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Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project Murrumbidgee River System Technical Report 2014-18

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project Murrumbidgee River System Selected Area Technical Report, 2014-18. March 2019

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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. The Murray-Darling Basin Plan (2012) (referred to hereafter as the Basin Plan) 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 inform environmental water management and demonstrate 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 2017-18, the first four years of the five year LTIM Project. This report draws on information presented in the **Murrumbidgee Monitoring and Evaluation Plan (M&EP)** (Wassens *et al.* 2014a).

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 Murray-Darling Basin (Kingsford and Thomas 2004). Wetlands make up over 4 per cent (370,000 ha) of the catchment, with over 1,000 individual wetlands identified (Murray 2008). Nationally important wetlands, including the mid-Murrumbidgee and Lowbidgee floodplain, cover over 208,000 ha (2.5 per cent 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 *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 1,600 km long, with the LTIM Project Selected Area covering the lowland section (approximately 786 km)(Wassens *et al.* 2014a). 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)** – Starts upstream of the Yanco and Oldman Creek regulators and extends to just above the Tom Bullen storage offtake. This zone includes major Murrumbidgee and Coleambally 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.
- **Balranald reach (241.4 km)** – Extends from Hay to Boundary Bend down stream of Balranald and aligns with the Lowbidgee floodplain.

Table 2-1Summary of monitoring activities and location in the Murrumbidgee River (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)			X	X	X	X	X	X
McKennas (River)				X	X	X	X	X
Bringagee				X	X	X	X	X
Birdcage								X
Gundaline claybar								X
Gundaline US								X
Hay Boat Ramp	Carrathool	Permanent lowland streams						
Pevensey								
Rudds Point								X
Toganmain DS								X
Toganmain Homestead								X
Toganmain US								X
Wyreema								
The Dairy				X	X		X	
Euroley Bridge			X	X	X		X	
Narrandera				X	X		X	
Buckingbong Station	Narrandera	Permanent lowland streams						
Berembed Weir DS								
Gogeldrie Weir US								
Lamonts Beach								

- US = upstream, DS = downstream, River = distinguishes site from comparable Wetland site with the same name see Table 4, C1 = Category 1 LTIM standard methods, C3 = Category 3 LTIM standard methods).

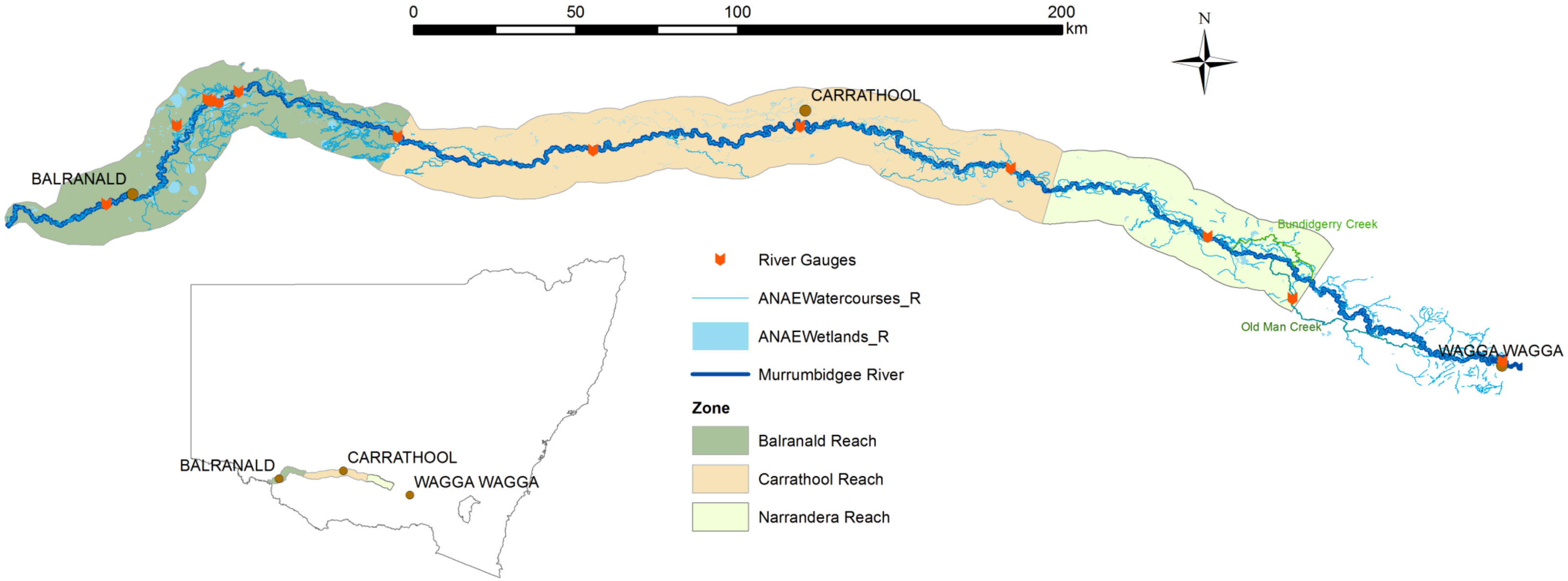

Figure 2-1 Distribution of riverine zones in the Murrumbidgee Selected Area.

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).

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

Table 2-2 Summary of monitoring activities and locations across three zones in the Murrumbidgee Selected Area (Figure 2-2)

Site Name	Site abbreviation	Zone	ANAE classification	nutrients , carbon, Chl a	Microinvertebrate	Fish community (C3)	Frogs, tadpoles, turtles	Waterbird Diversity	Vegetation Diversity
Gooragool Lagoon	GOO	mid-Murrumbidgee	Permanent floodplain wetland	X	X	X	X	X	X
McKennas Lagoon	MCK	mid-Murrumbidgee	Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Sunshower Lagoon	SUN	mid-Murrumbidgee	Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Yarradda Lagoon	YAR	mid-Murrumbidgee	Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Avalon Swamp	AVA	Nimmie-Caira	Temporary floodplain lakes	X	X	X	X	X	X
Eulimbah Swamp	EUL	Nimmie-Caira	Temporary floodplain wetland	X	X	X	X	X	X
Nap Nap Swamp	NAP	Nimmie-Caira	Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Telephone Creek	TEL	Nimmie-Caira	Permanent floodplain wetland	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	Redbank	Permanent floodplain tall emergent marshes	D	D	D	D	D	X
Two Bridges Swamp	TBR	Redbank	Intermittent River red gum floodplain swamp	D	D	D	X	X	X
Waugorah Lagoon	WAG	Redbank	Permanent floodplain wetland	X	X	X	X	X	X

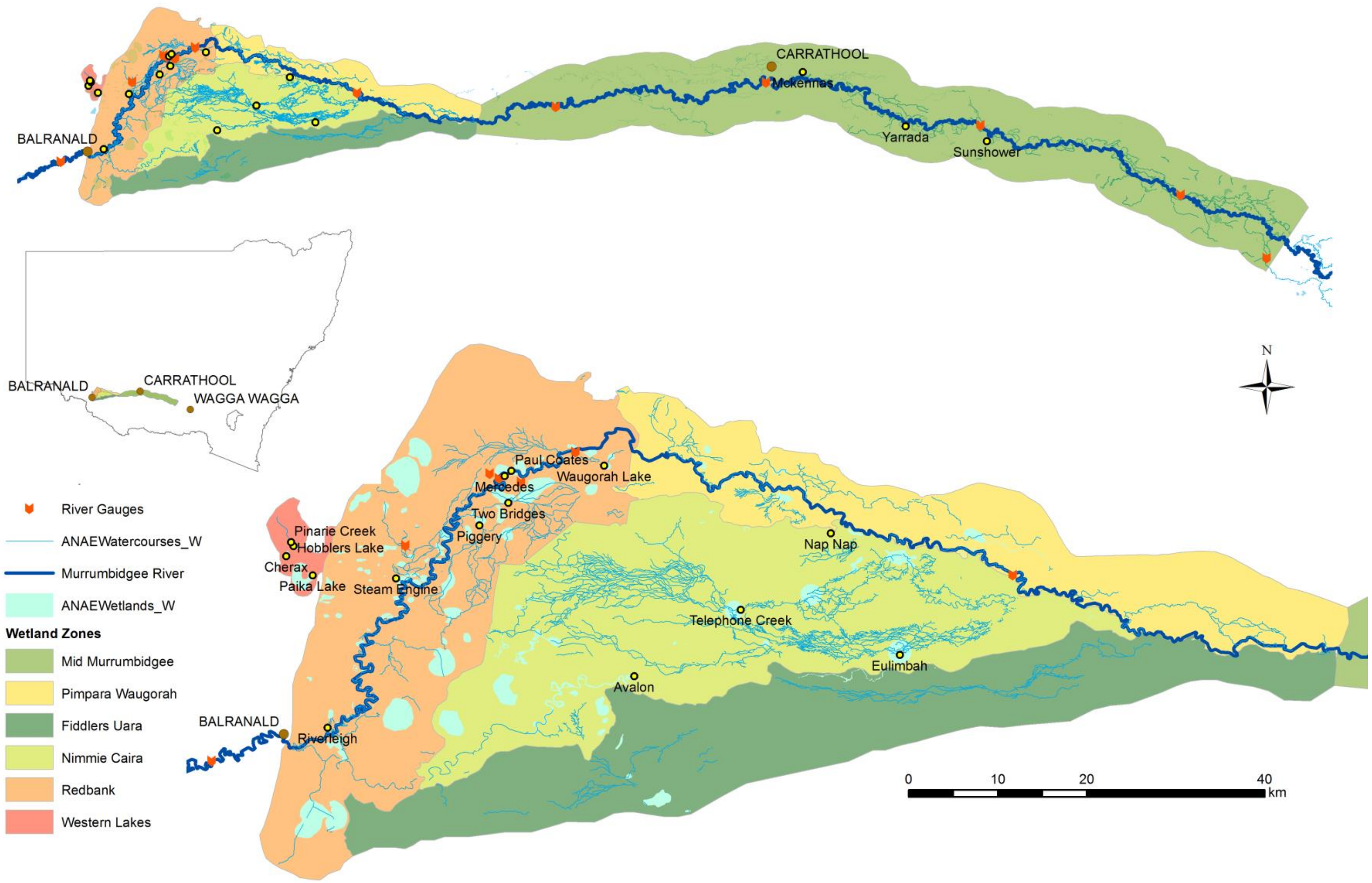

Figure 2-2 Distribution of wetland zones in the Murrumbidgee Selected Area and locations of key wetlands.

3. Environmental water delivered in 2017-18, 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. The timing of high flow periods, in particular, 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 *et al.* 2005; Frazier *et al.* 2006). Between 2000 and 2010 a significant drought event coupled with increasing consumptive water demand exacerbated the effects of river regulation (Dijk *et al.* 2013) leading to significant declines in the condition of floodplain vegetation (Wen *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. The 2017-2018 water year, saw below average rainfall across much of the MDB. In the twelve-month period, rainfall across the Murrumbidgee catchment was closer to the long-term average, with about 80% of the mean annual total falling in the upper regions of the catchment, however reasonable water levels in storage dams contributed to moderate water availability.

3.2 2017-18 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 2017-18 the Commonwealth environmental water holder in partnership with NSW delivered 179,241 ML of Commonwealth environmental water including and 89,702 ML NSW EWA environmental water as part of 13 watering actions targeting riverine, floodplain, wetland, anabranches and creek lines habitats in the Murrumbidgee (Table 3-1). The largest volume of water was utilised for the Murrumbidgee wetlands reconnection (236,205 ML). The primary objective of this action protect and maintain the ecological health and resilience of the mid-Murrumbidgee wetlands, Yanco Creek and adjacent wetlands. It was expected this action would;

- prevent further decline in wetland vegetation extent and condition;
- support reproduction and improved condition vegetation, waterbirds, native fish and other biota; and
- to support hydrological connectivity and biotic and nutrient dispersal.

In 2017-18 other Commonwealth environmental water actions in the Murrumbidgee catchment were delivered to achieve broad ecological objectives (Table 3-2), in particular:

- inundation of wetland habitats in the mid-Murrumbidgee and Yanco Creek systems;
- maintain extent and protect, maintain and, in some cases, improve the condition of in-channel; riparian, floodplain and wetland native vegetation communities;
- provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities;
- re-instating a more natural wetting-drying cycle for wetland vegetation;
- support the breeding, recruitment and habitat requirements of birds and native aquatic biota, including frogs, turtles and invertebrates;
- support spawning, recruitment, movement and habitat requirements of native fish, including access to a diversity of in-channel habitats, improving both structural and hydraulic habitat complexity;
- support ecosystem functions, such as dispersal of biota and transfer of abiotic material (e.g. sediment, nutrients and organic matter) that relate to longitudinal and lateral connectivity (i.e. connectivity between the river channel, wetlands and floodplain) to maintain populations; and
- improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

Secondary outcomes that Commonwealth environmental water may have contributed to include:

- scour biofilms; and
- provision of water to the Lower Murray, Lower Lakes, Coorong and Murray Mouth (dependent upon entire unregulated flow conditions in the River Murray, or implementation of return flow arrangements).

Table 3-1 Summary of environmental water usage from Commonwealth and state sources in 2017-18. (Drawn from Watering Action Acquittal Report Murrumbidgee 2017-18 (Commonwealth of Australia 2018). Shaded indicate flows associated with the LTIM Monitoring locations and occurring during the monitoring period

Watering Action Reference Target asset	Dates (start/end)	CEW volume used (ML)	Other volumes (ML)	Total (ML)
10062-01mid-Murrumbidgee wetlands reconnection	Start: 24/07/2017 End: 01/09/2017	159,283	71,922 (EWA); 5,000 (AEW)	236,205
10062-02 Yarradda Lagoon Pumping	Start: 04/07/2017 End: 01/08/2017	326	500	826
10068-06 Yarradda Lagoon Pumping	Start: 20/11/2017 End: 27/11/2017	177	0	177
10062-03 Gooragool Lagoon Pumping	Start: 18/07/2017 End: 31/07/2017	1426	0	1426
10068-11Gooragool Lagoon offset	Start: 15/06/2018 End: 15/06/2018	750	750	1500
10068-10 Nimmie-Caira Refuge	Start: 17/04/2018 End: 30/6/18	5,000	8,850	13,850
10034-13 Nimmie-Caira (LBG SAL)	Start: 15/12/2017 End: 18/12/2017	1,738	0	1,738
10068-02 North Redbank	Start: 9/10/2017 End: 19/10/2017	5,528	0	5,528
10068-03 Toogimbie IPA Wetlands	Start: 7/11/2017 End: 05/03/2018	1,000	0	1,000
10068-04 Murrumbidgee River and Floodplain Wetland Coonancoocabil	Start: 11/12/2017 End: 02/01/2018	900	0	900
10068-05 Murrumbidgee River and Floodplain Oak Creek	Start: 28/12/2017 End: 02/01/2018	620	0	620
10068-07 Waldaira Lagoon	Start: 09/02/2018 End: 30/04/2018	1,500	0	1,500
10068-08 Sandy Creek	Start: 17/02/2018 End: 23/04/2018	400	0	400
10068-09 Tuckerbil Swamp	Start: 09/04/2018 End: 16/04/2018	600	0	600

Table 3-2 Summary of Commonwealth environmental watering actions and expected watering outcomes in 2017-18. Adapted from (Commonwealth of Australia 2018).

Watering Action Reference Target asset	Flow component type	Expected outcomes	LTIM monitoring sites influenced by the action and relevant report sections
10062-01 mid-Murrumbidgee wetlands reconnection	Fresh Flow, Wetland Inundation	Primary: Avoid damage, protect and maintain the ecological health and resilience of the mid-Murrumbidgee wetlands, Yanco Creek and adjacent wetlands. It was expected this action would: • prevent further decline in wetland vegetation extent and condition; • support reproduction and improved condition vegetation, waterbirds, native fish and other biota; • support hydrological connectivity and biotic and nutrient dispersal. Secondary: The watering action was also expected to contribute to the ecological health and resilience of the wetlands, creek systems and river channel of the Murrumbidgee catchment.	YAR, GOO, SUN, MCK, WAG • Wetland hydrology • Wetland water quality • Wetland Microinvertebrates • Vegetation diversity • Wetland fish • Frogs and turtles • Waterbird Diversity • Riverine Hydrology • Riverine water quality • Stream metabolism • Riverine microinvertebrates
10062-02 Yarradda Lagoon Pumping	Wetland Inundation	Primary: Reduce losses, preserve the peak of the reconnection flow and maximise the inundation of the mid-Murrumbidgee wetlands during the low-level reconnection event (WUM10062-01). Secondary: • maintain and improve the condition of wetland vegetation. • support the habitat requirements of waterbirds, native fish and other aquatic animals.	
10068-06 Yarradda Lagoon	Wetland Inundation		
10062-03 Gooragool Lagoon Pumping	Wetland Inundation		
10068-11 Gooragool Lagoon offset	Wetland	To retain water in Gooragool Lagoon due to transfer of water in the lagoon to the environment	
10068-07 Waldaira Lagoon	Wetland Inundation	Primary: To maintain wetland health and resilience and provide habitat for wetland dependant species. Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion	• Wetland hydrology
10068-02 North Redbank	Wetland inundation	Primary: Maintain critical refuge habitats in Paul Coates, Steam Engine and Narwie Swamps in North Redbank. The swamps require environmental water to maintain critical habitats for a range of waterbirds, native fish, frogs and turtles. Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion.	• Wetland hydrology

Table 3-3 continued Summary of Commonwealth environmental watering actions and expected watering outcomes in 2017-18. Adapted from (Commonwealth of Australia 2018).

<table>
<tr><th>Watering Action Reference Target asset</th><th>Flow component type</th><th>Expected outcomes</th><th>LTIM monitoring sites influenced by the action and relevant report sections</th></tr>
<tr><td>10068-10 Nimmie-Caira Refuge</td><td>Wetland Inundation</td><td rowspan="2">Maintain critical refuge habitat for native fish, waterbirds, turtles and frogs, including the southern bell frog (EPBC Act vulnerable).
Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion</td><td>Not evaluated
Outside LTIM reporting period</td></tr>
<tr><td>10034-13 Nimmie-Caira (LBG SAL)</td><td>Wetland Inundation</td><td>Not evaluated
Outside LTIM survey area</td></tr>
<tr><td>10068-03 Toogimbie IPA Wetlands</td><td>Wetland inundation

Pumping</td><td>Primary: Maintain wetland health and resilience; providing habitat for wetland dependant fauna including the southern bell frog as well as supporting cultural outcomes and continued engagement with indigenous landowners, the Nari Nari Tribal Council. The Toogimbie IPA is also a site for the National Cultural Flows Research Project and some monitoring under this project will be undertaken.
Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion.</td><td>Not evaluated
Outside LTIM survey area</td></tr>
<tr><td>10068-04 Murrumbidgee River and Floodplain Wetlands: Coonancoocabil Lagoon and

10068-05 Murrumbidgee River and Floodplain Oak Creek</td><td>Wetland Inundation
Wetland Inundation</td><td>Primary: Maintain critical refuge habitat for a range of native fish, waterbirds frogs and turtles. Oak Creek and Coonancoocabil have been found to contain a relatively high diversity of native fish compared to other wetlands in the mid-Murrumbidgee, including catfish in Coonancoocabil, which are rare in the Murrumbidgee River. Water delivery will also inundate fringing vegetation to maintain and support the establishment of aquatic vegetation which has been observed to be establishing well following a couple of years and wetting and drying
Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion</td><td>Not evaluated
Outside LTIM survey area</td></tr>
</table>

Watering Action Reference Target asset	Flow component type	Expected outcomes	LTIM monitoring sites influenced by the action and relevant report sections
10068-08 Sandy Creek	Wetland Inundation	Primary: To water to maintain habitats for a range of waterbirds, native fish, frogs and turtles and have received Commonwealth and NSW environmental water each year since 2014-15 Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion.	Not evaluated Outside LTIM survey area
10068-09 Tuckerbil Swamp	Wetland Inundation	Primary: Maintain the ecological character of the site which requires environmental water to maintain vegetation condition, and in-particular critical habitat for the critically endangered (EPBC Act) Australasian bittern, supporting a range waterbirds, native fish, frogs and turtles. Secondary: Targeting wetland vegetation and habitat for native fish, frogs, turtles and waterbirds, including supporting significant waterbird breeding events to completion	Not evaluated Outside LTIM survey area
MBG16/17-15*	Nimmie-Caira refuge flows OEH	The Nimmie-Caira refuge action MBG 16/17-15 was undertaken by NSW OEH, this action is included here because it influenced hydrology of two LTIM monitoring sites in the Nimmie-Caira	EUL, TEL • Wetland hydrology

4. Evaluation of Commonwealth Environmental Watering Actions

Wetland outcomes

Mercedes Swamp January 2018

4.1 Wetland hydrology

Prepared by Rachael Thomas, Wayne Kuo, Jessica Heath (NSW OEH) and Andrew Hall (CSU)

Introduction

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). Commonwealth environmental water has been delivered to wetlands through the mid-Murrumbidgee, Redbank, and Nimmie-Caira to "inundate wetland and refuge habitats" in the Murrumbidgee catchment.

Flooding is the most influential driver of floodplain wetland ecosystems (Bunn *et al.* 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 *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 *et al.* 1993). These inundation regime components are known to be important for vegetation (Roberts *et al.* 2011) and waterbird breeding (Kingsford *et al.* 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 *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 pattern of flooding and drying. Note that this section reflects large scale inundation mapping across all zones in the Lowbidgee floodplain, including North Redbank and Pimpara-Wagourah which are not monitored under this program.

Relevant watering actions and objectives

In 2017-18, Commonwealth and NSW environmental water was delivered to floodplain wetlands in the Murrumbidgee Selected Area (Figure 4-1). We report on six of these Commonwealth environmental water actions in the Murrumbidgee Selected Area in 2017-18 (Table 4-1 and Figure 4-1b). Water actions occurred throughout the year starting in July 2017 with the Yarradda and Gooragool Lagoon pumping water actions occurring ahead of the mid-Murrumbidgee wetland reconnection event to reduce losses and preserve the peak of the reconnection flow to maximise inundation, Yarradda lagoon also received a top up watering action (in Nov 2017) while Gooroagool had the offset transfer of 1,500ML to preserve water within the lagoon (Table 3-1 and Table 3-2and Figure 4-1b). Further environmental water actions in October and November 2017 were delivered to increase inundation extent in core wetlands to maintain aquatic refuge habitats in the Nimmie-Caira and north Redbank zones of the Lowbidgee floodplain. Wetlands of the Nimmie-Caira were also targeted with environmental water in autumn 2017 using NSW environmental water and again in 2018 using Commonwealth Environmental water. Waldaira Lagoon in The Junction wetlands region, west of Balranald, was also targeted with environmental water in February 2018 (Table 4-1 and Figure 4-1b).

Table 4-1 Summary of 2017-18 environmental water actions evaluated in this section.

