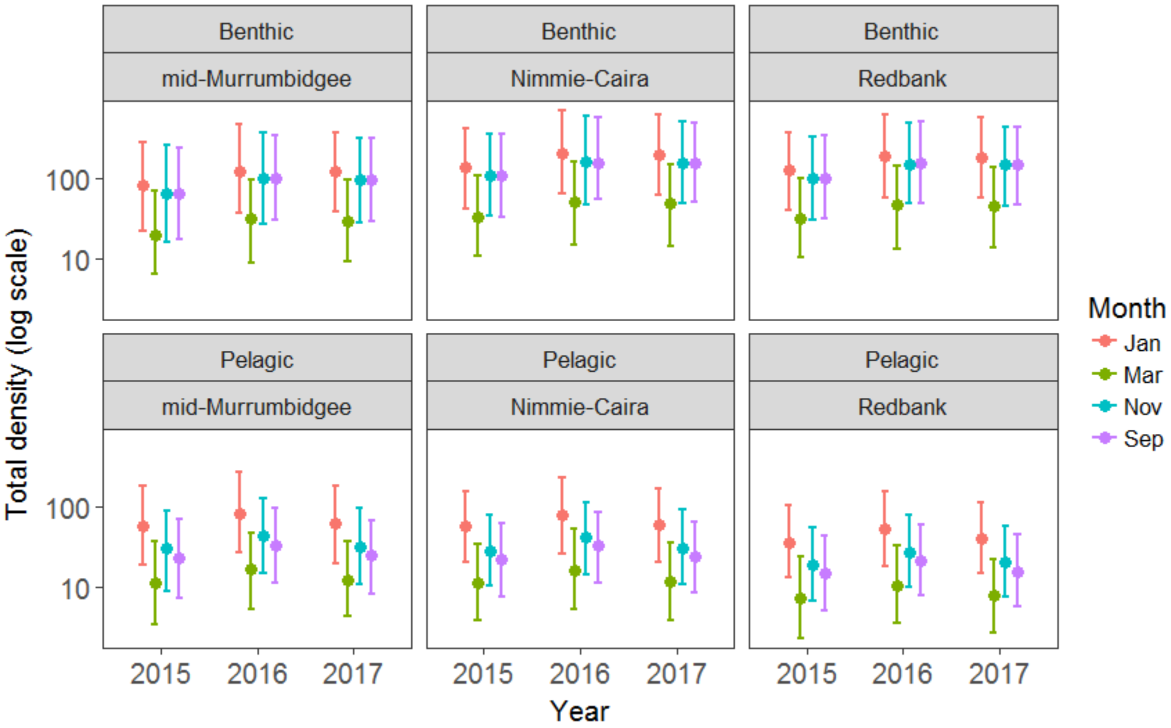


Figure 6-46 Model estimates (mean ± 95% confidence intervals) of total microinvertebrate density (log scale) in four sites each from the mid-Murrumbidgee, Nimmie-Caira and Redbank zones in both benthic (upper graphs) and pelagic (lower graphs) habitats sampled over 4 trips in 2014-15, 2015-16 and 2016-17.

Copepods, particularly cyclopoids and nauplii, dominated benthic assemblages in all three years and across the three zones (Figure 6-47). This pattern was reflected in the less productive pelagic habitats, where copepod nauplii were in higher densities than cyclopoids in both the Nimmie-Caira and Redbank zones (Figure 6-48). A suite of cladocerans, including Moinids, Chydorids, Bosminids and Macrothricids were also common in samples from all zones (Figure 6-48).

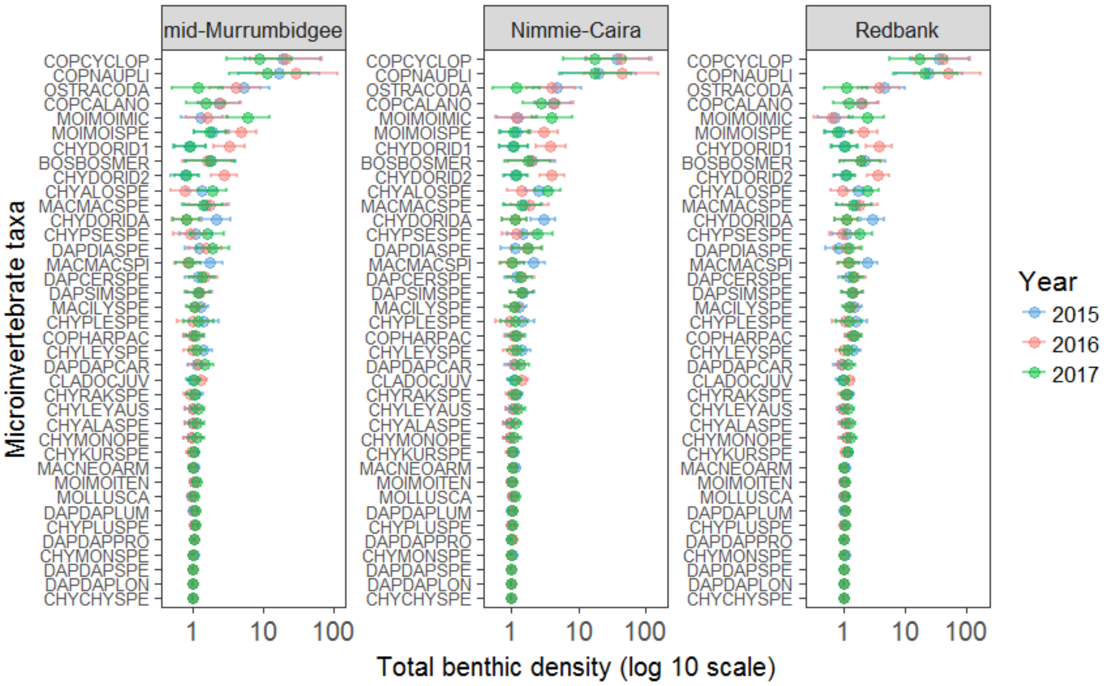


Figure 6-47 Model estimates (mean ± 95% confidence intervals) of total benthic microinvertebrate taxa density (log scale) in four sites each from the mid-Murrumbidgee, Nimmie-Caira and Redbank zones sampled in 2014-15, 2015-16 and 2016-17.

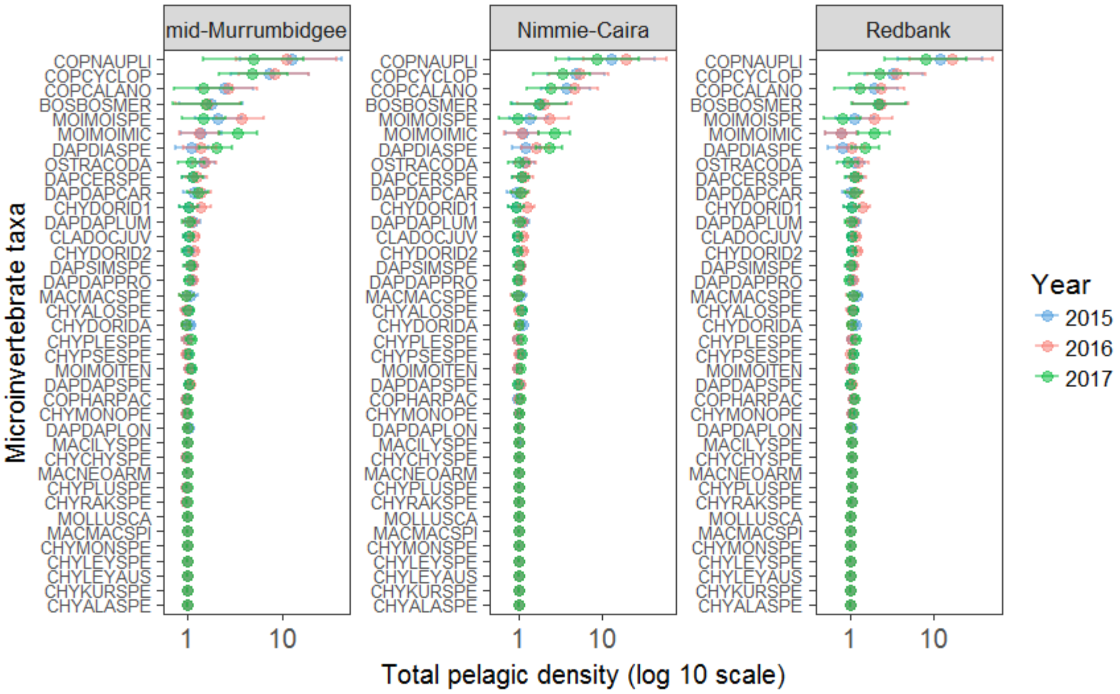


Figure 6-48 Model estimates (mean ± 95% confidence intervals) of total pelagic microinvertebrate taxa density (log scale) in four sites each from the mid-Murrumbidgee, Nimmie-Caira and Redbank zones sampled in 2014-15, 2015-16 and 2016-17.

Discussion

What did Commonwealth environmental water contribute to wetland secondary productivity (microinvertebrates)?

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee in order to support waterbird breeding following widespread unregulated flooding. Commonwealth environmental watering actions that are likely to have influenced microinvertebrate communities at the 12 monitoring wetlands were; Nimmie-Caira to South Yanga, Nimmie-Caira rookery maintenance and Yanga rookery maintenance. Inundation of these wetlands in 2016-17, 2015-16 and 2014-15 triggered a rapid and productive response of microinvertebrates in all zones with high densities throughout September, November and January. Benthic densities were very productive with densities above 1000 individuals/litre and a rich suite of microinvertebrates including copepods (cyclopoids, nauplii and calanoids), cladocerans (*Moina micrura*, *Bosmina meriodonalis*, chydorids and *Diaphansoma* sp.) and ostracods. Although densities tended to be lower in the mid-Murrumbidgee, this difference was not significant and was driven by the inclusion of dry wetlands as zero data points. Pelagic densities were higher in the mid-Murrumbidgee and lowest in the Redbank wetlands in all three years of the study, but it is not yet clear why this pattern exists.

The peak benthic densities (>1000/L) recorded across the three years of LTIM sampling were in the mid-Murrumbidgee in November 2016, with similar densities in that zone in January in 2015-16 and March in 2014-15 (although only from one wetland) (see Figure 6-44). Despite the higher densities recorded in the mid-Murrumbidgee following widespread flooding, there was not consistent response to the flooding across all wetlands and zones. In the Nimmie-Caira the highest benthic densities were recorded in September and January in 2014-15, while in Redbank the highest density was recorded in January 2017 (see Figure 6-44). Closer examination of the difference between extent and depth (Section 6-6) across years shows that it was not consistently higher following flooding. In addition, while floods are predicted to increase productivity by importing organic material, we sometimes do not see these effects until subsequent years as during a flood microinvertebrates can be diluted or flushed by floodwaters. Generally, the lowest densities were observed in March in all zones in 2017, but not in all zones in 2015. In March, temperatures and water levels are falling, making conditions less than ideal for microinvertebrates. In addition, after at least six months of inundation, nutrients may become depleted, compared to the initial high flush of nutrients, and productivity falls.

6.9 Vegetation diversity

Prepared by Dr Skye Wassens (CSU) and Erin Lenon (CEWO)

Introduction

The composition and diversity of wetland plant communities is influenced by a range of hydrological metrics. Over long time frames the composition and species richness of wetland plant communities is influenced by the frequency of inundation (Reid and Capon 2011), with extended dry periods potentially leading to losses from both the extant species pool and the seedbank (Brock, Nielsen et al. 2003). At shorter time frames, the duration of inundation, water depth, day-length and temperature can all influence the patterns of growth and flowering of wetland plants (Brock and Casanova 1997, Casanova and Brock 2000).

High level of natural variability in species richness and community composition as a result of vegetation communities transitioning between wet and dry phases as well as annual variability in wetland hydrology and inundation extent may influence the types of species dominating the wetland community in a given year (Bagella, Caria et al. 2009) as well as the overall number of species (species richness) present in the wetland (Myers and Harms 2009).

Evaluation of watering actions

In 2016-17 large scale, unregulated flows occurred across the Murrumbidgee Catchment due to above average rainfall and all 12 monitoring wetlands received inflows in spring 2016. Watering actions targeting vegetation condition were carried out in the Junction wetlands and Toogimbie IPA wetlands but these are outside of the LTIM monitoring area. Within the monitoring area, watering actions targeting waterbird breeding in the Nimmie-Caria were undertaken with the secondary objective of *"maintaining and improving the condition of wetland vegetation."*

Watering actions that influenced the hydrological regime of LTIM vegetation monitoring sites were:

- Nimmie-Caira: Eulimbah waterbird breeding support (Eulimbah Swamp)

- Nimmie-Caira: Telephone Bank waterbird breeding support (Telephone Creek)
- Nimmie-Caira: Nap Nap waterbird breeding support (Nap Nap Summer)
- Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) (Nap Nap autumn)
- Yanga National Park: waterbird support (Two Bridges Swamp)

Specifically, this monitoring program addressed the following evaluation questions:

- Did Commonwealth environmental water contribute to vegetation species diversity?
- Did Commonwealth environmental water contribute to vegetation community diversity?
- Did environmental watering influence the types of species present in wetlands?

Methods

The 12 wetlands monitored under this program represent four vegetation community types defined by the dominant over storey and understory communities, and wetland geomorphology. In the Nimmie-Caria zone the monitoring program includes one Lignum (Eulimbah Swamp), Lignum- black box (Nap Nap, Telephone creek, Avalon in the Nimmie-Caria and Wagourah Lagoon in the Redbank zone) (Plate 6-1). In the Redbank zone there are three tall emergent aquatic wetlands (Mercedes, Two Bridges and Piggery Swamp) which are open lakes with a dominant understory of spike rush (*Eleocharis* species) and fringing River Red gum (Plate 6-2). In the mid-Murrumbidgee vegetation communities are classified as river red gum woodland in with deeper open, ox bow lagoon with fringing river red gum (Sunshower, Gooragool, Yarradda, McKenna's).

Monitoring of vegetation communities is undertaken four times per year (September, November, January and March) and commenced in September 2014 as per Wassens, Jenkins et al. (2014). Surveys are conducted at twelve wetlands, with data collected along two to three set transects starting at the high-water mark and terminating at the centre of the wetland. Each transect contains three or five, 10 meter quadrats. In 2016-17 we were unable to access sites in the Nimmie-Caria during September as a result of road closures caused by widespread un-managed flooding. Data on the percentage cover of each species, open water, bare ground, leaf litter, and logs > 10cm, tree canopy crown cover, water depth (cm) and soil moisture is recorded in each quadrat.

Data analysis

Comparisons of community structure and species diversity were undertaken using Primer version 6 (Clarke and Gorley 2006). The percentage cover of each species was Log 10+1 transformed before analysis. Analysis of similarities (ANOSIM) was used to compare community composition between sites, water years and wet-dry phases. SIMPER is used to identify the species that contribute most to differences between sites (Anderson 2005). Species richness (SR) and species accumulation curves (Sobs and CHOA 1) were generated for species within the amphibious functional group and for all species combined for each wetland over the three year monitoring period. Spearman's RHO tests were used to describe the relationship between species richness and soil moisture. While Generalised Linear Models were used to compare water depths and species richness between vegetation communities and water years.

Black box-lignum community (Avalon Swamp, Nimmie-Caria)

Lignum community (Eulimbah Swamp, Nimmie-Caria)

Plate 6-1 Examples of Lignum and Lignum-black box communities

Tall emergent community (Piggery Lake, Redbank)

River red gum woodland (Gooragool Swamp, mid-Murrumbidgee)

Plate 6-2 Examples tall emergent and river red gum woodland communities.

Results

Hydrological conditions

As expected, large scale unregulated inundation of the wetlands in 2016-17 contributed to higher water depths along vegetation transects through the majority of wetlands but this pattern varied between vegetation communities (GLM water year x vegetation community F =6.471 p= <0.001). In the river red gum woodland wetlands of the mid-Murrumbidgee, water depths were particularly high compared to previous years, while water depth in black box lignum and tall emergent communities were higher than in 2015-16 but similar to 2014-15 levels, water depths along survey transects were similar at the lignum wetland between 2015-16 and 2016-17, but both years were significantly higher than in 2014-15 (Figure 6-49).

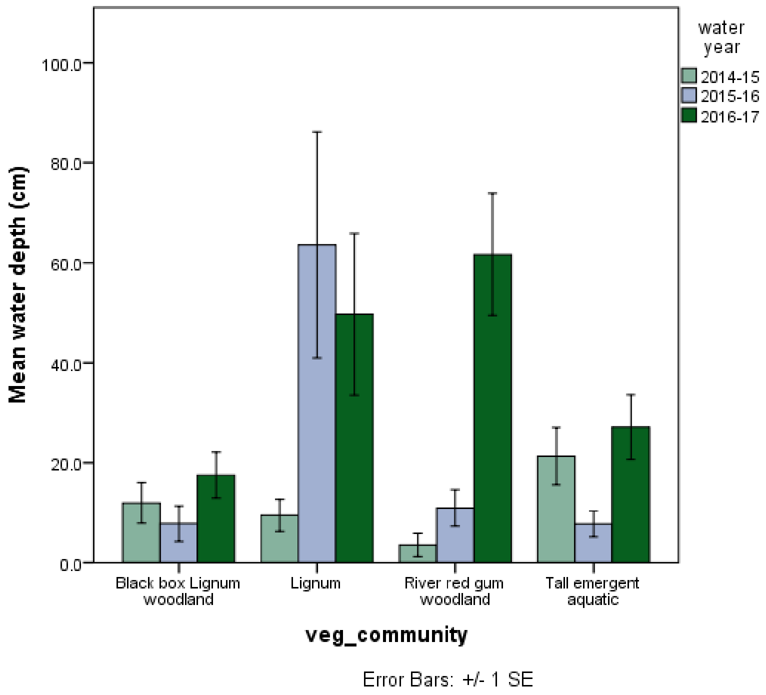


Figure 6-49 Mean water depth (cm) along each survey transect across sites in each monitoring zone and water year

Over the past three years, 10 of the 12 monitoring sites have received environmental water with most receiving water for at least two out of the three years. Two wetlands McKenna's and Sunshower lagoons, in the mid-Murrumbidgee did not receive any environmental water between 2013 and 2015 but filled during unregulated river flows in 2016.

Did Commonwealth environmental water contribute to vegetation species diversity?

Since September 2014, 225 species (162 native and 63 exotic) including 51 native aquatic species (as defined using functional groupings of Brock and Casanova 1997), have been recorded. When all species are considered, there was a decrease in species richness over the three water years for all vegetation community types (River red gum woodland, Black box-lignum, Lignum, and tall emergent aquatic) (vegetation community x year GLM F 2.528, $p = 0.0240$) this is expected and reflects a decline in terrestrial species diversity. In contrast the number of aquatic species did not change significantly over time across any of the four vegetation community types (vegetation community x year GLM F 1.436, $p = 0.206$) (Figure 6-50). We did not record any additional species listed threatened or vulnerable species in 2016-17 or changes in the extent of abundance of threated or vulnerable species.

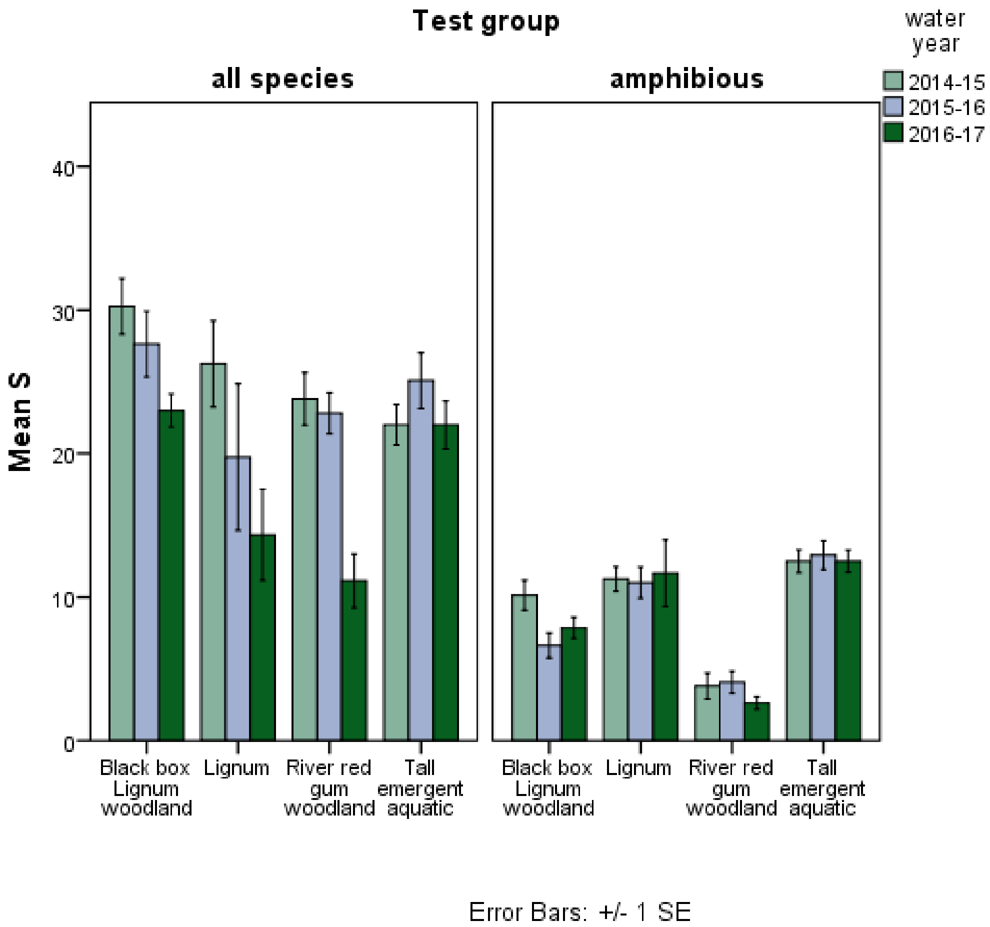


Figure 6-50 mean species richness (SR) across the three monitoring years within each vegetation community type for all species combined, and aquatic species (amphibious).

A more interesting pattern emerges when we consider the accumulation of new species to the wetlands over time. When we consider amphibious species, the ten sites that received Commonwealth and State environmental water between 2014 and 2017 accumulated new amphibious species at a faster rate and had higher overall richness than the two wetlands that did not receive environmental water and only filled during unregulated inflows in 2016-17 (Sunshower and McKenna's)(Figure 6-51). While the rate of accumulation of terrestrial species is similar across all wetlands.

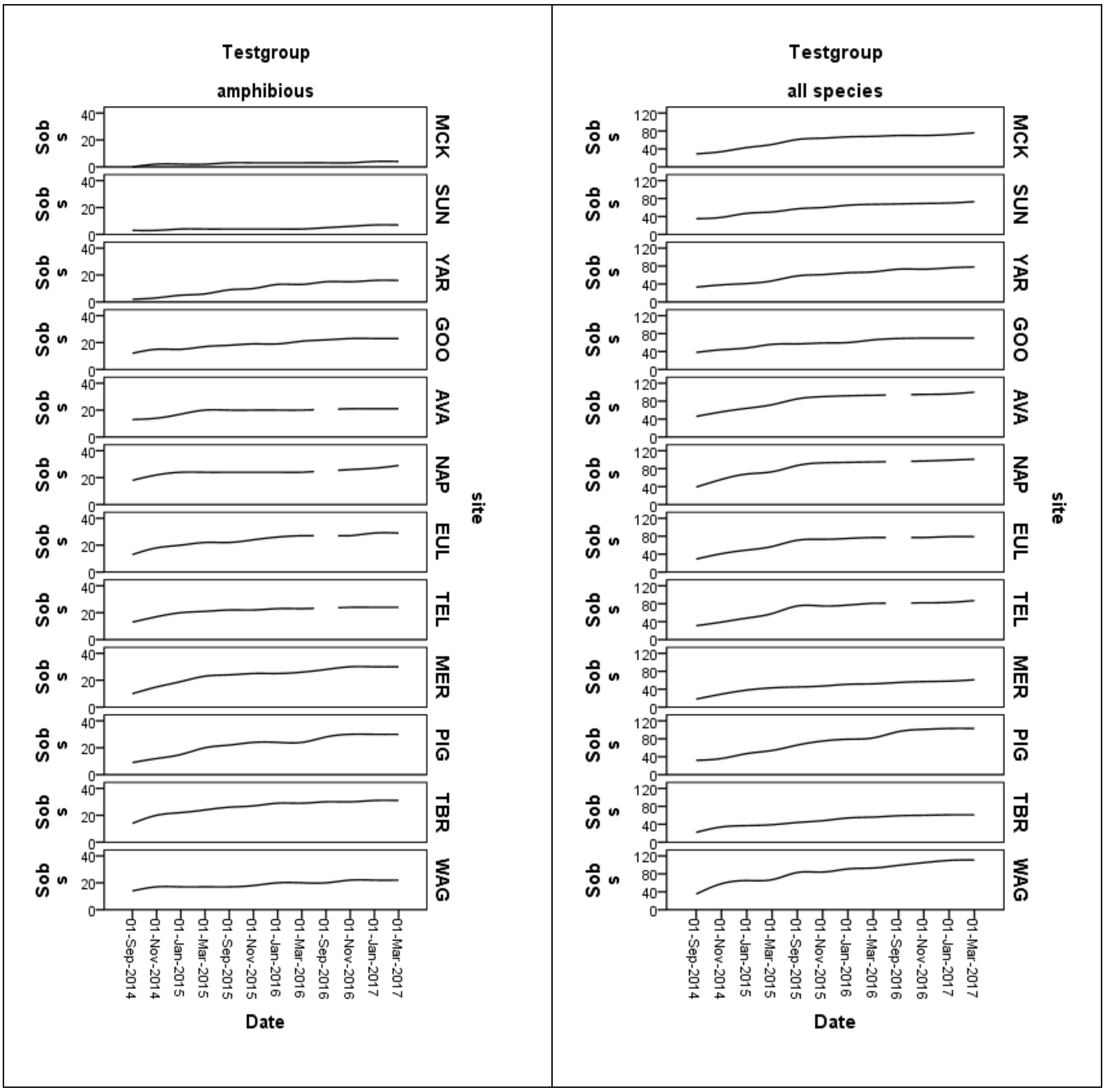


Figure 6-51 Cumulative species observations (sobs) for each survey occasion for all species and amphibious (water dependent species) at each site. MCK (McKenna's) and SUN (Sunshower) did not receive environmental water between 2014-17, while the remaining sites received environmental water on at least one occasion.

Species richness was influenced by wetland water depth and soil moisture. There is a significant positive relationship between the amphibious species richness and soil moisture (Spearman's r= 2.908, p=0.004), but not water depth (Spearman's r = -0.880, p = 0.380) (number of species increases as soils become increasingly water logged). In contrast, there was a significant negative relationship between terrestrial species richness and water depth (Spearman's r = -7.813, p<0.001), and soil moisture (Spearman's r = -6.052, p<0.001).

Did Commonwealth environmental water contribute to vegetation community diversity?

The 12 wetlands monitored under this program represent four vegetation community types, these are Lignum (Eulimbah Swamp), Lignum- black box (Nap Nap, Telephone creek, Avalon and Wagourah Lagoon), tall emergent aquatic (Mercedes, Two Bridges and Piggery Swamp) and river red gum woodland (Sunshower, Gooragool, Yarradda, McKenna's). In 2016-17 environmental watering actions targeted three communities Lignum, Lignum-black box and tall emergent aquatic, while river red gum woodland wetlands filled during unregulated flows. Overall the composition of understory plants species in each community differed significantly (ANOSIM Global R 0.552. p<0.001) taken across the three years, understory communities within the river red gum woodland, tall emergent and lignum - lignum black box differ significantly while understory communities in the lignum and lignum black box communities are similar (Pairwise R 0.08, p = 0.252) (Figure 6-52).

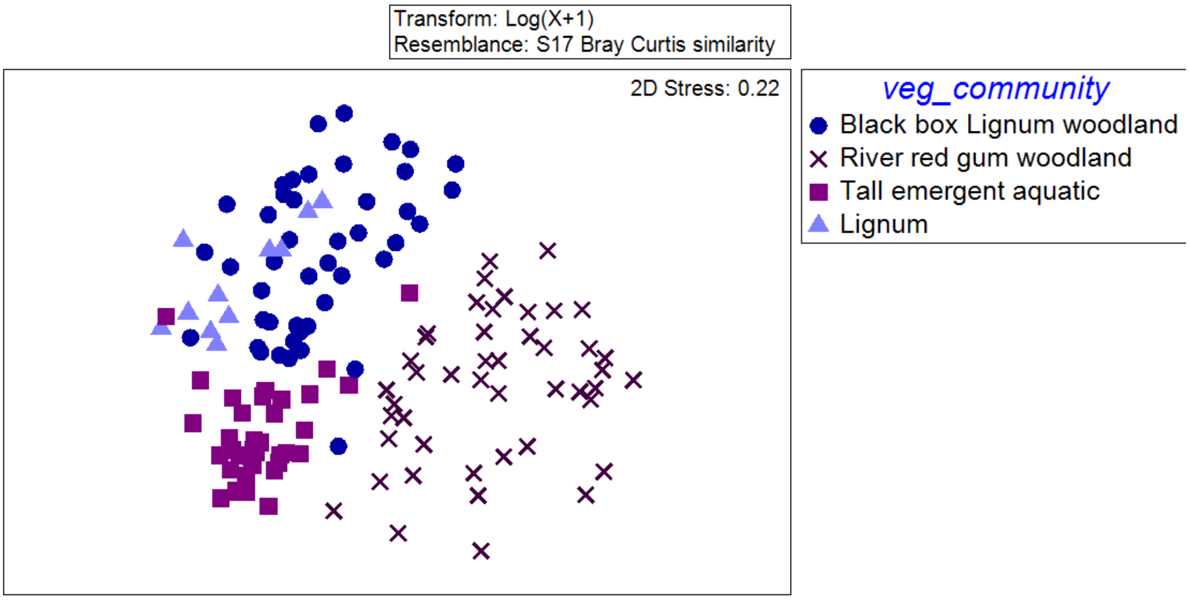


Figure 6-52 MDS plot of species composition across the four vegetation communities in 2014-15 to 2016-17. Points that are close together have more similar communities then those which are further apart.

Did environmental watering influence the types of species present in wetlands?

When considered across all wetlands and all monitored water years, there was a significant difference in the composition of plant communities between wetlands that never received environmental water, received environmental water two out of three years and three out of three years (ANOSIM Global R 0.446, $p < 0.001$). As would be expected the greatest differences were between wetlands that never received environmental water (filled by unregulated flows in 2016-17) and wetlands that received environmental water in each of the three years (ANOSIM Global R 0.743, $P < 0.001$). This reflects both wetting and drying cycles and the length of times that wetlands are allowed to contain water, with more regular inundation allowing wetlands to support water depend species for longer periods. Expressed in terms of functional groups, the two sites that did not receive any Commonwealth environmental water in either 2014-15 or 2015-16 (Sunshower and McKenna's) have lower proportion of species belonging to the amphibious and terrestrial damp functional groups (Figure 6-53). Considering this pattern with the river red gum woodland wetlands, there were significant differences in community composition between the wetlands that received environmental water in 2014-15 and 2015-16 and filled on un-regulated flow in 2016-17 (Gooragool and Yarradda) and the two wetlands that only filled during the unregulated reconnection flow (McKenna's and Sunshower) (ANOSIM Global R: 0.435 $p < 0.001$). SIMPER comparisons of wetlands in 2016-17 that had received water in either 1 out of 3, and 2 out of 3 of the past 3 years show clear differences in the types of species present (Table 6-15). Wetlands receiving environmental water in two of the past three years had lower abundance of river red gum (*Eucalyptus camaldulensis*) seedlings indicating lower levels of encroachment and higher abundances of water dependant species including spike rush (*Eleocharis acuta*), water primrose (*Ludwigia peploides ssp. Montevidensis*) and spiny mudgrass (*Pseudoraphis* spinescens) (Plate 6-3).