Water Action	Wetland Target	Water Delivery Timing
WUM10062-01	mid-Murrumbidgee wetlands reconnection	Start: 24/07/2017 End: 01/09/2017
WUM10062-02	Yarradda Lagoon Pumping	Start: 04/07/2017 End: 01/08/2017
WUM10062-03	Gooragool Lagoon Pumping	Start: 18/07/2017 End: 31/07/2017
WUM10068-02	North Redbank refuge	Start: 9/10/2017 End: 19/10/2017
WUM10068-10	Nimmie-Caira refuge	Start: 15/12/2017 End: 18/12/2017
WUM10068-07	Waldaira Lagoon	Start: 09/02/2018 End: 30/04/2018
WUM10034-13	Nimmie-Caira (LBG SAL)	Start: 17/04/2018 End: 30/6/18
MBG16/17-15*	Nimmie-Caira refuge flows NSW environmental water action	Start: 1/04/2017 End: 30/6/17

* The Nimmie-Caira refuge action MBG 16/17-15 was undertaken by NSW OEH, however this even influenced the floodplain inundation in the Nimmie-Caira

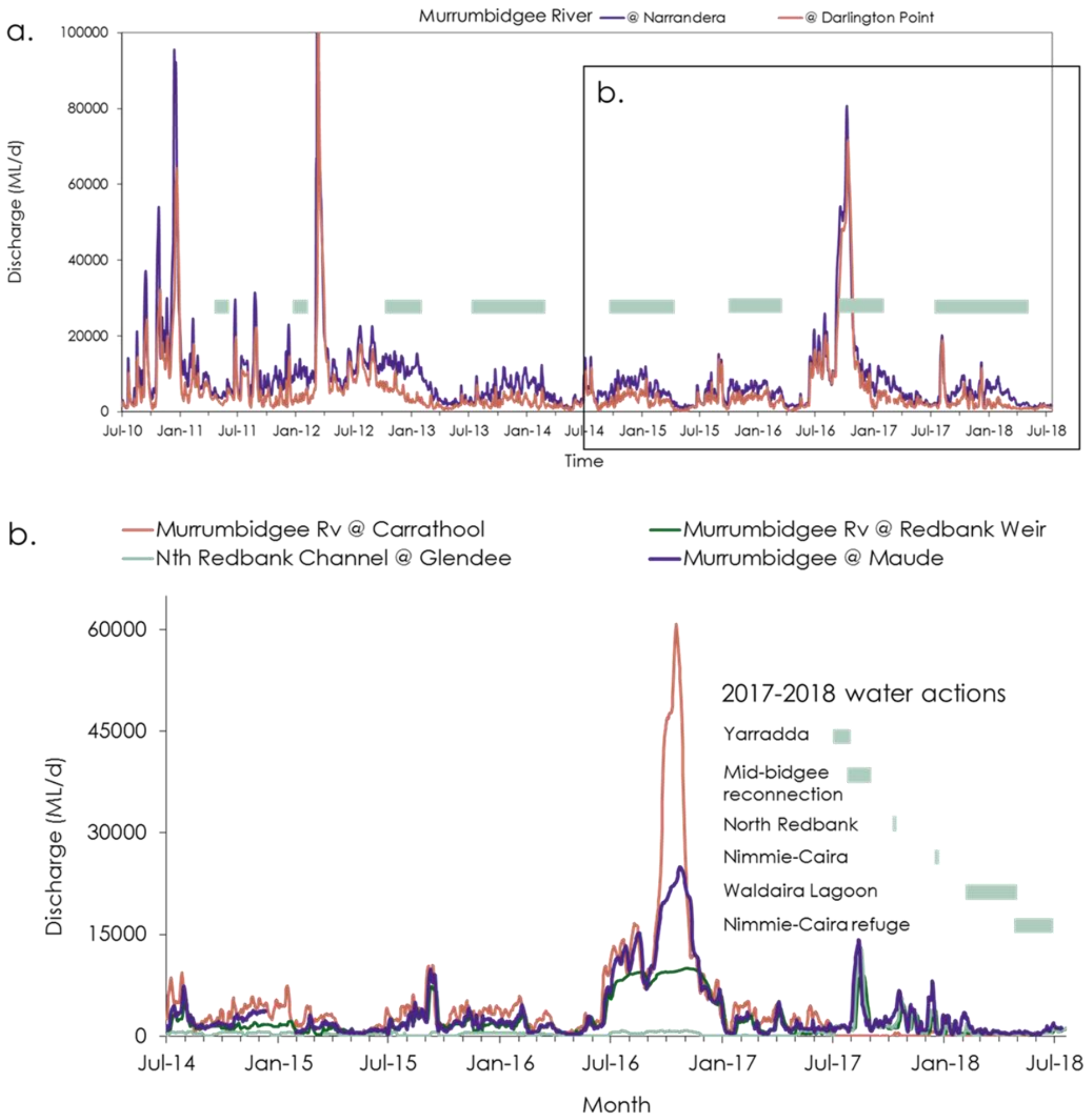

Figure 4-1: a. Mean daily discharge in the Murrumbidgee River at Narrandera and Darlington Point between 1 July 2010 to 30 June 2018. b. Mean daily discharge in the Murrumbidgee River between July 2014 and June 2018 at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glendee.

Horizontal green bars show Commonwealth and NSW environmental water action timing for water years since 2011-12 to 2017-2018 in relation to the timing of environmental water delivery water actions (horizontal green bars) during survey period (1 July 2017 to 30 June 2018).

Commonwealth environmental water is evaluated against the following criteria:

- Did Commonwealth Environmental Water contribute to inundation extent in the wetlands of the mid-Murrumbidgee and Lower Murrumbidgee floodplain?

Methods

Inundation mapping

To map floodplain wetland inundation, we used Landsat satellite images from both the Landsat 8 and Landsat ETM+ 7 sensors using methods developed by Thomas et al. (2015). During the 2017-18 water year there were periods of 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 et. al 2008). Images were automatically downloaded by NSW OEH from the USGS (Unites State 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 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 2017 to June 2018.

From each satellite image observation OEH automatically generated a water index (Fisher et al. 2016) and the NDVI vegetation index. We used these indices to classify inundation as classes of open water, water mixed with vegetation, and dense vegetation cover that was inundated (Thomas 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 et al. 2011; Thomas et al. 2012, and 2013; Thomas and Heath 2014). For observation dates affected by some cloud we manually reclassified areas of cloud shadow that were incorrectly detected as water. 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 to estimate inundation extents. An inundation map observation provided a snapshot of inundation extent and its distribution at a point in time. Within the Lowbidgee we tabulated the inundated areas for the entire Lowbidgee floodplain and for each wetland zone (Nimmie-Caira, Redbank (North and South), Pimpara-Waugorah, Fiddlers and Western Lakes) from each inundation map. For each of the LTIM surveyed wetlands where discrete wetland boundaries had been previously delineated (Wassens *et al.* 2016) we tabulated the inundated areas from each inundation map. We then estimated the percentage area inundated and plotted them over time.

We also provided an overview of the total area of Lowbidgee floodplain inundated during the 2014-2015 to 2017-2018 water years. These inundation extents represent the cumulative area of the floodplain inundated at least once in the water year. We used a spatial overlay of all inundation maps in the water year 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 in the water year.

Results

Annual Outcomes Lowbidgee Floodplain

During 2017-18 about 18,750 ha of the Lowbidgee floodplain was inundated (Figure 4-2), mostly as a result of environmental water delivery by NSW OEH, particularly the Nimmie-Caira refuge flow(NSW OEH) which was delivered in (and CEWO. Most of the inundation extent in the Lowbidgee Floodplain was distributed in the Redbank (48%) and Nimmie-Caira (25%) zones (Figure 4-3), from environmental water deliveries, although some of the larger floodplain lakes including Yanga (~1400 ha) and Tala (~660 ha) Lakes retained water from flows in the 2016-17.

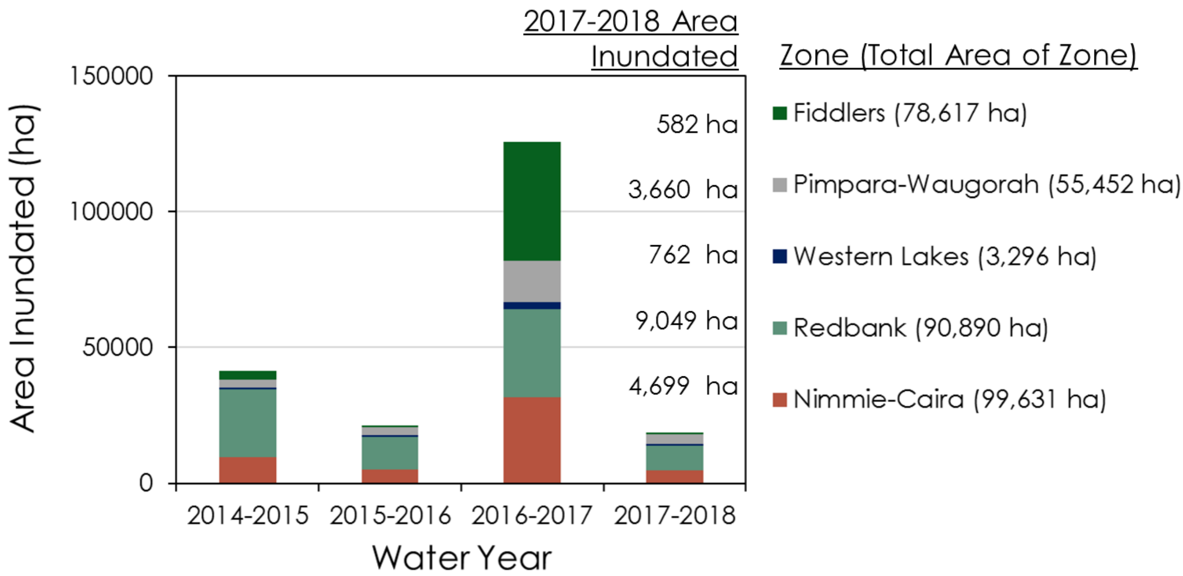

Figure 4-2: Annual cumulative total area (ha) of the floodplain inundated for the Lowbidgee floodplain and wetland zones for the water years from 2014-15 to 2017-18.

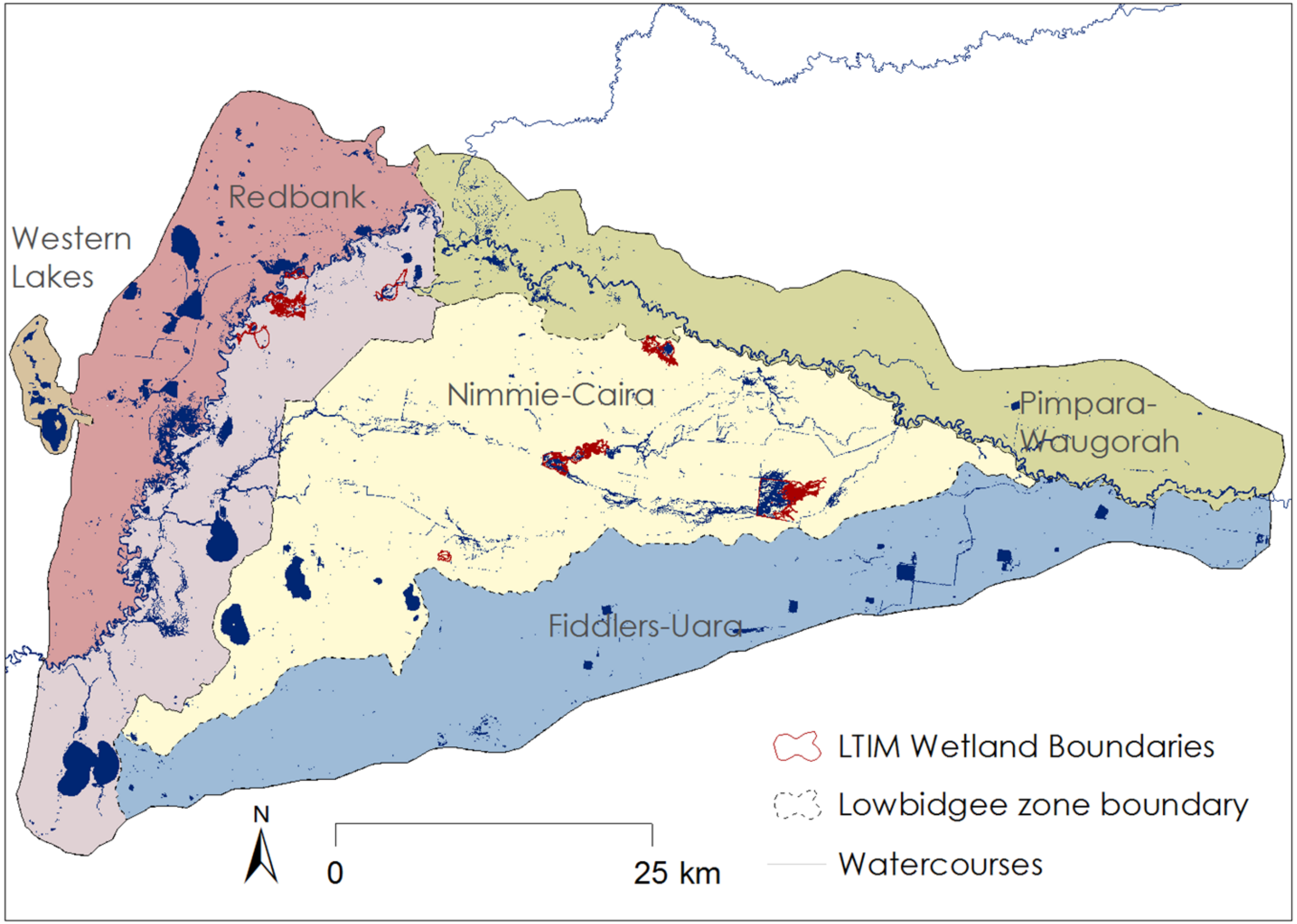

Figure 4-3 Distribution of the cumulative inundation across the Lowbidgee floodplain during July 2017 and April 2018 based on Inundation maps classified from Landsat satellite images.

Inundation extent contracted during July 2017 in the Lowbidgee Redbank, Nimmie-Caira and Pimpara-Waugorah zones but then increased in late August and peaked in September 2017 (Figure 4-4a). But these increases in inundation extent were only 10% of the extents that occurred in the previous year (Figure 4-4a) indicating that inundation was confined to core wetland areas rather than large expanses of floodplain. Wetlands dried out over spring 2017, more so in the Nimmie-Caira zone compared to the wetlands in the Redbank zone (Figure 4-4b).

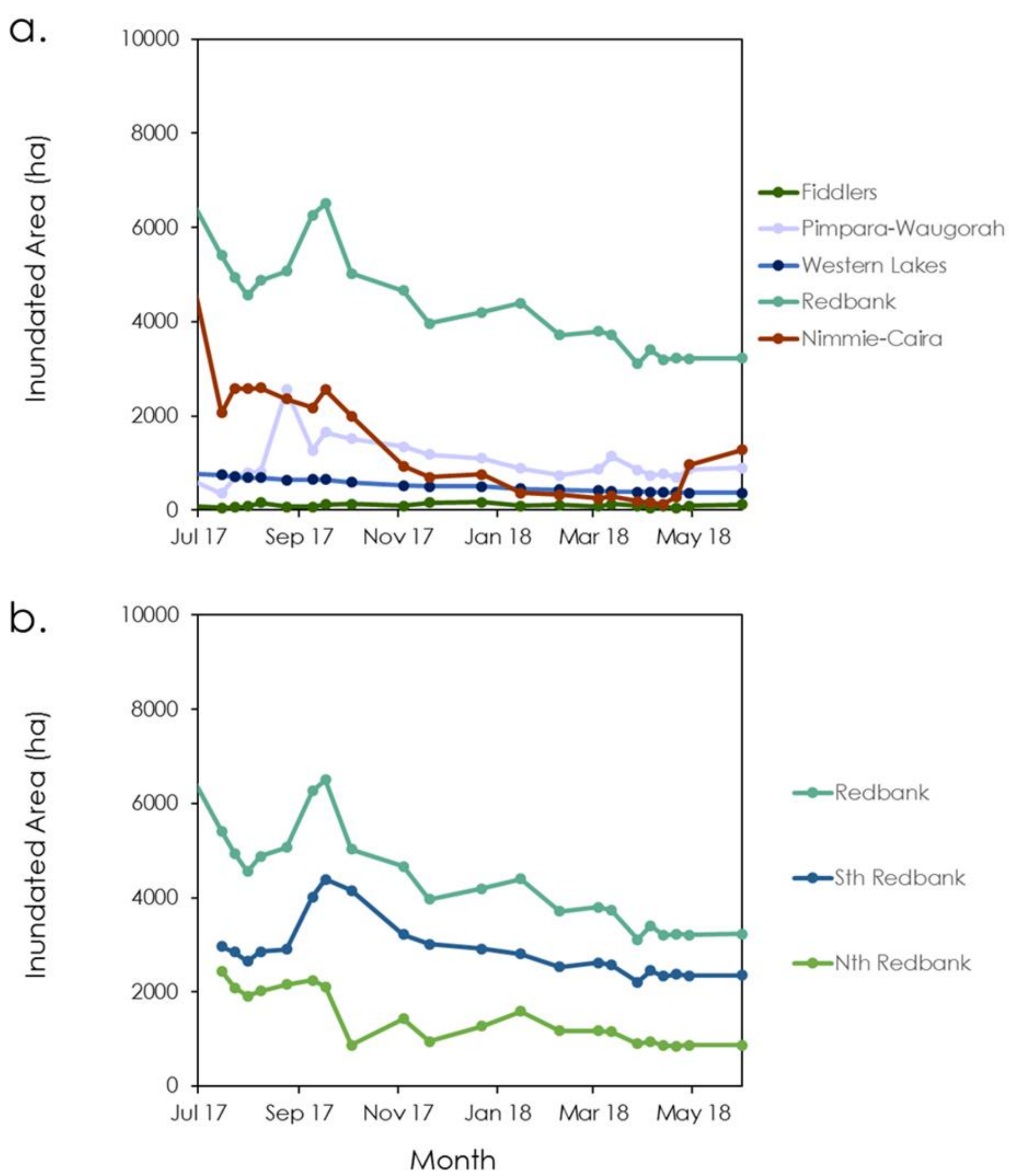

Figure 4-4 Inundated areas over time during 2017-18 for a. the Lowbidgee zones and b. the Redbank zone sub-regions (south and north).

Waldaira Lagoon

The Waldaira Lagoon action was initially approved for 1,000ML but was increased to 1,500ML to complete the inundation. Inundated area in Waldaira Lagoon increased during September 2017 to almost 20 hectares however due to cloud cover it was not possible to estimate inundated area during spring 2017 and early summer 2018. In early March inundation extent increased and peaked to almost 80 ha by mid-March (Figure 4-5 and Figure 4-6). Inundation extent fluctuated from about 60 to 70 hectares during April and May 2018 (Figure 4-5 and Figure 4-6).

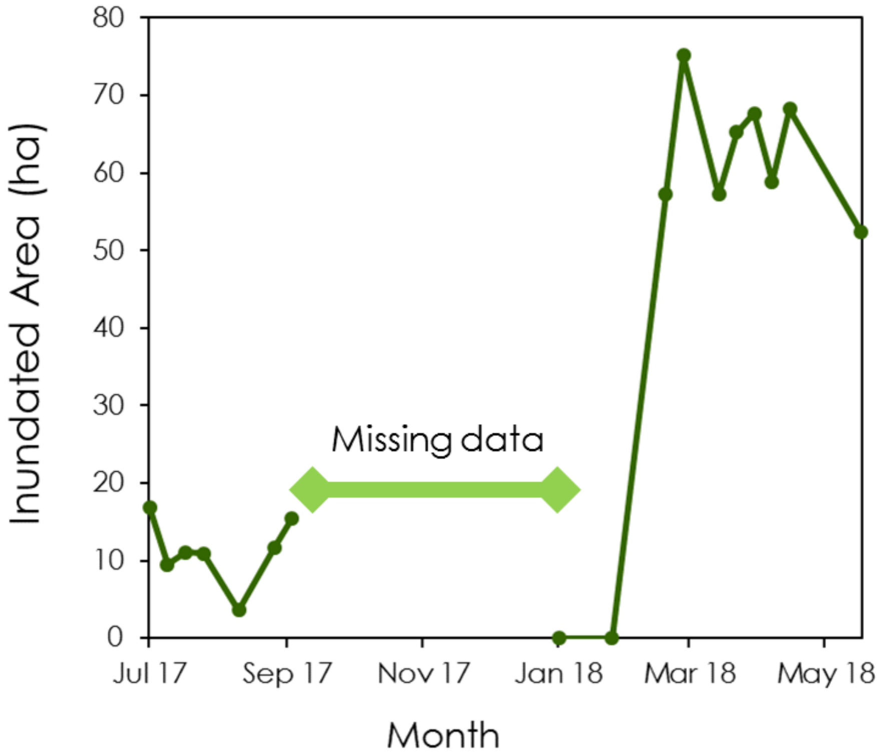

Figure 4-5 Inundation expansion in the Waldaira Lagoon from the environmental water action from 9 Feb to 30 Apr 2018. Due to cloud cover inundation was obscured from September 2017 to January 2018 (missing data).

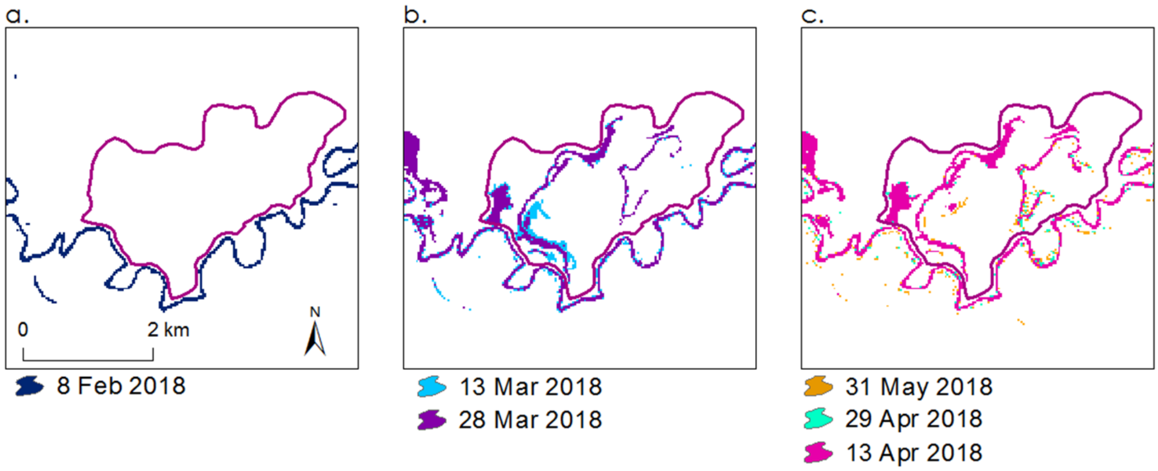

Figure 4-6 Inundation progression in the Waldaira Lagoon from the environmental water action from 9 Feb to 30 Apr 2018 showing a. no inundation in early February 2018, b. lagoon filling in March 2018, and c. retained inundation in April-May 2018.

Inundation outcomes for the LTIM monitoring sites - mid-Murrumbidgee

The Murrumbidgee reconnection inundated all four of the wetlands monitored under this program. With the exception of Sunshower Lagoon which had dried out briefly over winter 2017, the remaining three wetlands retained some water from unregulated flows that inundated large sections of the floodplain in spring 2016. Pumping actions at Yarradda and Gooragool lagoons in July 2017 raised water levels by over 80cm at Gooragool Lagoon and 100cm at Yarradda Lagoon in preparation for the mid-Murrumbidgee reconnection event. This gradual rise was followed by a rapid increase in water levels as the wetlands reconnected to the main river channel (Figure 4-7). The increase in water level occurred slightly later and lower at McKennas Lagoon. This was the result of generally lower river levels in the downstream section of the Murrumbidgee River and also obstructions in the inflow channel which reduced the level of connection to the river and prevented McKennas Lagoon from filling to the same extent as though further up-stream (see Figure 4-7).

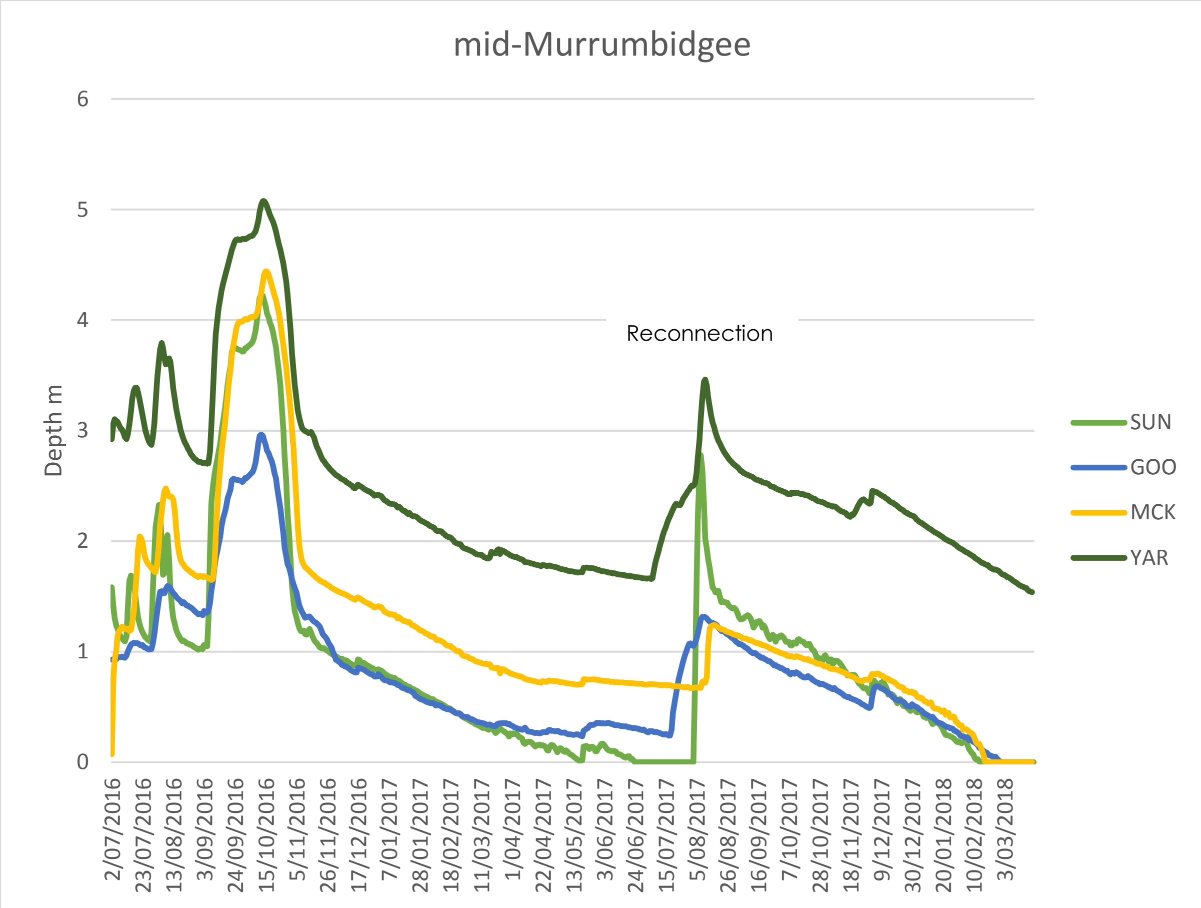

Figure 4-7 Water depth for the mid-Murrumbidgee lagoons from 01/07/2016 to 01/04/2018. YAR. Yarradda Lagoon, MCK McKennas Lagoon and SUN Sunshower Lagoon, GOO Gooragool Lagoon.

After having dried out to about 30% of its boundary in April 2017, Yarradda Lagoon began filling in late July 2017 to almost 50% of its boundary (Figure 4-8 and Figure 4-7). Inundation extent increased and peaked to 85% of its boundary in early August 2017 when surrounding wetlands were also inundated (Figure 4-7). Further inflows in November 2017 maintained a 50% inundated area from late July 2017 to mid-January 2018 (~5.5 months). By April 2018 inundation extent in Yarradda Lagoon had contracted to less than 20%. This was the third year that Yarradda Lagoon was inundated to at least 50% of its boundary after having almost dried out between inundation events (Figure 4-7).

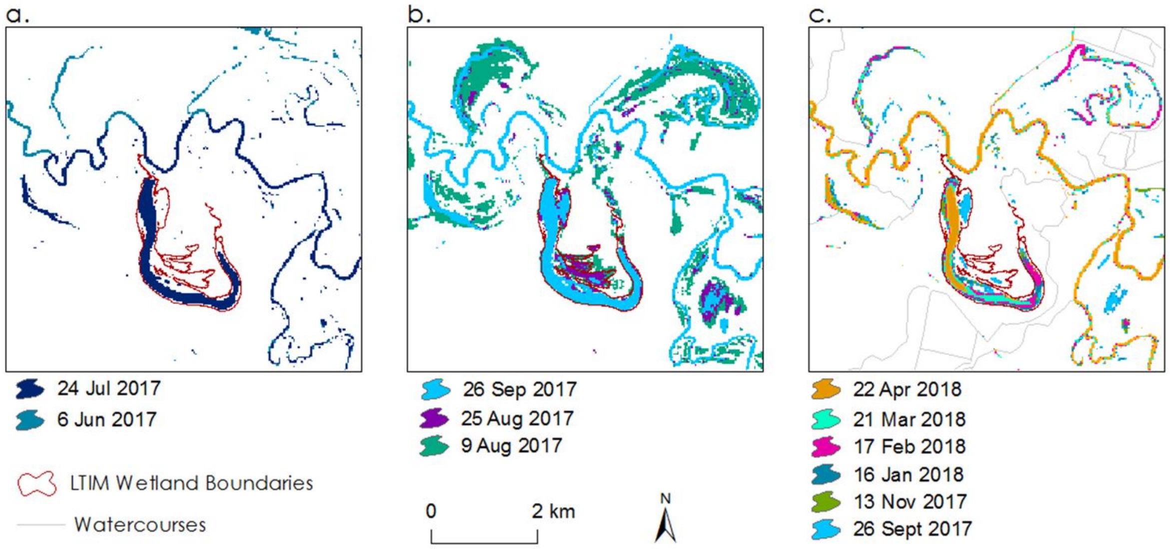

Figure 4-8 Inundation expansion in Yarradda Lagoon from the 2017-18 environmental water actions a. Yarradda Lagoon pumping and b. mid-Murrumbidgee wetlands reconnection flow and c. the inundation contraction.

Inundation outcomes for the LTIM monitoring sites – Nimmie-Caira

In the Nimmie-Caira there were two major events that influenced the hydrology of the monitored wetlands, the Nimmie-Caira refuge flows (NSW environmental water general security (15104 ML) 24/05/2017 to 18/06/2017 (MBG16/17-15)) which increased water levels in Telephone Creek and Eulimbah Swamp by over 100 cm in June 2017 and rain events over summer 2017-18 which contributed to small (30-40 cm) increases in water depths (Figure 4-9). The refuge watering actions were likely to have prolonged wetland inundation with the rain event delaying wetland drying for an additional 3-4 weeks. Despite this small rise in water levels in December 2017 all wetlands in the Nimmie-Caira zone were drying out during spring and summer and were either dry or mainly dry by February 2018.

In terms of percentage inundation: Nap Nap Swamp (30%) Eulimbah Swamp (56%), and Telephone Creek (27%) (Figure 4-10). However, the inundation extent in Telephone Creek continued to contract during spring 2017 through to February 2018. In April 2018 inundation extent increased in Telephone Creek to just over 40%, and in Eulimbah Swamp to almost 40% (Figure 4-10).

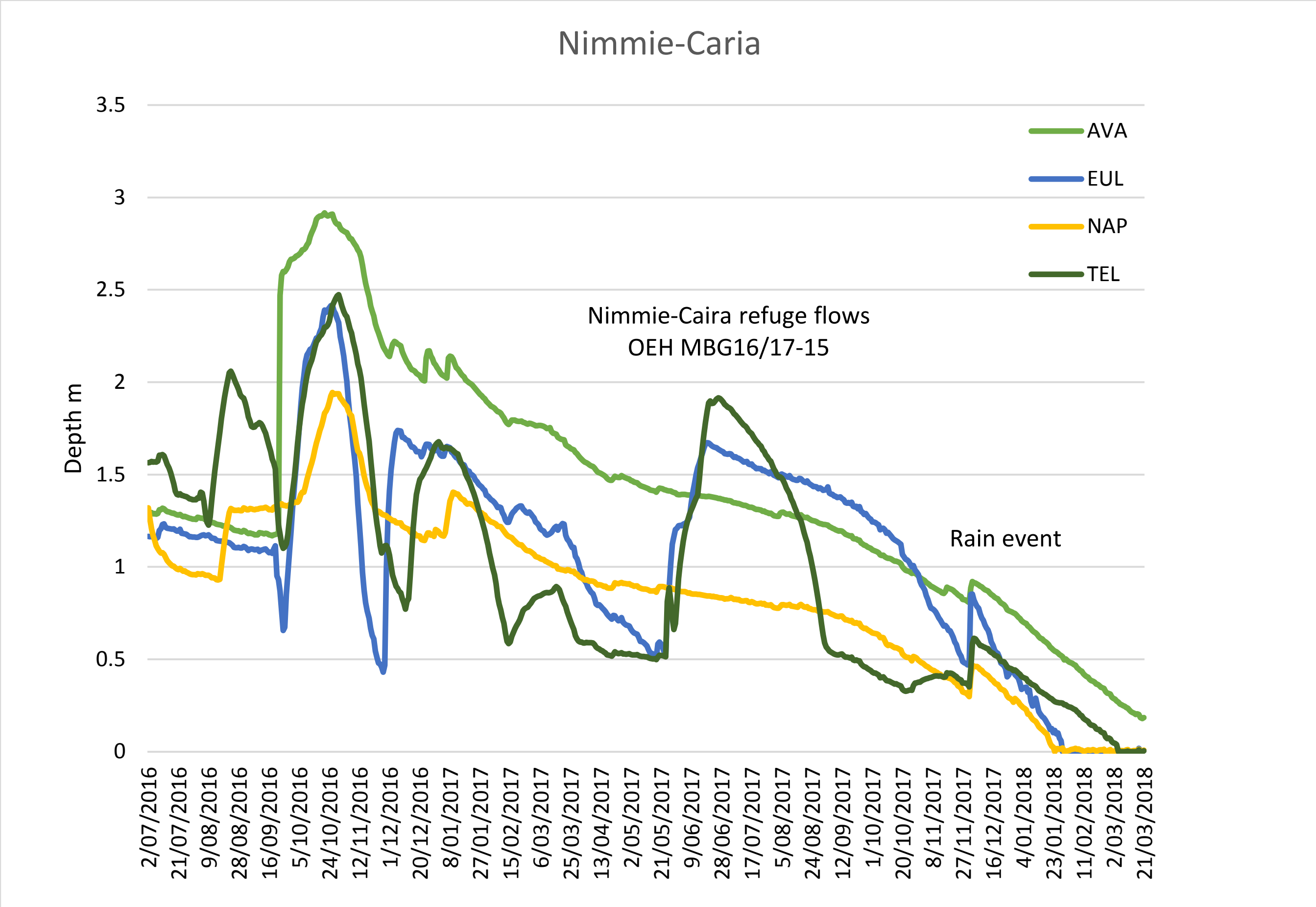

Figure 4-9 Wetland hydrographs for the four monitoring locations in the Nimmie-Caira. AVA Avalon Swamp, EUL Eulimbah Swamp, TEL Telephone Creek, NAP Nap Nap Swamp from July 2016 to March 2018.

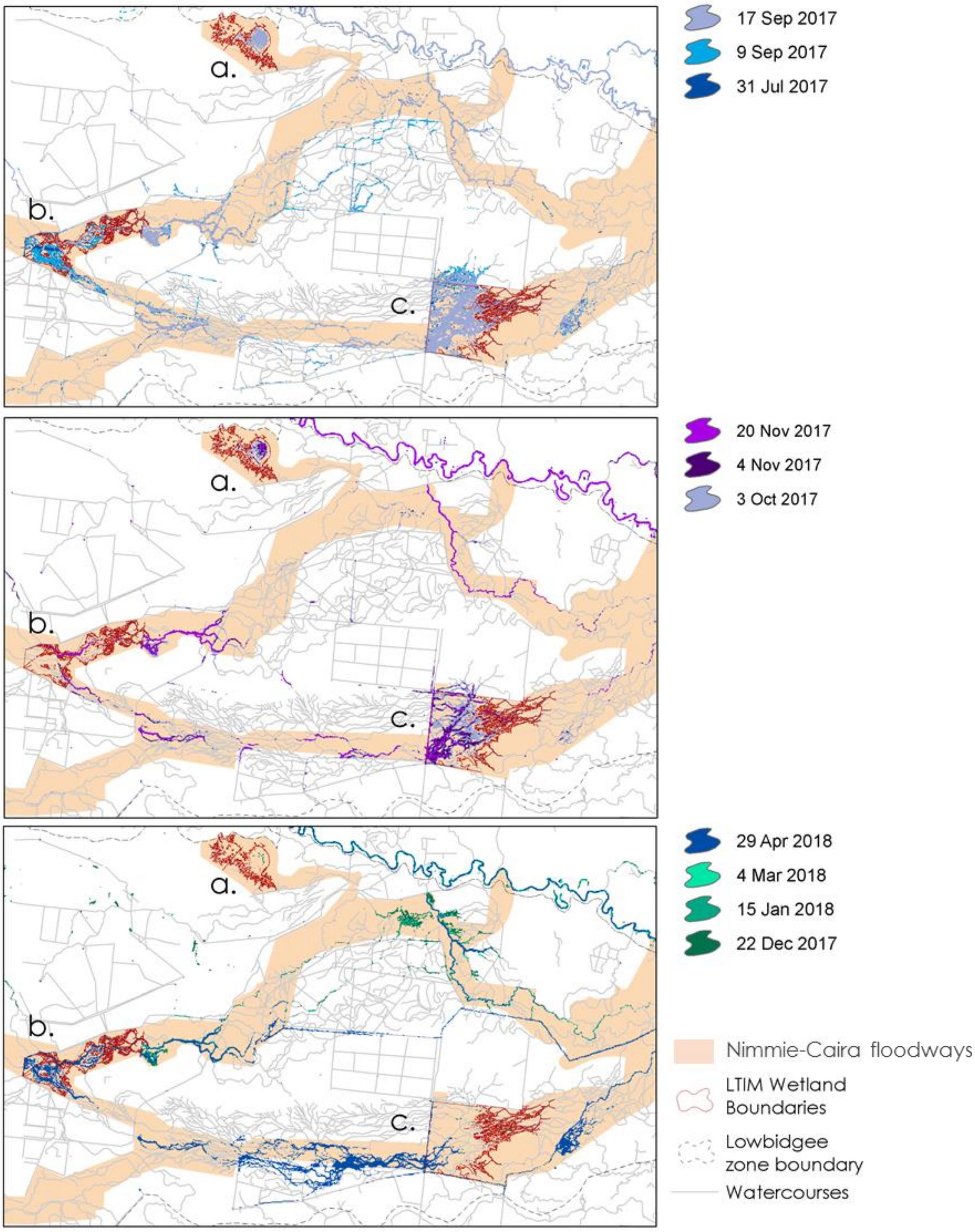

Figure 4-10 Inundation progression during 2017-18 within the surveyed wetlands of the Nimmie-Caira Zone: a. Nap Nap Swamp, b. Telephone Creek and c. Eulimbah Swamp

Inundation outcomes for the LTIM monitoring sites - Redbank

In the Redbank zone there were two key flow events that influenced the hydrology of the LTIM monitored wetlands, the Lower Murrumbidgee connectivity pulse was a combination of Commonwealth and NSW Environmental water (MBG16/17-14) ran between 1 April 2017 and 20 April 2017 and is likely to have influenced the hydrology at Two Bridges and Mercedes Swamps contributing to a 40-70cm increase in water levels. The mid-Murrumbidgee reconnection flow may have contributed to inundation of Wagourah Lagoon in September 2017. Unregulated (unplanned overbank flows) entered Mercedes Swamp in January 2018 contributing to an increase in depth and extent of inundation. Piggery Lake was dry throughout the 2017-18 water year, while Two Bridges Swamp despite holding small volume of water at the deepest section up until February 2018 (Figure 4-11).

After the large flood in 2016-2017 most of the LTIM wetlands in the South Redbank sub-zone had almost dried out in June 2017 to <10% of each wetland boundary (Figure 4-12). In late September Mercedes Swamp and Waugorah Lagoon (Figure 4-12) remained inundated to 20% and 30% respectively. By January 2018 Mercedes Swamp was inundated again to 50% of its boundary (Figure 4-12). This was the third year that Mercedes Swamp was inundated to at least 50% of its boundary.

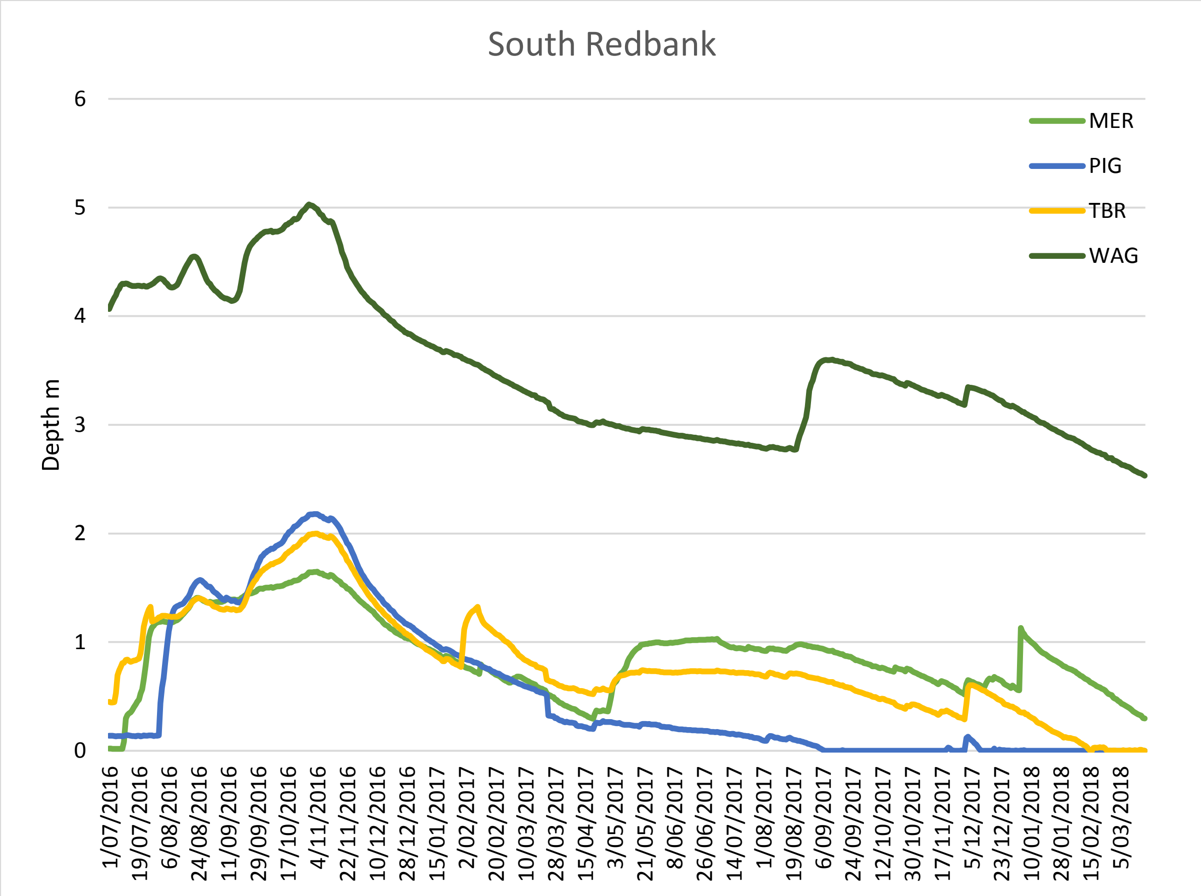

Figure 4-11 Wetland hydrographs for the four monitoring locations in South Redbank. MER Mercedes Swamp, PIG Piggery Lake, TBR Two Bridges Swamp, WAG Wagourah Lagoon from July 2016 to March 2018.

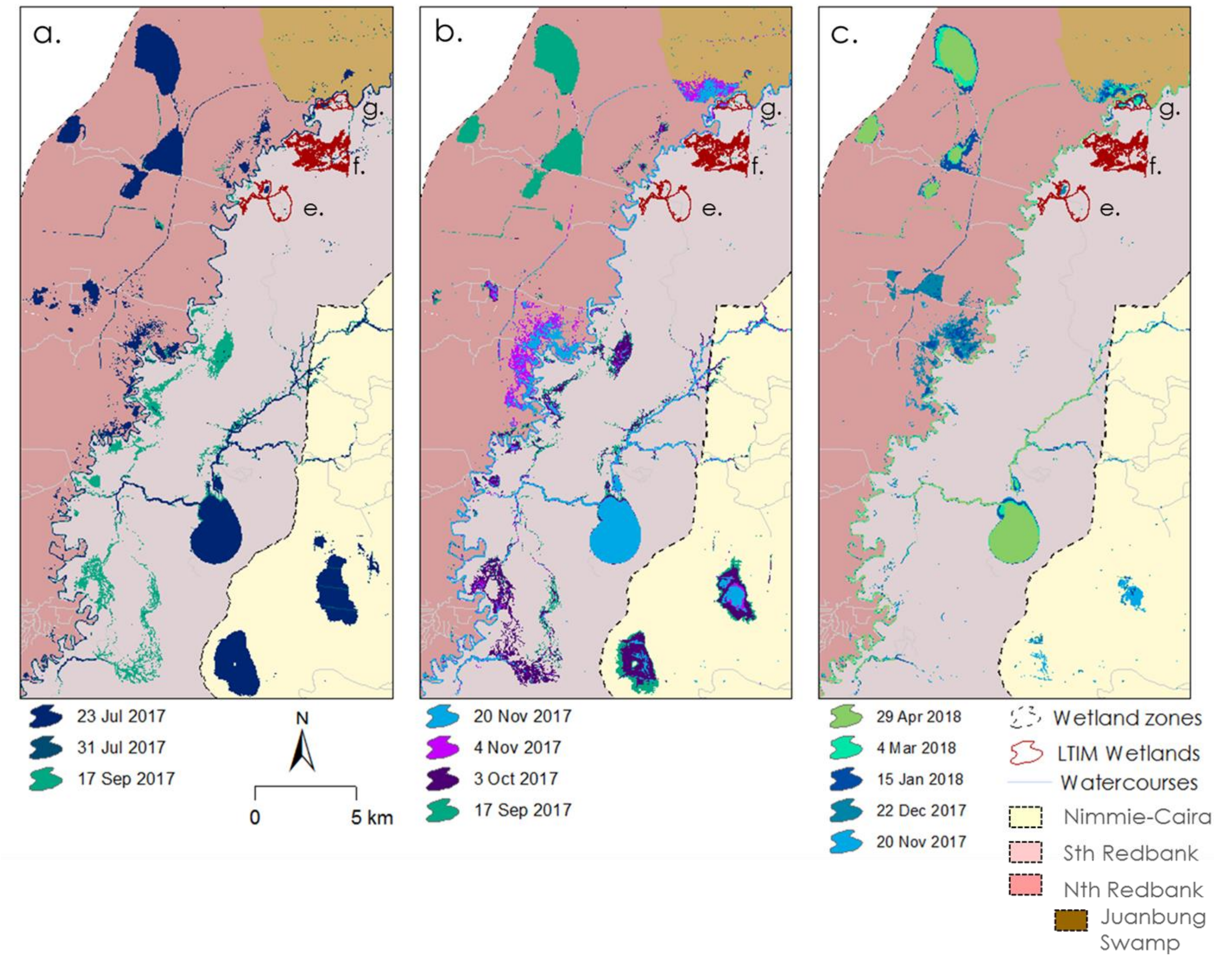

Figure 4-12 Inundation progression during 2017-18 showing the inundation expansion and contraction in wetlands within the Redbank zone (North and South Redbank sub-zones) for time periods a. July to September 2017, b. September to November 2017, and c. November 2017 to April 2018. LTIM surveyed wetlands of the Redbank zone: e. Piggery Lake, f. Two Bridges Swamp, and g. Mercedes Swamp.

Discussion

How did Commonwealth environmental water affect inundation extents in the wetlands of the mid-Murrumbidgee and Lower Murrumbidgee floodplain?

Commonwealth environmental water actions, combined with NSW environmental water, achieved inundation outcomes in targeted core wetlands in the mid-Murrumbidgee, the Nimmie-Caira and Redbank zones of the Murrumbidgee Selected Area. Inundation extent was confined to core wetlands and so whilst the area inundated was small, for some of these wetlands the proportional area of the wetland inundated was high (over 50%). For some of the core wetlands the 2017-18 water actions resulted in high inundation frequency being the third flooding after drying in as many years.

The Yarradda Lagoon Pumping water action increased the inundated area of Yarradda Lagoon from about 30% to 50%. The mid-Murrumbidgee wetland reconnection flow further increased inundation to 85% of the Yarradda Lagoon boundary in early August 2017 when surrounding wetlands were also inundated (Figure 4-8b), as well as other lagoons in the mid-Murrumbidgee such McKenna's and Sunshower lagoons (Figure 4-7). Additional environmental water delivered at the end of November 2017 maintained inundation extent in Yarradda Lagoon to over 50% for about 5.5 months but then contracted over the summer to autumn months. This was the third year that Yarradda Lagoon was inundated to at least 50% of its boundary after having almost dried out between each flood.

The mid-Murrumbidgee reconnection flow inundated some wetlands in the South Redbank sub-zone (Yanga National Park), including Waugorah Lagoon and to a lesser extent Mercedes Swamp but did not influence the remaining LTIM monitoring sites. Mercedes Swamp was also inundated in January 2018 during unregulated flows from the Redbank weir. Unfortunately, due to cloud cover we were unable to capture the full inundation outcome in the Waldaira Lagoon but there was some evidence that inundation extent started to increase in early September 2017.