Table 6-15 SIMPER community composition of river red gum woodland wetlands in the mid-Murrumbidgee zone in 2016-17 while all wetlands contained water, comparing sites that received environmental water in addition to natural inundation (2 in 3) and those that received natural inundation only (None).

E-water	Species	functional	status	Av.Abund	Av.Sim	Contrib%
2 in 3	*Eucalyptus camaldulensis*	Terrestrial	Native	0.75	5.44	0.72
	Eleocharis acuta	Amphib.	Native	1.00	4.91	0.71
	Alternanthera denticulata	Terrestrial	Native	0.55	2.29	0.48
	Cynodon dactylon	Terrestrial	Native	0.51	0.96	0.44
	Ludwigia peploides ssp. montevidensis	Amphib.	Native	0.22	0.89	0.33
	Pseudoraphis spinescens	Amphib.	Native	0.79	0.86	0.28
	Azolla filiculoides	Amphib.	Native	0.43	0.79	0.31
	Lolium sp	Terrestrial	Exotic	0.21	0.39	0.19
	Persicaria prostrata	Terrestrial	Native	0.47	0.37	0.19
None	*Eucalyptus camaldulensis*	Terrestrial	Native	1.09	12.9	0.98
	Calotis scapigera	Terrestrial	Native	0.59	3.07	0.79
	Wahlenbergia fluminalis	Terrestrial	Native	0.47	2.01	0.58
	Centipeda cunninghamii	Amphib.	Native	0.58	1.99	0.51
	Glinus lotoides	Terrestrial	Native	0.45	1.64	0.50
	Dysphania pumilio	Terrestrial	Native	0.51	1.62	0.42
	Eleocharis acuta	Amphib.	Native	0.48	1.44	0.37
	Alternanthera denticulata	Terrestrial	Native	0.29	0.82	0.48
	Paspalidium jubiflorum	Terrestrial	Native	0.18	0.49	0.34

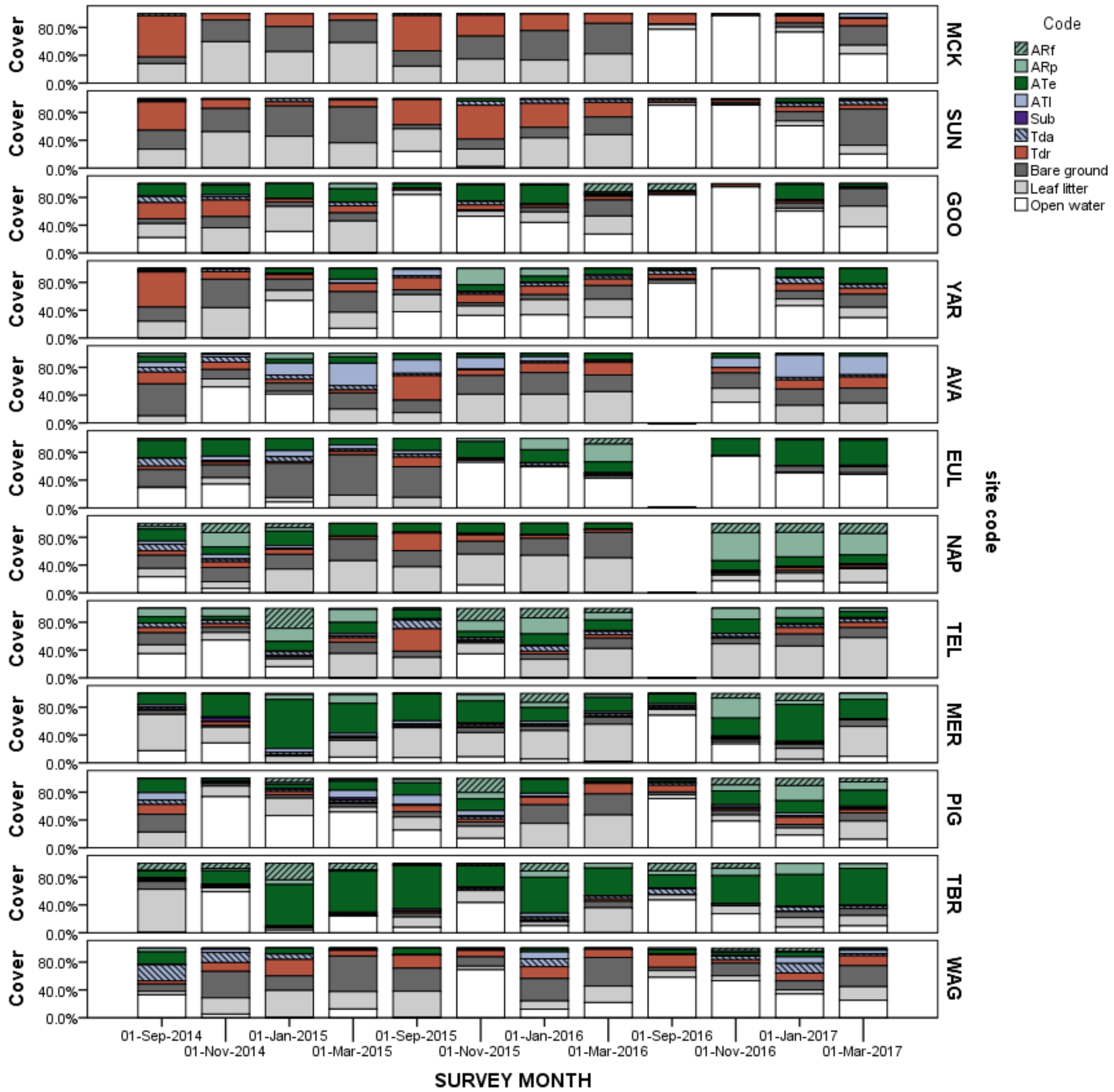


Figure 6-53 Changes in percentage cover of plant functional groups and abiotic factors (bare ground, open water and leaf litter) between September 2014 and March 2017.) ARf= amphibious fluctuation responder-floating, ARp= amphibious fluctuation responder-plastic, ATe= amphibious fluctuation tolerator emergent, ATl= amphibious fluctuation tolerator low growing, Sub =submerged, Tda-= terrestrial damp, Tdr= terrestrial dry (Brock and Casanova 1997).


Yarradda Lagoon- environmental water 2014-15 and 2015-16 with understory of spiny mudgrass January 2017


Mckennas Lagoon- no environmental water with river red gum encroachment January 2017

Plate 6-3 Vegetation responses to unregulated inflows in 2016-17 at a river red gum woodland wetland receiving regular environmental water between 2014 and 16 (top) and a wetland receiving no environmental water (bottom).

Discussion

In 2016-17 there was large-scale unregulated inflows into wetlands throughout the mid and lower Murrumbidgee floodplain, as a result water levels were very high during spring and early summer. Within the LTIM monitoring area Commonwealth environmental watering actions targeting waterbird breeding in the Nimmie-Caria and Redbank were undertaken with the secondary objective of "*Maintaining and improving the condition of wetland vegetation*" and had the effect of extending the duration of inundation at Nap Nap, Telephone Creek, Eulimbah (Nimmie-Caria) and Two Bridges swamp (Redbank). In the context of these four wetlands, Commonwealth environmental watering achieved this broad objective as there were no declines in the diversity or percent cover water dependent species in these wetlands.

While short term responses to environmental watering occurred in 2016-17 more significant patterns emerge when considering the history of environmental watering since 2014. Un-regulated flows inundated river red gum woodland wetlands (Mckennas and Sunshower Lagoons) that could not be reached with environmental water in 2014-15 or 2015-16 which provides an opportunity to compare the vegetation responses at these sites with two others (Yarradda and Gooragool Lagoons) that received environmental water in 2014-15 and 2015-16. While these four wetlands had similar geomorphologies and similar inundation frequencies prior to river regulation (Wassens, Ning et al. 2017) there were clear difference in the types of species present in 2016-17. Wetlands that have not received environmental water continued to be dominated by terrestrial species even after inundation and had higher percentages of river red gum seedlings, indicating encroachment, while the regularly watered sites contained higher percentages of water dependent species and lower percentages of river red gums. This pattern is consistent with predictions that restoring the natural hydrological regime through environmental watering will support the establishment and persistence of water dependent species to a far greater extent than unregulated flows alone.

6.10 Frogs and turtles

Prepared by Dr Skye Wassens (CSU)

Introduction

Environmental watering actions can be used to maintain frog and turtle populations via two key mechanisms: by providing persistent refuge habitat that supports frog and turtle populations during periods of low water availability, and through the provision of shallow temporary standing water that provides breeding habitat and a suitable environment for tadpole growth and survival. Pre-watering of key southern bell frog habitats was undertaken in autumn 2016 (*Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake)*), with the objective to "Maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC Act vulnerable)". This watering action was paused in winter as a result of widespread rainfall, which led to natural inundation across the mid-Murrumbidgee and Lower-Murrumbidgee floodplains. As water from the natural inundation receded, a series of environmental watering actions focussed on supporting waterbird breeding in the Nimmie-Caria and Redbank systems (Nimmie-Caira: Eulimbah waterbird breeding support, Nimmie-Caira: Telephone Bank waterbird breeding support, Nimmie-Caira: Nap Nap waterbird breeding support and Yanga National Park: waterbird support), which had the secondary objective of "supporting habitat for wetland vertebrates". These four watering actions extended duration of inundation at four monitoring sites (Eulimbah, Telephone and Nap Nap in the Nimmie-Caria, and Two Bridges in the Redbank system). In the mid-Murrumbidgee, all four monitored wetlands connected during natural periods of high river flows and there were no targeted environmental watering actions in these systems. However, two of the sites (Yarradda Lagoon and Gooragool Lagoon) benefited from environmental watering in 2014-15 and 2015-16 and Yarradda Lagoon was still partly full when it reconnected during unregulated flows in September 2016. McKenna's Lagoon filled for the first time since 2012, while Sunshower Lagoon had previously received a partial fill in 2015-16. Watering actions that influenced the hydrological regime of LTIM monitoring sites were:

- Nimmie-Caira: Eulimbah waterbird breeding support (Eulimbah Swamp)
- Nimmie-Caira: Telephone Bank waterbird breeding support (Telephone Creek)
- Nimmie-Caira: Nap Nap waterbird breeding support (Nap Nap Summer)
- Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) (Nap Nap autumn)
- Yanga National Park: waterbird support (Two Bridges Swamp)
- Murrumbidgee River Fresh action: flood recession and DO management flow (created a peak water levels in the mid-Murrumbidgee wetlands and slowed flow recession from Lowbidgee floodplain).

Evaluation questions

- What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?
- What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?
- What did Commonwealth environmental water contribute to the maintenance of refuge habitats?

Methods

Since 2014, frogs and tadpoles have been monitored across the 12 LTIM surveyed wetlands four times per year (September, November, January and March). Detailed survey methodology is contained in Wassens, Jenkins et al. (2014). Adult frogs are surveyed after dark using two timed 20 minute transects where all frogs observed or heard calling are recorded. Tadpoles are surveyed alongside wetland fish, using a combination of two large and two small fyke nets set overnight. The tadpole Catch-Per-Unit Effort (CPUE) is based on the number of tadpoles collected per hour, with this value adjusted for differences in the width of the net wings and water depth where the net is set (nets can only be set when water depths are above 30cm).

Data analysis

Spearman's rank correlations were used to identify significant relationships between the percentage wetland inundation on each survey occasion between September 2014 and March 2017 and frog and tadpole abundance. Mann-Whitney U test were used to compare size distributions of the three turtle species detected during the 2015-16 and 2016-17 water year. The prediction that populations of each species would increase over the three water years at wetlands receiving environmental water was tested using the Jonckheere-Terpstra test for ordered alternatives (Pallant).

Results

What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?

Six frog species were recorded in 2016-17, which is the same as in previous years (Wassens, Spencer et al. 2016). As expected there have been no changes in the diversity of frogs, when considered across all of the 12 wetlands, and no significant changes to the overall number of individuals encountered between 2014 and 2017, despite some variability in the number of individuals of each species recorded over time. There have been some general trends in species abundance over the three monitoring years, with southern bell frogs increasing in the Nimmie-Caria, barking marsh frogs increasing in the Redbank system and Plains froglet decreasing in the Nimmie-Caria and Redbank zones (Figure 6-54). However, high levels of variability between sites and survey occasions makes it difficult to identify statistically significant patterns either across zones or individual wetlands receiving environmental water and unregulated flows. The one exception is the plains froglet, where population numbers significantly decreased over time in the Nimmie-Caria zone (Jonckheere-Terpstra test for ordered alternatives $t = -3.562$, $p < 0.001$).

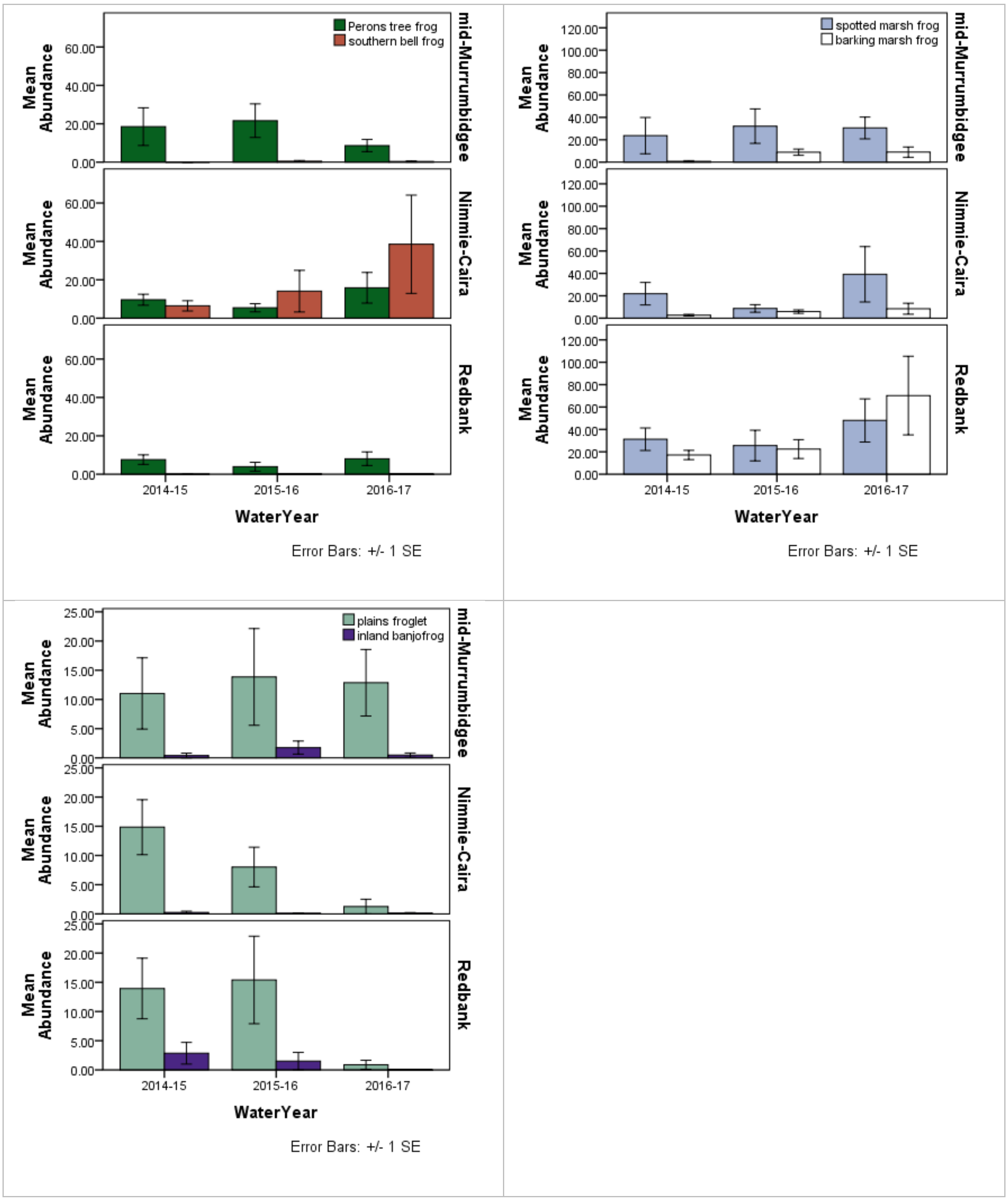


Figure 6-54 Overall trends in species observations, calling counts (40 survey minutes) and tadpoles across the three monitoring zones between 2014-15 and 2016-17. Note differing scales on y-axes.

Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) Southern bell frog outcomes

In autumn 2016, Commonwealth environmental water was delivered via the Nimmie-Creek systems to a large area of floodplain in order to "Maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC Act vulnerable)". This watering action included Nap Nap Swamp, which had received environmental water in 2014 and then was dry through most of 2015, before receiving water as part of the Nimmie-Caira to South Yanga in autumn 2016, followed by unregulated flows through September and December and a top up with environmental water in January 2017 for the Nap Nap waterbird breeding support event (Figure 6-55). Environmental watering actions in Nap Nap Swamp were associated with an increase in abundance of southern bell frogs, relative to wetlands that received unregulated flows followed by environmental water in summer to support waterbird breeding (Eulimbah and Telephone Creek) and wetlands that received unregulated flows alone (Avalon) (Figure 6-56).

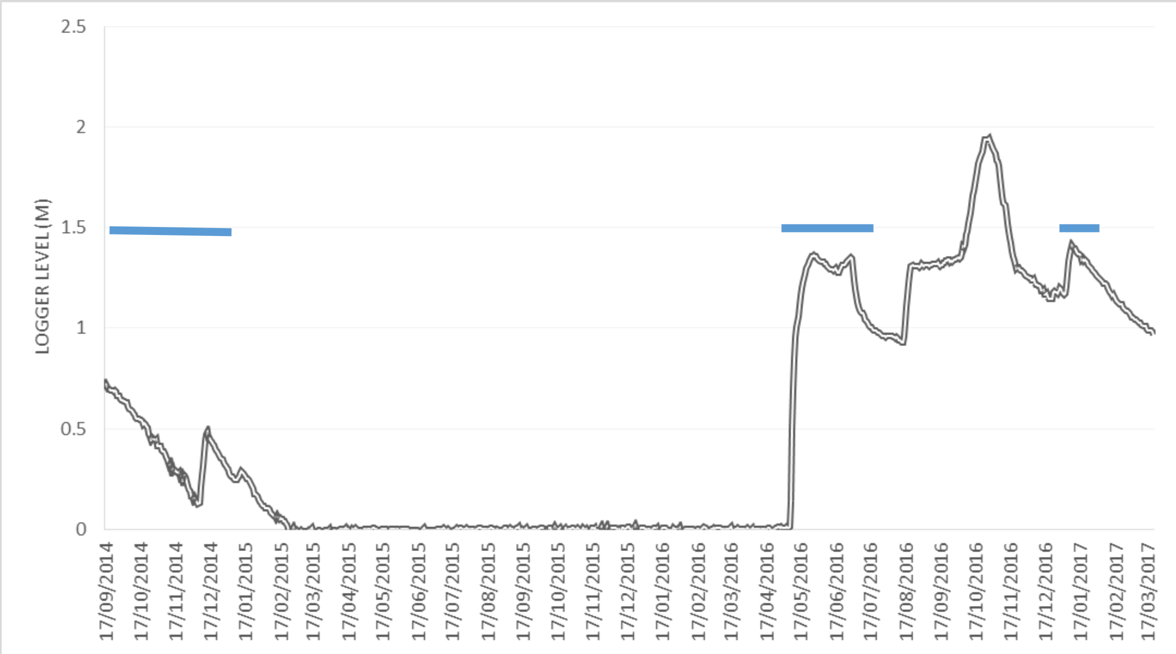


Figure 6-55 Hydrograph for Nap Nap swamp September 2014 – March 2017, blue lines show environmental watering actions.

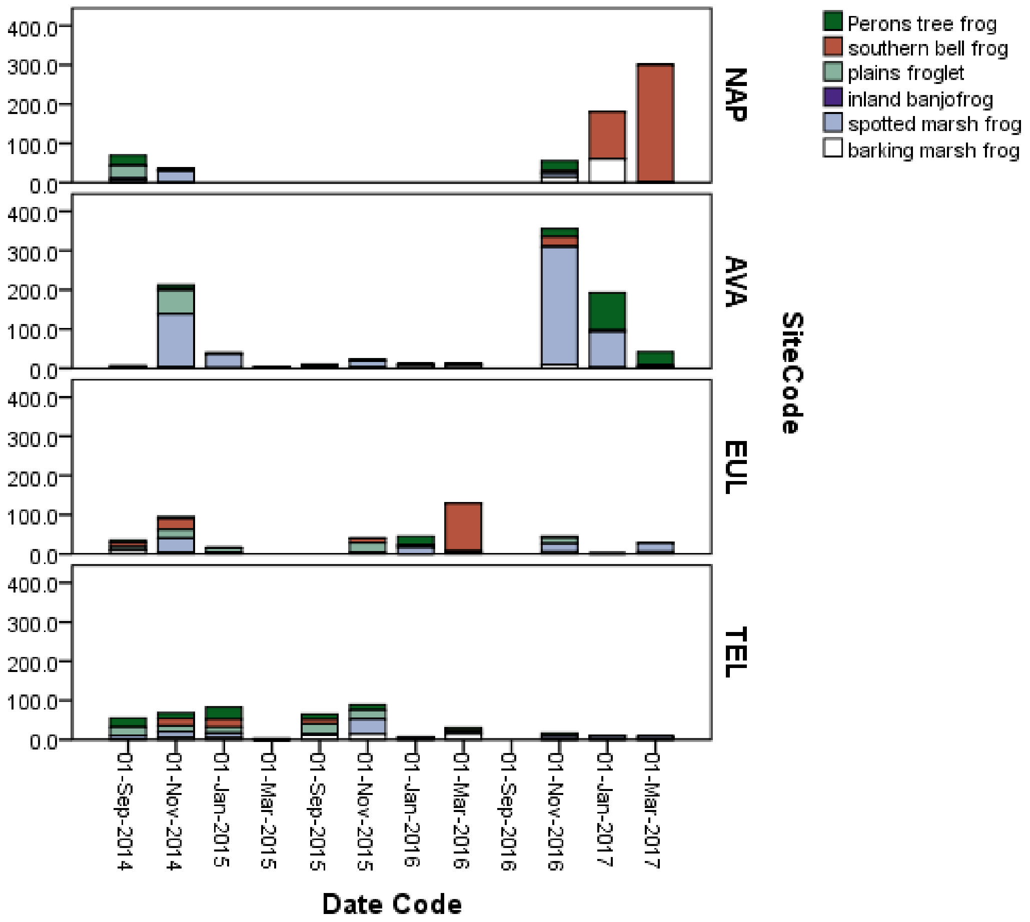


Figure 6-56 Change in abundance of key wetland frog species at the Nimmie-Caria monitoring sites (NAP Nap Nap swamp, AVA Avalon Swamp, EUL Eulimbah Swamp, TEL Telephone Creek).

Mid-Murrumbidgee wetlands

Yarradda and Gooragool Lagoons received environmental water in 2011-12, 2014-15, 2015-16 and have a higher diversity of species in higher abundance than McKenna's and Sunshower Lagoons, which received environmental water in 2011-12. Interestingly McKenna's and Sunshower both supported high abundances of inland banjo frogs, which is a burrowing species and had not been recorded in high abundances at these wetlands in previous years (Figure 6-57)

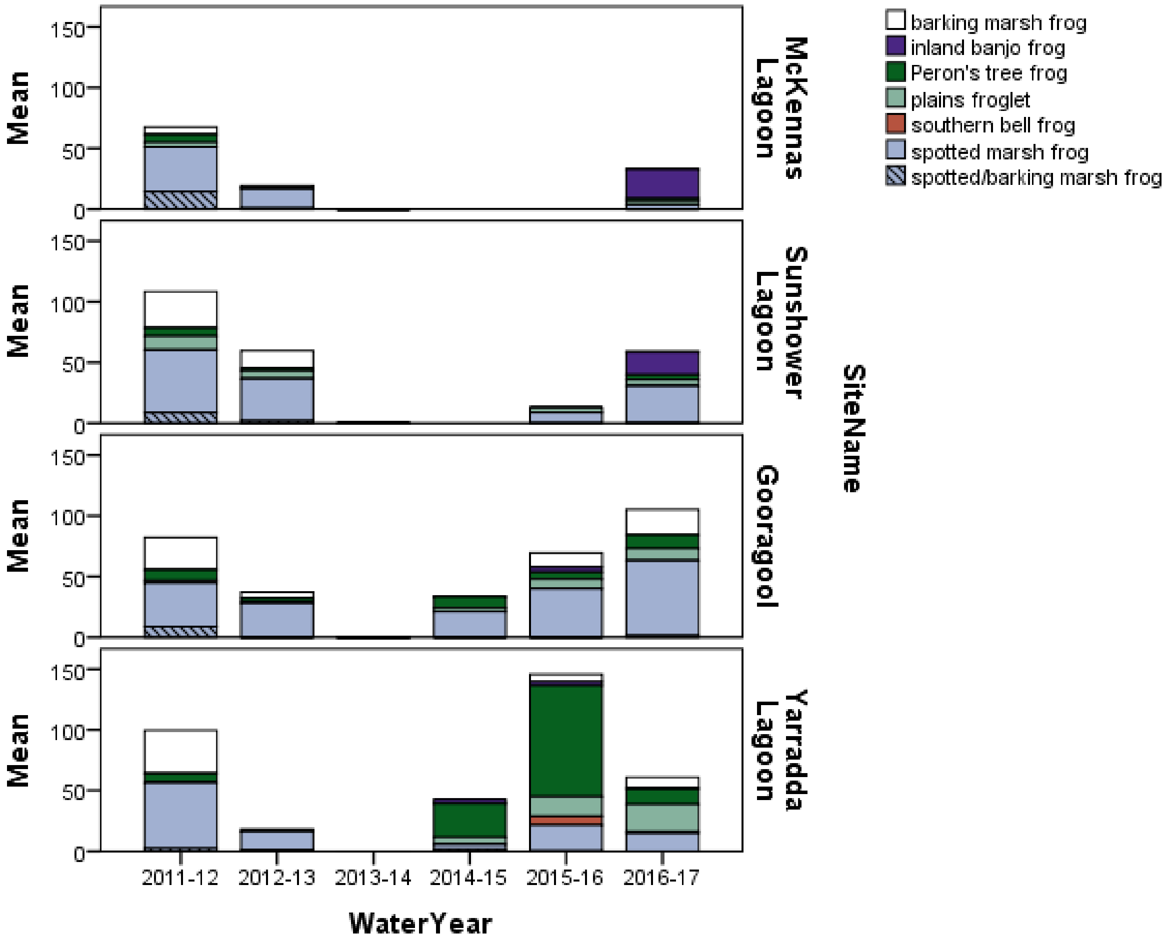


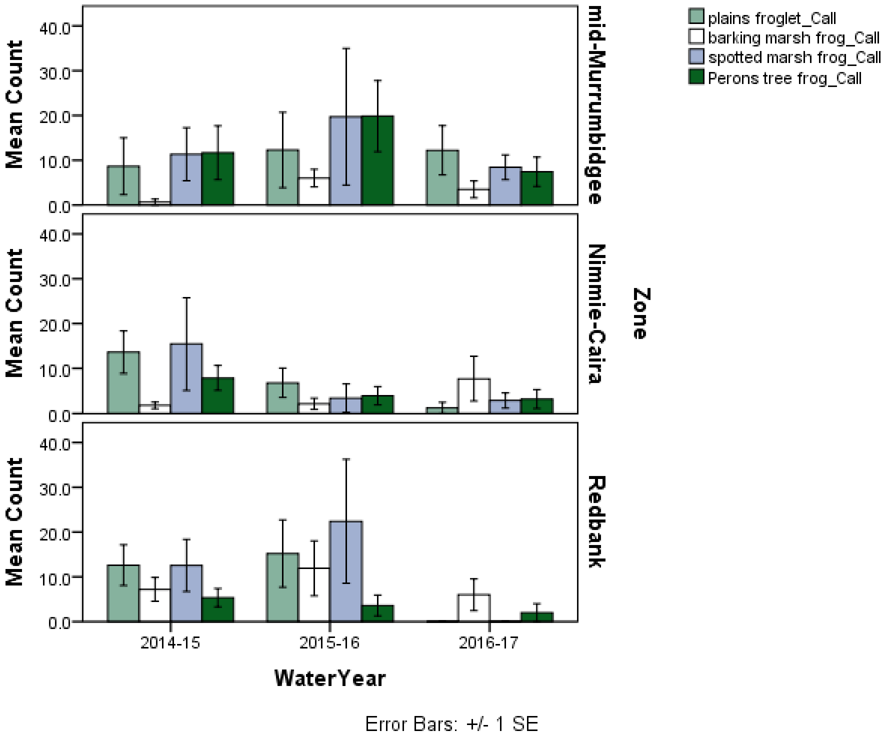
Figure 6-57 Change in abundance of key wetland frog species at the mid-Murrumbidgee monitoring sites since 2010. All wetlands were dry in 2013-14. (Wassens and Amos 2011, Wassens and Spencer 2012, Wassens, Watts et al. 2012, Wassens, Bindokas et al. 2013, Wassens, Spencer et al. 2013, Wassens, Jenkins et al. 2014, Wassens, Thiem et al. 2015, Wassens, Spencer et al. 2016).

What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?

Frog breeding

Limited access to wetlands in the Nimmie-Caria and Redbank system during spring 2016 due to large scale inundation resulted in a reduced survey effort in 2016-17. As a result, calling activity is likely to have been under-represented; nevertheless, calling activity was recorded at all 12 wetlands. As in previous years, plains froglet (*Crinia parinsignifera*), spotted marsh frog (*Limnodynastes tasmaniensis*), barking marsh frog (*L. fletcheri*) and Peron's tree frog (*Litoria peronii)* were widespread, while the southern bell frog (*Litoria raniformis) was restricted to wetlands in the Nimmie-Caria and Yarradda in the mid-Murrumbidgee* and inland banjo frog (*Limnodynastes interioris)* was most abundant in the mid-Murrumbidgee. Overall, there were few differences in calling activity over time, the exception being plains froglet which has declined in the in the Nimmie-Caria and Redbank zones. Plains froglets prefer shallow littoral habitat and so this apparent decline is likely a shift away from core sites as frogs seek more suitable habitat nearby.