North Redbank and Nimmie-Caira refuge water actions

Wetlands in the North Redbank sub-zone and Nimmie-Ciara zone was targeted with Commonwealth environmental water actions to maintain critical refuge habitat through an anticipated dry summer. The short North Redbank refuge flow increased inundation extent in wetlands of the North Redbank sub-zone in early November 2017, and then again in December-January 2018. The Nimmie-Caira refuge flow of December 2017 targeted Nimmie Creek and had no effect on inundation extent in core wetlands through the Nimmie-Caira zone however the restart of the water action in mid-April 2018 increased inundation extents in Telephone Creek to just over 40%, and in Eulimbah Swamp to almost 40%.

Conclusions

Commonwealth environmental water combined with NSW environmental water was successfully used to increase inundation extent in wetlands to maintain aquatic refuge habitat critical for biota during the anticipated dry conditions of 2017-18. Even though flow volumes were relatively small there were good outcomes in that a high proportion (>50%) of the individual wetland was inundated when they would have otherwise have been dry. Inundation extent was maintained by individual water actions for about a month in some wetlands. Many of the wetlands demand frequent inundation events, e.g. every year, to maintain their structure and function. The water actions delivered in 2017-18 maintained this inundation regime by targeting wetlands after they had dried out over the winter of 2017, and therefore, contributed to a more natural wetting and drying cycle for their long-term persistence.

4.2 Wetland water quality

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

Introduction

In ephemeral 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 *et al.* 1997), however, exceeding tolerance limits can cause sub-lethal impacts (i.e. impaired growth or reproduction) or mortality (Heugens *et al.* 2001; Bunn *et al.* 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 *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 2017-18 there were multiple deliveries of Commonwealth environmental and one delivery of NSW environmental water that contributed to water quality outcomes in the 12 LTIM-monitored wetlands across the Murrumbidgee Catchment (see Wetland hydrology 4.1). The most significant actions targeted the mid-Murrumbidgee wetlands with a combination of pumping, water offsets and the generation of a small flow peak within the river which created a connection between the river and low lying wetlands in the mid-Murrumbidgee (see Table 3-2). Further downstream, this pulse of environmental water also reached parts of Yanga National Park including Waugorah Lagoon. In-channel outcomes were also targeted by these flows, and are discussed elsewhere (Riverine water quality 4.9).

There were no specific watering objectives related to water quality, however maintaining satisfactory water quality contributes to the objective to "improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat."

We evaluated the effectiveness of these 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.

Commonwealth environmental water is evaluated against the following criteria:

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

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 2018. 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).

Water quality outcomes are evaluated against pre-2014 water quality data collected for the Murrumbidgee Catchment, noting that ANZECC water quality guidelines are not available for wetlands in south-eastern Australia. Potential relationships with wetland water depth were explored using generalised additive models (GAM) fitted using the 'gam' function in the ggplot2 package (version 3.0.0.9, Wickham et al. 2018). Models were checked using the gam.check function with the mgcv package (version 1.8.24, Wood 2018) and log (x+1) transformed prior to graphing.

Results

Physicochemical measurements collected from wetland sites in 2017-18 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 January 2018 (Table 4-2; Figure 4-13). This high mean conductivity value is due to McKennas Lagoon which reached 1.81 $mScm^{-1}$ while the wetland had dried to ~2% of its full volume in January 2018. Maximum dissolved oxygen, pH and turbidity were also much higher at McKennas Lagoon on this occasion, again exceeding the reference range. Other extreme values were recorded for Telephone Creek (Nimmie-Caira Zone) where turbidities consistently exceeded the calibrated range of field instruments (>1000 NTU).

Carbon, nutrient and chlorophyll-a concentrations seen in 2017-18 also typically fell within the reference range (Figure 4-14). Exceptions again include McKennas Lagoon during January 2018, which exceeded the 95th percentile of previous records all measured variables, and Avalon Swamp, with a recorded chlorophyll-a of (mean to be included).

Overall patterns of water quality show a consistent significant relationship with wetland water depth (Figure 4-15; Table 4-3). Across most measured variables, values are more likely to be high (i.e. poorer water quality) when water levels are less than approximately 1.2 m, with extreme values occurring at values <0.5 m. The only exception is wetland pH, which was not significantly related to wetland water depth (Table 4-3).

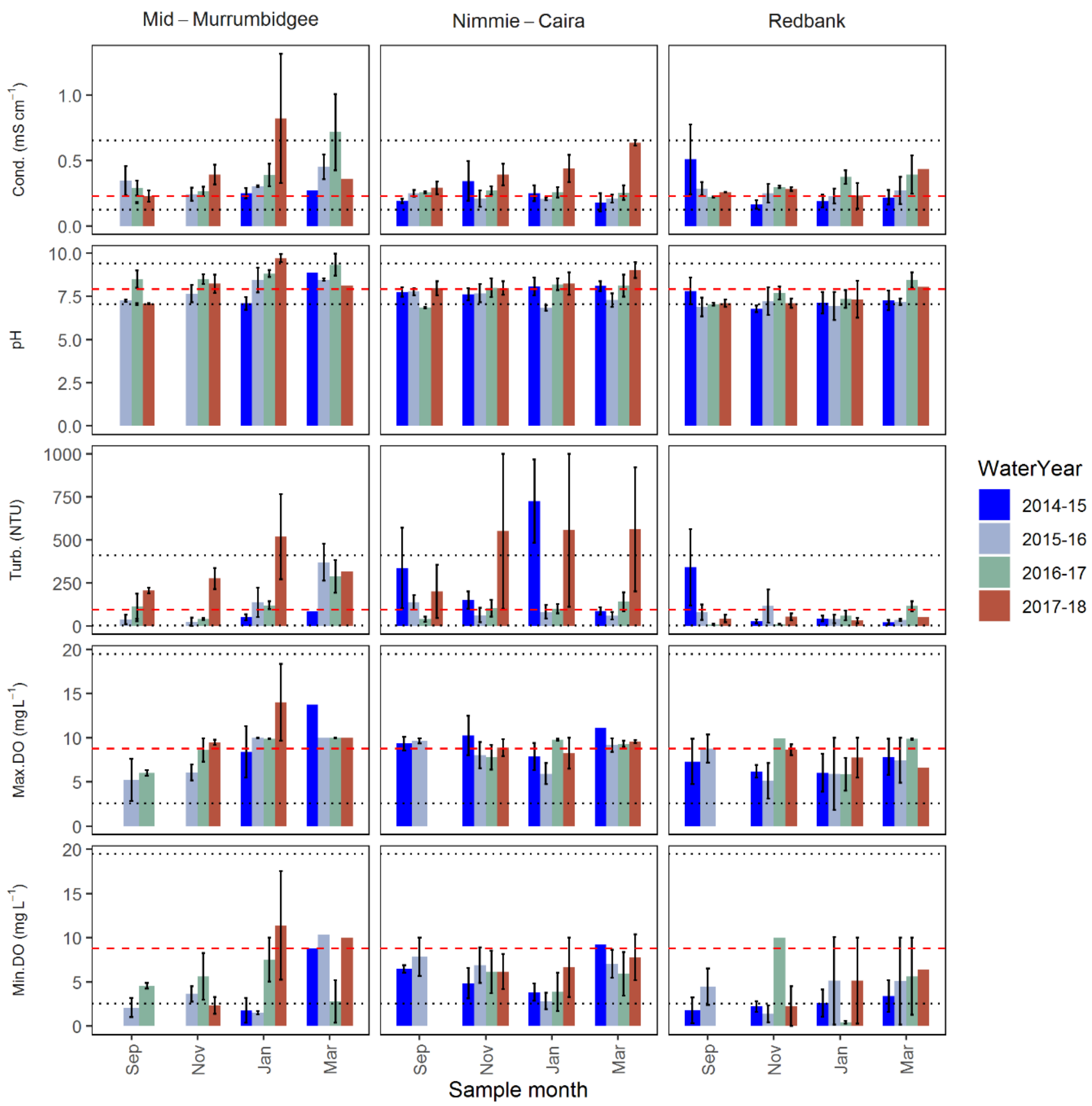

Figure 4-13 Mean ± standard error for physicochemical parameters (turbidity, pH, dissolved oxygen and conductivity) measured on four occasions between September and March during each of 2014-15, 2015-16 and 2016-17. Samples are collected across four sites within each of three monitored zones. Data are 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.

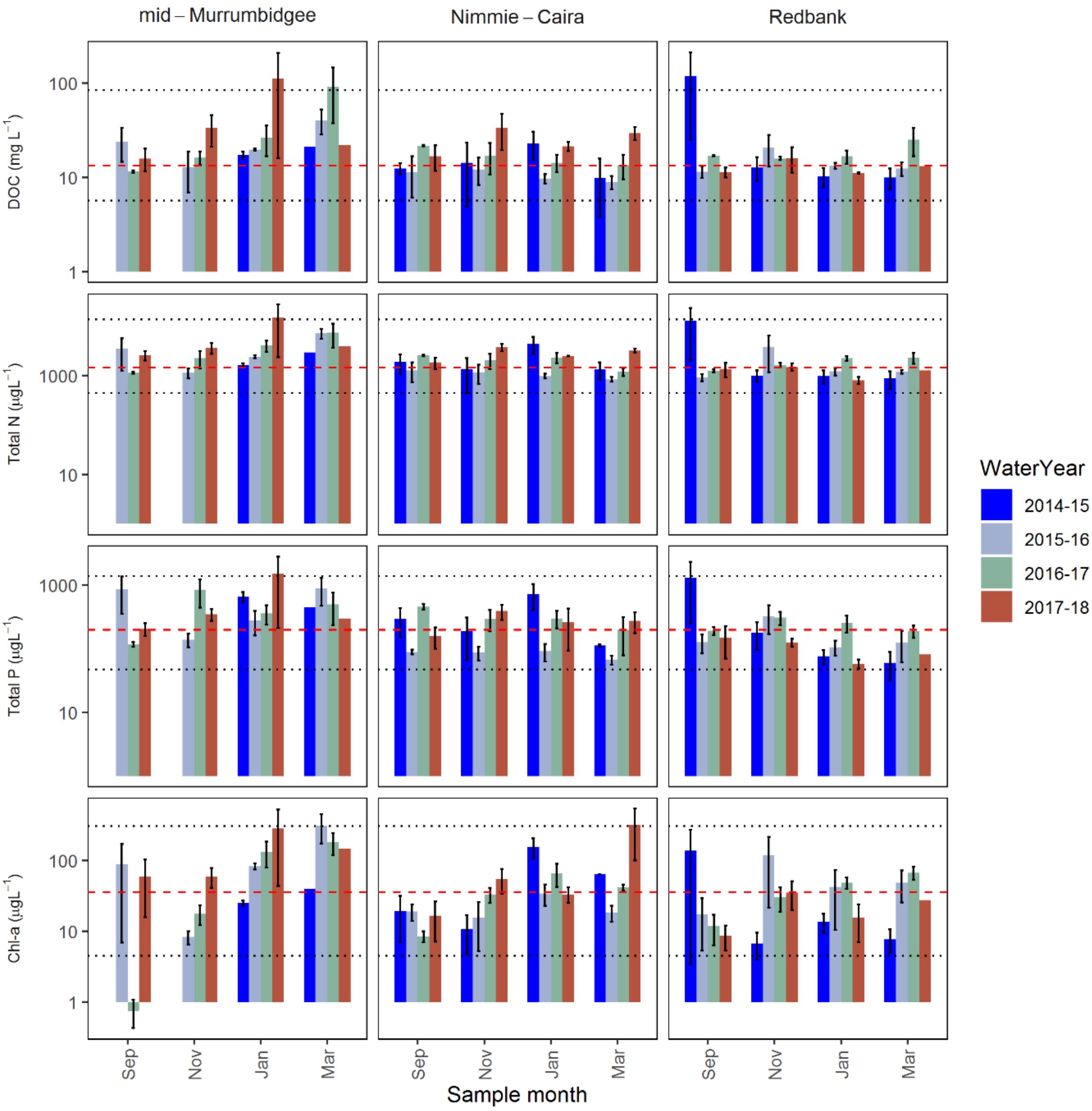

Figure 4-14 Mean ± standard error for dissolved organic carbon (DOC), total nitrogen (Total N), total phosphorous (Total P) and chlorophyll-a (Chl-a) measured on four occasions between September and March during each of 2014-15, 2015-16 and 2016-17. Samples are collected across four sites within each 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 4-2 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

Table 4-3 GAM results for water quality measurements against wetland water depth for composited water quality data (2014-2018) for the LTIM monitoring program.

Indicator	Chl-a	DOC	TN	TP	Cond	pH	Turb. NTU
R squared (adjusted)	0.219	0.317	0.397	0.379	0.355	0.172	0.292
Degrees of freedom	4.798	9.567	5.175	4.806	5.626	2.727	4.487
Wetland depth (F)	6.601***	5.303***	11.410***	11.07***	9.087***	0.978	6.630***

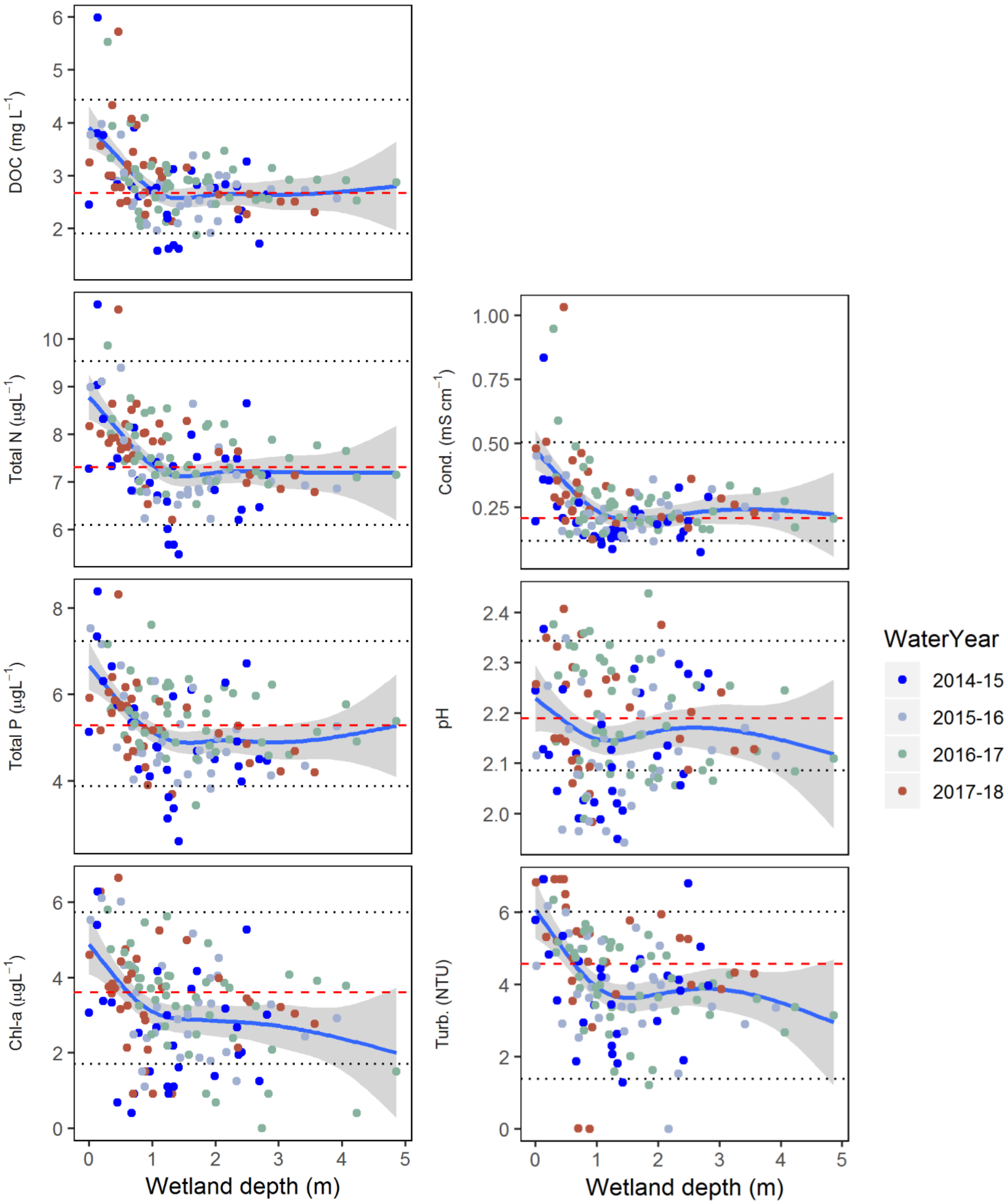

Figure 4-15 Scatterplots of wetland water quality measurements against depth for measured water column nutrients, carbon and chlorophyll-a (left column) and physicochemical properties (right column) for all data collected between 2014 and 2018. Y-axis data are log(x+1) transformed values. Blue lines show generalised additive model results (+/- 1 standard error). Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

Discussion

What did Commonwealth environmental water contribute to wetland water quality?

In ephemeral wetlands, poor water quality is typically associated with increasing conductivity, turbidity and pH, and more variable dissolved oxygen. Elevated values occur during the latter stages of drying, which often coincides with increased water temperature and rates of evaporation. Evaporation enables non-volatile compounds in the water column to become more concentrated. This leads to an increase in electrical conductivity as the concentration of dissolved ionic compounds increases, and is directly related to elevated salinity. Overall, the corresponding electrical conductivity where we expect to see impacts on aquatic species (~0.8 $mScm^{-1}$) is rarely observed even at the most advanced stages of drying the LTIM-monitored wetlands. Turbidity can similarly increase due to evaporation, however, in shallow wetlands the water column can also be disrupted by wind blowing across the water surface, resuspending benthic sediments, particularly where fine sediment has accumulated on the benthos and is not stabilised by aquatic plants. This means water quality is expected to vary broadly within individual hydrological cycles (i.e. inter-annual patterns).

Declining in water quality with drying is a feature of ephemeral wetlands that is an expected part of the hydrological cycle and is seen annually in the LTIM-monitored wetlands. We therefore expect evidence for declining water quality to be expressed as a function of wetland depth, with poorer water quality observed at higher water depths. During 2017-18, Commonwealth environmental water delivered to support wetland flora and fauna in 2017-18 were carried out early in the water year. Some wetlands were not inundated during the 2017-18, and all sites were relatively low or dried completely within the period of monitoring (only four of the twelve sites holding water in March 2018). This meant more extreme water quality values were reported in 2017-18 than previous years because lower water levels were observed overall, with no net decline in water quality occurring across years. Top-up water deliveries to both Gooragool and Yarradda Lagoons increased the water level at these sites, ensuring a longer period of good water quality. In the case of Yarradda Lagoon, pumping collectively added 1.00 m to the total depth. In the absence of environmental water, the residual water at Yarradda would have been <0.5 m (by March 2018) that would have been preceded by a long period of poor water quality.

Table 4-4 Summary of environmental watering actions that influence the hydrological regimes of the 12 monitored wetlands

Watering Action (s) in 2017-18	MEP and 2016-17 Acquittal Report Expected outcomes	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
mid-Murrumbidgee wetlands reconnection Yarradda Lagoon Pumping Gooragool Pumping and offset	"improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat."	What did Commonwealth environmental water contribute to wetland water quality?	Water quality in wetland sites that received Commonwealth environmental water improved with increasing depth of inundation. With water quality typically declining as the wetlands dried out which is consistent with the natural variability driven by wetland wetting and drying cycles	Yes

4.3 Wetland Microinvertebrates

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

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.

In 2014-15, 2015-16, 2016-17 and 2017-18 Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee 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 (Jenkins and Boulton 2007).

Relevant watering actions and objectives

During 2017-18 there were multiple deliveries of Commonwealth environmental and one delivery of NSW environmental water that contributed to microinvertebrate outcomes in the 12 LTIM-monitored wetlands across the Murrumbidgee Catchment (see Wetland hydrology 4.1). The most significant actions targeted the mid-Murrumbidgee wetlands with a combination of pumping, water offsets and the generation of a small flow peak within the river which created a connection between the river and low lying wetlands in the mid-Murrumbidgee (see Table 3-2). Further downstream, this pulse of environmental water also reached parts of Yanga National Park including Waugorah Lagoon.

There were no specific watering objectives related to microinvertebrates, however supporting productive and diverse communities of microinvertebrates contributes to the objective to "improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat." 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.

Commonwealth environmental water against the following criteria:

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

Methods

Wetland microinvertebrates were sampled four times per year (September, November, January and March), beginning in September 2014 and most recently sampled in March 2018. Sampling was conducted across all wetland sites that contained more than 10cm of water at the time of survey. 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 zone (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 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 inundation of wetlands in the mid-Murrumbidgee, Nimmie-Caira and Redbank zones with Commonwealth environmental water contributed to high levels of secondary productivity with densities of microinvertebrates between 500-1000/L throughout spring and summer (Figure 4-16). 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 4.11).

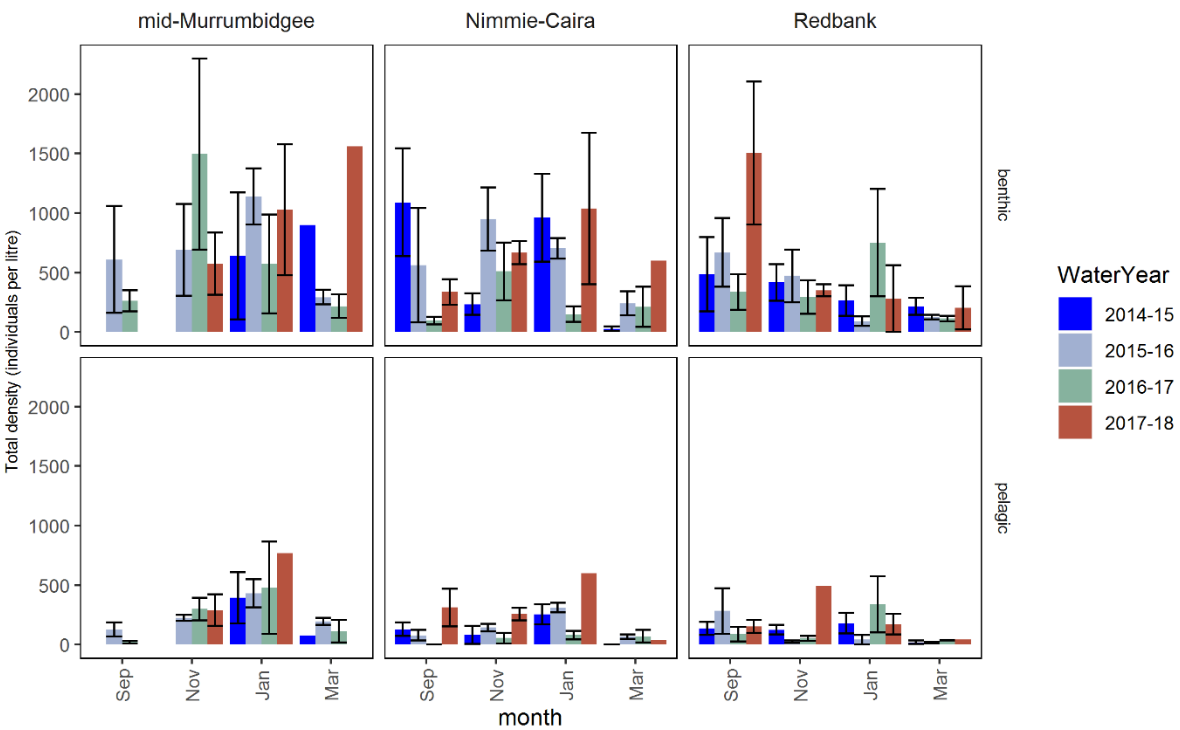

Figure 4-16 Mean densities of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) , 2015-16 (light blue) and 2016-17 (green) and 2017-18 (brown). Errors are standard errors. In September and November 2014-15 wetlands in the mid-Murrumbidgee were dry and not available to sample.

There were no significant differences between years or among trips nested within year in densities of microinvertebrates (Figure 4-17). Nevertheless, densities tended to be lowest in all wetlands in March and highest in November and January (Figure 4-17). Densities on all trips were lower in 2017-18 than the previous three years, but this difference was not significant (Figure 4-17).