In 2016-17, calling activity of the southern bell frog was higher at wetlands receiving Commonwealth environmental water than wetlands receiving only unregulated flows (Kruskal Wallis $t = 6.803$, $p = 0.033$), but this observation may have been influenced by the focus of environmental watering actions at key southern bell frog population sites in the Nimmie-Caria (Figure 6-58). For the remaining species, there was no difference in calling activity at wetlands receiving unregulated flows compared to those receiving environmental water in addition to unregulated flows.



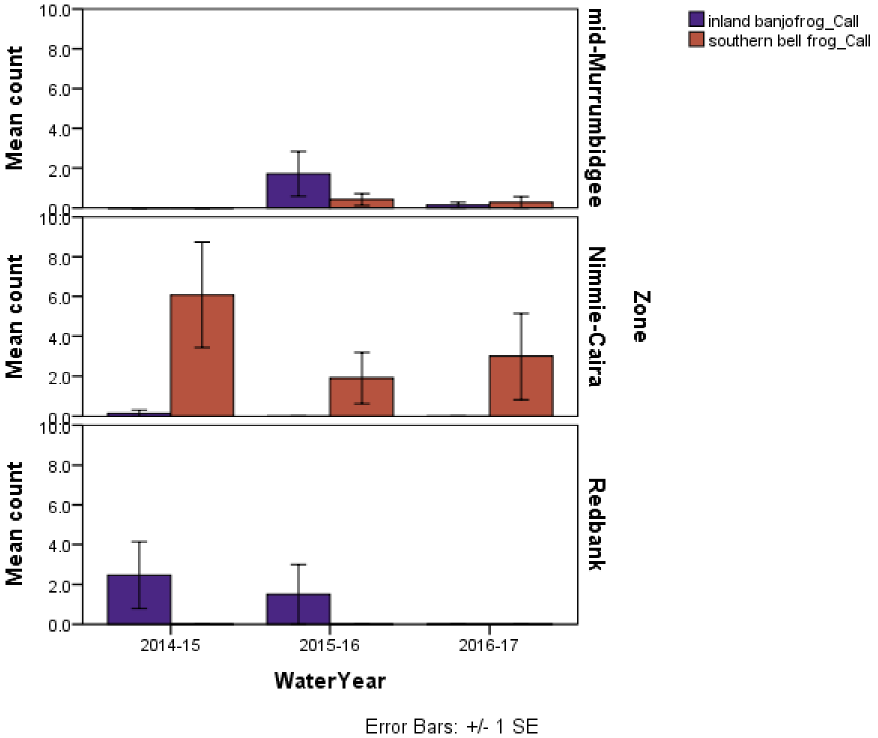


Figure 6-58 Calling activity (count) of resident frog species across each monitoring zone and water year. Note that survey effort in the Nimmie-Caria and Redbank was reduced in 2016-17 due to limited access.

Overall, tadpole Catch Per Unit Effort (CPUE) was higher in 2016-17 than in 2015-16 but comparable with 2014-15 (Figure 6-59). As in previous years there was a high level of variability between species, wetlands and survey occasions, making it difficult to resolve statistically significant patterns. Despite high numbers of adult southern bell frogs being recorded at Nap Nap swamp, no southern bell frog tadpoles were recorded and there was no significant difference in tadpole abundance between wetlands receiving environmental water in combination with unregulated flows and those receiving unregulated flows alone in 2016-17. In addition, inland banjo frog tadpoles were relatively abundant at McKenna's and Sunshower in the mid-Murrumbidgee, which were filled by unregulated flows in 2016-17 but had been dry through 2014-15 and 2015-16.

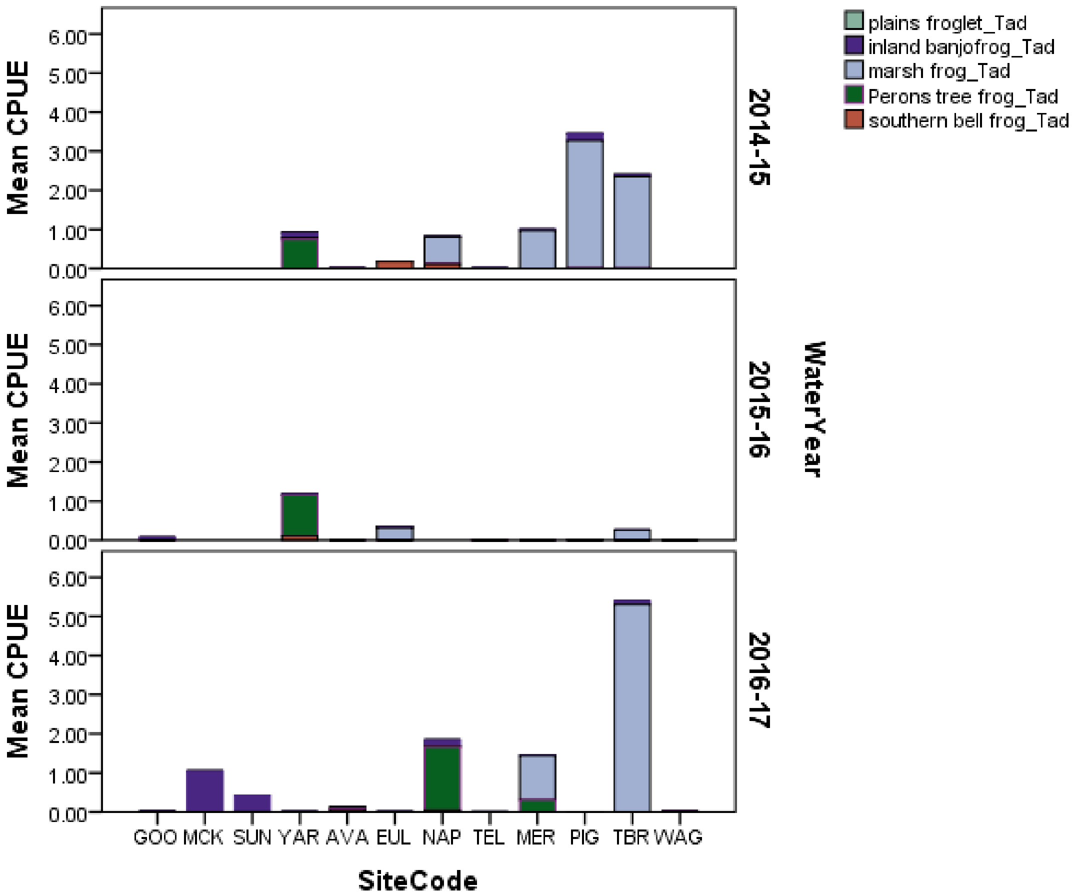


Figure 6-59 Tadpole abundance (mean Catch Per Unit Effort) at each site in the 2014-15 to 2016-17 water years.

When considered across all water years, calling activity was typically high soon after the wetlands had received water and diminished over time, resulting in a significant negative association between calling activity and the number of days since the wetland had received water (Table 6-16). Water quality influenced the calling activity of some species, with the exception of barking marsh frog, for which calling activity decreased with increasing temperature. Calling activity was lower at sites with higher turbidity for plains froglet, spotted marsh frog, inland banjo frog and Peron's tree frog. Turbidity also had a negative impact on the abundance of plains froglet, inland banjo frog and marsh frogs (spotted and barking marsh frog) tadpoles.

Table 6-16 Spearman's rank correlations between water quality and hydrology and calling activity and tadpole CPUE for resident frog species.

	Conductivity	DO %	DO mg/L	pH	turbidity	temp C	Days since last watered	Day since last dry	Water Depth
Calling activity									
Plains froglet	**-0.357** **0.000**	**-0.355** **0.001**	**-0.295** **0.005**	**-0.287** **0.006**	**-0.239** **0.022**	**-0.551** **0.000**	**-0.532** **0.000**	**-0.426** **0.000**	0.076 0.481
barking marsh frog	-0.096 0.364	-0.074 0.489	-0.094 0.377	-0.190 0.070	-0.231 0.027	-0.144 0.180	-0.151 0.164	-0.128 0.236	-0.089 0.412
spotted marsh frog	**-0.217** **0.038**	-0.205 0.053	-0.169 0.109	-0.147 0.161	-0.198 0.059	**-0.398** **0.000**	**-0.484** **0.000**	**-0.354** **0.001**	0.045 0.677
inland banjo frog	-0.055 0.600	-0.176 0.096	-0.156 0.139	-0.198 0.059	-0.278 0.007	-0.267 0.012	-0.193 0.074	**-0.228** **0.033**	-0.144 0.180
Peron's tree frog	-0.183 0.081	-0.170 0.108	-0.185 0.079	-0.106 0.314	**-0.311** **0.003**	-0.233 0.029	**-0.381** **0.000**	**-0.285** **0.007**	0.049 0.654
southern bell frog	-0.011 0.917	-0.038 0.720	-0.053 0.615	0.111 0.294	-0.051 0.627	**-0.265** **0.013**	-0.205 0.056	-0.056 0.606	0.129 0.232
Tadpoles									
plains froglet	**-0.218** **0.035**	-0.109 0.299	-0.081 0.438	-0.116 0.264	**-0.236** **0.022**	0.030 0.780	**-0.231** **0.029**	**-0.341** **0.001**	0.001 0.994
inland banjo frog	-0.033 0.752	-0.022 0.832	-0.061 0.560	-0.052 0.621	**-0.309** **0.002**	-0.056 0.599	0.049 0.645	-0.188 0.078	-0.107 0.315
marsh frog	-0.205 0.048	-0.188 0.073	-0.199 0.056	-.209 0.044	**-0.350** **0.001**	-0.086 0.420	-0.028 0.795	-0.140 0.190	0.022 0.839
Peron's tree frog	-0.083 0.427	-0.094 0.375	-0.122 0.244	-0.052 0.616	-0.196 0.059	0.012 0.913	-0.001 0.996	-0.080 0.453	0.128 0.230
southern bell frog	0.159 0.126	-0.105 0.321	-0.090 0.390	0.079 0.449	0.039 0.706	-0.084 0.432	-0.039 0.717	0.015 0.887	-0.009 0.930

Turtle breeding

The majority of Macquarie turtles collected in 2016-17 were hatchlings or juveniles, but there were insufficient numbers collected in 2014-15 and 2015-16 to statistically compare size distributions over the three years (Figure 6-60). In 2014-15, there were small numbers of hatchling eastern-long neck turtles, but no hatchlings were detected in 2015-16 or 2016-17. The size distribution did not change between 2016-17 and 2014-16 for broad shell turtle (Mann-Whitney U test, t= 0.542, p = 0.619) or long-necked turtle (Mann-Whitney U test, t = 1.123, p = 0.216).

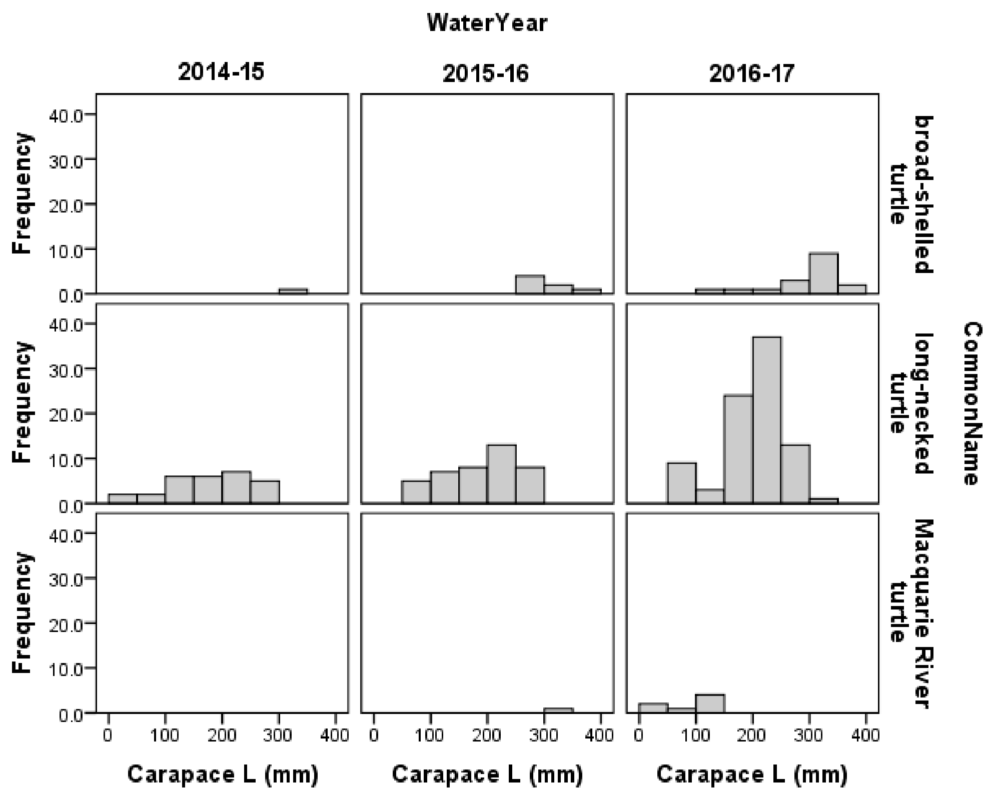


Figure 6-60 Size frequency of turtle catch between 2014 and 2017

What did Commonwealth environmental water contribute to the maintenance of refuge habitats?

Persistent off channel waterbodies are import for the long-term management of frog and turtle populations and serve an import role in maintaining populations during dry periods. Environmental watering actions that focussed on maintaining refuge habitats were the Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) watering in 2016-17 (Nap Nap Swamp) and watering actions targeting Yarradda and Wagourah Lagoon between 2014 and 2016 (Wassens, Spencer et al. 2016). In 2016-17, the Nimmie-Caria to South Yanga watering action was complimented by large scale unregulated inundation, which was associated with high abundance of southern bell frog at Nap Nap Swamp. With respect to turtle populations, the key refuge sites of Gooragool and Yarradda Lagoons (in the mid-Murrumbidgee), Telephone Creek (in the Nimmie-Caria) and Wagourah Lagoon (in the Redbank system) were maintained with environmental water in 2014-15 and 2015-16 and filled with unregulated flows in 2016-17 (Figure 6-61). The combination of these watering actions was associated with higher diversity of turtle populations, with Gooragool, Yarradda and Wagourah Lagoons and Telephone Creek all supporting the broad-shelled turtles in 2016-17 as well as eastern long-necked turtles. In addition, the number of turtles recorded at Yarradda Lagoon indicated that this wetland now supports all three turtle species, with Macquarie River turtles observed in 2016-17.

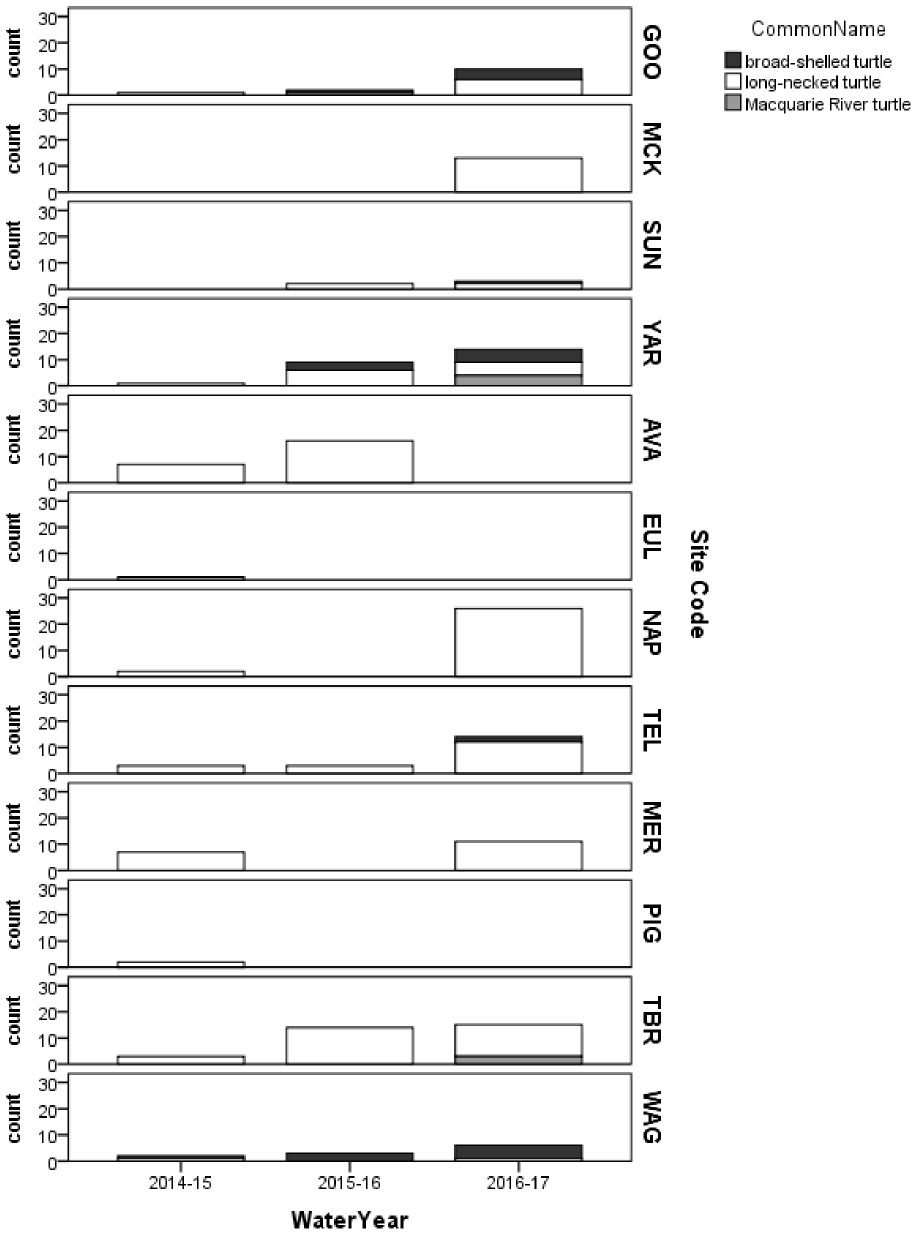


Figure 6-61 Turtle counts across the three water years at each monitoring location.

Discussion

Unlike previous years, where Commonwealth and state environmental water was the only source of water in floodplain wetlands, significant unregulated flows occurred in 2016-17 inundating all of the twelve monitoring sites as well as significant areas of the floodplain. In addition to the unregulated flows, five Commonwealth environmental watering actions related to frogs and turtles were carried out; four with the primary objective of supporting waterbird breeding and one with the primary objective of supporting frog and turtle populations and their habitats (Table 6-17). There was clear evidence the Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) supported frog populations and created opportunities for frog breeding. Most importantly, southern bell frogs (Vulnerable EPBC Act) at Nap Nap Swamp appeared to have benefited from a combination of a drying phase in 2015 followed by extended inundation. Evidence supporting positive outcomes for frogs from the remaining watering actions, which were primarily designed for waterbird breeding, is less clear with limited evidence of significant increases in frog populations. However, this result needs to be interpreted with caution, because limited access to monitoring sites in the Nimmie-Caria and Redbank during spring meant that spring breeding activities were probably missed, this might also explain why we failed to detect southern bell frogs at Nap Nap swamp as surveys could not be carried out during the main breeding period. In addition, large areas of available habitat created a number of alternative breeding locations for frogs; for example, large numbers of southern bell frogs were reported calling from inundated cropping bays immediately adjacent to Avalon swamp, suggesting that they had moved out of the wetland to take advantage of newly created habitats. While numbers were lower at Avalon swamp than in previous years, the ability of resident populations to move around the landscape to take advantage of temporary habitats demonstrates the success of recent Commonwealth environmental watering strategies aimed at maintaining refuge habitats e.g. (Wassens, Spencer et al. 2016). Evidence for successful maintenance of refuge habitats was also noted for turtles. Maintenance of an area of persistent water at Yarradda and Gooragool Lagoons, Telephone Creek and Wagourah Lagoon was associated with an increase in species richness and contributed to the support of the less common broad-shell and Macquarie River turtles.

Barking marsh frogs and spotted marsh frogs continue to dominate the Redbank system, although there have been no statistically significant changes in abundance over the past 3 years. In the mid-Murrumbidgee, frog and tadpole abundance were lower in environmental watering sites, particularly in Yarradda Lagoon in 2016-17 compared to 2015-16. One possible cause for declining tadpole abundance is the introduction of common carp, which occurred during the unregulated flows in spring 2016. While studies are limited on the relationship between common carp and tadpoles, there is a growing body of evidence that high carp numbers suppress the breeding response of frogs (Kloskowski 2009, Kloskowski 2011, Kaemingk, Jolley et al. 2017) and may be a factor influencing outcomes of Commonwealth environmental watering actions.

Table 6-17 Summary of watering actions with outcomes targeting frog and turtle habitat and responses

Target asset	Expected outcomes	LTIM sites receiving water	Outcomes
Yanga National Park: waterbird breeding support	supporting habitat for wetland vertebrates	Two Bridges	Large numbers of barking marsh frog and spotted marsh frog tadpoles recorded. Two Bridges swamp supported eastern long necked turtles and hatchling Macquarie turtles
Nimmie-Caira: Eulimbah waterbird breeding support Nimmie-Caira: Telephone Bank waterbird breeding support	supporting habitat for wetland vertebrates	Eulimbah Telephone Creek	Southern bell frogs recorded at Eulimbah and Telephone Creek. Broad shell and eastern long necked turtles recorded.
Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga Nimmie-Caira: Nap Nap waterbird breeding support	Maintain wetland and floodplain condition and provide suitable habitat for a range of waterbird, fish and frog species, including southern bell frog (EPBC vulnerable)".	Nap Nap	Very significant number of southern bell frogs recorded with over 300 individuals recorded in March 2017 suggesting successful recruitment occurred within and around Nap Nap swamp.

The management of frog and turtle populations through the Murrumbidgee floodplain wetlands requires a mix of long-term watering strategies to maintain key refuge habitats during dry years, and the provision of spring flows to support breeding. With respect to the southern bell frog, large scale inundation is critical (Bino, Wassens et al. 2018) and watering actions that target larger continuous sections of the floodplain (such as the Nimmie-Caria flood ways to Yanga national Park) are likely to be more successful in supporting Southern bell frog then smaller disconnected flows spread over a larger area.

6.11 Wetland fish

Prepared by Ben Wolfenden (CSU), Skye Wassens (CSU) and Jason Thiem (DPI Fisheries)

Introduction

Native fish communities in the Murrumbidgee catchment are severely degraded, exhibiting declines in abundance, distribution and species richness (Gilligan 2005). In particular small-bodied floodplain species such as the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis agassizii*) were historically abundant throughout Murrumbidgee River wetland habitats (Anderson 1915, Cadwallader 1977) but are now considered locally extinct from the mid and lower Murrumbidgee (Gilligan 2005). River regulation has significantly contributed to native fish declines in the Murrumbidgee Catchment. Reductions in the frequency and duration of small-medium natural flow events prevent regular connections between the river and off-channel habitats (Arthington and Pusey 2003).

Five watering actions delivered during 2016-17 were monitored as part of the LTIM project that have objectives relating to native fish communities in wetlands. The first of these was delivered to the Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake), seeking to maintain wetland aquatic communities, including wetland fish. This action inundated several wetlands of the Nimmie-Caira and Redbank zones in August and early part of September 2016, but was paused and later cancelled due to widespread rainfall in September and October. After the subsequent unregulated, overbank flow event that inundated all 12 LTIM wetlands, environmental water was delivered to the Nimmie-Caria and Redbank. Watering actions that influenced the hydrological regime of LTIM monitoring sites were:

- Nimmie-Caira: Eulimbah waterbird breeding support (Eulimbah Swamp)
- Nimmie-Caira: Telephone Bank waterbird breeding support (Telephone Creek)
- Nimmie-Caira: Nap Nap waterbird breeding support (Nap Nap Summer)

- Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) (Nap Nap autumn)
- Yanga National Park: waterbird support (Two Bridges Swamp)

Here, we evaluate the environmental watering actions targeting wetland fish communities under two overarching criteria:

- What did Commonwealth environmental water contribute to native fish populations and native fish diversity?
- What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?

Methods

Since 2014, wetland fish have been monitored across the 12 LTIM surveyed wetlands four times per year (September, November, January and March). Detailed survey methodology is contained in Wassens, Jenkins et al. (2014). Wetland fish are surveyed using a combination of large (n=2) and small (n = 2) fyke nets which are set overnight. The fish Catch-Per-Unit Effort (CPUE) is based on the number of fish collected per hour, with this value adjusted for differences in the width of the net wings and water depth where the net is set (nets can only be set when water depths are above 30cm). In 2016-17 all sites were wet, although not all sites in the Nimmie-Caira and Redbank zones could be sampled for fish in September or November because access to some sites was restricted by flooding.

Data analysis

We tested for differences in total community composition, and the species richness and abundance (CPUE) of native fish between monitoring zones (n=3) and sample occasions (n=4) during 2016-17 using a two way permuation analysis of variance (PERMANOVA, Anderson, Gorley et al. (2008). Because some sites were inaccessible on some occasions, PERMANOVA tests were run as unbalanced models. Community data were log (x+1) transformed prior to analysis to reduce the effect of abundant species. Resemblance matrices were calculated using a Bray Curtis distance measure. Post-hoc tests were used to further isolate significant terms. Results were considered significant at P<0.05. SIMPER was used to identify species contributing the most to patterns in community data. These analyses were carried out using Primer 6 with PERMANOVA (Primer-E Ltd.). The length-frequency distribution of the six most abundant fish species was compared among sample occasions within each wetland zone, pooling length data for each speceis across all sites sampled within each zone. Comparisons were made using a boot-strapped two-sample Kolmogorov-Smirnov test (Ogle 2015). Differences were considered significant at p<0.05. P-values were corrected for multiple comparisons. Length-frequency analyses were carried out using the FSA package in R (Ogle 2015).

Results

What did Commonwealth environmental water contribute to native fish populations and native fish diversity?

Eight native and six exotic species were captured across 12 LTIM surveyed wetland sites that contained water between September 2016 and March 2017. Flathead gudgeon and silver perch were both collected at Yarradda Lagoon, appearing for the first time in the LTIM wetland data, increasing the number of native fish species by one (Murray cod were not collected at any wetland in 2016-17). Golden perch were found consistently in the mid-Murrumbidgee wetlands, though in low numbers. Exotic species also increased, with redfin perch captured at Yarradda and McKenna's Lagoons.

Carp gudgeon were by far the most abundant (based on CPUE) native species occurring across all three monitoring zones (Figure 6-62), while bony bream and rainbowfish were recorded in relatively high numbers at some sites (Figure 6-63 and Figure 6-64). Overall, patterns of fish CPUE were highly variable across space and time. Native fish abundance did not differ among sites (df = 2, Pseudo-F=0.886, p(perm)=0.506) or sample occasions (df = 3, Pseudo-F=0.678, p(perm)=0. 766). Native fish species richness also did not differ among sites (df = 2, Pseudo-F=1.552, p(perm)=0.195) or sample occasions (df = 3, Pseudo-F=0.837, p(perm)=0.581).

Community analysis did show significant differences among zones (df = 2, Pseudo-F=2.559, p(perm)=0.013) and sample occasions (df = 2, Pseudo-F=6.255, p(perm)=0.001; Figure 6-65). Differences among zones were attributed to differences between the Nimmie-Caira / Redbank zones and the mid-Murrumbidgee (p(perm)=0.013 and 0.036, respectively). Community composition did not differ between the Nimmie-Caira and Redbank zones (p(perm)=0.127). SIMPER results show these observed patterns were driven by combinations of highly abundant species - common carp, gambusia and carp gudgeon.

As expected, exotic fish species were widespread through the monitoring sites, with gambusia, common carp, goldfish and oriental weatherloach (*Misgurnus anguillicaudatus*) the most commonly recorded exotic species (Figure 6-66). The total abundance of exotic fish differed significantly across time (df = 4, Pseudo-F=17.489, p(perm)=0.001) but not among Zones (df = 2, Pseudo-F=1.373, p(perm)=0.240), reflecting fewer exotic fish in September than other sample months. We note that the design is imbalanced, it is not known if greater numbers of exotic fish would have been recorded in the Nimmie-Caria and Redbank zones had they been sampled in September.

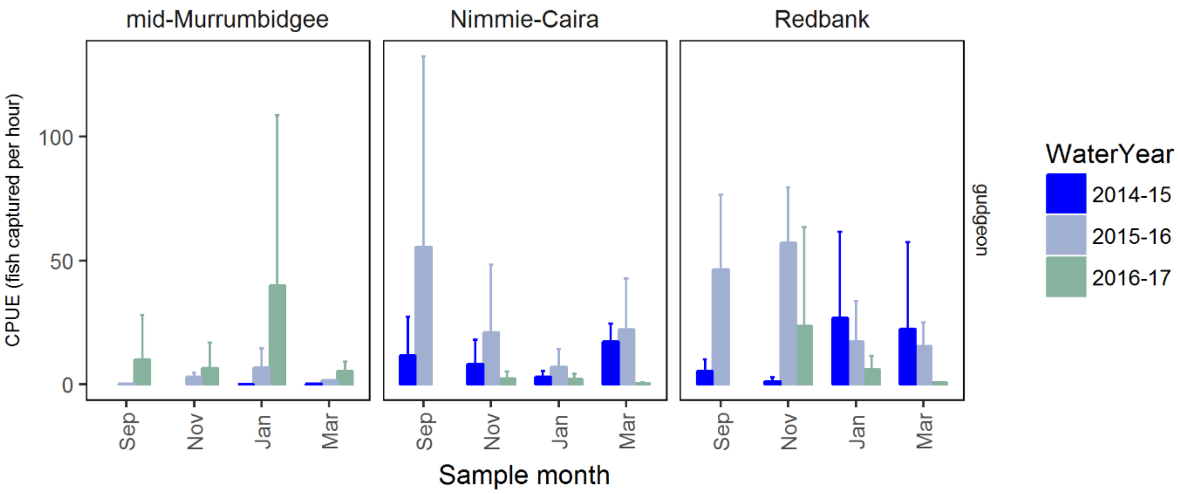


Figure 6-62 Mean catch per unit effort (fish per net hour) (CPUE) (+ SE) of carp gudgeon over the four sample periods in all years.

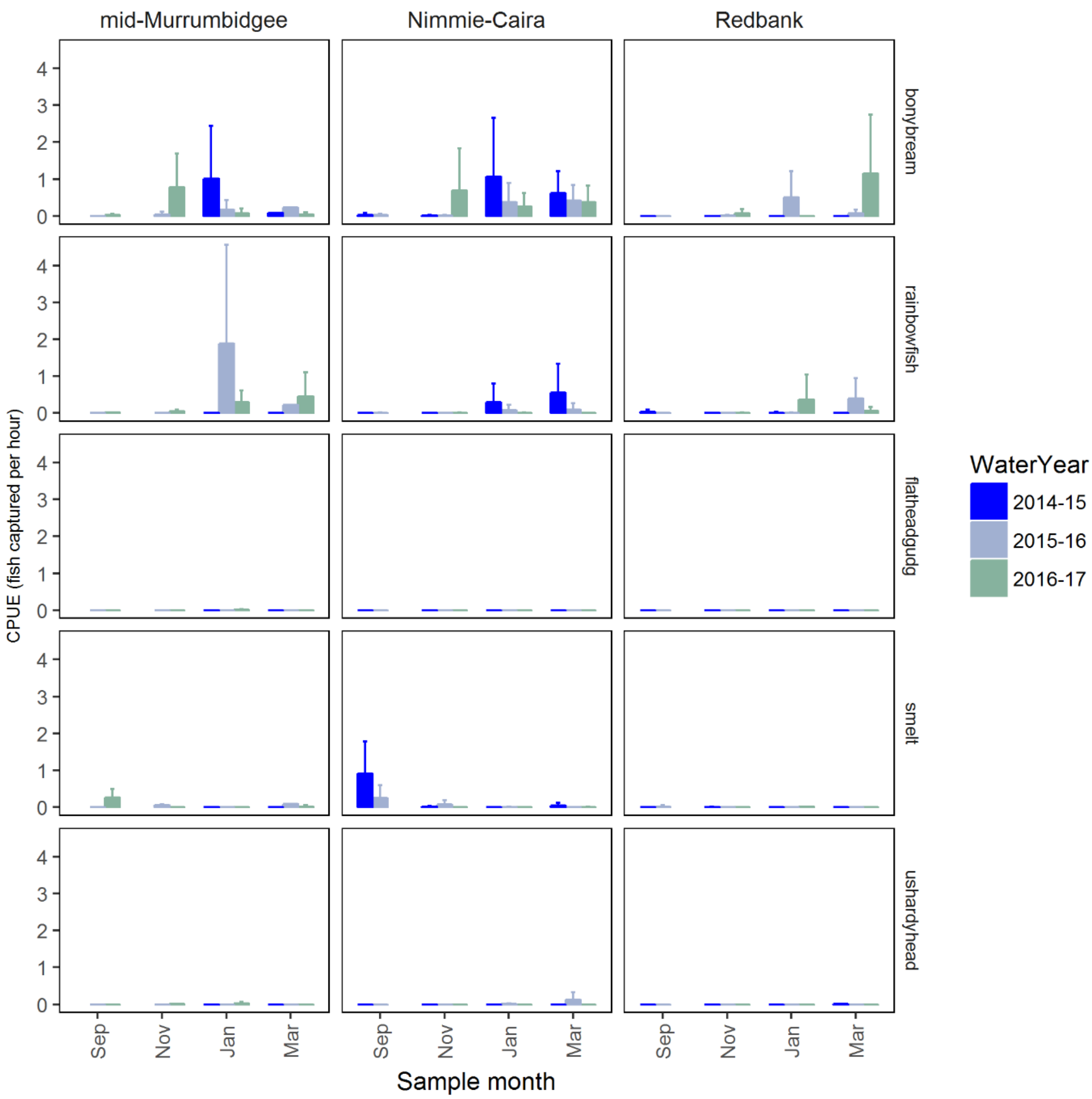


Figure 6-63(b) Mean catch per unit effort (fish per net hour) (CPUE) (+ SE) of small-bodied native fish species excluding carp gudgeon over the four sample periods in all years.

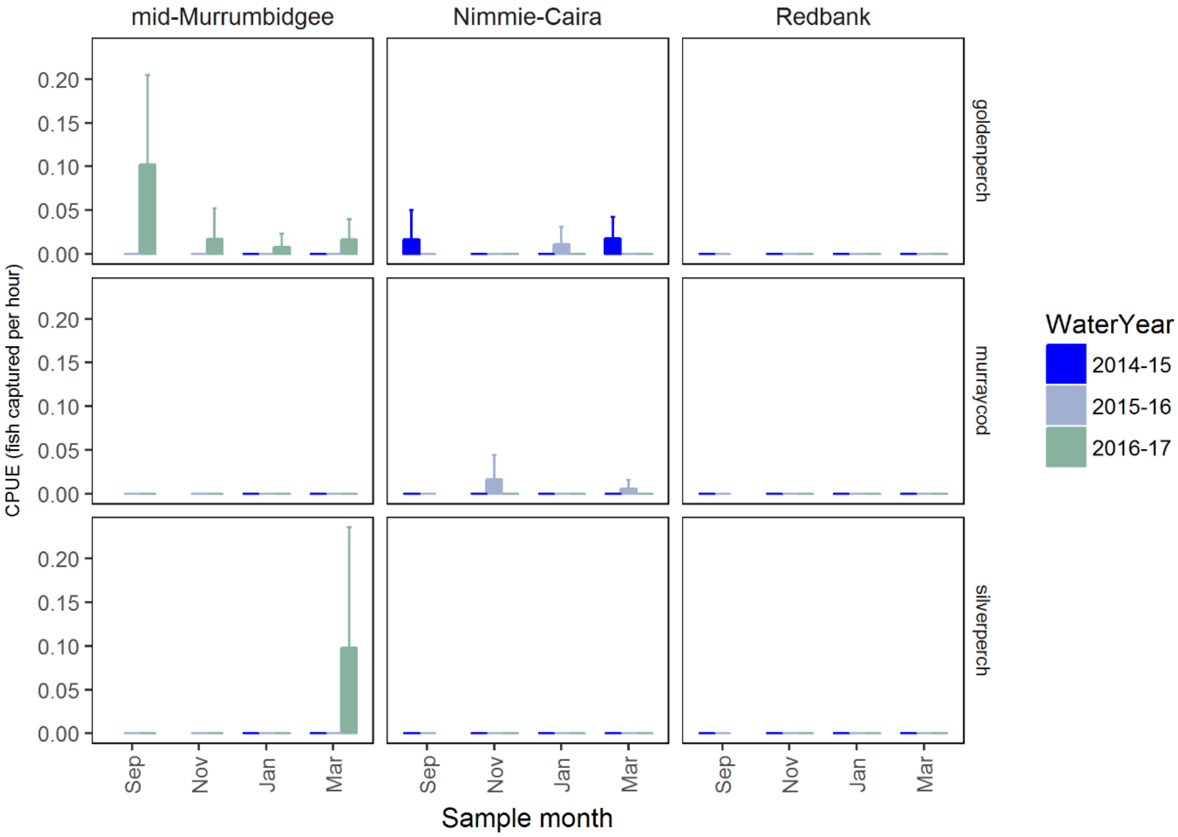


Figure 6-64 Mean catch per unit effort (fish per net hour) (CPUE) (+ SE) of large and medium-bodied native fish species excluding carp gudgeon over the four sample periods in all years.

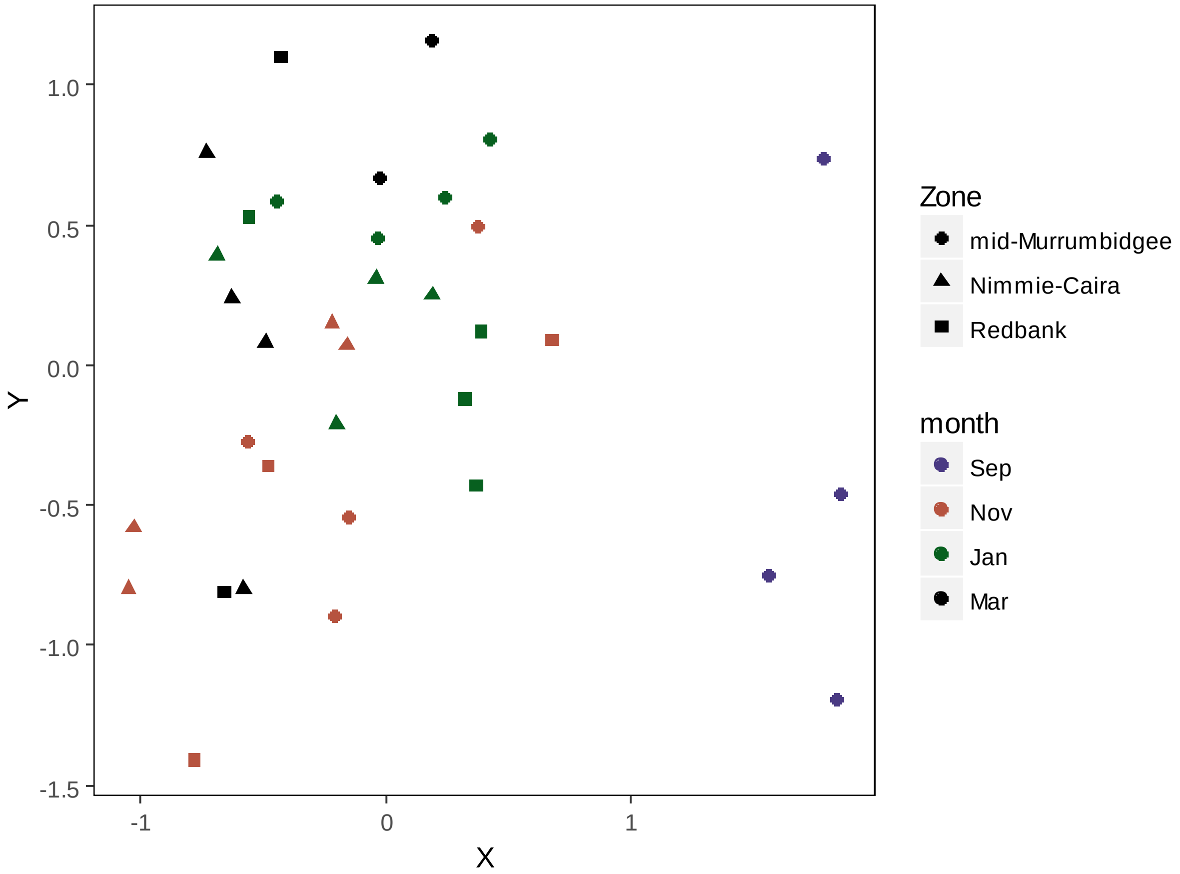


Figure 6-65 A non-metric multidimensional scaling plot of fish community composition for the Murrumbidgee Wetlands in 2016-17. Stress = 0.18.

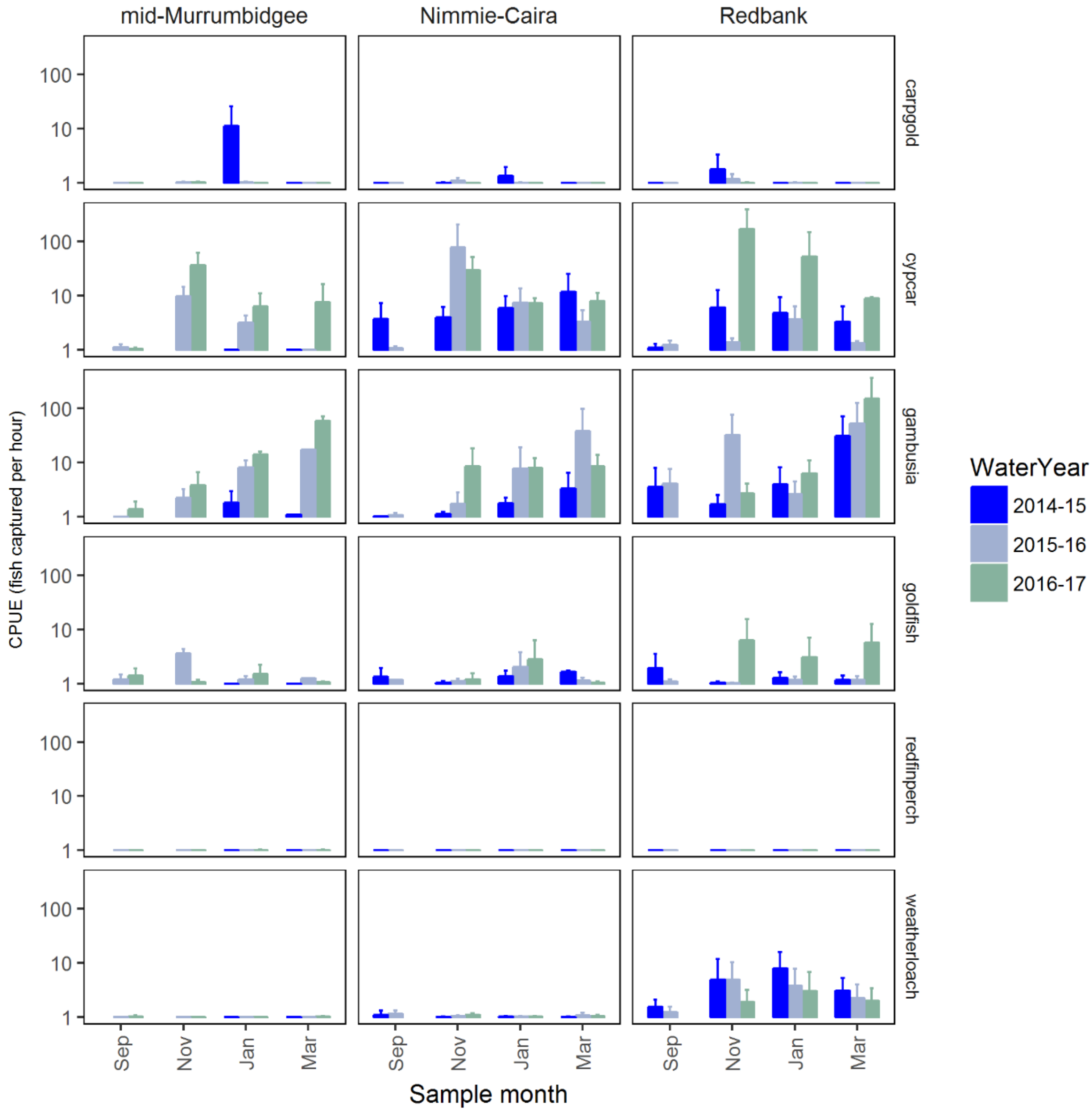


Figure 6-66 Mean catch per unit effort (CPUE) (±SE) of exotic fish species over the four sample periods. Note the log10 scale.

What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?

Resilience is maintained by supporting fish recruitment and survival across multiple seasons. Size distributions can be used to describe the age distribution of the populations, with higher proportions of smaller individuals indicating the presence of young-of-year. For most species we expect to observe higher proportions of juveniles early in the season with the size distribution tending towards larger individuals as fish grow through summer, but this can be influenced by water temperatures and the timing of inundation.

Overall, KS tests found significant differences among most sample occasions for all species (Table 6-19). The size structure of bony bream (Figure 6-67), carp gudgeon (Figure 6-71) and gambusia (Figure 6-72) was skewed toward larger individuals during the November sample occasion, dominated again by smaller individuals during March. For weatherloach (Figure 6-70) and carp (Figure 6-68), larger fish were instead seen during either of the latter two sample occasions. Some important exceptions include a higher proportion of larger bony bream and gambusia in the mid-Murrumbidgee during January, where in the Nimmie-Caira and Redbank zones larger individuals of these species were observed during November, suggesting that breeding may have taken place within the wetlands later in the year.

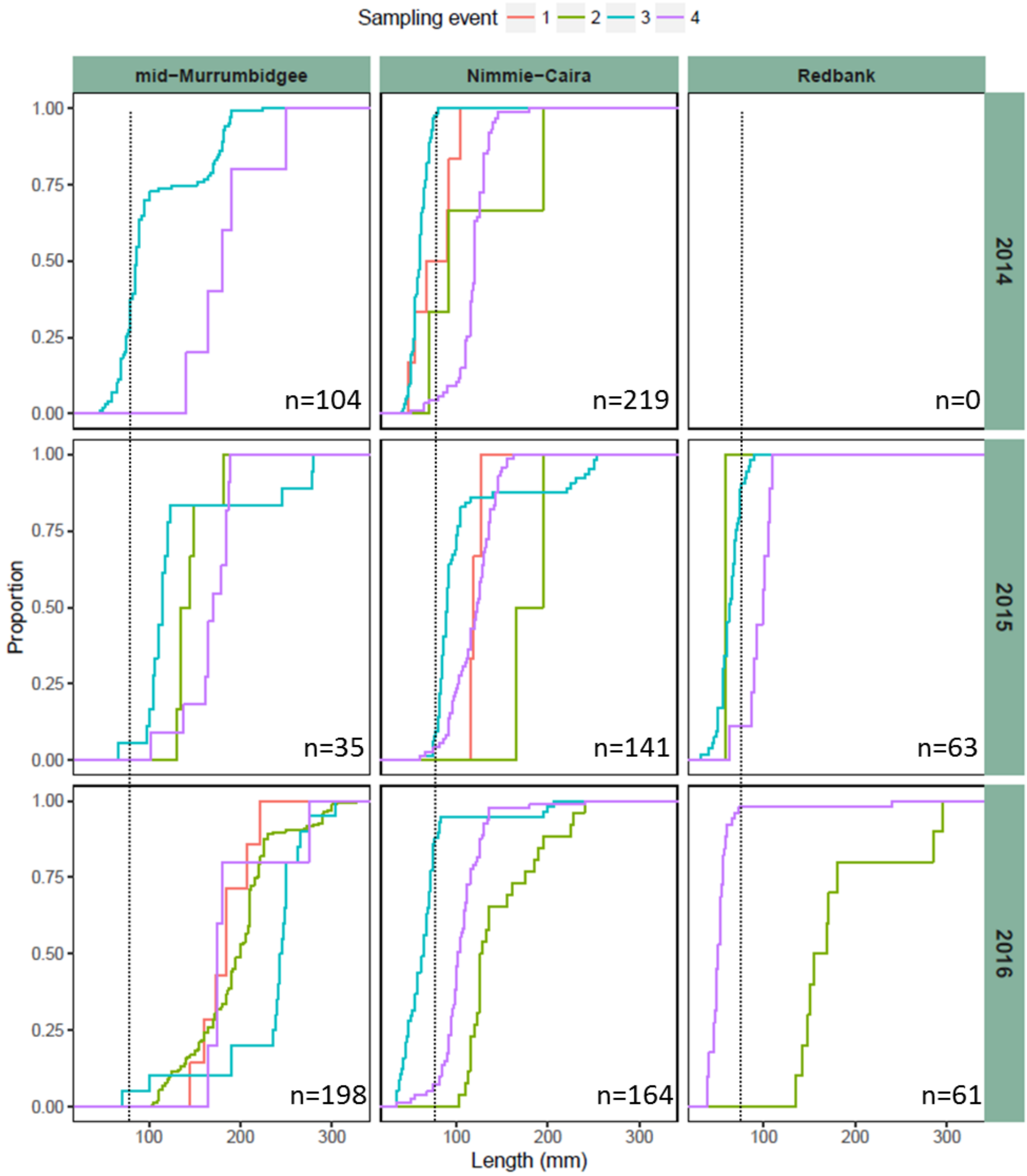


Figure 6-67 Length-frequency distribution diagrams showing differences in the age structure of bony bream captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

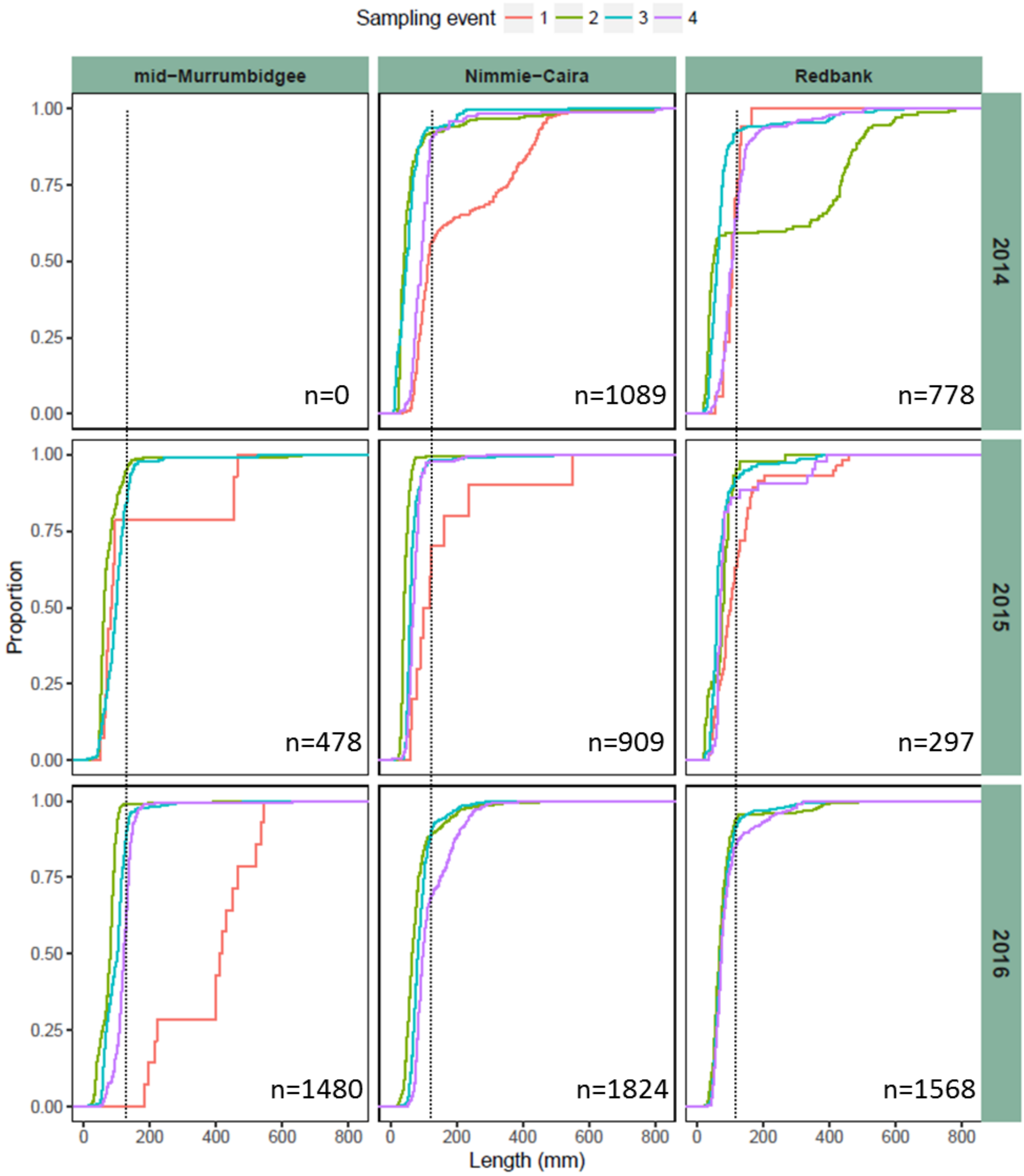


Figure 6-68 Length-frequency distribution diagrams showing differences in the age structure of common carp captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

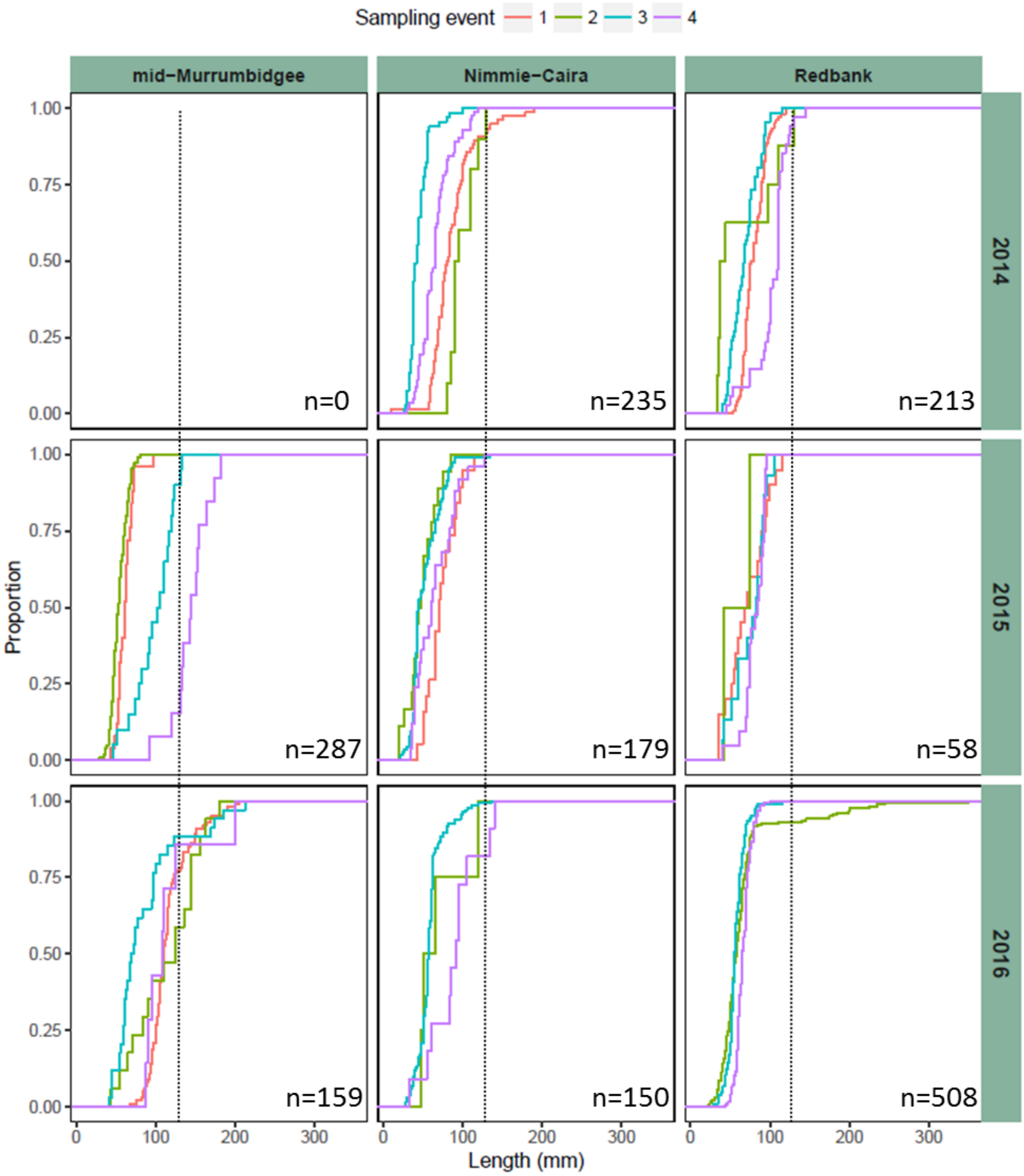


Figure 6-69 Length-frequency distribution diagrams showing differences in the age structure of goldfish captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

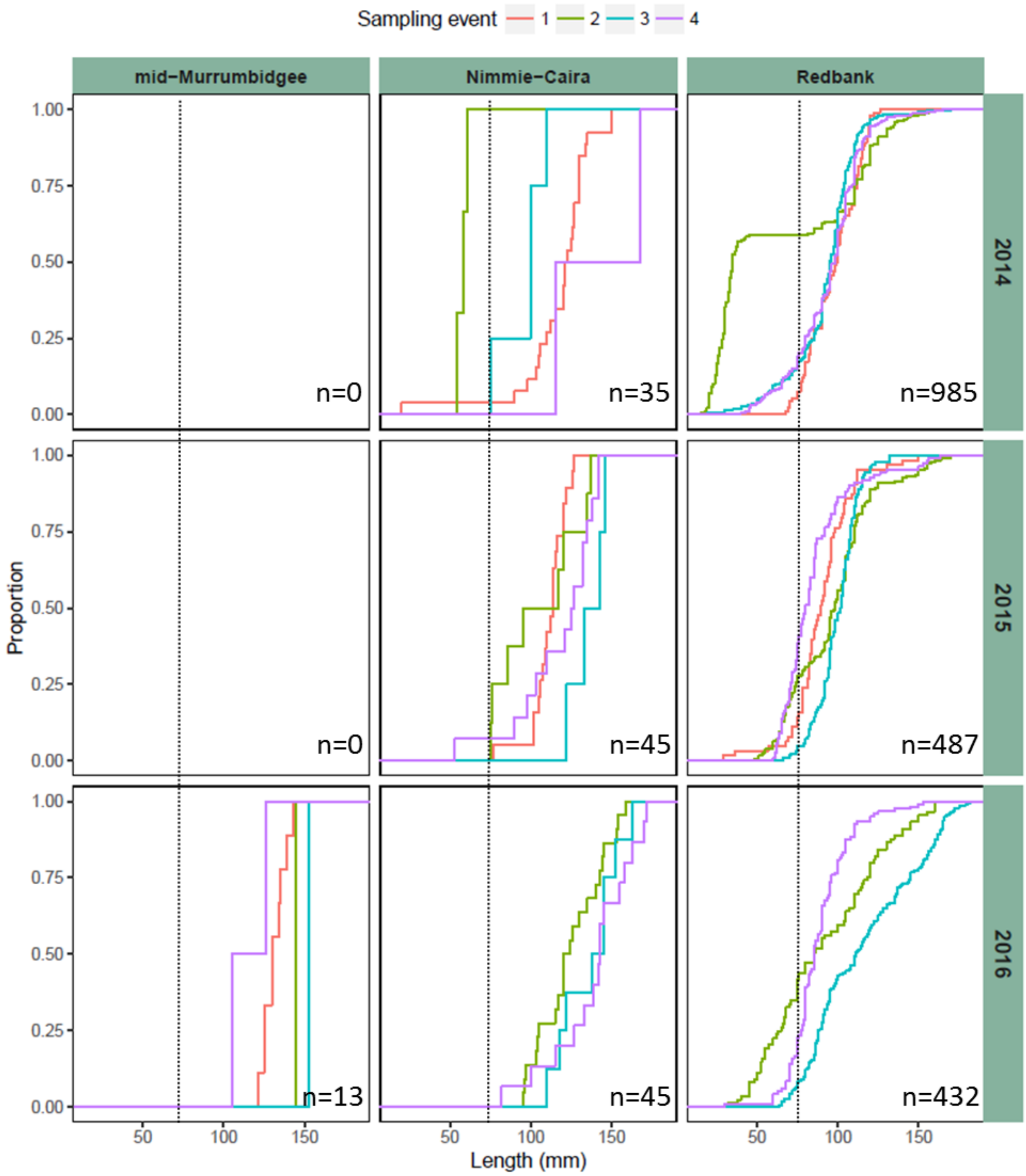


Figure 6-70 Length-frequency distribution diagrams showing differences in the age structure of oriental weatherloach captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