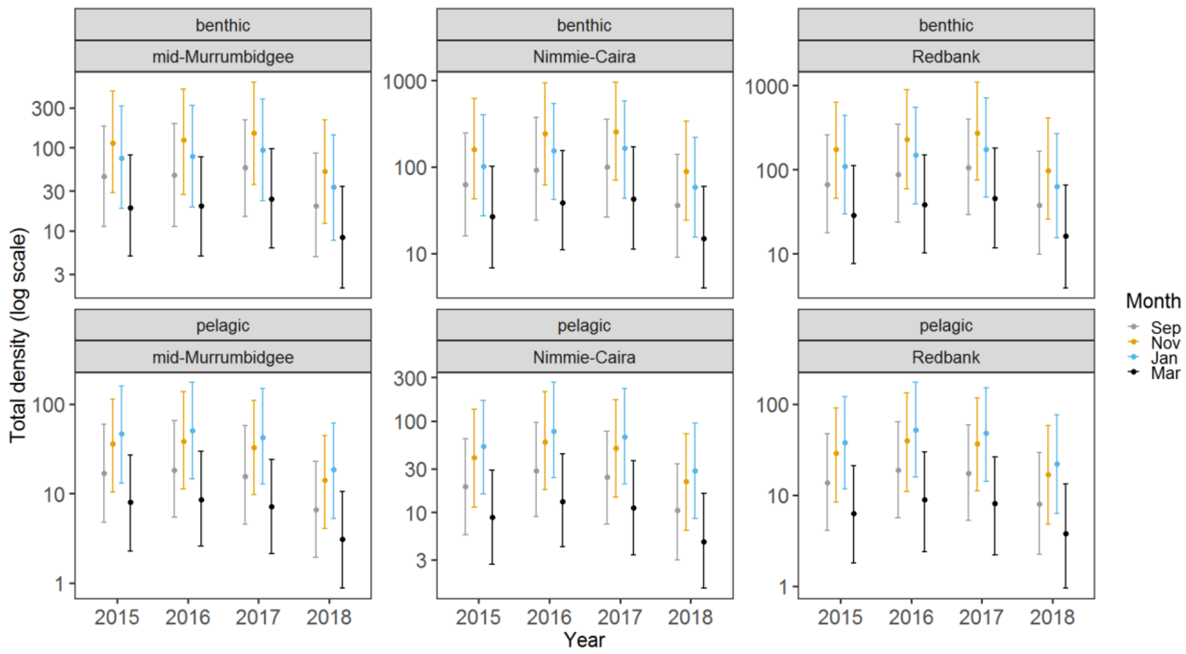

Figure 4-17: Model estimates of total microinvertebrate density (log scale) in four sites each from the mid-Murrumbidgee, Nimmie-Caira and Redbank zones in both benthic (upper graphs) and pelagic (lower graphs) habitats sampled over 4 trips in 2014-15, 2015-16 and 2016-17.

Copepods, particularly cyclopoids and nauplii, dominated benthic assemblages in all three years and across the three zones (Figure 4-18 Figure 4-64). 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 4-19). Densities of copepods were however lower in 2017-18 than in previous year (Figure 4-18 Figure 4-19). A suite of cladocerans, including Moinids, Chydorids, Bosminids and Macrothricids were also common in samples from all zones (Figure 4-18 Figure 4-19). However, in 2017-18 the dominant benthic cladoceran taxa was different to earlier monitoring years, with the following taxa being more abundant; Moinid *Moina micrura*, Macrothricids *Macrothrix* sp. and *Ilyocryptus* sp., Daphnid

Diaphanosoma sp. and Chydorids *Alona* sp., *Chydorus* sp, *Leydigia australis*. In pelagic habitats, *Moina micrura* and *Bosmina meriodonalis* were the most abundant cladocerans with densities of *Moina micrura* slightly below those observed in 2016-17 (Figure 4-19). A suite of Daphnid taxa were the other cladocerans contributing to the pelagic community in 2017-18 (Figure 4-19).

Figure 4-18: Model estimates 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.

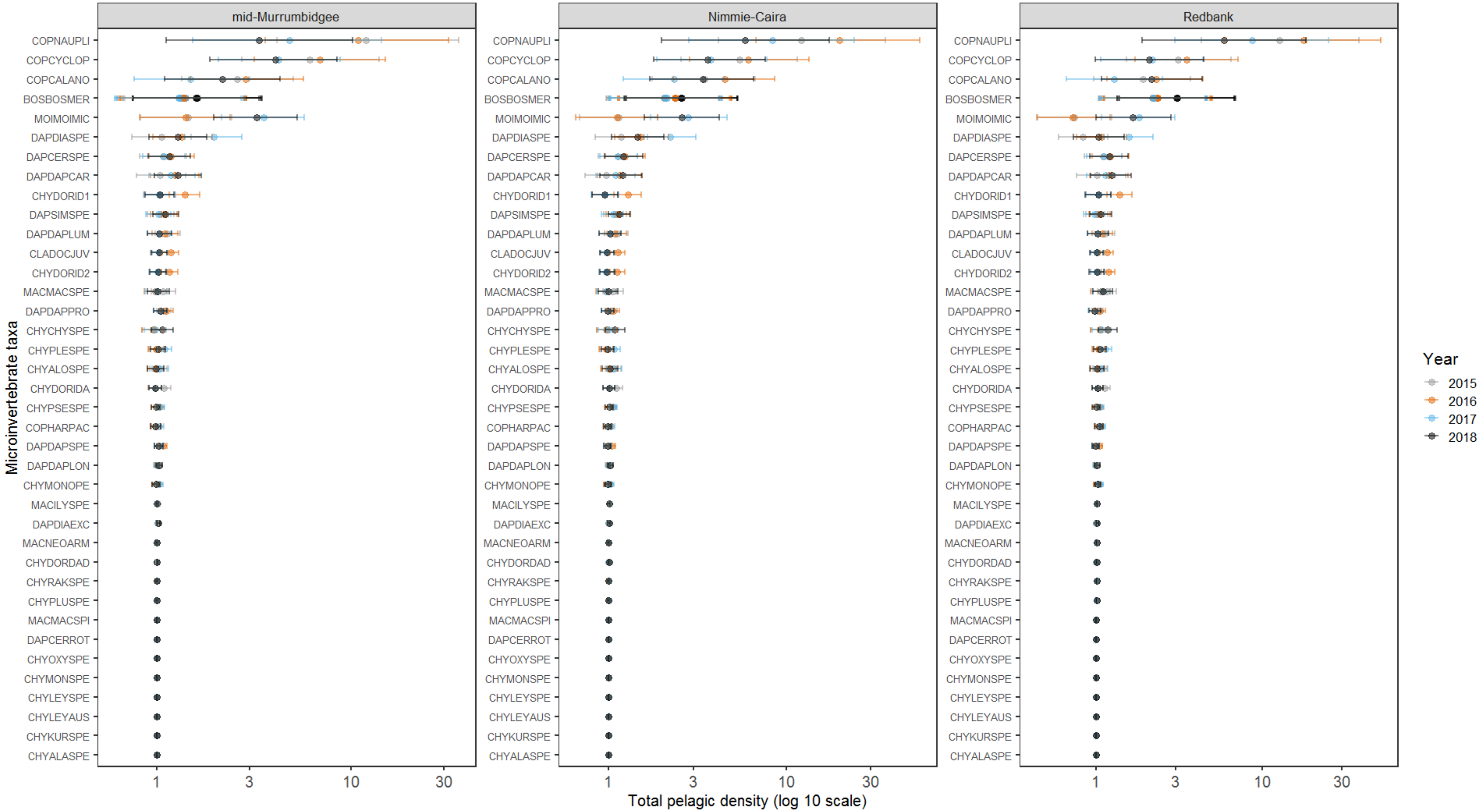

Figure 4-19: Model estimates of total pelagic microinvertebrate taxa density (log scale) in four sites each from the mid-Murrumbidgee, Nimmie-Caira and Redbank zones sampled in 2014-15, 2015-16 and 2016-17.

Discussion

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

In 2017-18 Commonwealth environmental water was primarily delivered to wetlands through the mid-Murrumbidgee. As in previous years, inundation of wetlands triggered a rapid and productive response of microinvertebrates with high densities throughout September, November and January. Benthic densities were above 1000 individuals/litre and a rich suite of microinvertebrates including copepods (cyclopoids, nauplii and calanoids) and cladocerans (*Moina micrura*, *Macrothrix* sp. *Ilyocryptus* sp., *Bosmina meriodonalis*, *Diaphanosoma* sp., *Alona* sp., *Chydorus* sp, *Leydigia australis*). Although densities tended to be lower overall this difference was not significant and may have been influenced by the higher than average number of wetlands which were dry through most of the monitoring period. Across all years there are some general trends to pelagic densities being were higher in the Nimmie-Caira and lowest in the mid-Murrumbidgee. Despite the slightly lower overall densities in 2017-18, responses of microinvertebrates to inundation were consistently high across years suggesting the current regime of wetting and drying is maintaining the egg bank and high levels of productivity. In all watering years, copepods dominated wetland assemblages, with cladocerans and lower densities of ostracods also present.

Research in the MDB for microinvertebrates, suggest frequent (annual for wetlands with this historical frequency) inundation of wetlands with some drawdown over winter yields the most productive sites for microinvertebrates. 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. Maintaining a mosaic of inundation frequencies will continue to provide suitable conditions for microinvertebrates.

4.4 Vegetation diversity

Prepared by Dr Skye Wassens (CSU)

Introduction

The composition and diversity of wetland plant communities is influenced by a range of hydrological and geomorphological metrics. Over long time frames the composition and species richness of wetland plant communities is influenced by the frequency of inundation (Reid *et al.* 2011), with dry periods that exceed the long-term average often leading to losses from both the extant species pool and the seedbank (Brock *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 *et al.* 1997; Casanova *et al.* 2000).

Wetland plant communities frequently experience a high level of natural variability in species richness and community composition as the vegetation community transitions between wet and dry phases (Bagella *et al.* 2009). The larger wetlands included in this monitoring and evaluation program typically fill completely early in the season (October – November) and then undergo a slow draw-down phase that gradually reveals damp sediments which are rapidly colonised by fast growing annual plant species and occasionally river red gum (*Eucalyptus camaldulensis*) seedlings. These annual species typically complete their lifecycle before the wetland refills giving way to a suite of aquatic species, many of which are perennial with persistent rhizomes or tubers, for example *Eleocharis* (spike rush) species). If wetlands remain dry for longer periods other longer-lived terrestrial species may establish, river red gum seedlings grow rapidly and the viability of perennial aquatic species starts to decline (Bagella *et al.* 2009; Wassens *et al.* 2017). Evaluating the response of aquatic communities to environmental water therefore needs to consider both the longer term aspects of hydrological regime which shape the dominant perennial overstorey and persistent seedbanks, the medium term (decadal) hydrological regime which may be impacted by reduced frequency of inundation due to regulation, and the short term (annual) responses of the vegetation community to a particular flow event or localised weather conditions (Wassens *et al.* 2017).

Evaluation of watering actions

In 2017-18 the largest volume of Commonwealth environmental water was delivered to produce a water level peak capable of connecting low lying wetlands in the mid-Murrumbidgee WAR 10062-01 (236,205ML). There was limited environmental watering activity across the Lowbidgee floodplain, and the majority of sites either contained residual water from unregulated flows and watering actions undertaken in 2016-17 or were dry. There was a small unregulated flow into Mercedes Swamp in the Redbank zone due to high water levels in the adjacent weir pool. The principle Commonwealth environmental watering actions that were monitored and influenced the hydrological regime of LTIM vegetation monitoring sites are outlined in Table 4-5.

Table 4-5 Summary of environmental watering actions that influence the hydrological regimes of the 12 monitored wetlands during the monitoring period

WAR	Event	Expected outcomes
	Nimmie Refuge (NSW Environmental water)	- protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities - improve reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities - reinstating a more natural wetting-drying cycle for wetland vegetation
WAR10062-01	mid-Murrumbidgee wetlands reconnection	
WAR10062-02 (additional water delivered under 10068-06)	Yarradda Lagoon Pumping	
WAR10062-03	Gooragool Lagoon Pumping and offset	

Mid-Murrumbidgee wetlands reconnection - Hydrological context

The Commonwealth environmental watering actions in 2017-18 influenced the hydrological regime of four of the LTIM monitoring sites in the mid-Murrumbidgee. Understanding the broader hydrological context of these wetlands (see wetland hydrology 4.1 for details) can help us to understand the observed responses to the environmental watering actions.

The mid-Murrumbidgee wetlands have been subject to significant reductions in inundation frequency, with current dry periods extending well beyond the long-term average (Page *et al.* 2005; Frazier *et al.* 2006). Extended drying has had significant impact on the cover, diversity and composition of aquatic vegetation communities that form following unregulated and managed inflows (Wolfenden *et al.* 2017). Prior to the mid-Murrumbidgee wetlands reconnection and pumping actions in 2017, Commonwealth and NSW environmental watering actions undertaken since 2014 have largely restored a seasonal inundation regime at two of the four monitored wetlands (Gooragool and Yarradda Lagoons) while the remaining two monitored wetlands (Sunshower and McKennas Lagoons) previously filled during unregulated flows in 2016-17 (Figure 4-20) but were dry in 2014-15, while Sunshower received a very small inflow in 2015-16. As a consequence, the starting condition of these four wetlands vary considerably. In 2016-17, Yarradda and Goorgool supported a relatively well-established aquatic vegetation community, which included a higher proportion of perennial species such as spike rushes (*Eleocharis sp*.) and spiny mudgrass (*Pseudoraphis spinescens*), while in 2016-17 Sunshower and McKennas supported a lower diversity of aquatic species and lower coverage of perennial aquatic species (Wassens *et al.* 2017).

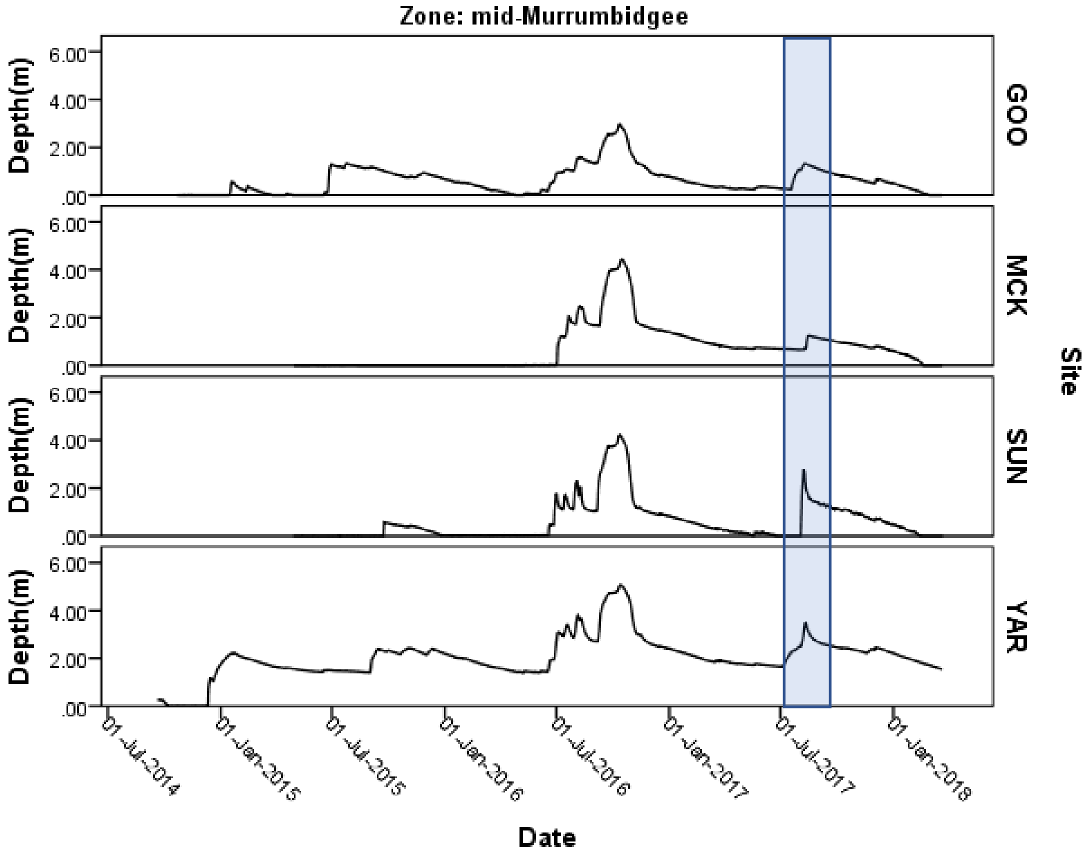

Figure 4-20 Hydrographs of the four monitored mid-Murrumbidgee wetlands from August 2014 until March 2018. Shaded section indicates approximate timing of Commonwealth environmental watering actions 2017-18 in the mid-Murrumbidgee. GOO Gooragool, MCK McKennas, SUN Sunshower, YAR Yarradda.

Commonwealth environmental water is evaluated against the following criteria:

- Did Commonwealth environmental water contribute to vegetation species diversity?
- Did Commonwealth environmental water contribute to vegetation community diversity?

Methods

The 12 wetlands monitored under this program represent four vegetation community types defined by the dominant overstorey and understory communities, and wetland geomorphology. In the Nimmie-Caira zone, the monitoring program includes one Lignum wetland (Eulimbah Swamp) (Plate 4-1), Lignum-black box wetlands (Nap Nap, Telephone Creek, Avalon) (Plate 4-2), and Wagourah Lagoon (Redbank zone). In the Redbank zone, there are three tall emergent aquatic wetlands (Mercedes, Two Bridges and Piggery Swamp) (Plate 4-3) which are open lakes with a dominant understory of spike rush (*Eleocharis* species) and fringing river red gum. In the mid-Murrumbidgee, vegetation communities are classified as river red gum woodland with deeper open ox bow lagoons and fringing river red gum (Sunshower, Gooragool, Yarradda, McKennas) (Plate 4-4).

Monitoring of vegetation communities is undertaken four times per year (September, November, January and March) and commenced in September 2014 (Wassens *et al.* 2014a). Surveys are conducted at twelve wetlands, with data collected along two to three fixed transects per wetland starting at the high-water mark and terminating at the centre of the wetland. Each transect contains three or five, 10 meter quadrats depending on transect length. 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 for each quadrat.

Plate 4-1 Eulimbah Swamp Lignum wetland January 2018: Nimmie-Caira (Transect 1)

Plate 4-2 Avalon Swamp Black Box–lignum wetland January 2018: Nimmie-Caira (Transect 1)

Plate 4-3 Two Bridges Swamp tall emergent aquatic wetland January 2018: Redbank (Transect 1)

Plate 4-4 Yarradda Lagoon river red gum wetland January 2018: mid-Murrumbidgee (Transect 1)

Data analysis

Comparisons of community structure and species diversity were undertaken using Primer version 6 (Clarke *et al.* 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 wetlands, water years and wet-dry phases. SIMPER is used to identify the species that contribute most to differences between sites (Anderson 2005). Species richness (S) values were generated for species within the aquatic species and for all species combined for each wetland over the four year monitoring period. Spearman's RHO tests were used to describe the relationship between species richness and soil moisture. Trends in species richness across the four water years were tested using the Jonckheere-Terpstra test for order alternatives, which is a non-parametric, rank-based trend test, utilisation of a rank based function is considered appropriate given the differing community composition and species richness of the study wetlands.

Results

Commonwealth environmental water contribution to vegetation species diversity

Across all sample sites there was a slight increase in overall species richness in 2017-18 compared to previous years (Jonckheere-Terpstra test $t = -3.585$, $p < 0.001$), but a slight, non-significant decline in aquatic species richness in 2017-18 ($t = -1.866$, $p = 0.062$). Within the three different zones, there was an increase in species richness overall in the Nimmie-Caira ($t = -2.112$, $p = 0.035$), and a decline in aquatic species richness ($t = -1.985$, $p = 0.047$) (Figure 4-21). In the Redbank system, overall species richness has remained relatively stable since 2014 ($t = -0.461$, $p = 0.644$), while aquatic species richness was lower in 2017-18 then previous years ($t = -2.008$, $p = 0.045$) because the majority of wetlands were dry. In the mid-Murrumbidgee wetlands, there was a significant increase in species richness overall following environmental watering action ($t = -3.490$, $p < 0.001$), while aquatic species richness was similar to previous years ($t = 0.716$, $p = 0.474$).

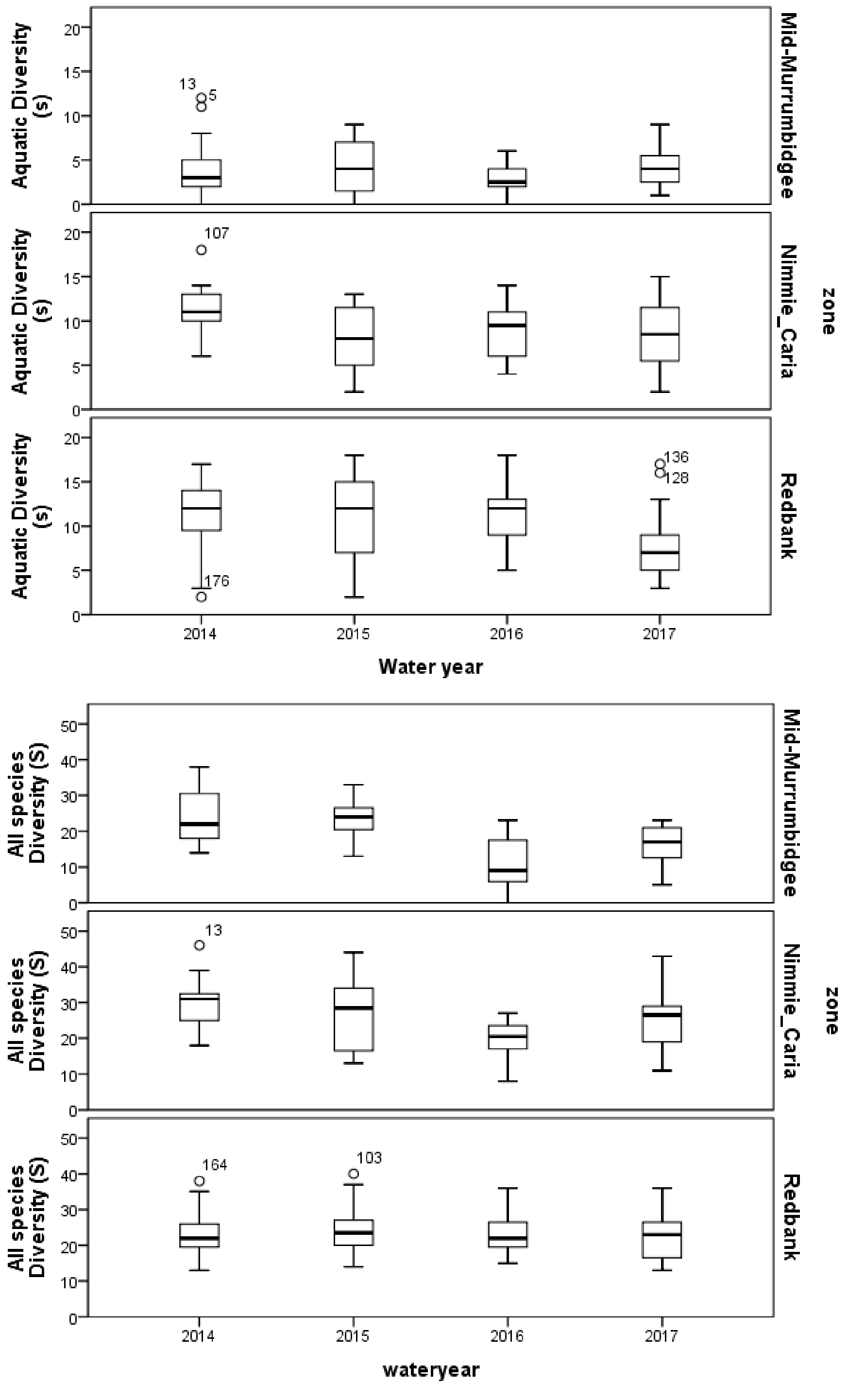

Figure 4-21 Species richness across the 12 monitored wetlands 2014-2018. Top all species, and bottom aquatic species diversity.

Relationship between watering and species richness

The inundation extent (wet or dry status) has a significant impact on both overall and aquatic species diversity but patterns varied between zones. When comparing wetlands that were entirely dry, residual - partially wet (usually during wetland draw down phase) and wet (full wetland) we predicted that the species diversity should increase with increasing proportion of the wetland inundated. However, the prediction was not well supported when all species (terrestrial and aquatic) are considered (Figure 4-22). The overall species diversity declined as the wetlands filled in the mid-Murrumbidgee (Jonckheere-Terpstra test for order alternatives $t=-4.082$, $p<0.001$), and was unchanged in Nimmie-Caira ($t= -1.283$, $p = 0.200$) and the Redbank system ($t= 0.172$, $p = 0.864$). However, aquatic species diversity increased with inundation in Nimmie-Caira ($t= 4.017$, $p <0.001$), Redbank ($t= 4.014$, $p<0.001$), and in mid-Murrumbidgee wetlands ($t= 2.235$, $p <0.025$).