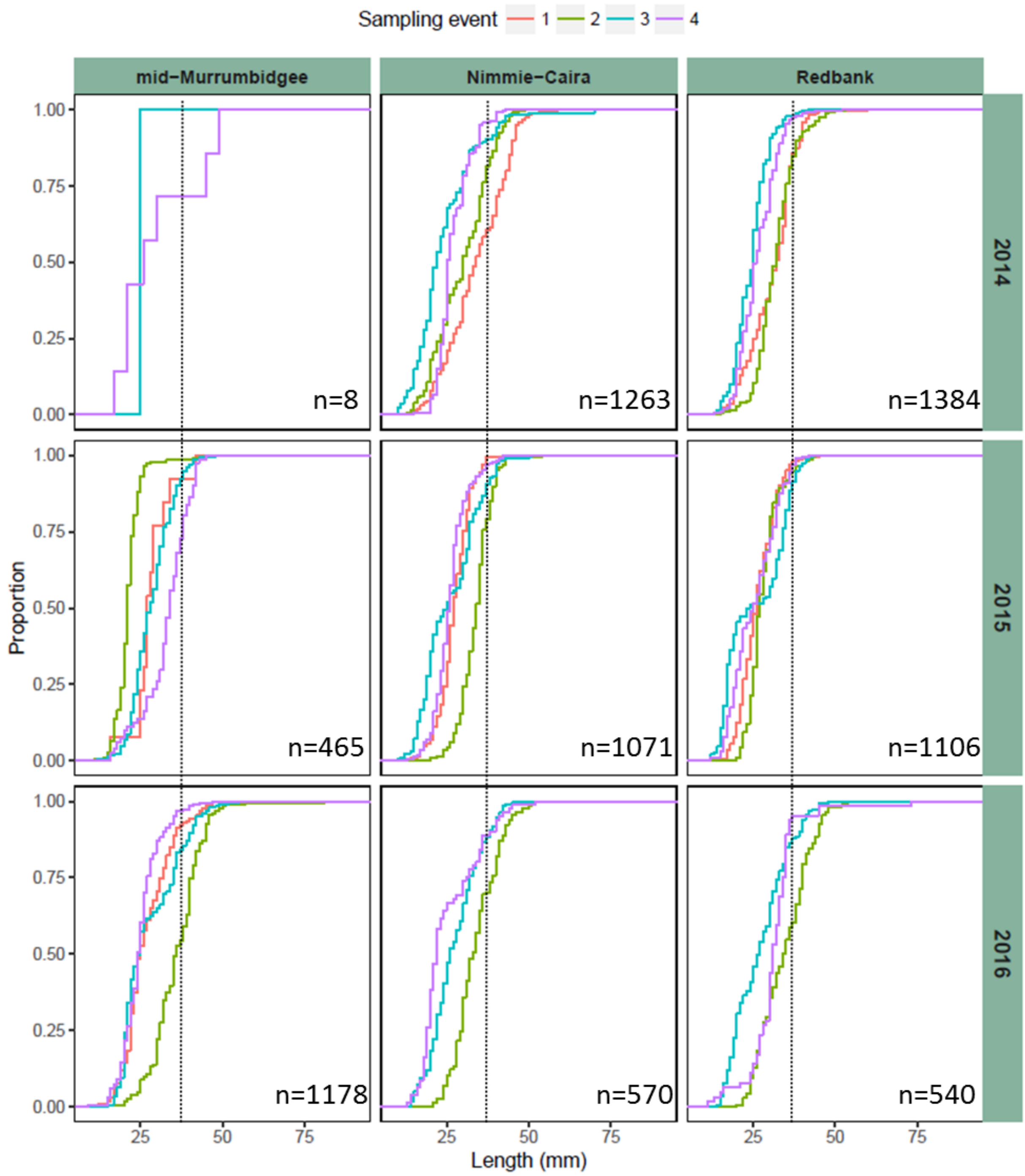


Figure 6-71 Length-frequency distribution diagrams showing differences in the age structure of carp gudgeon captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

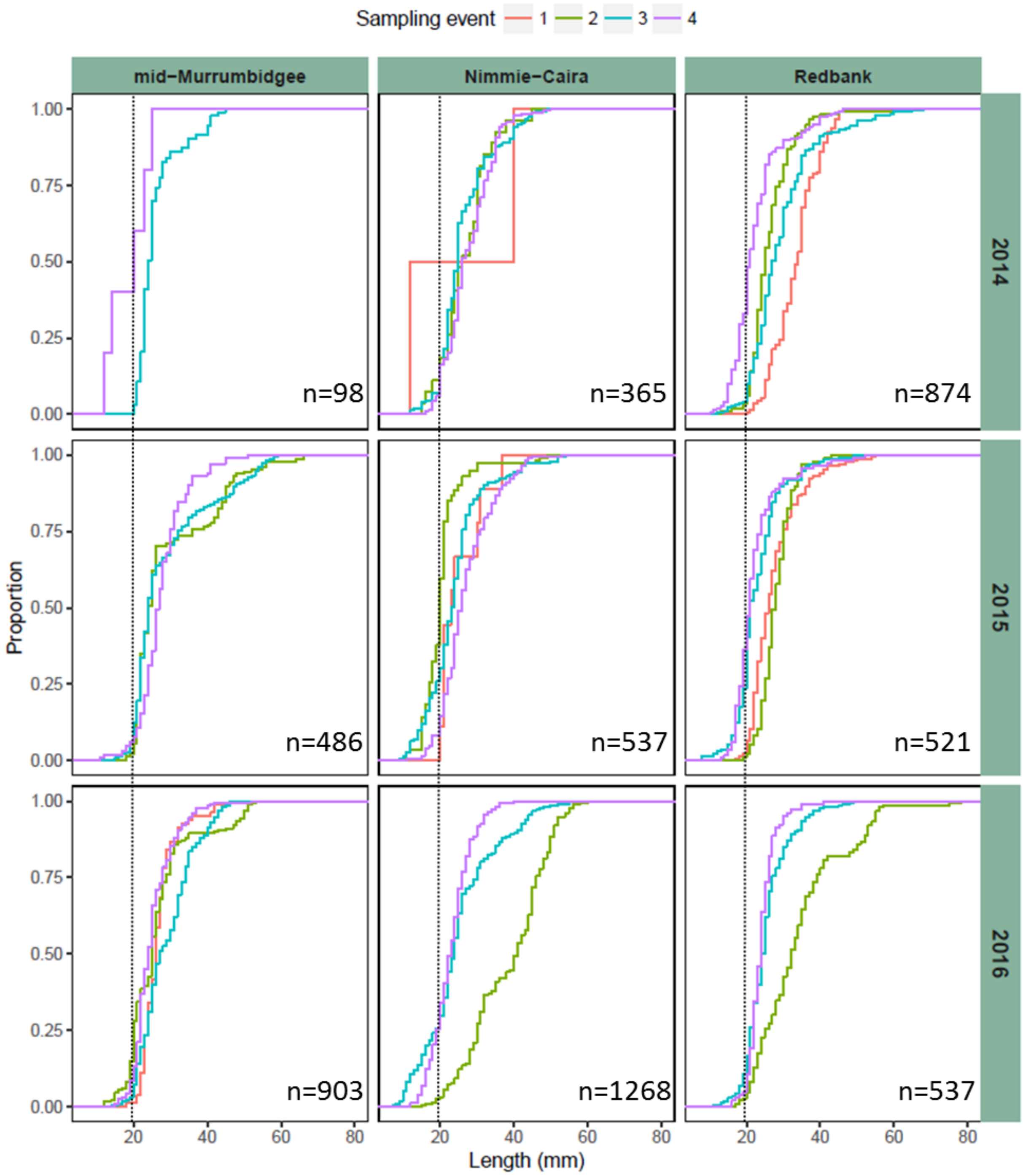


Figure 6-72 Length-frequency distribution diagrams showing differences in the age structure of eastern gambusia captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

Table 6-18 Length-frequency distribution Kolmogorov-Smirnov D-test statistics for the six most abundant fish species samples in 2016-17. Results compare distributions among sample occasions within zones. The number of samples available for each sample month is indicated in *italic font*. NS indicated where too few data were available for a comparison. Significance (grey shading) is indicated * = p<0.05, ** = p<0.01, ***=p<0.001.

Zone	Month	Species					
		Bony bream	Carp gudgeon	Gambusia	Common carp	Weatherloach	goldfish
Mid-Murrumbidgee	Sep/Nov	0.347 *(7/166)*	0.538*** *(309/318)*	0.311*** *(309/318)*	0.989*** *(14/743)*	NS *(9/1)*	0.292 *(101/17)*
	Sep/Jan	0.800** *(7/20)*	0.154*** *(309/337)*	0.154*** *(309/337)*	0.981*** *(14/496)*	NS *(9/1)*	0.611*** *(101/29)*
	Sep/Mar	0.371 *(7/5)*	0.167** *(309/212)*	0.167** *(309/212)*	0.989*** *(14/175)*	NS *(9/2)*	0.240 *(101/7)*
	Nov/Jan	0.698*** *(166/20)*	0.538*** *(318/337)*	0.538*** *(318/337)*	0.398*** *(743/496)*	NS *(1/1)*	0.420 *(17/29)*
	Nov/Mar	0.463 *(166/5)*	0.691*** *(318/212)*	0.691*** *(318/212)*	0.755*** *(743/175)*	NS *(1/2)*	0.294 *(17/7)*
	Jan/Mar	0.700* *(20/5)*	0.223*** *(337/212)*	0.223*** *(337/212)*	0.422*** *(496/175)*	NS *(1/2)*	0.655 *(29/7)*
Nimmie-Caira	Sep/Nov	NS *(0/2*	NS *(0/223)*	NS *(0/223)*	NS *(0/787)*	NS *(0/22)*	NS *(0/4)*
	Sep/Jan	NS *(0/57)*	NS *(0/266)*	NS *(0/266)*	NS *(0/526)*	NS *(0/8)*	NS *(0/135)*
	Sep/Mar	NS *(0/73)*	NS *(0/50)*	NS *(0/50)*	NS *(0/454)*	NS *(0/14)*	NS *(0/10)*
	Nov/Jan	NS *(2/57)*	0.408*** *(223/266)*	0.408*** *(223/266)*	0.342*** *(787/526)*	0.318 *(22/8)*	NS *(4/135)*
	Nov/Mar	NS *(2/73)*	0.393*** *(223/50)*	0.393*** *(223/50)*	0.525*** *(787/454)*	0.377 *(22/14)*	NS *(4/10)*
	Jan/Mar	0.865*** *(57/73)*	0.121 *(266/50)*	0.121 *(266/50)*	0.276*** *(526/454)*	0.232 *(8/14)*	0.626** *(135/10)*
Redbank	Sep/Nov	NS *(0/10)*	NS *(0/174)*	NS *(0/174)*	NS *(0/601)*	NS *(0/89)*	NS *(0/203)*
	Sep/Jan	NS *(0/0)*	NS *(0/302)*	NS *(0/302)*	NS *(0/629)*	NS *(0/223)*	NS *(0/105)*
	Sep/Mar	NS *(0/50)*	NS *(0/64)*	NS *(0/64)*	NS *(0/237)*	NS *(0/119)*	NS *(0/200)*
	Nov/Jan	NS *(10/0)*	0.337*** *(174/302)*	0.337*** *(174/302)*	0.092* *(601/629)*	0.353*** *(89/223)*	0.151 *(203/105)*
	Nov/Mar	1.000*** *(10/50)*	0.351*** *(174/64)*	0.351*** *(174/64)*	0.083 *(601/237)*	0.244** *(89/119)*	0.378*** *(203/200)*
	Jan/Mar	NS *(0/50)*	0.325*** *(302/64)*	0.325*** *(302/64)*	0.107 *(629/237)*	0.431*** *(223/119)*	0.485*** *(105/200)*

Discussion

Five watering actions that have outcomes targeting fish communities in Nimmie-Caira and South Yanga were undertaken in 2016-17. These actions were successful in prolonging the period of fish occupation in target wetlands (Telephone Creek, Eulimbah Swamp, Nap Nap Swamp, and the four sites in Yanga National Park), allowing the development of more mature fish and repeated opportunities for spawning (Table 6-18). By providing ongoing habitat for fish survival in wetlands these environmental watering actions achieved their stated objectives in providing support for breeding waterbirds that rely on fish as a food resource. However, we note that overall wetland fish communities remain in poor condition and are dominated by highly abundant opportunistic generalist species with floodplain specialist species, those that still survive in parts of the Murrumbidgee Catchment (such as Murray hardyhead), generally absent from wetland data.

What did Commonwealth environmental water contribute to native fish populations and native fish diversity?

We found no evidence that the diversity of native wetland fish has changed during the monitoring period, despite the appearance and disappearance of a small number of uncommon taxa among monitoring years. Overall, we've observed 9 out of 23 previously recorded native species (Gilligan 2005) though we note that not all of these recorded species might be expected to occupy wetlands. None of the species recorded earlier during LTIM appear to have been lost from wetland survey data and we continue to see increased use of floodplain wetlands by larger-bodied native fish (golden and silver perch) in the mid-Murrumbidgee following managed environmental watering actions in 2014-15 and 2015-16 coupled with unregulated flows that reconnected the wetlands in 2016-17. The ongoing use of wetlands by these species suggests the pattern of watering is maintaining existing populations.

The Murrumbidgee River is an important source of colonising individuals to wetlands, but the conditions present in the wetland during the water year can influence the establishment and persistence of populations. Any improvement (i.e. increase) in wetland fish diversity in the Murrumbidgee wetlands would require increased use of wetlands by species that do not typically occupy wetlands under the existing flow regime, and for many floodplain specialists such as Murray hardyhead, translocation and managed reintroduction. The former might be achieved during very large overbank flows when connectivity is increased, provided that wetland habitat is maintained thereafter and opportunities for individuals to return to the river are maintained. By managing environmental water in some areas in a manner that recreates historic water regimes including the provision of some areas of persistent off channel habitat. The unregulated overbank event in 2016-17 presented opportunities for broadscale fish movements and, depending on the hydrology and condition of wetlands in subsequent years, it is possible that some populations may return over successive years.

What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?

In 2016-17 the common, more abundant species are spawning, growing and recruiting in wetland habitats. At least two separate spawning events for most species occurred in 2016-17, one earlier in the season and one later, but this pattern varied among zones and species. Is isn't clear whether the follow-up watering to support waterbirds in the Nimmie-Caira and Redbank zones contributed to the second spawning event, but we expect most sites (except for Telephone Creek and Waugorah Lagoon) would have dried or developed poor water quality relatively early in the water season, and without environmental watering these fish populations would have been lost. Carp are an important exception, with much of the catch dominated by juveniles that were spawned during the early stages of the unregulated event consistently ageing across the monitoring year.

In regulated systems, where dry phases can fall outside their historical intensity or frequency, populations that lack the attributes needed to rebound from the new disturbance regime will falter or disappear. For fish in ephemeral systems, resilience is largely provided by refuges that allow subset of the populations that is of sufficient size, distribution and/or connectedness to repopulate disturbed areas (Magoulick and Kobza 2003). These remnant populations are considered ‘self-sustaining’ and we see examples of this resilience in other species like the southern bell frog whose distribution and survival has been assisted by the use of environmental water. The existing assemblage of fish found in the Murrumbidgee wetlands are able to tolerate the current regime of wetland inundation, but this is currently limited to species that are able to refuge in the river between wetland drying events. Almost all wetland areas are functionally dry between inundation events (except for Yarradda and Waugorah Lagoons). Environmental water that provides permanent wetland refuges will promote increased survival of fish, allowing them to carry over between water years. For example, the watering actions undertaken in 2016-17 to support waterbird breeding and recruitment in the Nimmie-Caira and Yanga Zones supported fish communities until the final sampling occasion in March 2017 and, for some sites, will have created the conditions needed for communities to last until the following water year. This will impart increased resilience to the broader population and improve survival outcomes, particularly for marginal species. In general fish communities in seasonally dry wetlands do not make a major contribution to long-term changes in community structure or population persistence, because individuals perish during dry phases, instead high abundance of fish in seasonally dry wetlands can contribute to food availability for waterbirds. However wetlands were are associated with persistent refuges, either through the maintenance of permanent water in deep creek lines or reconnection to the main river channel, environmental; water can contribute to native fish populations as is the case in telephone Creek in the Nimmie-Caria, Wagourah lagoon in the Redbank and Yarradda in the mid-Murrumbidgee.

6.11 Waterbird Diversity

Prepared by Jennifer Spencer (NSW OEH), Joanne Ocock (NSW OEH) and Erin Lenon (CEWO)

Introduction

Waterbirds respond to habitat availability at large spatial scales, with the total number of species and abundance often increasing rapidly in response to wetland flooding. The Lowbidgee Floodplain is regionally significant for waterbird populations and has been identified as a key site that can be actively managed to contribute to the recovery of waterbird populations across the MDB (Murray-Darling Basin Authority 2014). Waterbirds need opportunities to breed in order to maintain and improve diversity and abundance across the MDB.

The major watering actions in the Murrumbidgee Selected Area in 2016-17 targeted waterbird foraging and breeding habitat. Environmental water was delivered to large parts of the Nimmie-Caria and Redbank wetland zones in August 2016 prior to widespread rainfall and high river flows that caused large overbank flooding in these wetland zones from October-November 2016. The delivery of Commonwealth and NSW OEH environmental water was paused at this time, recommencing in late November 2016 after floodwaters had receded. Environmental water was delivered from late November 2016 through to March 2017 to extend the duration and depth of inundation of waterbird breeding and feeding habitats in the Lowbidgee Floodplain. Waterbird diversity is accessed at 12 permanent LTIM monitoring sites

Watering actions that influenced the hydrological regime of LTIM monitoring sites were:

- Nimmie-Caira: Eulimbah waterbird breeding support (Eulimbah Swamp)
- Nimmie-Caira: Telephone Bank waterbird breeding support (Telephone Creek)
- Nimmie-Caira: Nap Nap waterbird breeding support (Nap Nap Summer)

- Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake) (Nap Nap autumn)
- Yanga National Park: waterbird breeding support (Two Bridges Swamp)

Methods

Ground surveys to assess waterbird species diversity, maximum abundance and breeding activity were conducted at the 12 LTIM wetland survey sites spread across the mid-Murrumbidgee, Nimmie-Caira and Redbank zones (four sites per zone). Methods followed those employed previously to survey waterbirds in the Murrumbidgee Catchment and are documented in Wassens, Jenkins et al. (2014). Waterbird ground surveys were carried out on four occasions between September and March in the three water years from 2014-17. While the mid-Murrumbidgee sites were completed in mid-September 2016, due to access issues following widespread flooding in spring 2016, the sites in the Nimmie-Caira and Redbank wetland zones were surveyed in mid-October 2016. It was not possible to survey Nap Nap Swamp and Telephone Creek in the Nimmie-Caira wetland zone between September-November 2016. All wetland sites were surveyed in late November-early December 2016, and again in late January-early February 2017 and mid-late March 2017.

Complementary annual spring and event- based waterbird diversity and waterbird breeding monitoring was also undertaken by NSW OEH (in collaboration with University of New South Wales (UNSW) and CEWO staff) across the Murrumbidgee Selected Area (see Section 6.12 Waterbird Breeding). UNSW also completed an aerial survey of the Lowbidgee floodplain in mid-October as part of long-term Aerial Waterbird Surveys of Eastern Australia (AWSEA program) (Porter, Kingsford et al. 2016).

Data analysis

In order to determine the extent to which the Commonwealth environmental watering actions achieved their objectives with respect to waterbird diversity and abundance, we considered three key aspects of the waterbird response: 1) species diversity (number of species), 2) functional guild diversity, and 3) maximum abundance recorded in each surveyed wetland on each survey occasion.

Waterbird species were separated into eight functional groups as per Hale, Stoffels et al. (2014) (see Appendix A) to investigate differences in bird assemblages among the surveyed wetlands. Note that species belonging to two other wetland-dependent guilds identified by, raptors and reed-inhabiting passerines, were also recorded during the surveys, but as these species occurred in low abundance they were not included in the waterbird diversity and abundance analysis presented in this section. The total abundance of the eight functional groups was calculated per hectare for each survey based on known coverage of each site in relation to the wetland boundaries (Wassens, Spencer et al. 2016). Across the 12 wetland survey sites approximately 152 ha of wetlands were surveyed in Redbank zone, 198 ha in the Nimmie-Caira zone and 104 ha in the mid-Murrumbidgee zone.

Multivariate analyses (Primer 2002) were used to investigate differences in waterbird guild assemblages among the survey sites as per Wassens et al. (2014). We also used Generalised Linear Modelling (GLM) with a binomial distribution (R Core Team 2015) to investigate waterbird responses (total species diversity and maximum waterbird abundance (birds per ha)) to patterns in wetland inundation. This approach was used to investigate whether waterbird responses differed among sites that were inundated and sites that were dry for the 2014-17 monitoring period. The proportion of each site that was inundated was determined using a combination of survey observations and inundated area estimates from inundation mapping (inundated sites were more than >10% inundated and sites that were dry were <10% inundated).

Results

What did Commonwealth environmental water contribute to waterbird diversity and abundance?

A total of 63 (31 breeding) wetland-dependent species (included raptors and reed-inhabiting passerines) have been recorded during surveys of the Murrumbidgee Selected Area from September 2014 to March 2017. In 2016-17, widespread natural flooding and multiple watering actions supported a high (60 species) diversity of wetland-dependent bird species (Table 6-19). Waterbird species diversity was higher in all three wetland zones in 2016-17 compared to the two previous water years (Figure 6-73). Total species diversity increased from November 2016 across all three wetland zones following widespread natural flooding (Figure 6-74).

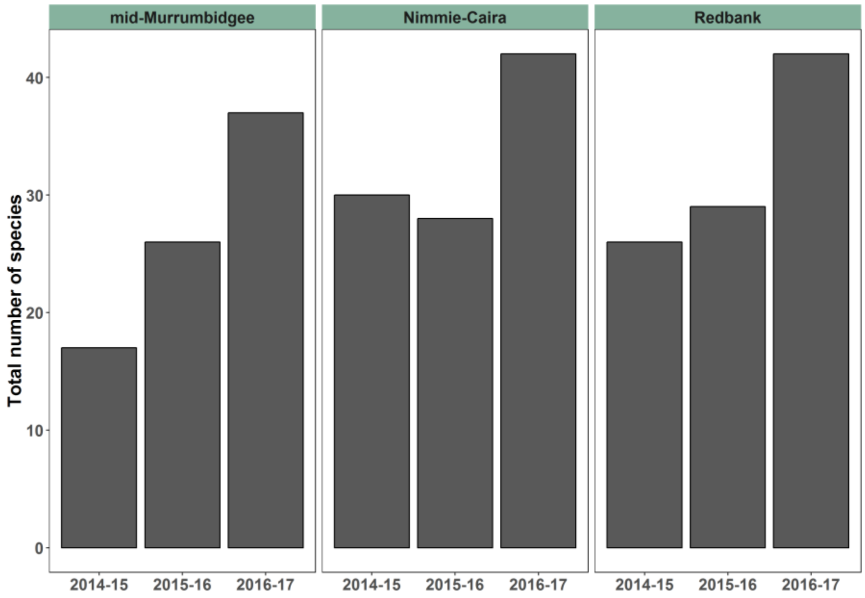


Figure 6-73 Total number of waterbird species recorded in each wetland zone in the 2014-15, 2015-16 and 2016-17 survey periods. (Note that reed-inhabiting passerines and raptors are not displayed here).

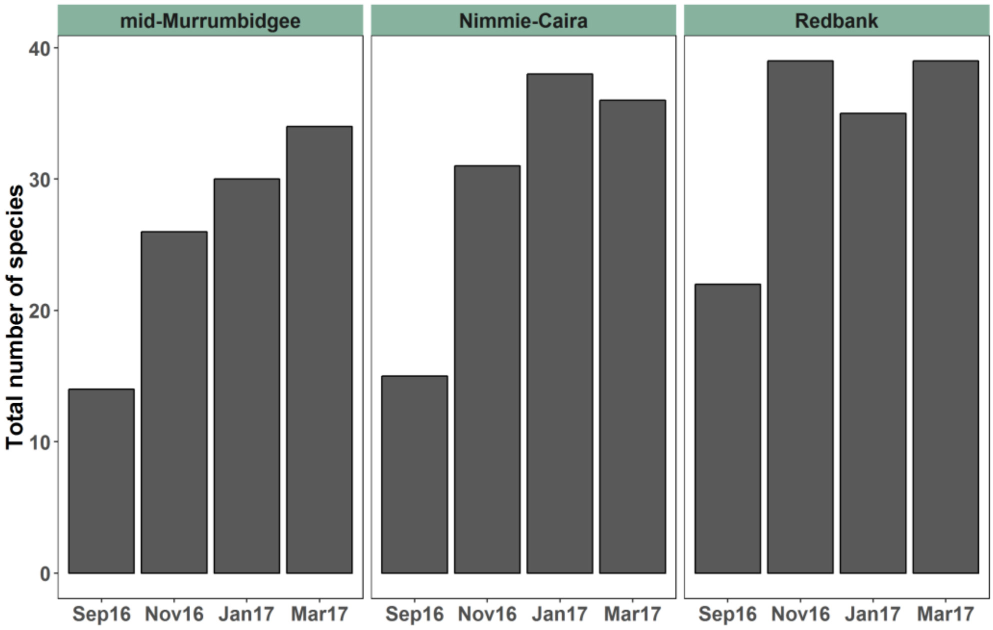


Figure 6-74 Total number of waterbird species recorded in each wetland zone in the four survey periods in 2016-17. (Note that reed-inhabiting passerines and raptors are not displayed here).

Across the Murrumbidgee Selected Area, all functional guilds (when resident and migratory shorebirds were combined) were observed in the three years of surveys (2014-15, 2015-16 and 2016-17). Fish-eating waterbirds, dabbling ducks and large waders comprised the majority of waterbirds (>80%) observed in the Nimmie-Caria and Redbank zones. The mid-Murrumbidgee wetland zone was dominated by dabbling ducks, fish-eating waterbirds and diving ducks. Shorebirds (resident and migratory species) made up the smallest proportion of total counts followed by rails and shoreline gallinules in all three water years (Figure 6-75).

Table 6-19 Maximum count of each species recorded in each of the wetland zones (MM mid-Murrumbidgee, NC Nimmie-Caria, RB Redbank) during 2014-15, 2015-16 and 2016-17 surveys (*indicates breeding detected).

	2014-15			2015-16			2016-17		
Common name	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***
Australasian bittern E e	0	0	0	0	2	0	0	1	0
Australasian darter	0	8*	2*	31*	14*	2*	23*	26*	11*
Australasian grebe	45*	0	4	20	11	73*	25*	8	2
Australasian shoveler	6	0	0	0	0	8	4	5*	2
Australian gull-billed tern	0	0	0	0	0	0	15	0	0
Australian hobby	0	0	0	0	0	0	0	0	1
Australian pelican	0	75	64	80	20	131	0	16*	60
Australian pratincole	0	0	0	0	0	0	0	0	1
Australian reed-warbler	0	1	0	1	1	6	6	9	17
Australian shelduck	0	3	2	2	0	6	2	6*	20
Australian spotted crake	0	0	0	0	0	0	0	6*	0
Australian white ibis	9	39	10*	8	24*	135*	9*	27*	76*
Australian wood duck	38*	16	17	23*	15*	12	20	31	34
Baillon's crake	0	0	0	0	0	0	0	5	0
Black-fronted dotterel	0	7	0	0	0	0	3	2*	2
Black-tailed native-hen	0	23	0	0	36	0	0	67	2
Black-winged stilt	0	4	0	0	2	101	7	42	119
Black kite	0	0	0	0	0	0	2	2	0
Black swan	0	8	57	31*	6	245*	5*	13*	80*
Brown falcon	0	0	0	0	0	0	1	0	0
Buff-banded rail	0	0	0	0	0	0	0	0	1
Cattle egret J	0	0	0	0	0	0	0	0	1*
Chestnut teal	0	0	0	0	0	0	4	0	0
Dusky moorhen	0	0	0	0	0	3	2	1	5
Eastern great egret J	2	17	4*	2	32*	38*	45*	18*	80*
Eurasian coot	65	4	204	575	8	710*	26	88*	353*
Glossy ibis	0	0	0	0	0	270	0	6*	120
Golden-headed cisticola	0	0	0	0	0	1	2	0	0
Great cormorant	38	2	12*	65*	58*	20	15*	36*	85*
Great crested grebe	0	0	0	0	0	0	4*	0	155*
Grey teal	215*	202*	312	383*	99*	422*	497*	112*	474*
Hardhead	32	0	15	110	0	10	3	12	7
Hoary-headed grebe	58	0	110	24	2	0	1	11	22
Intermediate egret	0	1	7	6	12	61*	19	12*	252*
Little black cormorant	5	100*	21*	7*	75*	12*	88*	66*	65*
Little egret	0	5	0	0	4	7*	4	1	14*

Table 6.22 continued

	2014-15			2015-16			2016-17		
Little grassbird	0	0	0	0	1	1	2	4	5
Little pied cormorant	4	7*	17*	56*	50*	24*	21*	52*	127*
Magpie goose v	0	0	0	1	0	0	0	0	0
Masked lapwing	0	2	2	2	2	5*	0	13	6
Musk duck	0	1	0	0	0	0	1	4*	0
Nankeen kestrel	0	0	0	1	0	2	0	0	1
Nankeen night-heron	0	0	5	0	0	0	16*	94*	137*
Pacific black duck	48*	55	52	100*	50*	18*	170*	16*	65*
Pied cormorant	0	0	0	6	1	0	2*	1	2
Pied heron	0	0	0	0	0	0	0	0	3*
Pink-eared duck	259	18	125	16	0	0	75*	29*	2
Plumed whistling-duck	0	35	0	0	0	0	10	5	0
Purple swamphen	0	0	0	0	0	8*	4	4	34
Red-capped plover	0	2	0	0	0	0	0	0	0
Red-kneed dotterel	0	0	0	0	0	0	0	1	21
Red-necked avocet	0	0	0	0	0	0	0	0	20
Royal spoonbill	0	7	0	22	6*	12	4	14*	94*
Sacred kingfisher	0	0	1	2	1	0	3	2	6
Sharp-tailed sandpiper J,C,R	0	2	0	0	0	0	0	0	0
Straw-necked ibis	4	200	40	0	28	15	80	1104*	75
Swamp harrier	0	0	0	1	3	0	0	2	1
Unidentified duck	0	0	0	0	0	0	0	0	159
Unidentified egret	0	0	0	0	2	0	1	0	188
Unidentified kingfisher	0	1	0	0	0	0	0	0	0
Unidentified small wader	0	0	0	1	0	0	0	0	0
Unidentified spoonbill	0	0	0	0	0	0	0	0	10
Unidentified tern	0	0	0	0	0	0	1	0	0
Whiskered tern	0	0	0	0	120	0	4	68*	20
Whistling kite	2	0	4	1	4	3	4	4	2
White-bellied sea-eagle v	0	2	2	1	1	2	1	1	1
White-faced heron	3	19	2*	7	4	4	6	6	42
White-necked heron	0	3	9	5	1	9*	33	16*	48*
Yellow-billed spoonbill	2	25	4	51	16	210*	42*	18*	26*
Total waterbird species from LTIM surveys	**18**	**31**	**27**	**31**	**33**	**34**	**44**	**48**	**50**
Total breeding species*	**4**	**4**	**7**	**8**	**10**	**16**	**15**	**25**	**19**

^ Status: J = JAMBA, C = CAMBA, R = ROKAMBA (listed under international migratory bird agreements Australia has with Japan, China and Republic of North Korea, respectively), listing under the NSW *TSC Act 1995* (e = endangered, v = vulnerable), and under Commonwealth *EPBC Act 1999* (E = Endangered). *Breeding records were determined from the results of LTIM quarterly wetland surveys, LTIM waterbird breeding surveys and complementary monitoring undertaken by NSW OEH (see Spencer *et al.* 2017).