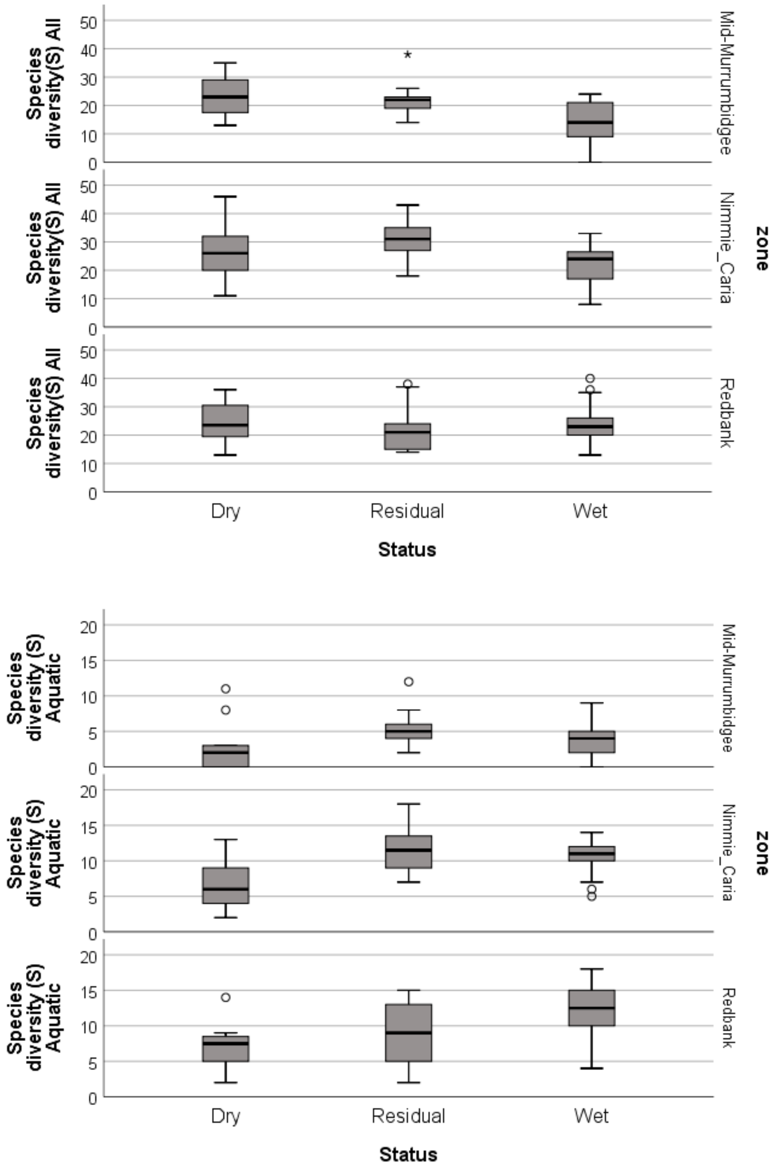

Figure 4-22 Species diversity changes in response to wetland wet and dry status. Top all species, and bottom aquatic species diversity.

Cumulative species richness

Cumulative species richness is a measure of the number of new aquatic species added on each sampling occasion. An increase in cumulative species richness indicates that new species are being detected at the wetland, while a relatively flat curve indicates that the community is relatively stable over time with few new species being detected on each survey.

The mid-Murrumbidgee watering action contributed to increases in the number of aquatic species identified at three of the four wetlands monitored in the mid-Murrumbidgee (Figure 4-23). Two new aquatic species, common water milfoil (*Myriophyllum papillosum)* and floating pondweed (*Potamogeton tricarinatus*) were identified at McKennas and Sunshower wetlands following the Commonwealth environmental watering action, while curly pondweed *(P. crispus*) was also identified at Sunshower for the first time. Yarradda Lagoon has shown a steady increase in the number of aquatic species being identified with two additional species identified following Commonwealth environmental watering, water primrose (*Ludwigia peploides* ssp. *montevidensis*) and nardoo (*Marsilea drummondii*). Gooragool Lagoon has a high diversity of aquatic species overall, but there were no new species identified in 2017-18 which suggests that this community is relatively stable over time.

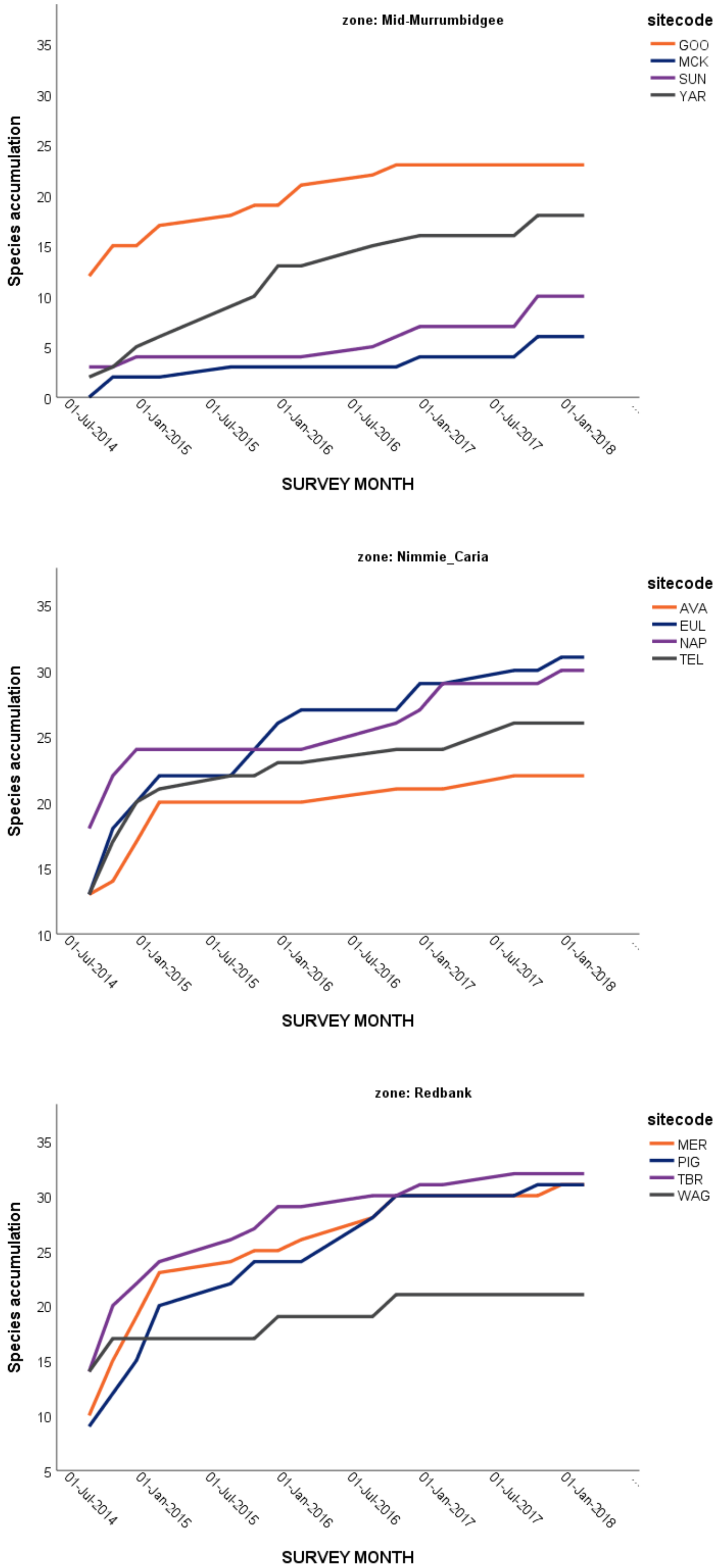

Figure 4-23 Species accumulation curve for aquatic species in wetlands in the mid-Murrumbidgee between September 2-14 and March 2018.

Did Commonwealth environmental water contribute to vegetation community diversity?

Considered across all sample years, there are still clear differences in the composition of vegetation communities at both the site (ANOSIM R 0.76, p < 0.001) (Figure 4-24) and zone (water management unit) scale (ANOSIM R 0.486, p < 0.001)(Figure 4-25). The differences in the composition of plant communities between sites and zones are consistent across years, essentially demonstrating that each of the 12 wetlands supports a unique vegetation community and that wetlands within the three zones, while still significantly different to one another, are typically more similar to one another then they are to wetlands in the other zones. For this reason, we evaluate the contribution of environmental water to vegetation communities at both the site and zone scale.

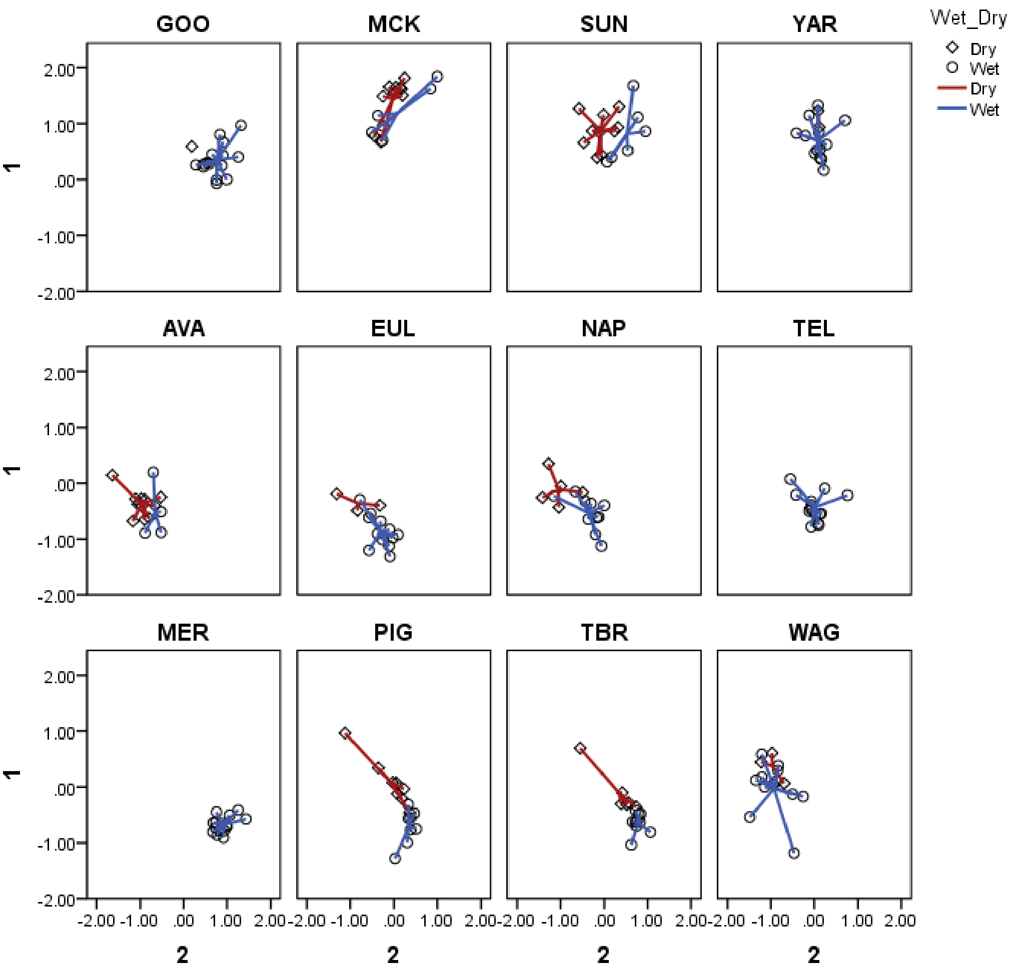

Figure 4-24 Multidimensional scaling plot of wetland vegetation community structure at each monitoring site during wet and dry phases between September 2014 and March 2018. The greater the overlap the more similar the wet and dry phase communities. (GOO = Goorogool, MCK = McKennas, SUN = Sunshower, AVA = Avalon, EUL = Eulimbah, NAP = Nap Nap, TEL = Telephone, MER = Mercedes, PIG = Piggery, TBR = Two Bridges, WAG = Wagourah).

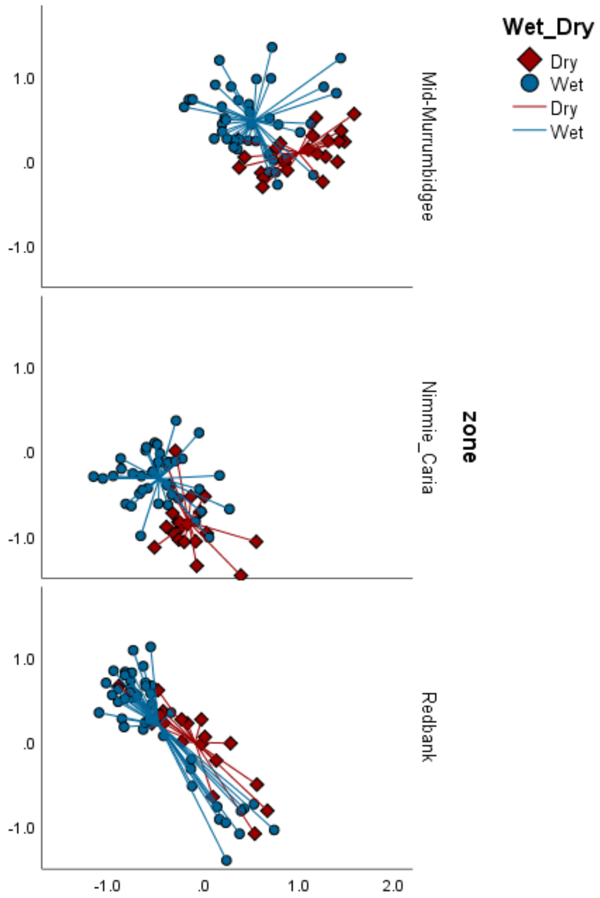

Figure 4-25 Multidimensional scaling plot of wetland vegetation community structure within the three water management zones during wet and dry phases between September 2014 and March 2018. The greater the overlap the more similar the wet and dry phase communities.

At the vegetation community scale, and as in previous years, vegetation communities in the Nimmie-Caira and Redbank zones were more similar to one another (R = 0.357 p <0.001) than to the wetlands in the mid-Murrumbidgee (R = 0.678, p <0.001 and R = 0.457, p <0.001 respectively). Within individual wetlands environmental watering actions since 2014 supported the establishment of aquatic communities which differed significantly from those occurring during the dry phase (Figure 4-24).

Within each of the water management zones, environmental watering actions since 2014 (complimented by unregulated flows in 2016) contributed to significant differences in the composition of vegetation communities, which differed significantly between wet and dry phases in the Nimmie-Caira (R = 0. 33, p <0.001), Redbank (R = 0.126, p=0.027) and mid-Murrumbidgee (R = 0. 186, p <0.001) (Figure 4-25).

Environmental water was particularly important in supporting the establishment of aquatic communities in all three water management sites. In the mid-Murrumbidgee environmental watering contributed to the establishment of spiny mud grass (*Pseudoraphis spinescens*), common spike rush (*Eleocharis acuta*) and two fringing species, lesser joyweed (*Alternanthera denticulata*) and the culturally significant old man weed (*Centipeda cunninghamii*) (Table 4-6). Dry wetlands were dominated by annual terrestrial species and had higher coverage of the weed species spear thistle (*Cirsium vulgare*). In the Nimmie-Caira wetlands are characterised by fringing black box with lignum and nitre goosefoot overstoreys. Wetlands receiving environmental water over the past four years were dominated by native aquatic species including Azolla (*Azolla filiculoides*), water milfoils (*Myriophyllum verrucosum* and *M. papillosum*), and water primrose (*Ludwigia peploides*). Wetlands in their dry phase supported a mix of native species including old man weed (*Centipeda cunninghamii*) and nardoo (*Marsilea drummondii*), along with exotic annual species heliotrope (*Heliotropium europaeum*) and trailing verbena (*Verbena supina*). Wetlands in the Redbank zone are predominantly tall emergent aquatic systems with fringing river red gum, and environmental watering supported tall spike rush (*Eleocharis sphacelata*), swamp buttercup (*Ranunculus undosus*) and poison pratia (*Pratia concolor*).

Table 4-6 SIMPER comparisons of vegetation communities while wetlands are wet (environmental water and unregulated flows) and dry in each water management zone

Species supported by environmental water	Average abund. Wet	Average abund. Dry	Species occurring during dry phases	Average abund. Wet	Average abund. Dry
mid-Murrumbidgee					
Pseudoraphis spinescens	0.68	0.05	*Cirsium vulgare**	0.29	1.03
Eleocharis acuta	0.98	0.36	*Dysphania pumilio*	0.27	0.71
Alternanthera denticulata	0.55	0.25	*Poaceae**	0.17	0.60
Centipeda cunninghamii	0.74	0.44	*Calotis scapigera*	0.24	0.64
Persicaria prostrata	0.39	0.13	*Polygonum aviculare**	0.14	0.53
Panicum effusum	0.32	0.1	*Lactuca serriola**	0.05	0.29
Nimmie-Caira					
Azolla filiculoides	0.77	0.01	*Marsilea drummondii*	0.72	1.23
Eleocharis acuta	0.90	0.18	*Heliotropium europaeum**	0.1	1.03
Myriophyllum verrucosum	0.75	0.06	*Centipeda cunninghamii*	0.64	1.00
Ludwigia peploides	1.00	0.36	*Verbena supina**	0.1	0.54
Eleocharis pusilla	1.01	0.52	*Dysphania pumilio*	0.13	0.48
Myriophyllum papillosum	0.43	0.06	*Xanthium occidentale**	0.05	0.35
Redbank					
Eleocharis sphacelata	1.89	0.78	*Centipeda cunninghamii*	0.41	1.15
Ranunculus undosus	0.61	0.13	*Dysphania pumilio*	0.21	0.46
Azolla filiculoides	0.87	0.47	*Chamaesyce drummondii*	0.11	0.33
Marsilea drummondii	0.92	0.55	*Persicaria decipiens*	0.27	0.49
Ludwigia peploides	0.91	0.56	*Sclerolaena muricata*	0.29	0.49
Pratia concolor	0.41	0.09	*Heliotropium europaeum*	0.16	0.36

*Denotes introduced species

Discussion

There were four key watering actions undertaken in 2017-18 that influenced the hydrology of four of the 12 monitored wetlands and that were monitored under LTIM. These actions connected wetlands in the mid-Murrumbidgee to the main river channel in order to:

- protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities
- improve reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities
- reinstating a more natural wetting-drying cycle for wetland vegetation

Overall these watering action were successful in achieving the stated objectives with respect to vegetation, but outcomes varied between individual wetlands (Table 4-7). The connectivity created during the mid-Murrumbidgee wetland reconnection may have contributed to the dispersal and subsequent establishment of two new aquatic species at McKenna's and Sunshower Lagoons, which were previously inundated by an unregulated flow in 2016-17, but have not received Commonwealth environmental water since 2012 (Wolfenden *et al.* 2017). Gooragool and Yarradda Lagoons have received environmental water more frequently and consequently support a more diverse and temporally stable aquatic vegetation community.

While the wetlands in the mid-Murrumbidgee contained water through most of the monitoring period, monitored wetlands in the Nimmie-Caira which received Commonwealth and NSW OEH environmental water between April and June 2017, as well as those in the Redbank system, were largely dry by the start of the monitoring period. Allowing for an occasional short drying period can have a positive impact on vegetation communities in some seasonally inundated wetlands, and can be particularly important for improving the condition of overstorey species such as black box and river red gum which may become stressed if inundated for extended periods. In this case the decision to allow wetlands in the Redbank zone to dry over 2017-18 may assist in the breakdown of tall spike rush litter which can otherwise contribute to poor water quality. As a consequence, while species diversity and percentage cover of aquatic species were lower overall in the Nimmie-Caira and Redbank wetlands in 2017-18 the drying intervention may contribute to greater diversity and improved water quality in 2018-19, and wetlands in the Nimmie-Caira and Redbank systems will be the priority for Commonwealth environmental watering actions in 2018-19.

Summary of expected outcomes

Table 4-7 Evaluation of expected outcomes of monitored environmental watering actions watering actions

Event	Expected outcomes	Evaluation	Was this outcome achieved
mid-Murrumbidge wetlands reconnection Yarradda Lagoon Pumping Gooragool Lagoon Pumping Gooragoll Lagoon offset	- protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities	Species diversity and cover of key aquatic species was maintained at Gooragool and increased at Yarradda, Sunshower and McKennas	Yes
	- improve reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities	While this program does not specifically monitor flowering and seed set of aquatic plant species, the hydrological regimes created at Goorgool, Yarradda, Sunshower where sufficient to allow resident native aquatic plant species to achieve seed set.	Yes (for 3 of 4 wetlands)
	- reinstating a more natural wetting-drying cycle for wetland vegetation	The wetting and drying cycle for Gooragool and Yarradda have been maintained close to their long-term average since 2014. Inundation frequency at McKennas and Sunshower is lower than the long-term average and this is reflected in lower diversity and cover of aquatic species at these wetlands.	Yes (for 2 or 4 wetlands)

Management implications

Wetlands included in this monitoring program represent a wide range of hydrological regimes and geomorphologies ranging from deep permanent lagoons and creek lines to shallow temporary wetlands. While the hydrological regimes of all wetlands have been modified to some extent by river regulation, the condition of the wetlands also varies, particularly in the mid-Murrumbidgee where river regulation has greatly altered the frequency of reconnections between the river and the wetlands thereby greatly extending the drying periods at McKennas and Sunshower Lagoons. Given the diversity of wetland types and vegetation communities represented in this study it is difficult to make generalisations on the expected outcomes with respect to the contribution of Commonwealth environmental water to species and community diversity. Seasonally inundated wetlands that have been maintained through repeat delivery of environmental water are typically in good condition, transitioning between stable, high diversity aquatic communities during wet phases and a predictable suite of largely native annual species during brief dry periods. The stable nature of these communities mean that both species losses and additions are infrequent, with species additions more likely to represent increased detection over time rather than genuine changes to the species pool. In contrast, wetlands in the mid-Murrumbidgee that have received limited environmental water over the past four years tend to be more variable, with new additions to the species pool and increases in species diversity more common, and the composition of aquatic and terrestrial communities is more variable from year to year. Understanding the water needs of individual wetlands and the context in which the watering action is taking place is therefore important.

4.5 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). Reductions in the frequency and duration of small-medium natural flow events prevent regular connections between the river and off-channel habitats (Arthington *et al.* 2003; Balcombe *et al.* 2006b), permanently changing the hydrological cycle of wetlands. For species that rely on permanent off-channel sites for growth and recruitment, these changes have significantly contributed to native fish declines in the Murrumbidgee Catchment.

During July-September 2017 all four of the wetlands in the mid-Murrumbidgee zone that are monitored under LTIM were inundated during the pumping, off sets and subsequent reconnection during the mid-Murrumbidgee wetland reconnection flow. Further downstream, this pulse of environmental water also inundated Waugorah Lagoon in the Redbank zone.

These deliveries sought to inundate fringing wetlands to continue recovery of wetland vegetation communities, and provide habitat to support survival and maintain the condition of waterbirds and native aquatic biota (including fish, turtles, frogs and invertebrates). In this section, we evaluate the environmental watering actions targeting wetland fish communities against the following 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 where the net is set (NB: nets can only be set when water depths are above 30cm). The total CPUE for all four nets is summed to create a single catch per unit effort for each site per sampling occasion.

Data analysis

We tested for differences in fish community composition (CPUE) using a two way permutational analysis of variance (PERMANOVA) with Water Year (n=4) and Zone (n=3) as fixed factors. Because many sites were dry, we took the average CPUE for across all sample times for each site for each species, and ran the above model in it's unbalanced form, noting that this results in a loss of statistical power. Data were fourth-root transformed to reduce the influence of highly abundant species on community data. Resemblance matrices were calculated using a Bray Curtis distance measure. Post-hoc tests were used to further isolate significant terms. Because of the reduced design power, post-hoc results were considered significant at p<0.10. Species contributions to significant factors were calculated using a similarity percentages test (SIMPER). For highly influential species identified by SIMPER, separate univariate tests were carried out, using a linear mixed-effects model testing for an interation between Water Year and Zone, with a random effect for site netsed within zone. The length-frequency distribution of the four most abundant fish species was compared among sample occasions within each wetland zone, pooling length data for each species across all sites sampled within each zone. Comparisons were made using a boot-strapped two-sample Kolmogorov-Smirnov test (Ogle 2015) for all species with a minimum of 30 individuals. Differences were considered significant at p<0.05. P-values were corrected for multiple comparisons.