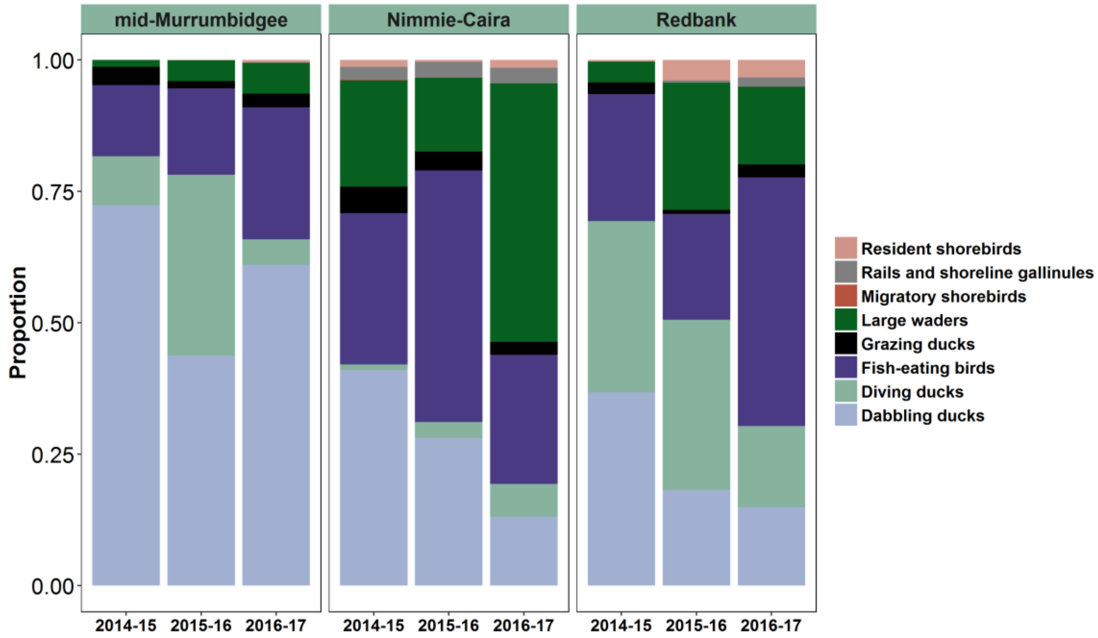


Figure 6-75 Overall waterbird community composition (max count per waterbird guild) in each wetland zone in the 2014-15, 2015-16 and 2016-17 survey periods. (Functional groups are described in Appendix A).

There were significant differences in waterbird guild assemblages across the surveyed LTIM wetlands among the three water years (ANOSIM *Global R* 0.141, p = 0.001) and across the three wetland zones (ANOSIM *Global R* 0.052, p = 0.001). Overall, the waterbird assemblages in the Nimmie-Caira and Redbank zones were more similar than waterbird communities observed in the mid-Murrumbidgee zone (Pair-wise tests Nimmie-Caira (NC): mid-Murrumbidgee (MM) *Global R* 0.163, p = 0.001; NC: Redbank (RB) *Global R* -0.026, p = 0.909; MM: RB *Global R* 0.195, p = 0.001). Waterbird assemblages were also significantly different in the third water year (2016-17) compared to the previous two years of surveys (Pair-wise tests 2014-15: 2015-16 *Global R* 0.029, p = 0.106; 2014-15: 2016-17 *Global R* 0.272, p = 0.001; 2015-16: 2016-17 *Global R* 0.136, p = 0.001).

There was a notable increase in the number of large waders observed in the Nimmie-Caria zone in 2016-17 (highest number of individuals in the September and November wetland surveys) compared to the previous two water years. This was a result of large ibis colonies establishing in the Nimmie-Caria zone from October-December 2016.

Similarly, large numbers of fish-eating waterbirds were recorded in the Redbank zone in 2016-17 where large egret, heron and cormorant colonies formed from October 2016 onwards. Dabbling ducks (e.g. grey teal *Anas gracilis* and pink-eared duck *Malacorhynchus membranaceus*) dominated waterbird communities in the mid-Murrumbidgee zone in each of the survey years. Fish-eating birds (cormorants and darters) increased in abundance in mid-Murrumbidgee wetlands and were recorded nesting in 2016-17 (Figure 6-75 and Figure 6-76).

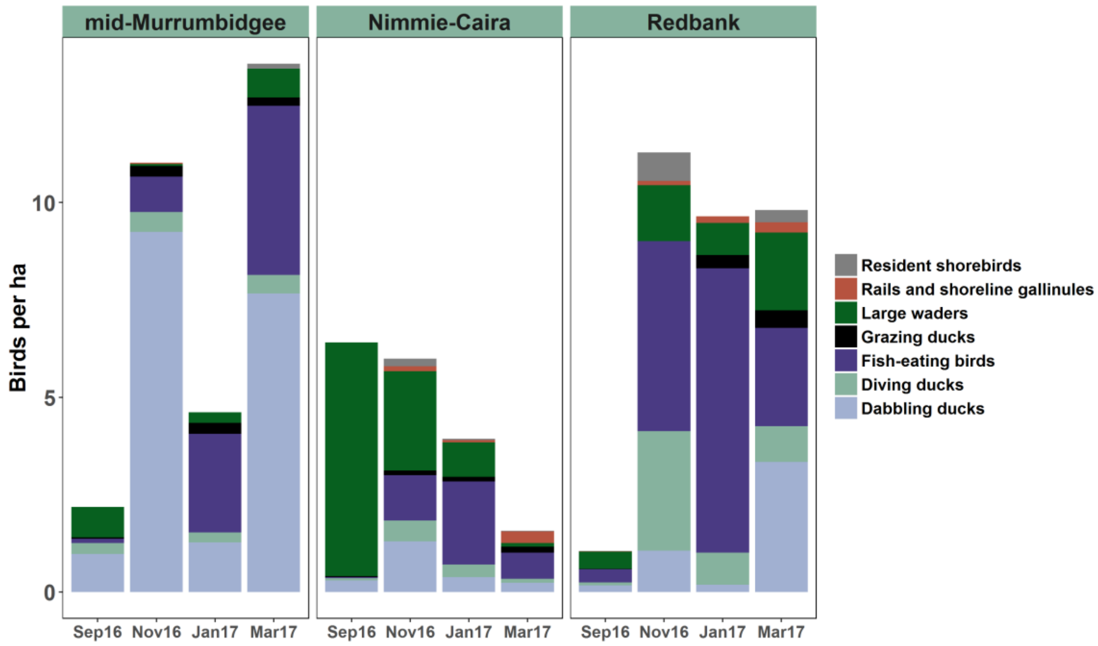


Figure 6-76 Total number of waterbirds per ha grouped by functional guild, recorded across each wetland zone in the 2016-17 survey periods. Note that reed-inhabiting passerines and raptors were not recorded in sufficiently large numbers to be displayed here. (Functional groups are described in Appendix A).

We predicted that waterbird diversity and abundance would be higher in sites that were inundated and this was supported by results from surveys between September 2014 and March 2017 at the 12 LTIM wetland sites. Overall, total species diversity and abundance of waterbirds was greater during surveys of inundated sites compared to sites which were predominately dry (<10% inundated) (GLM diversity Z value = 16.4, p >0.001; abundance Z value = 9.9, p >0.001) (Figure 6-77).

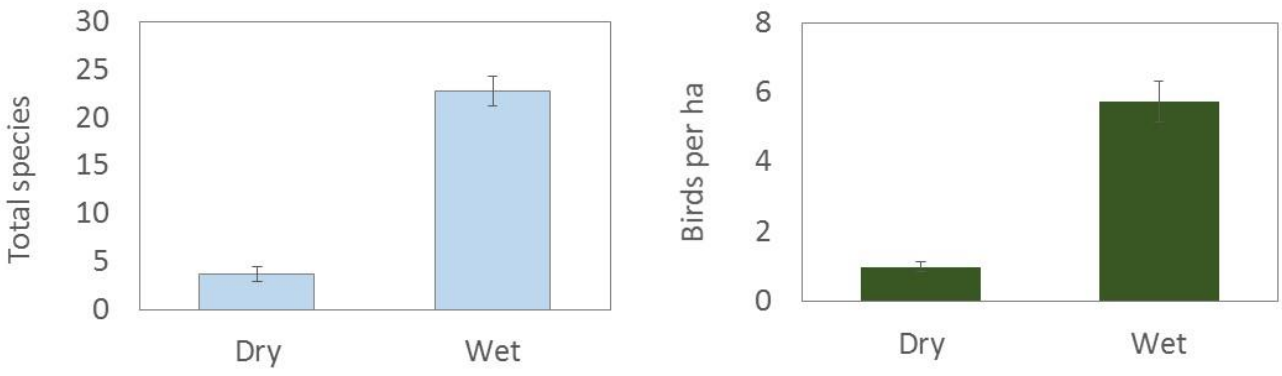


Figure 6-77 Comparison of average (+/- standard error) diversity (*left*) and abundance (max. count/ha) (*right*) recorded in inundated (>10% wet) and drier (<10% wet) surveyed LTIM wetlands in 2014-17.

Redbank watering actions

The results of the LTIM wetland surveys in January and March 2017 showed that there was a high diversity of waterbird species at the Two Bridges wetland (26 species in total). This site received Commonwealth environmental water as part of the Yanga National Park rookery maintenance watering event in late summer 2017 (29/01/2017 - 7/02/2017), which provided feeding habitat for JAMBA listed Eastern great egrets *Ardea alba modesta* breeding in Yanga National Park, and a small number of pied herons *Egretta picata*. Pied herons are typically found in the northern Australia and have only been observed in parts of the MDB during major floods. Two pairs of pied herons were observed nesting in the Steam Engine egret and heron colony in North Redbank. It is likely they also bred at the Two Bridges egret colony in Yanga National Park as several birds were observed during the December 2016 and January 2017 surveys, though nesting was not confirmed.

The Yanga National Park watering event provided feeding habitat for juvenile ibis, egrets, herons and spoonbills from active colonies in the Redbank system. This included the neighbouring large ibis colony in North Redbank which was active from December 2016 through to March 2017. The Tori Lignum Swamp ibis colony was supported by the North Redbank rookery maintenance watering event in late summer 2017 (27/01/2017 - 13/02/2017). In addition to supporting active ibis and spoonbill breeding in this colony (see Section 6.12 Waterbird Breeding), the North Redbank watering action also extended the availability of foraging habitat for a range of waterbird species (38 species in total) including the nationally listed Australasian bittern *Botaurus poiciloptilus* (EPBC Act Endangered), and NSW listed magpie goose *Anseranas semipalmata* and blue-billed duck *Oxyura australis* (NSW *TSC Act 1995*).

Nimmie-Caira watering actions

There were two periods of watering of the Nimmie-Caira zone. The first was the Nimmie-Caira to South Yanga watering action in winter-early spring 2016 (4/08/16 - 3/09/16). The second period comprised four watering events from late November 2016 to March 2017 (24/11/2016 - 20/03/2017) that were used to maintain colonial watering breeding in Eulimbah Swamp (ibis and spoonbills), Telephone Swamp (ibis, egrets and spoonbills), Nap Nap Swamp (egrets, herons and ibis) and Kieeta Lake (pelicans). The outcomes of these watering actions are discussed in more detail in the Waterbird Breeding (Section 6.12).

While maintaining the depth and duration of flooding in the waterbird colonies was the focus of the Nimmie-Caira watering actions, non-target species also benefited from the delivery of Commonwealth environmental water. This included the Australasian bittern at Eulimbah Swamp and at least 11 non-colonial waterbird species recorded breeding across wetlands in the Nimmie-Caria in 2016-17. Overall, there was a significant increase in non-colonial waterbird breeding activity in the Nimmie-Caira zone compared to the two previous water years (2014-15 grey teal only, 2015-16 three non-colonial species recorded with broods) (see Table 6-19).

The delivery of Commonwealth and NSW OEH environmental water to Kieeta Lake also provided feeding habitat at nearby Kia Lake for a large diversity of waterbird species. Complementary monitoring by NSW OEH and CEWO recorded 40 waterbird species during surveys of Kia Lake in March 2017. This included migratory shorebirds (marsh sandpiper *Tringa stagnatilis* and sharp-tailed sandpiper *Calidris acuminata,* both listed under bilateral agreements *JAMBA, CAMBA and ROKAMBA*) and large numbers of dabbling ducks and Australian resident breeding shorebirds. More than 200 red-kneed dotterel *Erythrogonys cinctus*, 100 black-winged stilt *Himantopus* *leucocephalus*, 130 red-necked avocet *Recurvirostra novaehollandiae* and small numbers (<5 birds) of juvenile black-fronted dotterel *Elseyornis melanops*) were observed. Complementary monthly surveys of the large Australian pelican *Pelecanus conspicillatus* colony at Kieeta Lake from February-June 2017 (see Section 6.12) also demonstrated that the delivery of environmental water provided foraging habitat for a high diversity of waterbird species. Thirty-five species were observed across all the pelican colony surveys, including the vulnerable blue-billed duck and freckled duck *Stictonetta naevosa* (NSW *TSC Act 1995*), and migratory sharp-tailed sandpiper (*JAMBA, CAMBA and ROKAMBA*).

Discussion

In 2016-17, wetlands in the Redbank and Nimmie-Caria zones received Commonwealth environmental water as part of multiple watering actions focused on supporting the habitat requirements of waterbirds, including active waterbird breeding colonies in the Lowbidgee floodplain. Commonwealth and NSW environmental water achieved their stated watering objectives for waterbirds under each specific watering actions as demonstrated by monitoring by both LTIM providers and complementary NSW OEH and CEWO surveys.

What did Commonwealth environmental water contribute to waterbird diversity and abundance?

Monitoring results from the past three seasons support our prediction that wetland inundation would increase the abundance and diversity of waterbirds in the Murrumbidgee Selected Area.

We observed an increase in waterbird diversity and abundance following widespread natural flooding and the delivery of environmental water in 2016-17, compared to the previous two water years when the total area of inundation was lower (see Wassens, Spencer et al. 2016). Environmental water delivered in 2016-17 also provided feeding and breeding habitat for waterbird species of conservation significance including nationally endangered Australasian bittern (EPBC Act), vulnerable blue-billed duck, freckled duck and magpie goose (NSW TSC Act 1995), and internationally-listed Eastern great egrets, cattle egrets *Bubulcus ibis* (*JAMBA*), marsh sandpiper and sharp-tailed sandpiper (*JAMBA, CAMBA* and *ROKAMBA)*.

Sites that were inundated in the three years of surveys had a higher overall species richness and abundance when compared to wetlands that were dry for extended periods during this period. Timing of both the initial environmental watering and natural flows from late winter into spring 2016 suited the water requirements of many waterbird species with total numbers increasing rapidly in all wetland zones in late spring following the end of the natural over-bank flooding. Environmental water was used to support colonial waterbird breeding by maintaining the inundation extent and depth of flooding through summer months into early autumn 2017. This action also benefited non-colonial waterbird species such as dabbling, diving and grazing waterfowl, and resident shorebirds.

What did Commonwealth environmental water contribute to non-colonial waterbird breeding?

Wetland habitat was made available for colonial and non-colonial waterbird species as a consequence of the delivery of environmental water and natural overbank flooding during the 2016-17 water year. While maintaining the depth and duration of inundation in active waterbird colonies was the focus of the 2016-17 colonial waterbird breeding watering actions, non-colonial waterbird species also benefited and this included the endangered Australasian bittern (Commonwealth *EPBC Act 1999*). Overall, we observed a high number of non-colonial waterbird species breeding in the Murrumbidgee Selected Area in 2016-17 (14 species) compared with the previous two water years (2014-15 four species; 2015-16 eight species). Dabbling ducks, diving ducks and swans, and resident shorebird species were recorded with multiple broods of young in the 2016-17 surveys (Table 6-19). In comparison, we detected only single or only small numbers of broods of dabbling ducks, grazing ducks, diving ducks and swans, and resident shorebirds in the previous two water years.

Recommendations

Commonwealth environmental water should be prioritised to provide seasonally-inundated habitat (spring-summer) for waterbirds in the Lowbidgee floodplain and mid-Murrumbidgee wetlands. Most waterbirds commence breeding in spring, however, the stimuli for breeding is usually a combination of season, rainfall and flooding, with the timing of initial floodplain inundation influencing the lag time between the start of flooding and the commencement of nesting (Briggs and Thornton 1999). Specifically, large-scale watering actions in late winter-early spring can act to 'prime' the system if they occur prior to large-scale natural flooding. These types of watering events can provide foraging habitats for colonial waterbird species allowing species to build up body condition before commencing breeding (when natural overbank flows do occur). Inundation of a range of foraging habitat types by large-scale watering actions has added benefits. It enhances overall waterbird diversity in spring and provides breeding opportunities for non-colonial species including dabbling ducks, swans and resident shorebird species, regardless of whether natural flood events occur in the following months.

Follow-up watering actions that maintain inundation into summer and autumn months can also benefit a broad range of waterbird species, particularly where flows are delivered to encompass large areas of foraging habitat. The Nimmie-Caira watering breeding maintenance actions in 2016-17 extended the duration of natural flooding into autumn 2017, providing habitat for a longer period than spring and summer watering alone. Extending duration of inundation also provides opportunities for migratory shorebird species which feed opportunistically in inland wetlands, including open shallow lagoons and lakes, and inundated wetlands with low-lying vegetation. These species are listed on international migratory bird agreements Australia has signed with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA)) and they spend their non-breeding season in Australia from late August through to early May. The provision of wetland habitat in autumn can provide habitat for these types of waterbirds prior to their return migration to the northern hemisphere. For example, we observed these outcomes for waterbird diversity following the Nimmie-Caira pelican support watering action which inundated Kieeta Lake and neighbouring habitat in Kia Lake, which provided feeding habitat for migratory shorebird species and a range of resident shorebird species and dabbling ducks.

Following large natural flood events in the Murrumbidgee Selected Area and neighbouring catchments, Commonwealth environmental water should be prioritised to deliver water to key waterbird foraging areas. Creating foraging habitat will promote the survival of juvenile waterbirds, and therefore, contribute to the maintenance of waterbird diversity and increased abundance of waterbirds across the MDB.

6.12 Waterbird Breeding

Prepared by Jennifer Spencer (NSW OEH), Kate Brandis (UNSW) and Diane Callaghan (UNSW)

Introduction

The Lowbidgee floodplain can support major colonial waterbird breeding and is one of the most important breeding sites in Eastern Australia for straw-necked ibis (*Threskiornis spinicollis*) and glossy ibis (*Plegadis falcinellus*) (Lowe 1983, Kingsford and Thomas 2004, Bino, Steinfeld et al. 2014). Colonial waterbird breeding has been recorded at more than 25 wetlands across the Lowbidgee floodplain (Nimmie-Caira and Redbank zones) and five sites in the mid-Murrumbidgee wetlands over the past 30 years (Table 6-20). In the Nimmie-Caira zone, Eulimbah and Telephone Bank are the principle areas that support large straw-necked ibis colonies (e.g., 35,000 – 50,000 nests recorded in 2010) (Brandis, Ryall et al. 2011). The Redbank zone has also supported large egret, heron and cormorant (> 1,000 nests recorded in 2010) in three principle locations (Two Bridges, Tarwillie and Steam Engine swamps) (Spencer, Thomas et al. 2011) (Table 6-20).

Table 6-20 Records of major breeding locations in the Lowbidgee floodplain from 1981 onwards including records from the 2016-17.

Zone	Wetland name	Records of breeding for each spring										
Nimmie-Caira	Eulimbah Swamp	1986	1990	2005	2010	2012	2013	2015	2016			
	Nap Nap Swamp	1987	1988	1989	1990	1991	2010	2016				
	Telephone Bank	1981	1984	1990	1991	2000	2005	2010	2012	2013	2015	2016
	Nimming Creek	1983	1996									
	Suicide Swamp	1989	1990									
	Kieeta Lake	2017										
	Pollen Creek	1986	1989	1990	1991	1992						
Redbank	Redbank Swamp	1989	1991									
	Sapling Swamp	1990										
	Tarwillie Swamp	1989	1990	2005	2010	2012	2014	2015	2016			
	Steam Engine Swamp	1989	1990	2005	2010	2016						
	Two Bridges (West)	2010	2016									
	Tori Lignum Swamp	2016										

Sources: Australian Colonial Waterbird Breeding Database (Brandis 2010); data from NSW OEH ground surveys (2008-17).

Colonial waterbird breeding can provide a useful index of the effectiveness of environmental water delivery, because successful waterbird breeding is heavily dependent on adequately timed flows of sufficient frequency, duration, depth and extent to inundate breeding habitat and stimulate sufficient food resources (Scott 1997, Kingsford and Auld 2005). Environmental flows have been delivered to support annual small-scale waterbird breeding in the Murrumbidgee Selected Area (Spencer and Wassens 2010, Wassens, Spencer et al. 2016) and to extend or build on natural flows to support large-scale waterbird breeding (Brandis, Ryall et al. 2011, Spencer, Thomas et al. 2011). Straw-necked ibis are particularly sensitive to rapid draw down of water levels in their breeding habitats and where flows are maintained successfully can provide evidence of effective river management.

The timing and duration of flooding is important as breeding success is maximised when flooding coincides with spring and summer months and food availability is optimal (Scott 1997). Most waterbirds commence breeding in spring, however, the stimuli for breeding is usually a combination of season, rainfall and floodwaters, with the timing of inundation influencing the lag time between the start of flooding and the commencement of nesting (Briggs and Thornton 1999). Overall, breeding habitats need to be inundated for long enough to allow birds to achieve pre-breeding condition, pair up, build nests, lay eggs, and raise and fledge their young (Scott 1997). For many colonially-nesting species, ensuring water levels are stable underneath nesting birds is essential as rapid falls in water levels can lead to perceived declines in food availability and/or increases in risk of predator by ground predators, leading to in some cases to nest abandonment (Brandis, Kingsford et al. 2011).

Many of the colony sites that were active in 2016-17 and in previous water years have been reliant on management interventions that were undertaken to maintain water levels in each colony and surrounding foraging habitats for the duration of breeding. Monitoring of colony sites plays a critical role in providing real-time information to support decisions around environmental water delivery, particularly with respect to the diversity of breeding species, and the duration and depth of inundation needed to maintain nests of these species through to completion.

Evaluation of watering actions

The major watering actions in the Murrumbidgee Selected Area in 2016-17 targeted waterbird foraging and breeding habitat. This included delivery of environmental water to large parts of the Nimmie-Caria and Redbank wetland zones in August 2016 prior to widespread rainfall and high river flows in September 2016 that caused large overbank flooding in the mid-Murrumbidgee, Nimmie-Caira and Redbank wetland zones. In addition to wet conditions within the Murrumbidgee Catchment, the neighbouring lower Lachlan wetlands also experienced major flooding form late August 2016 onwards which initiated major ibis breeding events from late August 2016 through to March 2017 (Dyer, Broadhurst et al. 2017).

The delivery of Commonwealth and NSW OEH environmental water was paused in early September, recommencing in late November 2016 after floodwaters had receded. Environmental watering restarted in late November 2016 and continued through to March 2017 to extend the duration and depth of inundation of waterbird breeding and feeding habitats in the Lowbidgee Floodplain. The primary objective of delivering Commonwealth environmental water to support waterbird breeding in 2016-17 was to extend the period of inundation and maintain water levels where needed to support colonial waterbird breeding, fledging and recruitment. Specifically, this monitoring program addressed the following evaluation questions:

- What did Commonwealth environmental water contribute to waterbird breeding?

- What did Commonwealth environmental water contribute to waterbird fledging and survival?

Methods

Under the approved Murrumbidgee Monitoring and Evaluation Plan (M & E Plan) there is provision to undertake event based Category 1 (Optional) and Category 3 monitoring (Wassens, Jenkins et al. 2014). We used two monitoring approaches (outlined in more detail in Wassens, Jenkins *et al.* 2014) to evaluate waterbird breeding responses to Commonwealth environmental watering actions in wetland habitats across the Murrumbidgee Selected Area in 2016-17:

- Waterbird Breeding (Category 1) which targeted large ibis colonies in the Nimmie-Caira and Redbank zones
- Waterbird Breeding (Category 3) targeting known egret, heron and cormorant breeding sites in the Redbank, Nimmie-Caira and mid-Murrumbidgee wetland zones and a new pelican colony in the Nimmie-Caira.

Survey sites

In total two colony sites were monitored through Category 1 methods and 26 colony sites through Category 3 methods (Table 6-21). The traditional locations for large ibis colonies are in Eulimbah Swamp and Telephone Bank, in the Nimmie-Caira zone (Table 6-20) and so these sites were prioritised for Category 1 monitoring. However, on-ground access to Telephone Bank was limited in earlier stages of this colony (over November-December 2016) due to widespread natural flooding and damaged roads which prevented access to the Telephone Bank for several weeks beyond the start of the Eulimbah monitoring which commenced in late November 2016.

A new ibis colony established in the Tori Lignum Swamp (North Redbank) in December 2016. This site is a wetland storage covering around 215 hectares where ibis have not previously been recorded breeding. The colony was observed during a NSW OEH and CEWO aerial survey on 20 December. As this was a large colony which was at risk due to falling water levels and poor water quality, onground monitoring using Category 1 methods was set up at the Tori colony to survey the colony at fortnightly intervals from early January to mid-March 2017. Both Category 1 and Category 3 ground surveys of the colony were limited to two periods, either in early morning (6-11am) or late afternoon (3-8 pm) to avoid causing heat stress to nesting birds and their offspring.

Table 6-21 Summary of colonial waterbird breeding sites in the Murrumbidgee Selected Area and monitoring coverage in 2016-17. Cat 1 sites were monitored using the Category 1 standard methods; while reduced intensity of sampling was carried out at Cat 3 sites (see detailed methods in Wassens *et al*. 2014). ^Colony size categories are small (<500 nests), medium (>500-<5000 nests), large (>5,000 nests). *Note Riverleigh and Dry Lake colonies were found after colony completion (Oct 2017).

Colony site name	Dominant nesting species	Monitoring category	Size category ^ (small, medium or large)	Timing of 2016-17 surveys	Received ewater in 2016-17
Nimmie-Caira					
Eulimbah Swamp	Ibis and spoonbills	**Cat 1 & 3**	Large	Oct-Mar	Yes
Telephone Bank	Ibis and spoonbills	Cat 3	Large	Dec-Feb	Yes
Nap Nap Swamp	Cormorants, herons and egrets	Cat 3	Medium	Dec-Mar	Yes
Kieeta Lake	Pelicans	Cat 3	Large	Feb-May	Yes
House Creek	Cormorants, herons	Cat 3	Small	Jan-Feb	Yes
Loorica Lake	Cormorants and herons	Cat 3	Medium	Oct-Mar	No
Redbank North					
Tori Lignum Swamp	Ibis and spoonbills	**Cat 1 & 3**	Large	Dec-Mar	Yes
Steam Engine	Egrets and herons	Cat 3	Medium	Oct-Mar	No
Glenn Dee	Cormorants	Cat 3	Small	Nov-Mar	No
Narwie Swamp	Cormorants	Cat 3	Small	Nov-Mar	No
Riverleigh	Cormorants	Cat 3	Small	*	No
Redbank South (Yanga National Park)					
Two Bridges (West)	Egrets and herons	Cat 3	Medium	Dec-Feb	Yes
Tarwillie Swamp	Egrets and cormorants	Cat 3	Medium	Oct-Mar	Yes
Top Narockwell Swamp	Egrets and cormorants	Cat 3	Small	Oct-Feb	Yes
Two Bridges (East)	Cormorants	Cat 3	Small	Dec-Feb	Yes
Breer Swamp	Cormorants	Cat 3	Small	Oct	No
Tala Lake	Cormorants	Cat 3	Small	Feb-Mar	No
Tala Creek	Cormorants	Cat 3	Small	Feb only	No
McGabes	Herons	Cat 3	Small	Nov-Mar	Yes
Piggery Lake	Cormorants	Cat 3	Small	Oct-Mar	Yes
Waugorah Lagoon	Cormorants	Cat 3	Small	Dec-Mar	Yes
Waugorah Lake	Cormorants	Cat 3	Small	Oct-Jun	Yes
Yanga Creek	Herons	Cat 3	Small	Dec-Feb	Yes
North Stallion Swamp	Herons and cormorants	Cat 3	Small	Dec-Feb	Yes
Monkem Creek	Herons and cormorants	Cat 3	Small	Dec-Feb	No
Mid-Murrumbidgee					

Yarradda Lagoon	Cormorants	Cat 3	Small	Oct-Mar	No
Gooragool Lagoon	Cormorants	Cat 3	Small	Oct-Mar	No
Dry Lake	Cormorants	Cat 3	Small	*	No
Pimpara-Wagourah					
Maude Lagoon	Herons, spoonbills	Cat 3	Small	Oct-Feb	No

Category 1 methods

Four species of colonially-nesting waterbirds were monitored using Category 1 methods developed for measuring reproductive success of species in relation to hydrological conditions: straw-necked ibis, Australian white ibis *Threskiornis molucca*, royal spoonbill *Platalea regia* (Eulimbah and Tori Lignum Swamps), and glossy ibis (Tori Lignum Swamp only) (Table 6-22). The reproductive success monitoring was not conducted at Telephone Bank as access to this site was only possible after the chicks were well developed and had left nests. Additional variables monitored in the three ibis colonies included water quality, water depth and waterbird species diversity including the presence of breeding activity in non-colonial species (see Section 6.11).

Table 6-22 Total number of marked clumps (and total number of nests) for each species monitored in the Eulimbah and Tori colonies.

Species	Eulimbah Swamp	Tori Lignum Swamp
Straw-necked ibis	33 (364 nests)	17 (378 nests)
Australian white ibis	6 (24 nests)	2 (2 nests)
Royal spoonbill	11 (11 nests)	N/A
Glossy ibis	N/A	5 (14 nests)

To measure reproductive success in the Eulimbah and Tori ibis colonies, a marked set of randomly selected nest clumps were monitored at fortnightly intervals for the three-month breeding period (Table 6-22). A nesting clump was defined as a group of nests on a clump of lignum separated from another clump of lignum by open water or non-flattened vegetation (Plate 6-4). Royal spoonbills typically nest singly in individual lignum clumps while ibis pairs typically nest together in close proximity on a single clump. The selected nest clumps of ibis and spoonbills were monitored by trained observers throughout the breeding period (six surveys in total) from egg to fledgling development stages.

Table 6-23 Survey dates for the ibis colonies in Eulimbah Swamp (Nimmie-Caira) and Tori Lignum Swamp (North Redbank) in 2016-17.

Survey No.	Eulimbah survey dates	Tori survey dates	Survey methods
Initial survey	20 October 2016 (ground), 21 October 2016 (aerial)	20 December 2016 (aerial)	Cat 3
1	21 November 2016 (including UAV survey)	6 January 2017	Cat 1
2	2 December 2016	22 January 2017	Cat 1
3	18 December 2016	1 February 2017	Cat 1
4	28 December 2016	16 February 2017	Cat 1
5	4 January 2017	2 March 2017	Cat 1
6	20 January 2017	15 March 2017	Cat 1
Follow up survey	3 March 2017		Cat 3

Note that additional Category 3 surveys of Eulimbah were carried out on 20 October 2016 and 3 March 2017 which represented the approximate start and end dates for the Eulimbah colony. Tori Lignum Swamp ibis colony was detected during aerial survey on 20 December 2016 but based on the advanced nature of the colony the approximate start date was early December with the colony completed by the final ground survey on the 15 March 2017.

During each colony survey the development stages of offspring (see Table 6-24) on each nest clump was recorded. Reproductive success was calculated for between survey periods (e.g. survival rates between survey 1 & 2) and total breeding period (overall survival rate from egg to fledging) for straw-necked ibis (only). Reproductive success for Australian white ibis, royal spoonbill and glossy ibis were not calculated due to low sample sizes (see Table 6-22). The low number of nests monitored was indicative of the lower abundance of these species in the colonies (<10% in total). Surveys of lignum nesting species (ibis, spoonbills) continued fortnightly until chicks fledged or it was no longer possible to associate chicks with specific nest clumps. Any evidence of waterbird mortality in the colony was also recorded.

Water depths at each nest clump were measured during each survey and water quality measurements (temperature, pH, conductivity, salinity, total dissolved solids, and resistivity) were recorded from four random locations on each survey date in each colony. Water quality ratings discussed in the results are based on ANZECC (2000) guidelines for Freshwater Lakes and Reservoirs in South-East Australia (no comparable data is available for freshwater wetlands).

Plate 6-4 Nest monitoring of an active ibis colony (Credit: J Spencer 2017).

Table 6-24 Chick development stages recorded during each colony survey (based on Marchant and Higgins 1998).

Development stage	Characteristics	Age (days)
Egg	Whole egg, being incubated by adult	1-20
Chicks	Recently hatched (1-5 days old), downy feathers, immobile	21-25
Squirters	Early sheathed feathers starting on wings, still in nest, immobile	26-30
Runners	Development of pin feathers. Mix of down and feathers, walking awkwardly, can leave nest on foot	31-35
Flappers	Nearly fully feathered, cannot fly but flaps between nests	36-40
Flyers	Fully feathered, able to fly and leave nests, still attended by parents at nest	41-47
Fledged	Independent, does not return to nest but roosts in nearby trees	>48

We included two methodological change from the original M & E Plan (Wassens, Jenkins et al. 2014), which allowed for extended data collection on ibis colonies in the Lowbidgee floodplain. This included addition of the new ibis colony in Tori Lignum Swamp, in North Redbank, to the Category 1 monitoring program and use of Unmanned Aerial Vehicles (UAVs or Drones) to collect colony size information. The original methodology proposed to use boat/canoe with a differential GPS to map colony extent (Wassens, Jenkins et al. 2014), however, recent advancements in the use of UAVs has allowed us to collect detailed information on boundary extent, nest locations, number of nests and species mix across an entire colony (Lyons, Brandis et al. 2017). UAVs were also used successfully in the Lachlan Selected Area in 2016-17 to capture colony extent for large ibis colonies in the Lower Lachlan (Dyer, Broadhurst et al. 2017).

A UAV was used to capture colony extent for the Eulimbah ibis colony on 21 November 2016. Flying height for colony monitoring began at 100 m with height slowly decreased to approximately 40-50 m provided no adverse reactions were detected, which allowed for capture of high resolution photography (4cm resolution). Data captured by the UAV was processed using specialised software (Pix4D) to create an orthomosiac of the Eulimbah Swamp colony. Using GIS software each nest location was marked, and the colony boundary mapped to provide a detailed measure of colony size (number of nests) and extent (Figure 6-78). UAV data was also cross referenced with ground based data (GPS locations of nests and colony boundaries) to assess accuracy. The accuracy of nest identification in the Eulimbah colony from UAV survey compared to ground surveys was 90% with UAV derived counts underestimating total number of nests. Due to access and timing issues, it was not possible to use UAVs to capture colony extent of the Tori Lignum Swamp or Telephone Bank ibis colonies. A combination of ground surveys and oblique aerial photographs taken during aerial surveys of the Lowbidgee floodplain (see Plate 6-5) were used instead to estimate colony size.

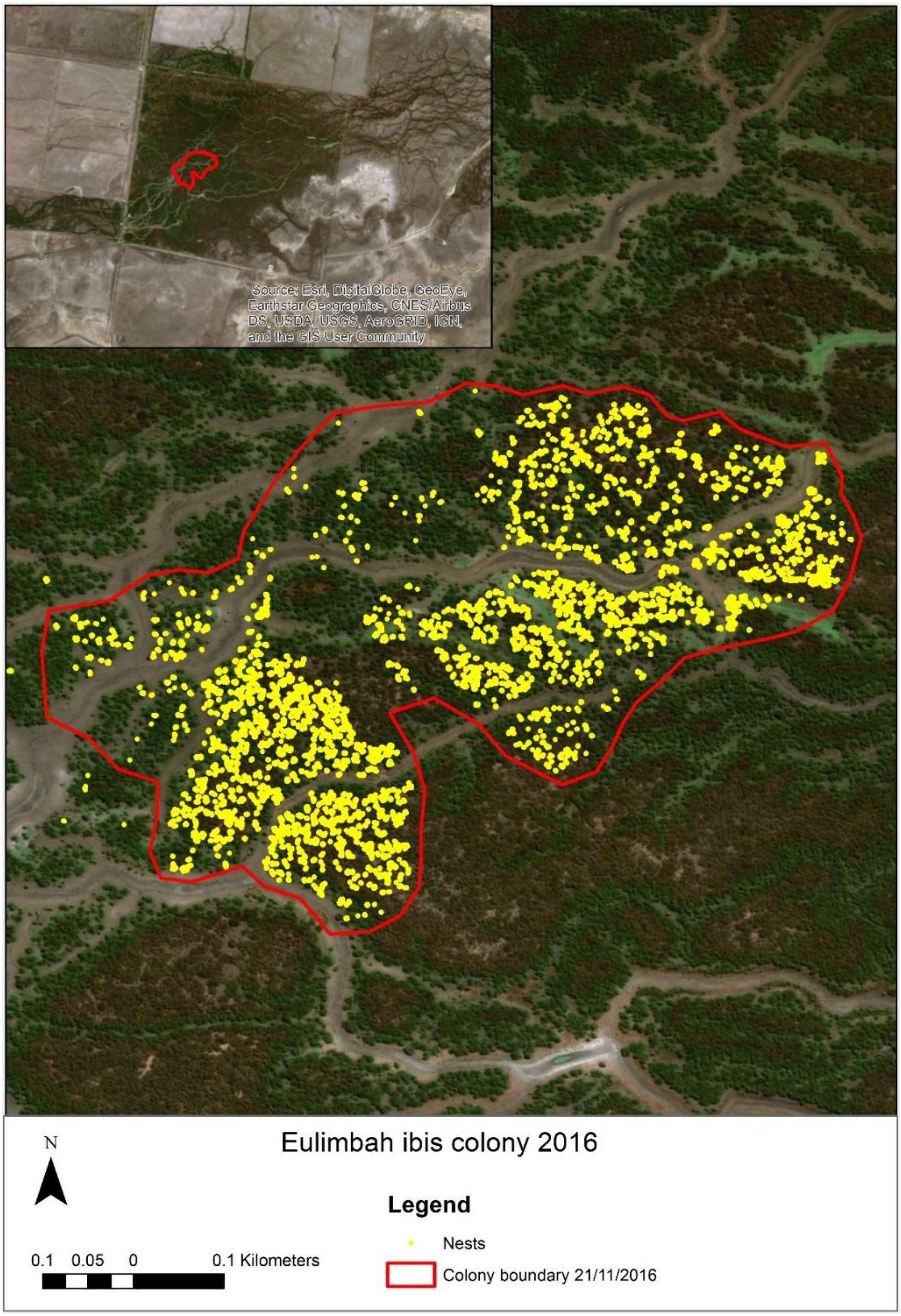


Figure 6-78 Map indicating extent of the Eulimbah ibis colony, in the Nimmie-Caira wetland zone, as determined from a UAV survey on 21 November 2016.

Category 3 Waterbird Breeding Monitoring

Category 3 colony sites in the Redbank and Nimmie-Caira zones focused on wetlands which have historically supported large numbers of nesting egrets, including the eastern great egret (*Ardea modesta*)(listed under JAMBA migratory bird agreement). UNSW annual spring aerial surveys (21 October 2016) and CEWO/OEH (20 December 2016) aerial surveys provided information on the location and size of colonies in the Redbank and Nimmie-Caira systems. Follow-up ground surveys focused on accessible egret, cormorant, heron and pelican colony sites were done by OEH and CEWO staff from October 2016 through to June 2017 (Table 6-21). The ground surveys were conducted on foot, or using a large canoe or small boat allowing for estimates of colony boundary, total number of nests for each species, stage of nesting, evidence of mortality and information on water depths across each colony (as detailed in Wassens, Jenkins et al. 2014).

For most colony sites, a complete assessment of total number of nests per species was possible by two observers systemically moving from one nesting tree to the next. For the large pelican colony at Kieeta Lake the density of nests at the start of the nesting event was estimated by detailed counts of four subsections (approximately 50m in length) spread across the colony and these estimates were used to provide an extrapolated count of total number of pelican nests. An evaluation of breeding success for each site was based on observations made during the monthly surveys where the number of birds in each development stage (as shown in Table 6-24) was recorded and the end of the breeding events based on a count of total number of fledged birds, number of predators (i.e. feral predators and raptors) observed and number of dead birds (if present) recorded in each colony.

Water level gauging

As some colonially-nesting waterbird species are sensitive to sudden changes in water level, real-time information on the status of nesting birds and water levels is needed during breeding events to support adaptive management of environmental water. Automated depth loggers were installed at Eulimbah and Telephone Bank as part of the LTIM program to provide continuous measurements of water depth over each water year. Additional water level sensors were installed at Eulimbah Swamp

(21 November 2016), Tori Lignum Swamp (1 February 2017) and Two Bridges Swamp (31 January 2017) so that water level information could be accessed in real time to guide water management of major colony sites (note that a water level sensor had already been installed by NSW OEH at Telephone Bank in 2010-11).

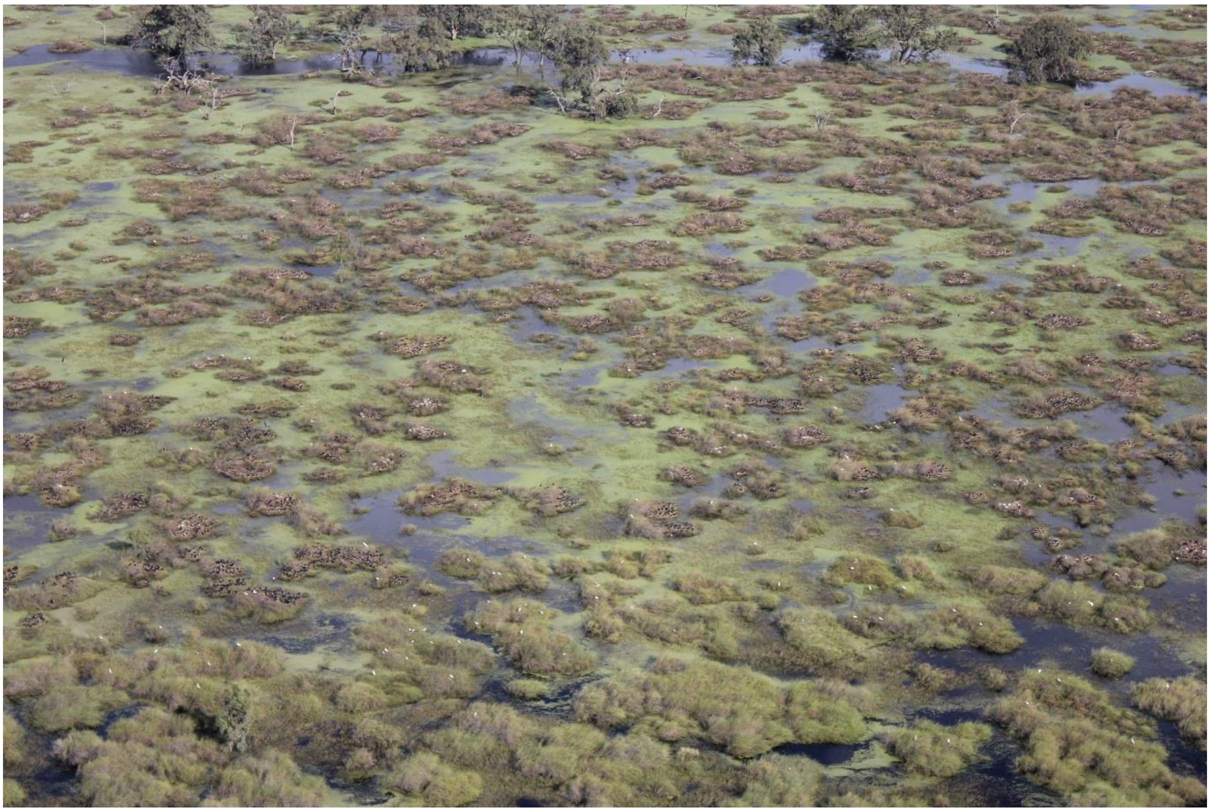


Plate 6-5 Aerial view of nesting straw-necked ibis, glossy ibis, Australian white ibis and royal spoonbill in Tori Lignum Swamp (Photo. A. Borrell, NSW NPWS, 20 December 2016).

Results

What did Commonwealth environmental water contribute to waterbird breeding?

Colony surveys (Cat 1 and Cat 3)

Commonwealth environmental water delivered in 2016-17 contributed to breeding in 19 species of colonial waterbirds (and at least 14 non-colonial waterbird species) in wetlands across the Murrumbidgee Selected Area (the contribution of Commonwealth environmental water to non-colonial waterbird diversity, abundance and breeding activity is assessed in more detail in Section 6.11 Waterbird Diversity). There were six Commonwealth environmental watering actions that supported waterbird breeding in the Lowbidgee Floodplain in 2016-17. These watering actions were focused on three large ibis colonies (totally more than 50,000 ibis nests, predominately straw-necked ibis) at Eulimbah (15,000 nests), Telephone Bank (30,000 nests) and Tori Lignum (5,000 nests) Swamps, and four medium (500-1,000 nests each) egret and heron colonies in the Redbank zone (including two sites in Yanga National Park) and the Nimmie-Caira zone (Nap Nap Swamp), and a large pelican breeding event (6,000 nests) at Kieeta Lake in the Nimmie-Caira zone (Plate 6-6).

Four of these major colonies (Nap Nap, Telephone, Tarwillie and Two Bridges (Yanga National Park) which received Commonwealth environmental water supported nesting JAMBA listed Eastern great egret (Japan-Australia Migratory Bird Agreement). In addition to these nine major colonies there were an additional 19 colonies supporting nesting cormorants and herons across the Murrumbidgee Selected Area (

Table 6-25).

The magnitude of colonial waterbird breeding (number of colony sites, number of breeding species and number of nests) observed in 2016-17 has not been recorded in the Lowbidgee Floodplain since the 2010-11 water year. In both the 2010-11 and 2016-17 water years, cumulative inundated area across the Lowbidgee Floodplain exceeded 150,000 ha with flooding commencing late winter-early spring. Note that where flooding exceeded this threshold in 2011-12 the majority of overbank flooding occurred in mid-autumn outside of the preferred breeding period for most colonially-nesting waterbird species (Figure 6-79).

In total 29 colony sites were active in the Murrumbidgee Selected Area in 2016-17 with four new colony sites detected (

Table 6-25 and Figure 6-79). This included new large colony sites in Tori Lignum Swamp (ibis), in North Redbank and Kieeta Lake (pelicans), in the Nimmie-Caira. Additional nesting species recorded in 2016-17 included Australian pelican *Pelecanus conspicillatus* and pied heron *Egretta picata* which have not been confirmed breeding in the Lowbidgee Floodplain in previous years of surveys (Figure 6-79).

Plate 6-6 Young pelicans on the Kieeta Lake colony, Nimmie-Caira during a survey in early March 2017 (Credit: E. Lenon).

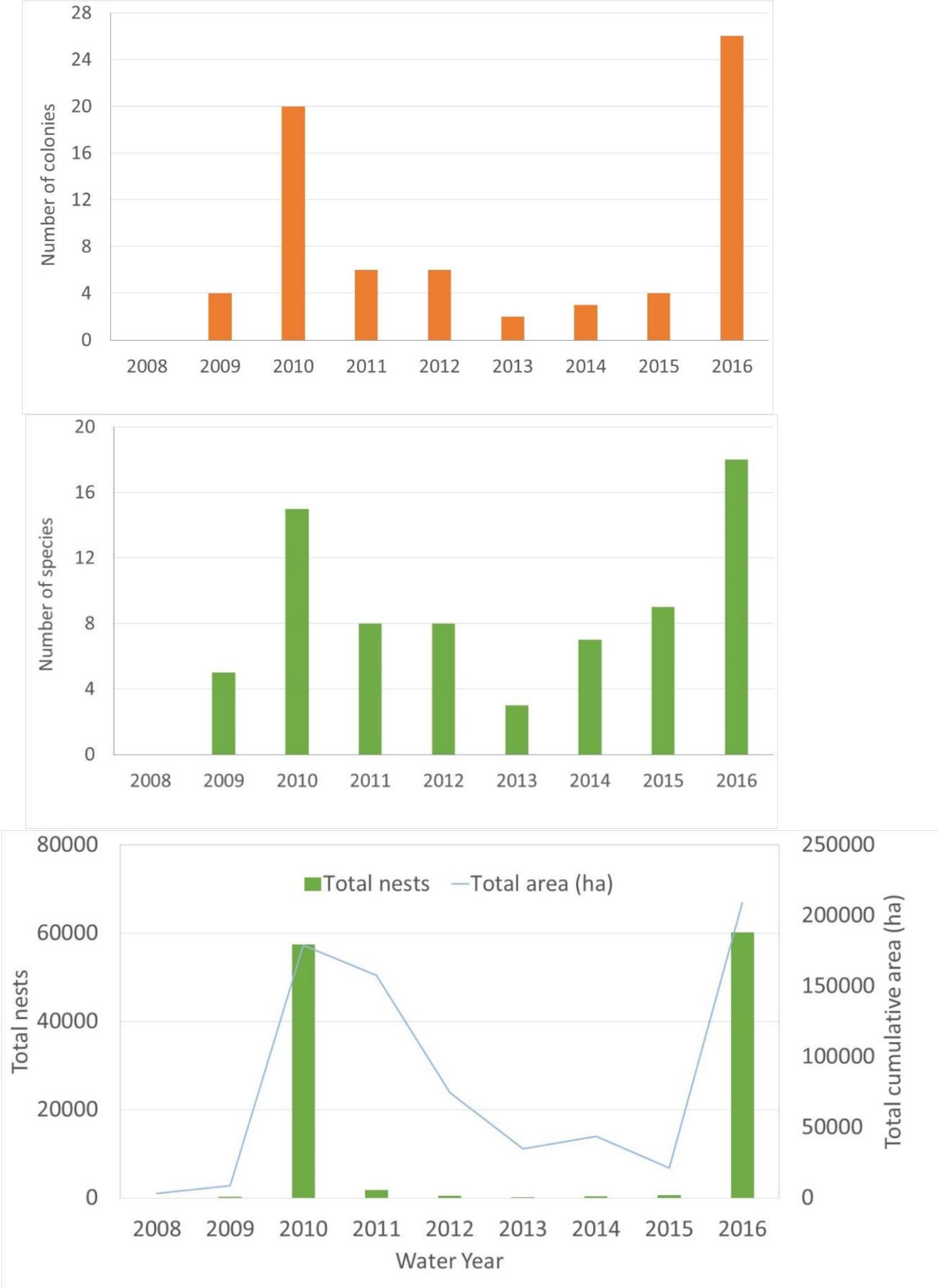


Figure 6-79 Summary of colonial waterbird breeding recorded across the Lowbidgee Floodplain from 2008 onwards including total number of colony sites (upper), total number of breeding species (middle) and total number of nests (lower) observed in each water year from 2008-17.

Table 6-25 Overview of colonial waterbird breeding in the Murrumbidgee Selected Area in 2016-17 including estimated total number of nests and total number of species. *Incomplete counts. Note assessments of total numbers of nests for Dry Lake, Breer and Riverleigh Swamps were made in spring 2017 surveys based on total number of recently used nests.

Colony Name	Total nests	Total species	Dominant species
Nimmie-Caira			
Eulimbah Swamp	15,104	4	Straw-necked ibis
Kieeta Lake	6,000	1	Australian pelican
Telephone Bank	30,799	4	Straw-necked ibis
Nap Nap Swamp	671	10	Nankeen night-heron & cormorants
House Creek	44	4	Cormorants
Loorica Lake	532	6	Cormorants
Redbank			
Breer Swamp*	53	1	Little pied cormorant
Glenn Dee Swamp	417	5	Cormorants
McGabes Regulator*	50	1	Nankeen night-heron
Monkem Creek	2	2	Little pied cormorant, white-faced heron
Narwie Swamp	84	2	Cormorants
North Stallion Swamp	133	5	Cormorants & herons
Piggery Lake	128	6	Cormorants
Riverleigh Swamp*	119	>1	Cormorants
Steam Engine	1,493	11	Nankeen night-heron & intermediate egret
Tala Creek	45	2	Nankeen night-heron & white-necked heron
Tala Lake	269	8	Cormorants
Tarwillie Swamp	793	10	Eastern great egret, cormorants
Two Bridges (East)	160	3	Cormorants
Two Bridges (West)	1,049	9	Nankeen night-heron & egrets
Top Narockwell	164	6	White-necked heron, Eastern great egret
Tori Lignum Swamp	6,106	5	Straw-necked ibis
Waugorah Lagoon	5	3	Yellow-billed spoonbill & cormorants
Waugorah Lake	500	6	Cormorants
Yanga Creek	75	4	White-necked heron
Mid-Murrumbidgee			
Gooragool Lagoon	629	4	Cormorants
Yarradda Lagoon	171	10	Cormorants
Dry Lake*	10	1	Cormorants
Pimpara-Wagourah			
Maude Lagoon	11	3	Herons & spoonbills

What did Commonwealth environmental water contribute to waterbird chick fledgling and survival?

Nesting was first detected at the Eulimbah colony in late October during annual spring aerial and ground surveys. Counting nests from UAV imagery (acquired on 21 November 2016) indicated that there were approximately 15,000 nests in the Eulimbah colony which covered around 25 hectares of channelised lignum and open water (Figure 6-78). For the main nesting period (October – December 2016.) the composition of the Eulimbah colony was around 99% straw-necked ibis, <1% Australian white ibis and <1% royal spoonbill. Mean clutch size for straw-necked ibis nests was 2.36 eggs/nest. Straw-necked and Australian white ibis bred at this colony location from late October/early November to the end of December 2016. Royal spoonbill nesting began early January 2017 (Figure 6-80). Additional pairs of royal spoonbill (around 30 nests), Australian white ibis (around 5 nests) and nankeen night heron (around 10 nests) nested from late January through to early March.

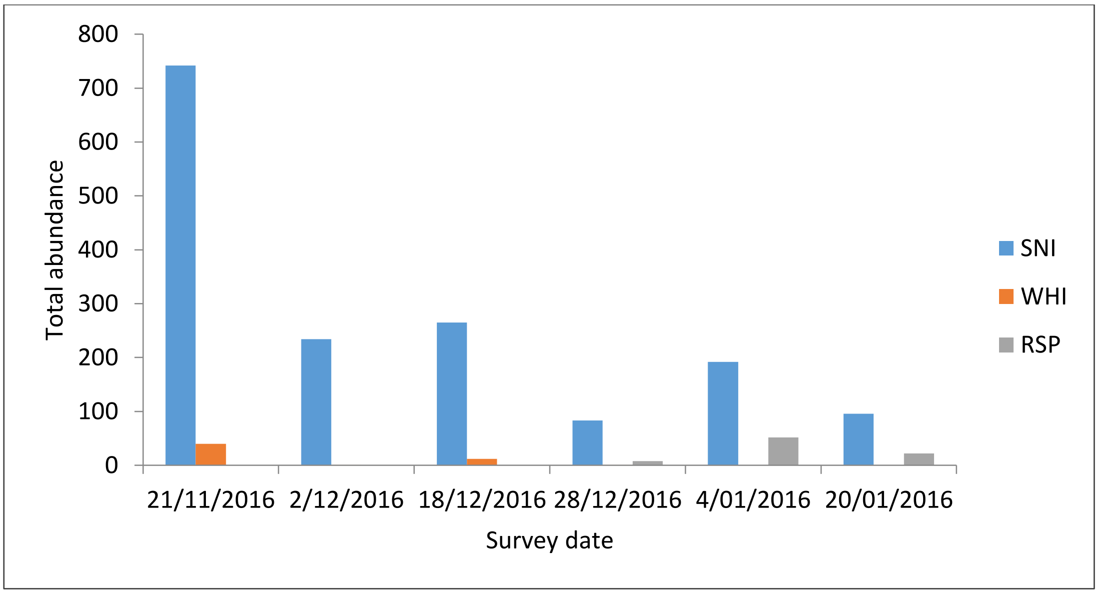


Figure 6-80 Breeding species composition of the Eulimbah colony to include straw-necked ibis (SNI), Australian white ibis (WHI) and royal spoonbill (RSP).

Straw-necked ibis, Australian white ibis, glossy ibis and royal spoonbill bred at Tori Lignum Swamp in North Redbank from early December 2016 through to March 2017. The area of the colony contained around 5,000 nests spread over a core area of 35 hectares with additional small clumps of nesting Australian white ibis and royal spoonbill outside of the core colony boundary (Figure 6-81 and Plate 6-5). It is thought that this was the first time this wetland has supported major colonial waterbird breeding. The site supported predominantly nesting straw-necked ibis (82%), but Australian white ibis (7%), royal spoonbill (8%) and glossy ibis (3%) were also recorded in lower abundance. Mean clutch size for straw-necked ibis nests in Tori Lignum Swamp was 2.01 eggs/nest.

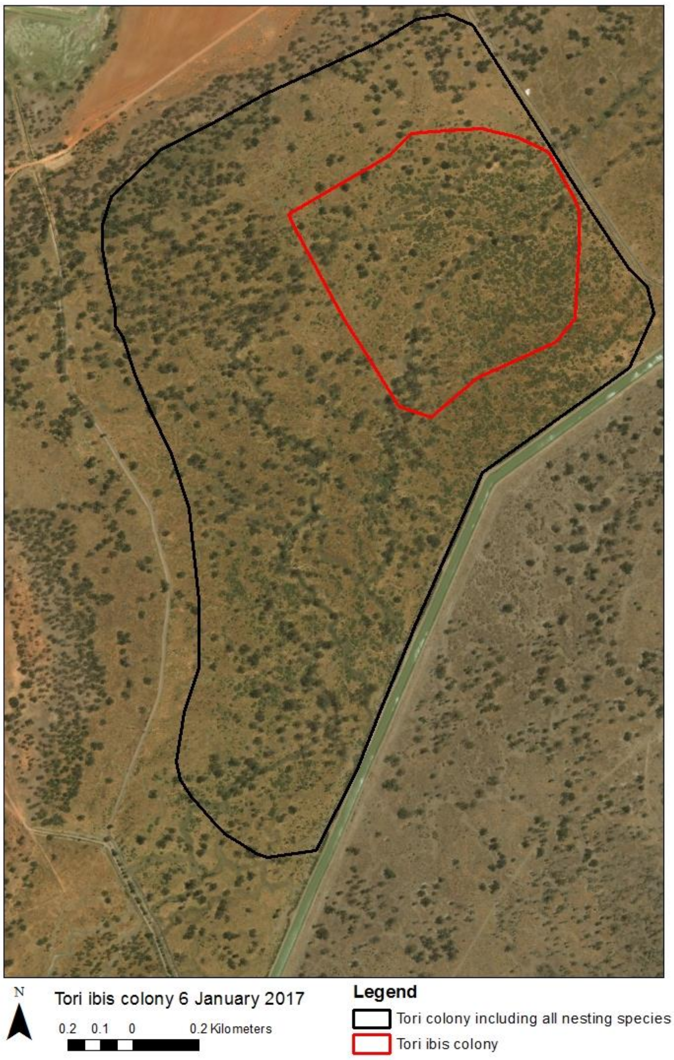


Figure 6-81 Map depicting extent of the waterbird colony at Tori Swamp

Chick development

Ibis were observed trampling in the Eulimbah Swamp colony in late October (20 October) during the annual spring surveys. The first nest survey in late November showed that straw-necked ibis offspring were primarily at egg stage with a small number of chicks; the first survey sampled 700 offspring in marked nests (Figure 6-82). Subsequent monitoring surveys recorded a significant fall in offspring numbers in marked nests (<300) (see Figure 6-82). The composition of the final survey was mostly flapper stage chicks with a small number of offspring representing the other age groups. The Tori Lignum Swamp colony was first detected during an aerial survey in late December (20 December) with 678 offspring sampled in marked nests in early January 2017. Nest surveys of Tori Lignum Swamp indicated that all chick development stages, from eggs to flyers, were represented over the course of the monitoring (Figure 6-82).

Reproductive success

Overall reproductive success rates for straw-necked ibis (number of eggs laid that became fledged juvenile birds) were higher in the Eulimbah Swamp colony (59.44%) than the Tori Lignum Swamp ibis colony (39.74%) (Table 6-26). Eulimbah Swamp had a low success rate between the first two surveys (18.87%) while it had dried down following the blow out of levee banks which were repaired and the site was re-inundated with environmental water (Figure 6-82 and Plate 6-7). Following re-inundating of the Eulimbah Swamp colony reproductive success rates increased to 100% between surveys two (2nd December 2016) and three (18th December 2017) (Table 6-27).

The total number of individuals varied substantially from one survey to the next of the Tori Lignum Swamp colony. In the first survey, there were 678 total offspring (636 eggs) and by the second survey this was down to 304. The number of visible dead straw-necked ibis (juveniles and adults) near the marked clumps reached a maximum of 91 individuals at the third survey time (Table 6-27 and Figure 6-82). In comparison, the nests in the Eulimbah Swamp colony were abandoned at egg stage and had no dead birds in the nests, although there were around seven adult dead or dying adult straw-necked ibis observed in the colony during the first survey. The final surveys of the

Eulimbah and Tori Lignum Swamps recorded several thousand juvenile birds that were foraging and roosting in the colonies (Figure 6-82 and Plate 6-8). While reproductive success was not measured for Telephone Bank, surveys undertaken during the latter part of nesting reported large numbers of healthy, young runners, flappers and fledged young in this site.