All analyses were performed using the R environment. PERMANOVA tests were carried out in R using the vegan package (Oksanen *et al.* 2011) with Bonferroni-corrected pairwise contrasts calulcated using the adonis.pair function in the EcoUtils package.

Mixed effects models were calculated using the lmer function in the lme4 package (version 1.1.17, (Bates *et al.* 2015). Length-frequency anaalyses were carried out using the FSA package (version 0.8.20, (Ogle 2015).

Results

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

During 2017-18 a total of 22,019 fish were captured in wetland fyke nets, which is fewer than previous LTIM monitoring years (2014-15 = 40,025; 2015-16 = 78,206; 2016-17 = 118,463). Six native and six exotic fish species were captured across the 12 LTIM wetland sites between September 2017 and March 2018. Silver perch and unspecked hardyhead were not observed during 2017-18 and so the number of native species is fewer than the 8 recorded for 2016-17.

As noted previously, carp gudgeon were by far the most abundant native species, occurring across all three monitoring zones (Figure 4-26) and comprising 65% of the total catch for 2017-18. The next most common native species, bony herring and smelt, each represented just 0.6% of total fish caught. Although fewer native carp gudgeon were caught in 2017-18 relative to the three previous LTIM monitoring years, fewer eastern gambusia and European carp meant the overall ratio of native to exotic fish was 1.96, the highest for any LTIM year in the Murrumbidgee (2014-15 = 1.03, 2015-16 = 1.02, 2016-17= 0.22).

Overall, patterns of fish CPUE were variable across space and time (Figure 4-26 to Figure 4-29). Community analysis found broad general patterns of variability, suggesting fish communities were broadly similar across Zones and Water Years (note overlapping areas in Figure 4-30). However, significant differences among zones and water years were detected (df = 6, Pseudo-F=2.122, p(perm)<0.001; Figure 4-30). These patterns 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 confirm that these observed patterns were driven by several highly abundant species – carp gudgeon, common carp and gambusia.

Native carp gudgeon exhibited different patterns over time across the three zones. In the mid-Murrumbidgee, numbers of carp gudgeon have increased each year since

2014-15, although differences were only significant between the 2014-15 (range 0.004-0.248 individuals m^{-2} hr^{-1}) and 2017-18 (range 2.141-11.900 individuals m^{-2} hr^{-1}) water years (Table 4-8; tukey's p=0.008). In the Redbank and Nimmie-caira zones, carp gudgeon numbers appeared to increase slightly in 2015-16 and have since declined (these trends are not statistically significant at alpha=0.05).

Exotic fish were found widespread and in high abundances during 2016-17 with gambusia, common carp, goldfish and oriental weatherloach (*Misgurnus anguillicaudatus*) the most commonly recorded exotic species (Figure 4-29). Numbers of carp increased in 2016-17 but were significantly lower in 2017-18 than 2016-17 for both the Redbank (tukey's p<0.001) and Nimmie-Caira (tukey's p=0.005) zones. Across all zones, there were significantly fewer eastern gambusia caught in 2014-15 than 2016-17 (**Error! Reference source not found.**; tukey's p=0.010).

Table 4-8 Linear mixed-effects model results (f-ratio and significance) for the three most common species reported in Murrumbidgee LTIM weltand surveys.

	Carp	Gambusia	Carp gudgeon
WaterYear (n=4)	14.028***	4.126**	2.937*
Zone (n=3)	2.479	1.142	0.715
WaterYear x Zone	4.388***	0.157	6.197***
r-squared	0.34	0.23	0.48

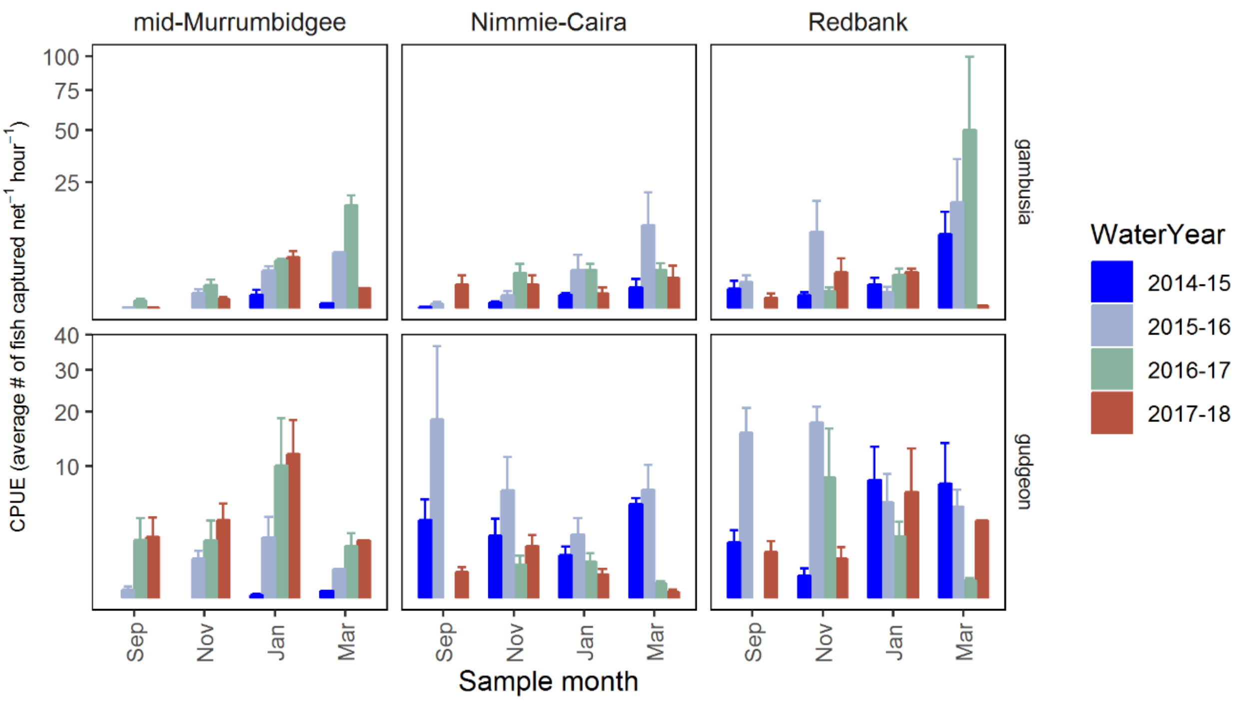

Figure 4-26 Mean catch per unit effort (fish m^{-1} h^{-1})((CPUE) (+ SE) of exotic mosquito fish (Gambusia holbrookii) and native carp gudgeon (Hypseleotris spp.) over the four sample periods in all years. Note that the y-axis is on a square root scale.

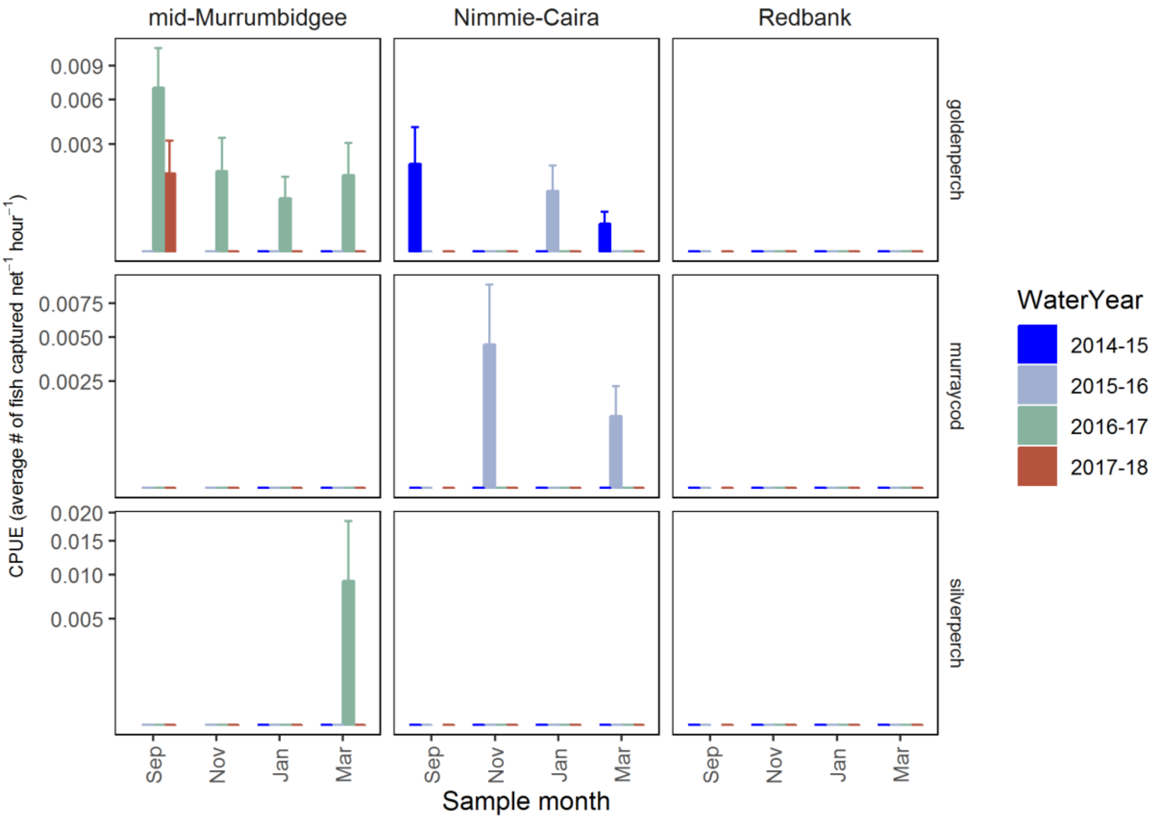

Figure 4-27 Mean catch per unit effort (fish per net hour)((CPUE) (+ SE) of large and medium-bodied native fish species excluding carp gudgeon over the four sample periods in all years. Note that the y-axis is on a square root scale.

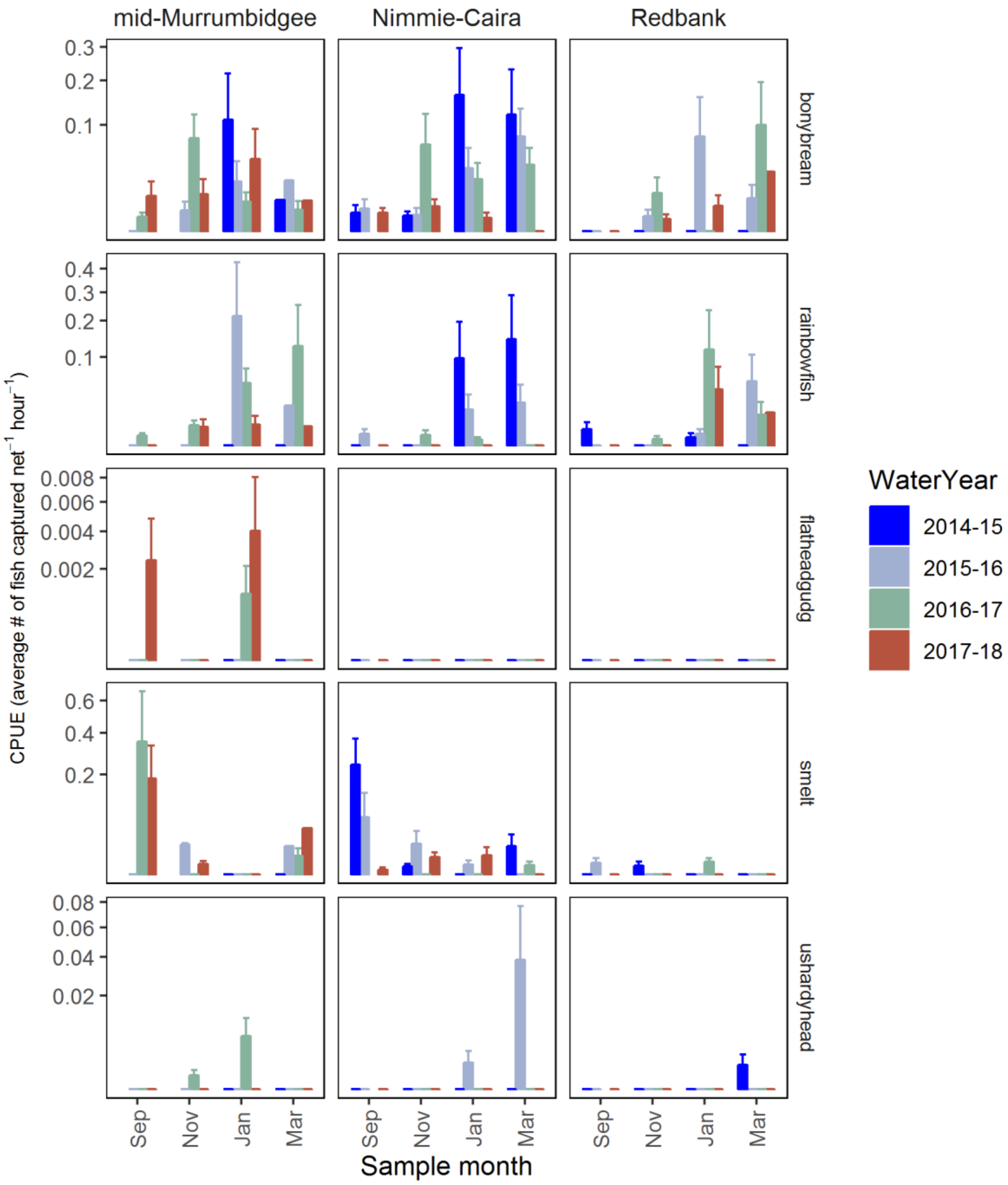

Figure 4-28 (b) Mean catch per unit effort (fish per net hour)((CPUE) (+ SE) of small-bodied native fish species excluding carp gudgeon over the four sample periods in all years. Note that the y-axis is on a square root scale.

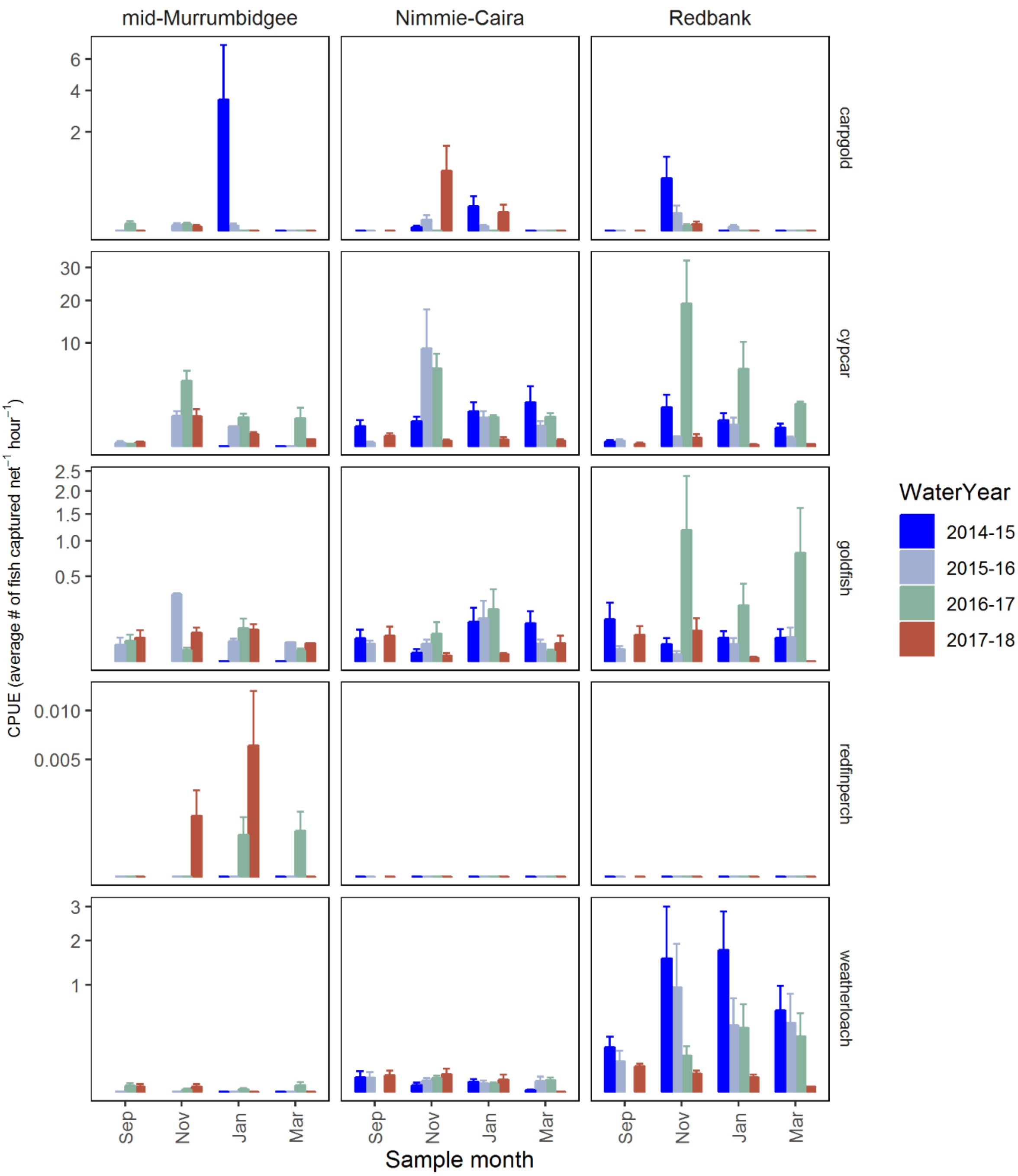

Figure 4-29 (b) Mean catch per unit effort (fish per net hour) +/- standard error of exotic fish species excluding gambusia over the four sample periods in all years. Note that the y-axis is on a square root scale.

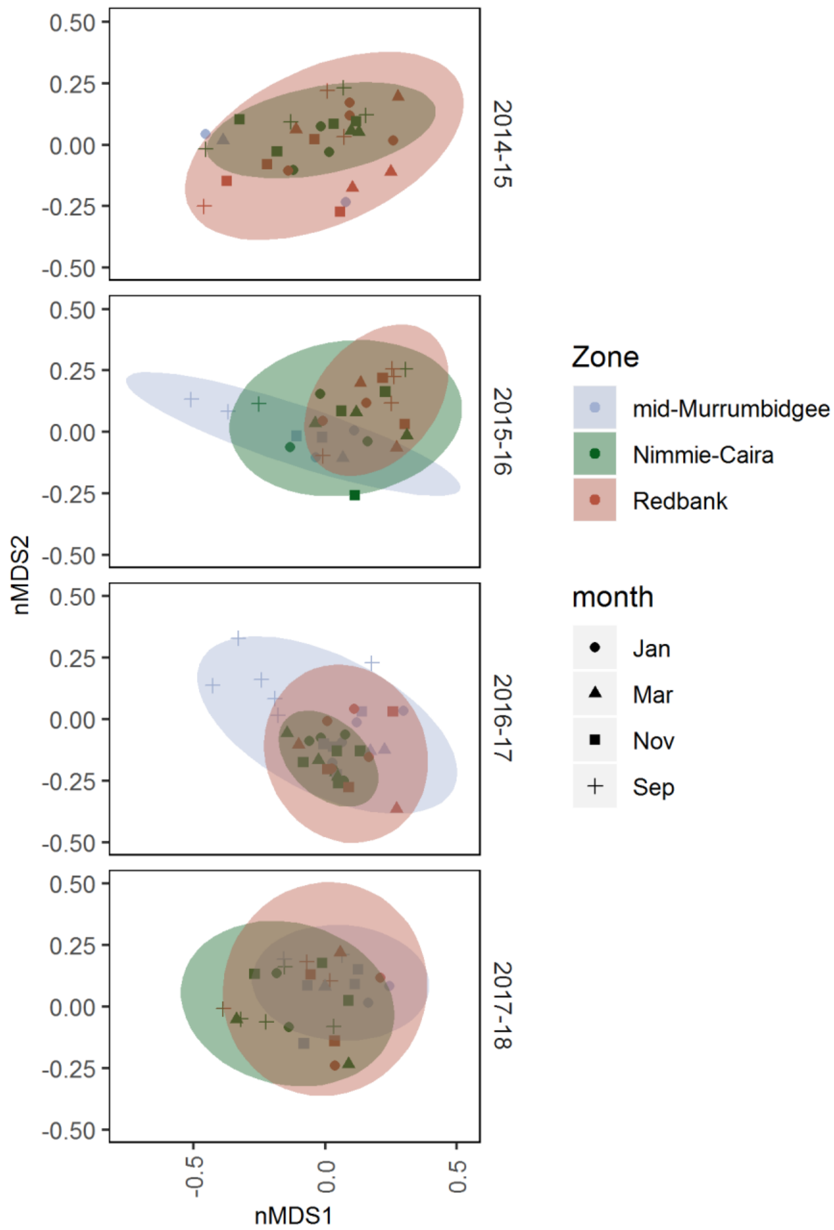

Figure 4-30 A non-metric multidimensional scaling plot of fish community composition for the Murrumbidgee Wetlands 2014 to 2018. Stress = 0.18.

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 approximate 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 individual 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, although few individuals captured during 2017-18 means many tests could not be carried out (Table 4-9). The size structure of bony bream (Figure 4-31), carp gudgeon (Figure 4-35) and gambusia (Figure 4-36) was skewed toward larger individuals during the November sample occasion, dominated again by smaller individuals during March. For weatherloach (Figure 4-34) and carp (Figure 4-32) 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.