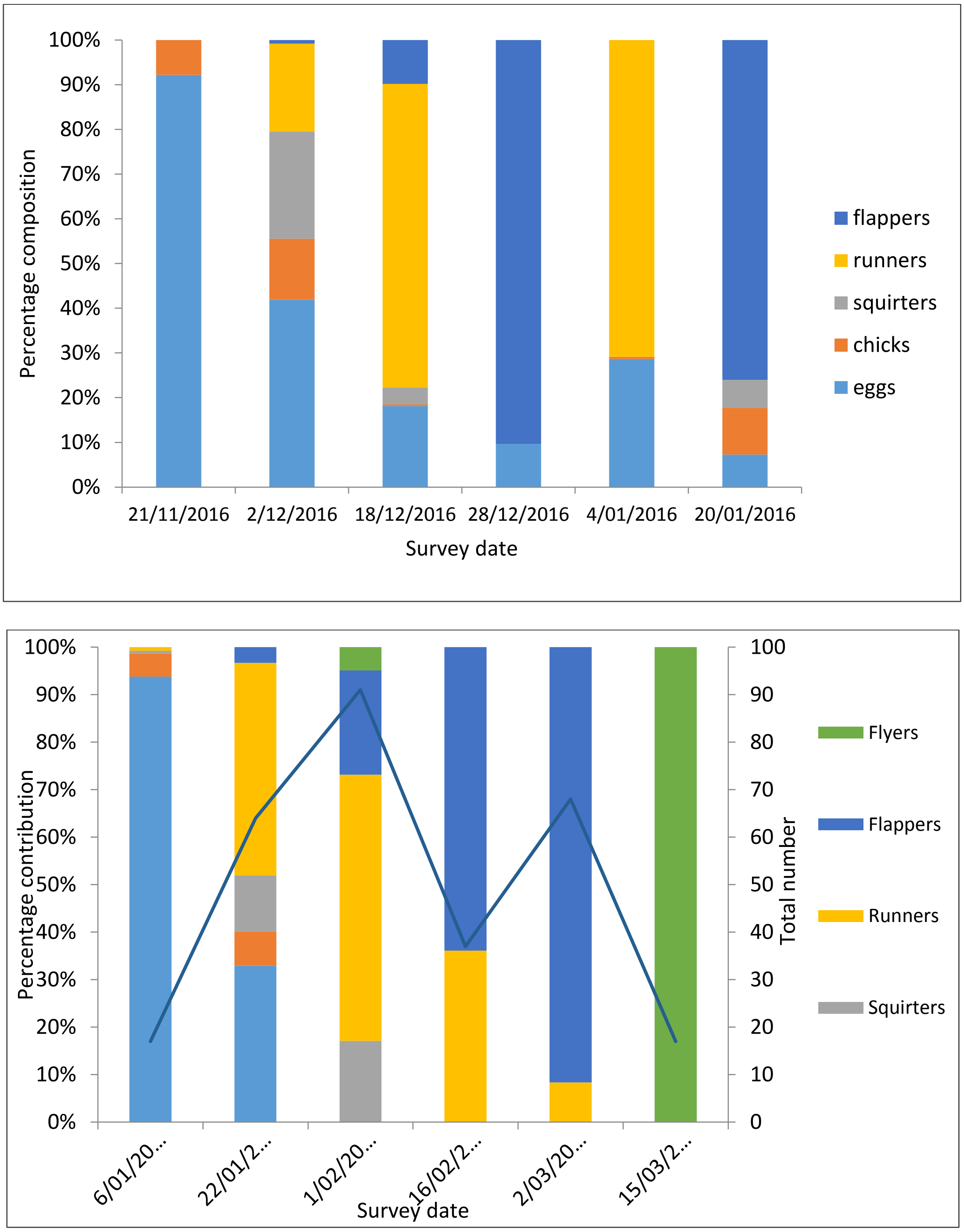


Figure 6-82 Composition of straw-necked ibis offspring stages at marked nest clumps in the Eulimbah Swamp colony (*Upper*) over the six surveys from November 2016 to January 2017 and nest composition in the Tori Lignum Swamp colony (*Lower*) over the six surveys from January – March 2017.

Table 6-26 Summary of breeding period, number of nests and offspring success rate for each colony.

Colony	Breeding period	Number of nests	Overall offspring success rate
Eulimbah	Oct. 2016 – Jan. 2017	14,994	59.44%
Telephone Bank	Oct. 2016 – Jan. 2017	30,000	#
Tori Lignum Swamp	Dec. 2016. – Mar. 2017	~ 5,000	39.74%

Reproductive success was not monitored in the Telephone Bank ibis colony.

Table 6-27 Summary of colony survey data for Eulimbah (*Upper*) and Tori Lignum (*Lower*) Swamps. Total numbers of eggs and chicks (alive) and total dead at nest monitoring sites in Tori Lignum Swamp (no dead chicks were observed in Eulimbah but some nests were abandoned (empty) between surveys 1 and 2). Note that as offspring develop into flappers and flyers they are off the nests and counts are not as accurate.

Eulimbah Swamp	21/11/2017	2/12/2017	18/12/2017	28/12/2017	4/01/2017	20/01/2017
Total eggs/chicks (alive)	742	234	265	83	136	73
Dead birds at nest sites	0	0	0	0	0	0

Tori Lignum Swamp	6/01/2017	22/01/2017	1/02/2017	16/02/2017	2/03/2017	15/03/2017
Total eggs/chicks (alive)	678	304	123	36	12	1
Dead birds at nest sites	17	64	91	37	68	17

Plate 6-7 UNSW Eulimbah Swamp colony survey 21st November 2016. (Photo. K. Brandis).

Plate 6-8 Large numbers of juvenile ibis and spoonbill were roosting in trees in Tori Lignum Swamp ibis colony (upper) and feeding on the edge of the colony (lower) (Credit: E. Lenon).

Water measurements

Environmental water was delivered to Eulimbah and Tori Lignum Swamps to increase water depth to maintain breeding habitat for the duration of both breeding events (Figure 6-83). There was variation in minimum and maximum water depth recorded under nest clumps in Eulimbah Swamp during the colony monitoring (min = 0 cm and max = 81 cm), but mean water depth remained relatively stable between each survey time following re-inundating in late November 2016 (Figure 6-84). Water depth varied considerably between surveys as well as between nest clumps in the Tori Lignum Swamp colony (Figure 6-84). Maximum values ranged from 31 cm - 57 cm while minimum values were between 0-13 cm.

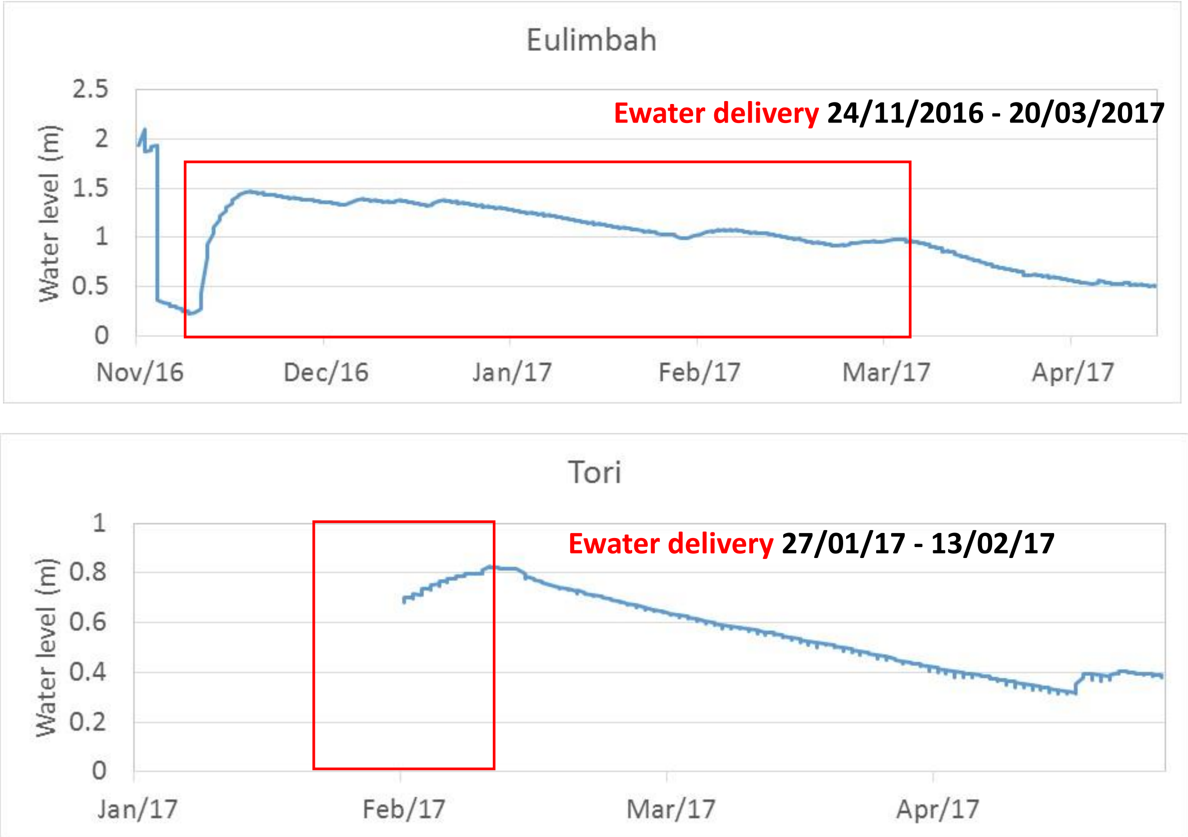
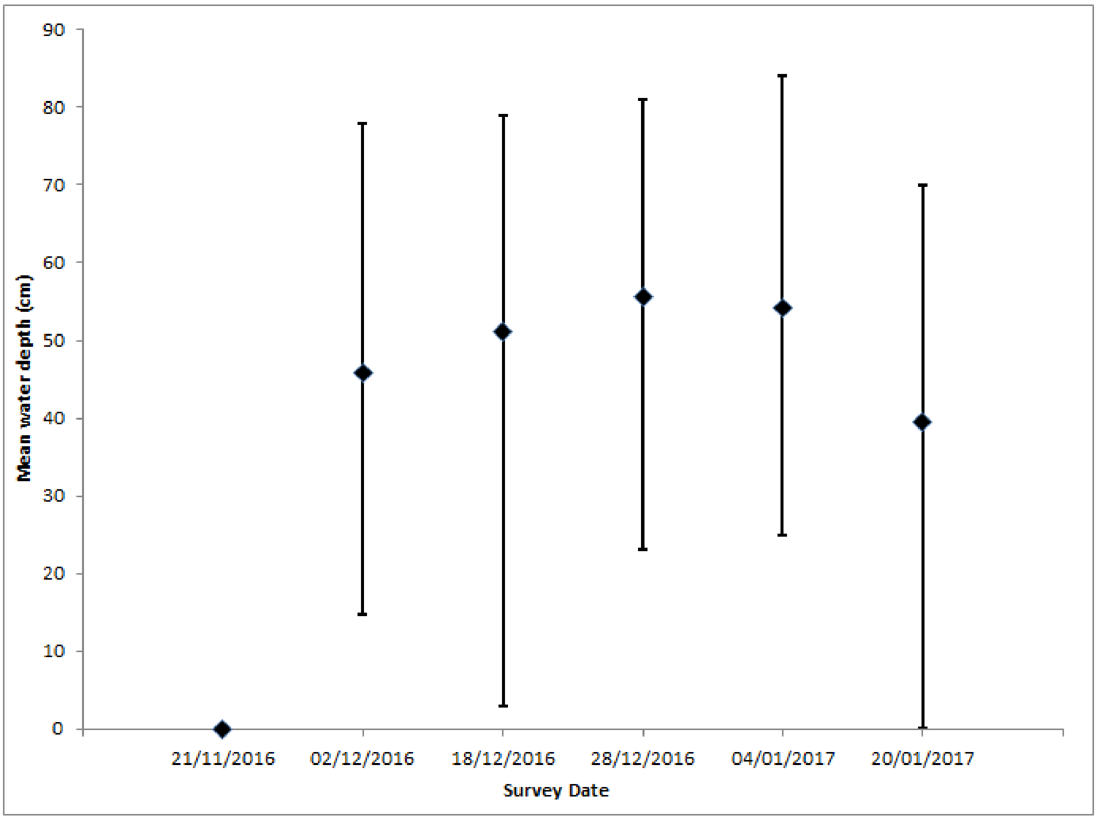


Figure 6-83 Daily water depth measurements taken in the Eulimbah (*Upper*) and Tori Lignum (*Lower*) Swamp ibis colonies and the period of environmental water deliveries to both colony sites.



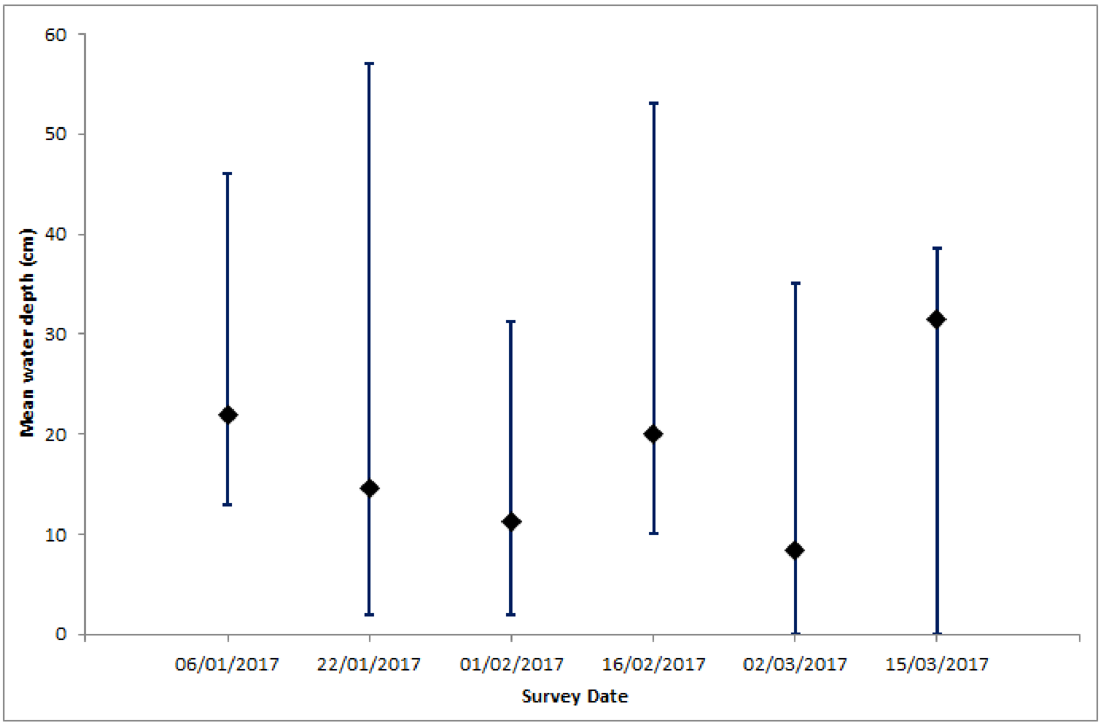


Figure 6-84 Average water depth measurements (and maximum and minimum recorded values) around monitored nest clumps from each survey to Eulimbah Swamp (*Upper*) and Tori Lignum Swamp (*Lower*).

Repeated measurements of water quality taken in Eulimbah and Tori Lignum Swamps are summarised in Table 6-28 and Table 6-29. pH, conductivity and salinity levels at Eulimbah Swamp were within the expected ranges (Table 6-28). Table 6-29 shows that pH levels were elevated above desirable levels (6.5-9.0) for some surveys of Tori Lignum Swamp. The conductivity measures which are closely correlated with salinity values were also higher in Tori Lignum Swamp than the desirable range for still waters (0-0.2 ppt). Spot measurements for dissolved oxygen taken at Tori Lignum Swamp (only) indicated that levels of dissolved oxygen were highly variable across the colony.

Table 6-28 Mean water quality metrics measured at Eulimbah Swamp from three sampling dates. Note that no data was collected on the first survey trip due to water depths being at zero.

Water Quality Metric	18/12/2016	4/01/2017	20/01/2017
Temperature (°C)	20.50	25.33	22.23
pH	7.61	8.02	7.63
Conductivity (S/m)	0.24	0.23	0.23
Salinity (mS/m)		0.10	0.10
Total dissolved solids (ppm)		124.67	122.67
Resistivity MΩ-cm		4.35	4.38

Table 6-29 Mean water quality metrics measured at Tori Lignum Swamp from four sampling dates. Note that no data was collected on the first survey trip due to equipment availability and on the last trip due to water depths being at zero.

Water Quality Metric	22/01/2017	1/02/2017	16/02/2017	2/03/2017
Temperature (°C)	30.68	22.79	29.63	22.35
pH	9.33	7.48	9.04	7.29
Conductivity (S/m)	0.46	0.67	0.48	0.36
Salinity (mS/m)	0.25		0.23	
Total dissolved solids (ppm)	243.00		256.00	
Resistivity (MΩ-cm)	2.24		2.15	
Turbidity (NTU)		82.79		45.07
DO (mg/L)		3.63		1.99
Dissolved Oxygen%		43.21		23.63

Discussion

Commonwealth environmental water was delivered to wetlands in the Redbank and Nimmie-Caria zones in 2016-17 as part of multiple watering actions focused on supporting the water requirements colonial waterbird breeding sites in the Lowbidgee floodplain. The measured outcomes relevant to each specific watering actions monitored under the LTIM program and complimentary monitoring by NSW OEH demonstrated that Commonwealth and State environmental water achieved their stated watering objectives for waterbirds in the Murrumbidgee Selected Area in 2016-17.

What did Commonwealth environmental water contribute to waterbird breeding?

Waterbirds need opportunities to breed in order to maintain and improve waterbird diversity and abundance across the MDB. We predicted the provision of large-scale landscape watering in late winter-early spring would provide habitat for waterbirds and effectively prime the system prior to natural flooding in years the climate outlooks predicted this might occur. The Nimmie-Caira to South Yanga winter watering event inundated more than 49,500 ha of the Lowbidgee floodplain (see Wetland Hydrology Section 6.6). In comparison in the previous water year environmental water was delivered to targeted wetland sites to maintain refuge habitats in late spring 2015 and this benefited small-scale waterbird breeding only (Wassens, Spencer et al. 2016).

We predicted that maintenance of water levels in colony sites using Commonwealth environmental water would support successful breeding of colonial waterbird species and this was supported by our 2016-17 monitoring results. Following the delivery of environmental water in winter 2016 and widespread natural flooding we observed an increase in the number of active waterbird colonies and number of breeding species in the Murrumbidgee Selected Area. Following the recession of natural floodwaters, environmental water was required to increase and/or maintain the depth of inundation for active colony sites in the Nimmie-Caira and Redbank zones. If environmental water had not been delivered these sites would have dried out quickly and made the nesting birds vulnerable to predation by ground predators including foxes, cats and pigs.

What did Commonwealth environmental water contribute to waterbird fledging and survival?

We predicted that maintenance of water levels and increased flow rates in colony sites using Commonwealth environmental water would support successful fledging of colonial waterbird chicks and this was supported by our 2016-17 monitoring results. Re-inundation of the Eulimbah Swamp colony using Commonwealth environmental water improved the reproductive success rate of nesting ibis and allowed those young that had survived the initial dry period to fledge.

Reproductive success rates at Tori Lignum Swamp were low when compared to Eulimbah Swamp and other colonies active in the MDB in 2016-17 (Brandis *et al.* unpublished data), however, the delivery of Commonwealth environmental water provided newly inundated foraging habitat adjacent to the colony that was exploited by juvenile ibis and spoonbills and may have improved water quality within the rookery site. We recorded 1,500 juveniles in the late stage of the Tori Lignum Swamp breeding event in early March 2017.

Observations of dead or dying birds were made in Eulimbah Swamp during surveys 3 and 4 and throughout all surveys at Tori Lignum Swamp (Table 6-27). This included straw-necked ibis (adults and juveniles) and a range of waterfowl species. The results of testing by the CSU Veterinary Diagnostic Laboratory showed the absence of significant (non-terminal) gross and histopathology which was suggestive of a subacute toxicity such as botulism as the main cause of death. Avian botulism is a naturally occurring disease that has been shown to cause major mortality in waterbirds in the northern hemisphere (Rocke and Samuel 1999). The disease is caused by ingestion of the toxin produced by the bacteria *Clostridium botulinum.* The bacteria is naturally widespread in soil but needs warm temperatures, protein source (such as dead fish) and anaerobic (low oxygen) environment to become active to produce the toxin. The impact of this disease on Australian waterbirds is less understood and the full complements of Botulinum toxicity tests are not readily available in Australia as yet.

Water quality testing in Tori Lignum Swamp also indicated that pH and salinity levels were elevated in this site compared to Eulimbah Swamp and the ANZECC guidelines for freshwater systems. The implication for water quality measures outside the ranges preferred by aquatic organisms has implications for the availability and quality of aquatic food resources for waterbirds and other wetland fauna. In a wetland ecosystem pH can be affected by carbon dioxide (CO2) in the water. Higher levels of CO_2, as a result of plant photosynthesis, respiration and decomposition is a common cause of acidity in the water. In a study by Rocke and Samuel (1999) the risk of botulism outbreaks in sampled wetlands are increased where water pH was between 7.5-9.0 and water temperatures were greater than 20◦C.

Spot measurements for dissolved oxygen measurements were only taken at Tori Lignum Swamp and these were highly variable across the colony site (for example measurements taken on 1 February ranged from 1.2-6.1 mg/l (Table 6-29) but this is not uncommon for naturally-functioning wetlands where DO levels can vary hourly. The Tori Lignum Swamp ibis colony was active later in the season than the Eulimbah Swamp colony therefore the Tori Lignum Swamp colony was active during a period of extreme temperatures over January-February 2017, combined with lower water levels at this site compared to Eulimbah Swamp and Telephone Bank, these conditions probably contributed to the higher rates of dead birds in the Tori Lignum Swamp colony.

Recommendations

In the last 15-year period, large colonial waterbird and non-colonial waterbird breeding in the Lowbidgee floodplain have coincided with widespread flooding (Table 6-21). While small-scale colonial-waterbird breeding (<500 nests) did occur outside of these large flood events (Figure 6-79), colonial-nesting waterbirds and non-colonial waterbird species require widespread overbank flooding to maximise opportunities to breed and for recruitment of their young. These large events are crucial for the long-term maintenance of waterbird species in the MDB. Historically adjoining habitats to the main colony sites, Eulimbah, Telephone, Nap Nap and Avalon Swamps in the Nimmie-Caira zone, would have been inundated during wet years creating large areas of foraging habitat for colonial and non-colonial waterbird species and supporting the establishment of large breeding colonies.

Key hydrological variables that contribute to successful breeding by colonial waterbirds such as ibis and spoonbill, include sufficient water depths, duration of inundation, flow movement and provision of foraging habitat. As previously recognised (Brandis, Ryall et al. 2011), and demonstrated again at Eulimbah Swamp during the 2016-17 season, water depth is a key driver of reproductive success for ibis species. Adequate water depths are critical as they not only provide suitable nesting habitat (inundated vegetation) but when sufficiently deep enough prevent predation by ground based predators (e.g. pigs, foxes, cats). It is important that the duration of inundation covers the full nesting period including the trampling and establishment of nesting, through to fledging of young. This is particularly successful when done in combination with complementary actions to control feral predators. For example, feral pigs were observed outside the Tori Lignum Swamp ibis colony and Kieeta Lake pelican colony and an active program of feral pig control was undertaken by the Tori Lignum Swamp landholder, and by NSW DPI Water and NSW OEH in Kieeta Lake.

Extended periods of inundation provide opportunities for young birds to build up body condition prior to leaving the nesting site. They also provide further opportunities for breeding by other species as was observed in Eulimbah Swamp and Telephone Bank. The breeding period for straw-necked ibis, from laying to chicks leaving their nests and taking short flights (flapper stage), is around 45-53 days with an additional 14 days of post-fledging feeding by adults (Brandis, Kingsford et al. 2011).

Ongoing flow and movement of water through the colony site is important for managing water quality issues including eutrophication and avian diseases, such as botulism. Observations of dead or dying birds were made in Eulimbah Swamp during surveys 3 and 4 and throughout all surveys at Tori Lignum Swamp. Autopsies were carried out on a black swan and straw-necked ibis (collected from Tori Lignum Swamp), with the results showing the absence of significant (non-terminal) gross and histopathology was suggestive of a subacute toxicity such as botulism. Future management of large breeding events should consider monitoring key variables that will assist in the management of the risk of avian botulism to improve outcomes for waterbird populations.

Inundation also needs to encompass foraging grounds adjoining key colony sites to support successful breeding. It is likely that the early watering event in August 2016 acted to prime the system prior to the natural widespread flooding. This pattern of inundation with large environmental flows occurring prior to widespread natural flooding occurred in 2010-11 which also coincided with the establishment of large ibis colonies in the Telephone and Eulimbah Swamps (Brandis, Ryall et al. 2011). Inundation of key colony sites and also adjoining foraging grounds is necessary to support successful breeding. Sufficient food supplies need to be available prior to breeding for adult birds to build up condition, and then for the duration of the breeding event and post-fledging period to support adult birds and their young (Scott 1997, Brandis and Bino 2016).

Future planning of Commonwealth environmental water use in the Murrumbidgee Selected Area should also consider inundating habitats known to historically support colonially-nesting waterbirds which have since been degraded. This includes lignum shrubland in the Nimmie-Caira zone, and river red gum sites in south Yanga National Park and parts of the mid-Murrumbidgee zone which have not supported breeding in the last decade.

If colonial waterbird breeding is detected in the Murrumbidgee Selected Area and/or neighbouring catchments Commonwealth environmental water should be used to maintain inundation of foraging habitat over summer and autumn months to promote the survival of young birds. This approach will also maximise opportunities for breeding in non-colonial waterbird species. Following colonial waterbird breeding events in the Lowbidgee floodplain and neighbouring wetlands (i.e. the Lower Lachlan and mid-Murray) Commonwealth environmental water should be prioritised for delivery to key foraging areas in months and the water year following breeding to promote survival of first year birds which in turn will contribute to the maintenance of waterbird diversity and abundance across the MDB.

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Appendix A: Wetland-dependent bird species recorded from 2014-17.

Functional Group	Common Name	Scientific Name	CAVS Code
Australian-breeding Charadriiform shorebirds	Australian pratincole	*Stiltia isabella*	173
	Black-fronted dotterel	*Elseyornis melanops*	144
	Black-winged stilt	*Himantopus leucocephalus*	146
	Masked lapwing	*Vanellus miles*	133
	Red-capped plover	*Charadrius ruficapillus*	143
	Red-kneed dotterel	*Erythrogonys cinctus*	132
	Red-necked avocet	*Recurvirostra novaehollandiae*	148
Dabbling and filter-feeding ducks	Australasian shoveler	*Anas rhynchotis*	212
	Chestnut teal	*Anas castanea*	210
	Grey teal	*Anas gracilis*	211
	Pacific black duck	*Anas superciliosa*	208
	Pink-eared duck	*Malacorhynchus membranaceus*	213
Diving ducks, aquatic gallinules and swans	Black swan	*Cygnus atratus*	203
	Dusky moorhen	*Gallinula tenebrosa*	56
	Eurasian coot	*Fulica atra*	59
	Hardhead	*Aythya australis*	215
	Musk duck	*Biziura lobata*	217
Grazing ducks and geese	Australian shelduck	*Tadorna tadornoides*	207
	Australian wood duck	*Chenonetta jubata*	202
	Magpie goose v	*Anseranas semipalmata*	199
	Plumed whistling-duck	*Dendrocygna eytoni*	205
Migratory Charadriiform shorebirds	Sharp-tailed sandpiper J,C,R	*Calidris acuminata*	163
Piscivores (including grebes, cormorants, egrets, bitterns, terns and kingfisher)	Australasian bittern E e	*Botaurus poiciloptilus*	197
	Australasian darter	*Anhinga novaehollandiae*	8731
	Australasian grebe	*Tachybaptus novaehollandiae*	61
	Australian gull-billed tern	*Gelochelidon macrotarsa*	8794
	Australian pelican	*Pelecanus conspicillatus*	106
	Cattle egret J	*Bubulcus ibis*	977
	Eastern great egret J	*Ardea alba modesta*	8712
	Great cormorant	*Phalacrocorax carbo*	96
	Great crested grebe	*Podiceps cristatus*	60
	Hoary-headed grebe	*Poliocephalus poliocephalus*	62
	Intermediate egret	*Ardea intermedia*	186
	Little black cormorant	*Phalacrocorax sulcirostris*	97
	Little egret	*Egretta garzetta*	185
	Little pied cormorant	*Microcarbo melanoleucos*	100
	Nankeen night-heron	*Nycticorax caledonicus*	192
	Pied cormorant	*Phalacrocorax varius*	99
	Pied heron	*Egretta picata*	190
	Sacred kingfisher	*Todiramphus sanctus*	326
	Whiskered tern	*Chlidonias hybrida*	110
	White-faced heron	*Egretta novaehollandiae*	188
	White-necked heron	*Ardea pacifica*	189
Rails and shoreline gallinules	Australian spotted crake	*Porzana fluminea*	49
	Baillon's crake	*Porzana pusilla*	50
	Black-tailed native-hen	*Tribonyx ventralis*	55
Rails and shoreline gallinules	Buff-banded rail	*Gallirallus philippensis*	46
	Purple swamphen	*Porphyrio porphyrio*	58
Raptor	Australian Hobby	*Falco longipennis*	235
	Black kite	*Milvus migrans*	229
	Brown falcon	*Falco berigora*	239
	Nankeen kestrel	*Falco cenchroides*	240

	Swamp harrier	*Circus approximans*	219
	Whistling kite	*Haliastur sphenurus*	228
	White-bellied sea-eagle v	*Haliaeetus leucogaster*	226
Reed-inhabiting passerines	Australian reed-warbler	*Acrocephalus australis*	524
	Golden-headed cisticola	*Cisticola exilis*	525
	Little grassbird	*Megalurus gramineus*	522
Storks, cranes, ibis and spoonbills (large wading birds)	Australian white ibis	*Threskiornis moluccus*	179
	Glossy ibis	*Plegadis falcinellus*	178
	Royal spoonbill	*Platalea regia*	181
	Straw-necked ibis	*Threskiornis spinicollis*	180
	Yellow-billed spoonbill	*Platalea flavipes*	182

^Status: J = JAMBA, C = CAMBA, R = ROKAMBA (listed under international migratory bird agreements Australia has with Japan, China, Republic of Korea, respectively), listing under the NSW *TSC Act 1995* (e = endangered), and under Commonwealth *EPBC Act 1999* (E = Endangered). Functional groups as described by (Hale, Stoffels et al. 2014) Nomenclature follows (Christidis and Boles 2008)

Appendix B: Colonial waterbird species recorded breeding in the Murrumbidgee Selected Area in 2016-17.

Family	Common Name	*Scientific Name*	Functional Group	CAVS Code
Anhingidae	Australasian darter	*Anhinga novaehollandiae*	Piscivore	8731
Ardeidae	Cattle egret J	*Bubulcus ibis*	Piscivore	977
	Eastern great egret J	*Ardea alba modesta*	Piscivore	8712
	Intermediate egret	*Ardea intermedia*	Piscivore	186
	Little egret	*Egretta garzetta*	Piscivore	185
	Nankeen night-heron	*Nycticorax caledonicus*	Piscivore	192
	Pied heron	*Egretta picata*	Piscivore	190
	White-faced heron	*Egretta novaehollandiae*	Piscivore	188
	White-necked heron	*Ardea pacifica*	Piscivore	189
Pelicanidae	Australian pelican	*Pelecanus conspicillatus*	Piscivore	106
Phalacrocoracidae	Great cormorant	*Phalacrocorax carbo*	Piscivore	96
	Little black cormorant	*Phalacrocorax sulcirostris*	Piscivore	97
	Little pied cormorant	*Microcarbo melanoleucos*	Piscivore	100
	Pied cormorant	*Phalacrocorax varius*	Piscivore	99
Threskiornithidae	Australian white ibis	*Threskiornis moluccus*	Large wader	179
	Glossy ibis	*Plegadis falcinellus*	Large wader	178
	Royal spoonbill	*Platalea regia*	Large wader	181
	Straw-necked ibis	*Threskiornis spinicollis*	Large wader	180
	Yellow-billed spoonbill	*Platalea flavipes*	Large wader	182

^Status: J = JAMBA (listed under Japan-Australia Migratory Bird Agreement). Functional groups as described by (Hale, Stoffels et al. 2014) Nomenclature follows (Christidis and Boles 2008). Census of Australian Vertebrate Species (CAVS) Codes have been developed by the Australian Fauna Directory (AFD).