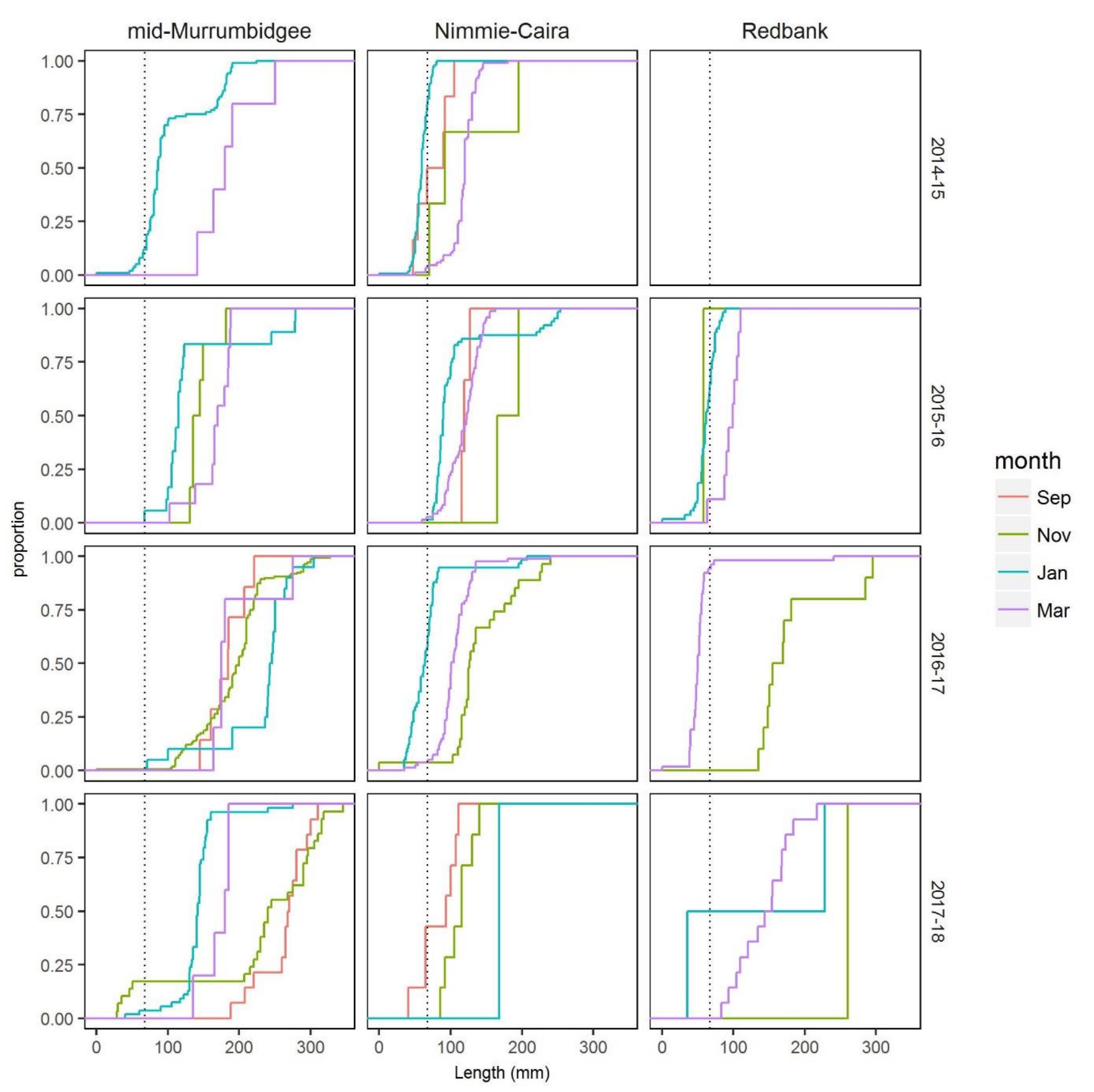

Figure 4-31 Length-frequency distribution diagrams showing differences in the age structure of bony bream captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

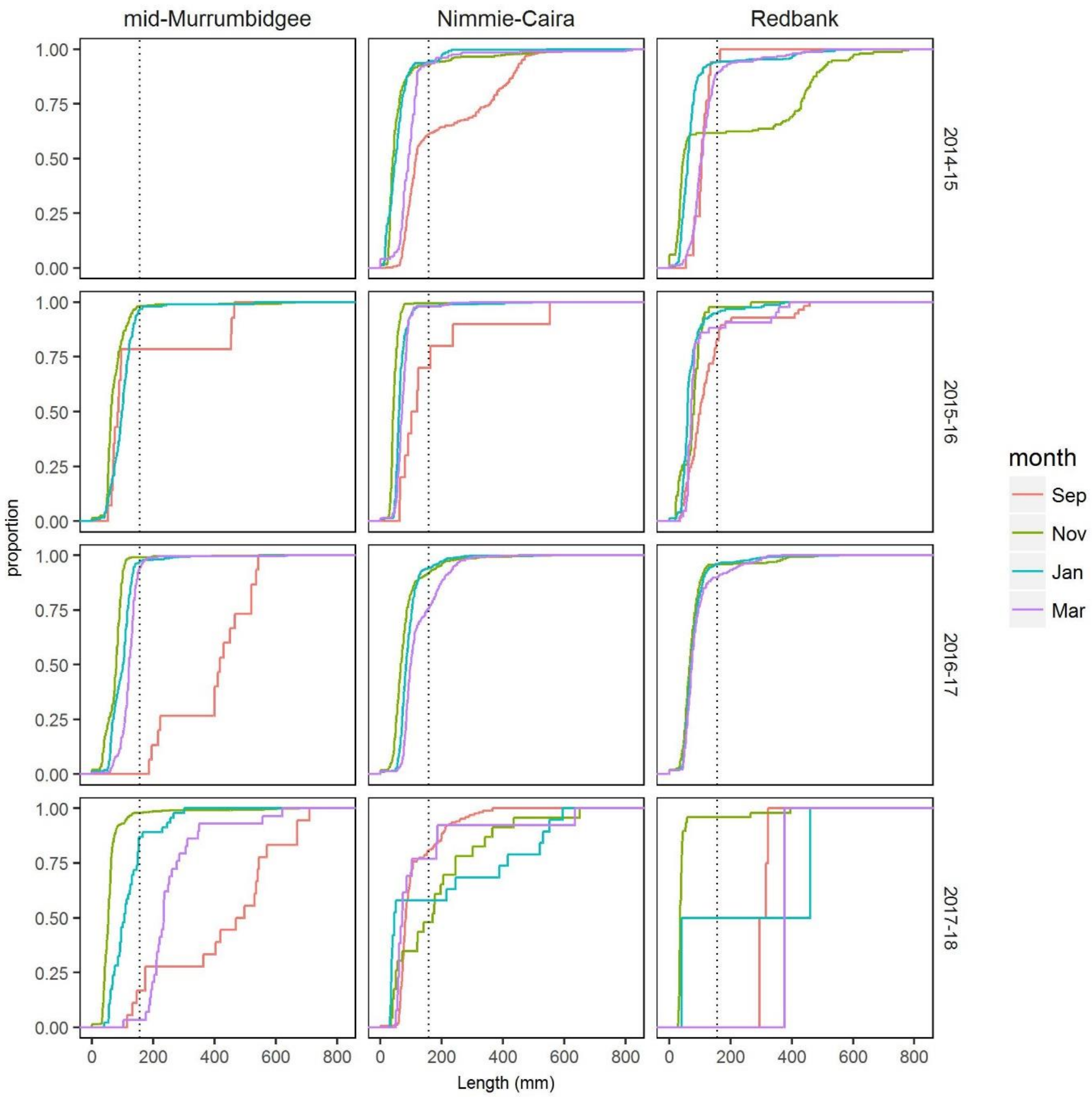

Figure 4-32 Length-frequency distribution diagrams showing differences in the age structure of common carp captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

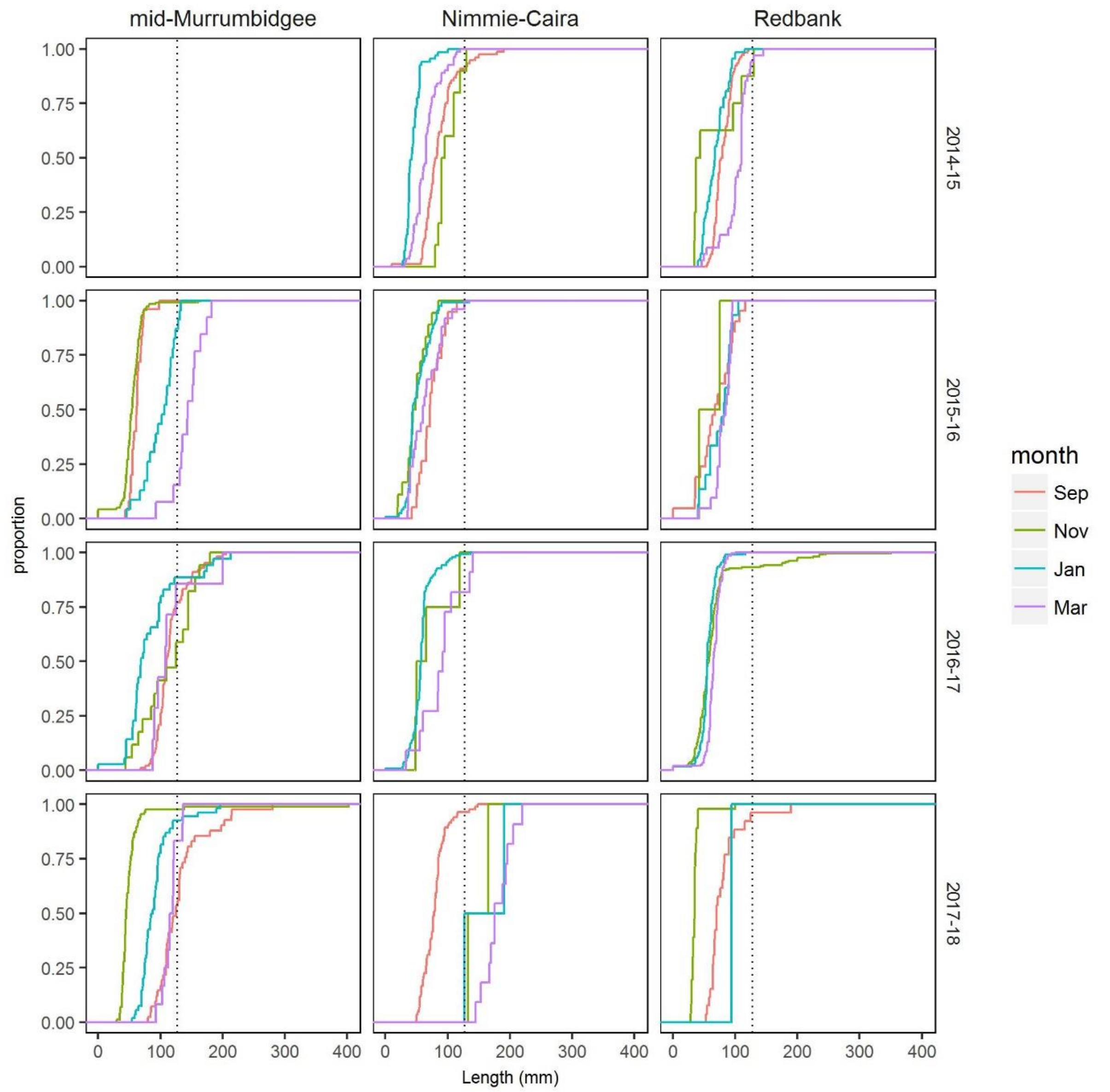

Figure 4-33 Length-frequency distribution diagrams showing differences in the age structure of goldfish captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

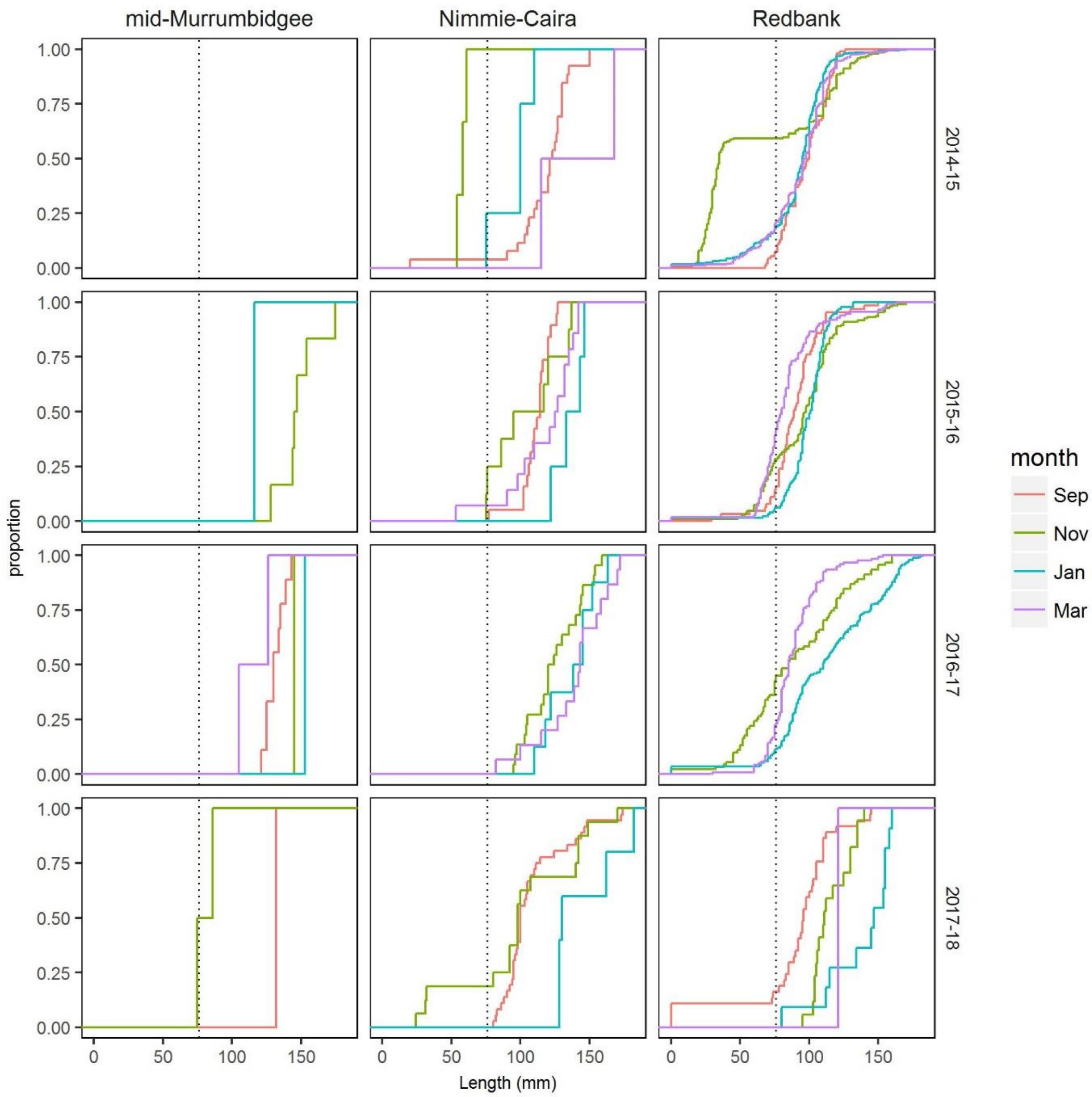

Figure 4-34 Length-frequency distribution diagrams showing differences in the age structure of oriental weatherloach captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

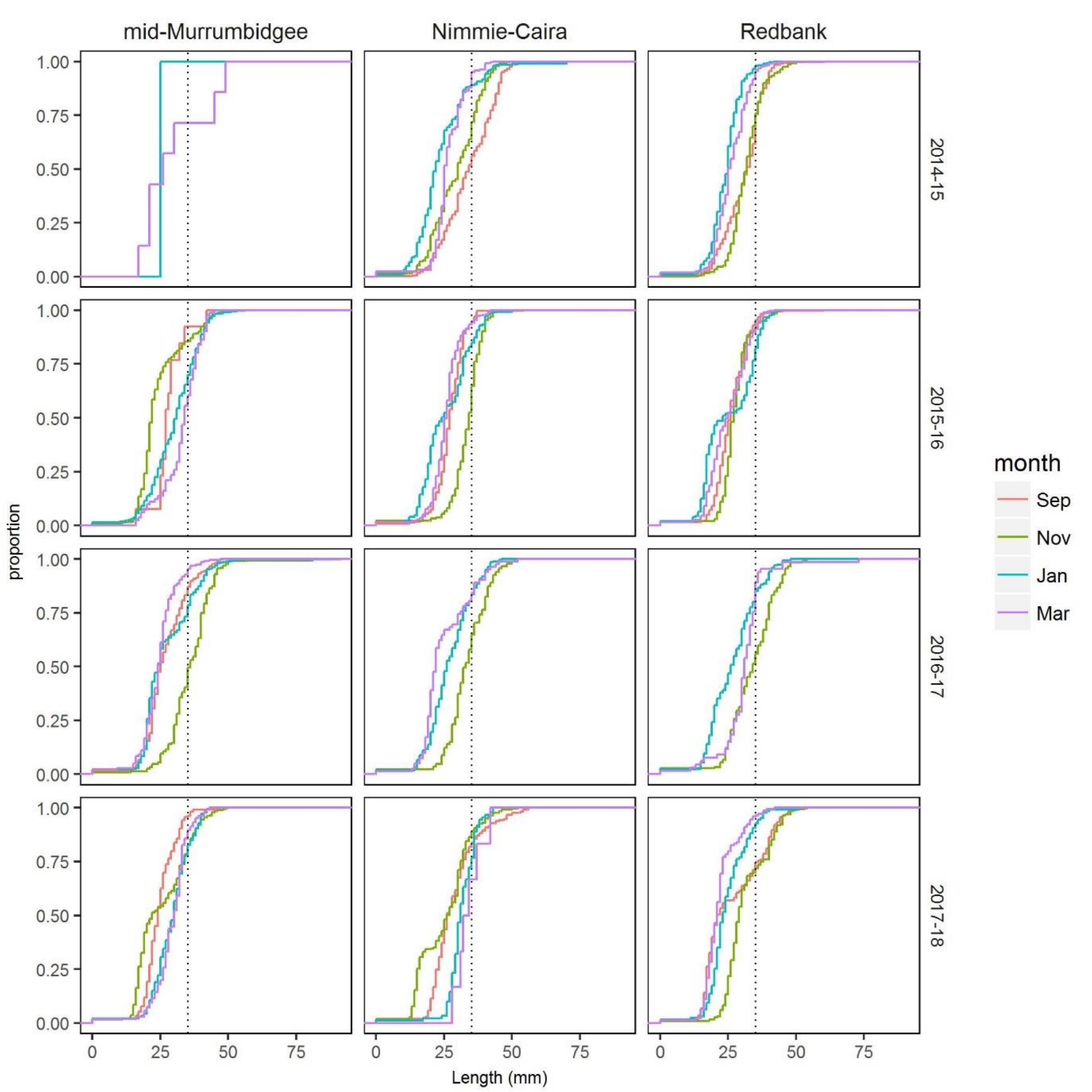

Figure 4-35 Length-frequency distribution diagrams showing differences in the age structure of carp gudgeon captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

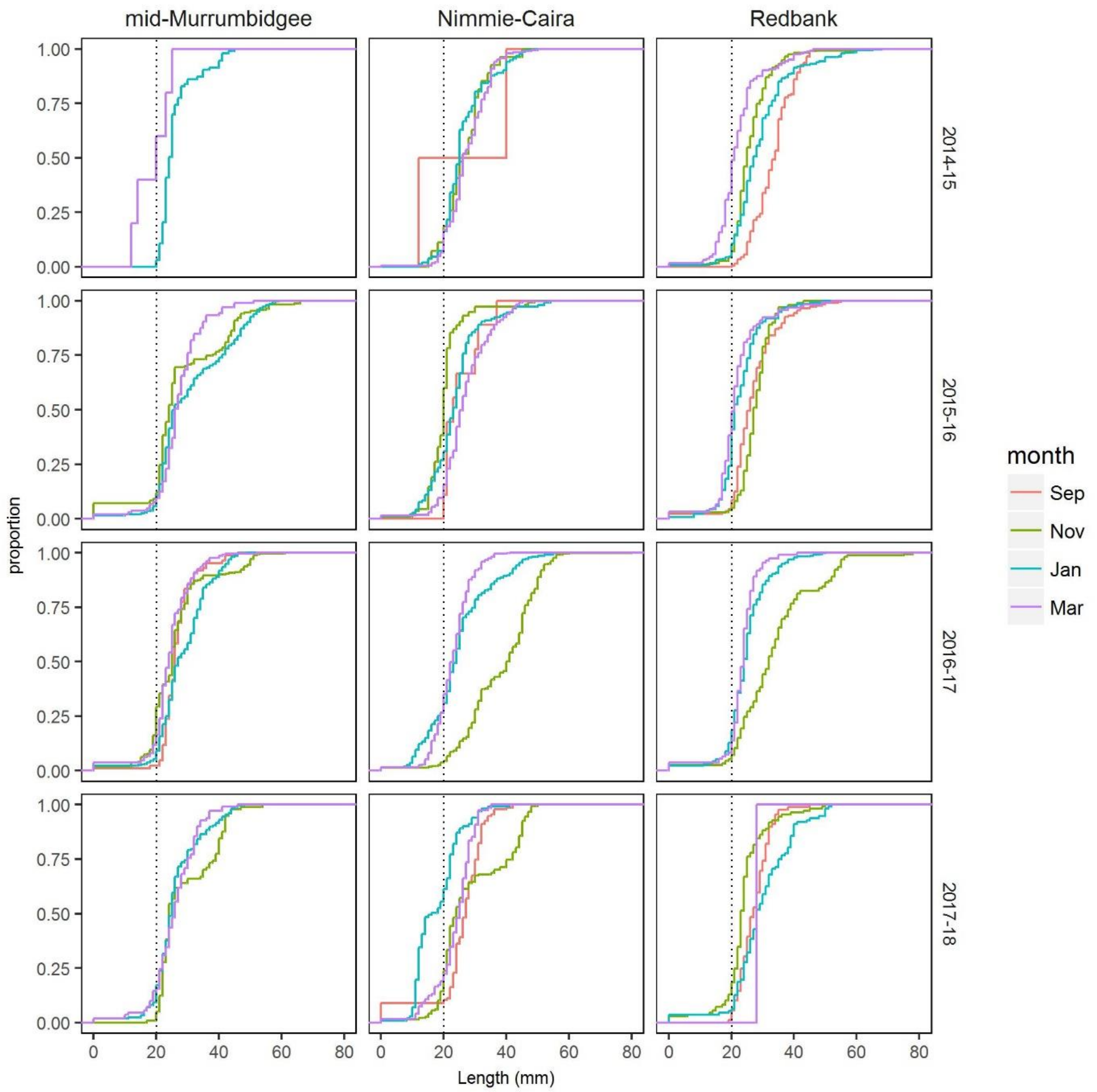

Figure 4-36 Length-frequency distribution diagrams showing differences in the age structure of eastern gambusia captured across the three monitoring zones during the four sampling events (1=September, 2=November, 3=January, 4=March) from 2014 to 2017.

*Table 4-9 Length-frequency distribution Kolmogorov-Smirnov D-test statistics for the six most abundant fish species samples in 2017-18. 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 (<30 individuals) were available for a comparison. Significance (grey shading) is indicated * = p<0.05, ** = p<0.01, ***=p<0.001.*

Zone	Month	Species			
		Carp gudgeon	**Gambusia**	**Common carp**	**goldfish**
mid-Murrumbidgee	Sep/Nov	0.31*** (205/371)	NS (0/97)	NS (18/487)	0.977*** (41/86)
	Sep/Jan	0.363*** (205/176)	NS (0/211)	NS (18/46)	0.651*** (41/54)
	Sep/Mar	0.45*** (205/103)	NS (0/108)	NS (18/29)	NS (41/12)
	Nov/Jan	0.402*** (371/176)	0.192* (97/211)	0.637*** (487/46)	0.879*** (86/54)
	Nov/Mar	0.41*** (371/103)	0.256** (97/108)	NS (487/29)	NS (86/12)
	Jan/Mar	0.105 (176/103)	0.117 (211/108)	NS (46/29)	NS (54/12)
Nimmie-Caira	Sep/Nov	0.322*** (205/253)	0.353*** (123/145)	NS (168/23)	NS (84/2)
	Sep/Jan	0.413*** (205/89)	0.689*** (123/100)	NS (168/19)	NS (84/2)
	Sep/Mar	NS (205/6)	0.255*** (123/119)	NS (168/13)	NS (84/11)
	Nov/Jan	0.452*** (253/89)	0.466*** (145/100)	NS (23/19)	NS (2/2)
	Nov/Mar	NS (253/6)	0.317*** (145/119)	NS (23/13)	NS (2/11)
	Jan/Mar	NS (89/6)	0.434*** (100/119)	NS (19/13)	NS (2/11)
Redbank	Sep/Nov	0.481*** (161/194)	0.361*** (89/106)	NS (4/48)	NS (26/46)
	Sep/Jan	0.23** (161/124)	0.251** (89/108)	NS (4/2)	NS (26/1)
	Sep/Mar	0.275*** (161/142)	NS (89/1)	NS (4/1)	NS (26/0)
	Nov/Jan	0.457*** (194/124)	0.458*** (106/108)	NS (48/2)	NS (46/1)
	Nov/Mar	0.695*** (194/142)	NS (106/1)	NS (48/1)	NS (46/0)
	Jan/Mar	0.26*** (124/142)	NS (108/1)	NS (2/1)	NS (1/0)

Discussion

The overall wetland fish communities across the Murrumbidgee remain in poor condition and are dominated by highly abundant opportunistic generalist species while more sensitive floodplain specialist species, such as Murray hardyhead are typically absent. There were two types of watering action that have influenced short and long-term outcomes for floodplain fish communities since 2014. Each year, multiple actions have been undertaken to maintain persistent refuge habitat, this includes watering actions targeting Wagourah Lagoon, Telephone Creek and Yarradda Lagoon. In very dry years these refuge habitat are critical for the survival of longer lived species, including native fish and turtles. The second type of action relate to creating breeding habitat and short term reconnection between floodplain and riverine habitat which is achieved by raising water levels first in the river to support reconnection to low lying wetlands and then in the wetland itself. The mid-Murrumbidgee wetland reconnection was largely designed to improve vegetation recovery and support fish movement into and out of floodplain wetlands. In the case of Yarradda and Gooragool lagoons, the mid-Murrumbidgee wetland reconnection and associated pumping actions prolonged the period of fish occupation in target wetlands and may have created opportunities for resident fish to leave the floodplain wetlands and return to the river. By providing ongoing habitat for fish survival in wetlands these environmental watering actions also achieved their stated objectives in providing support for breeding waterbirds that rely on fish as a food resource.

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

The diversity of native wetland fish declined in 2017-18 compared with previous monitoring years, with two less native species (silver perch and unspecked hardyhead) detected than 2016-17. Overall, 9 out of 23 previously recorded native species (Gilligan 2005) have been observed during LTIM, though not all of these recorded species might be expected to occupy wetlands. Silver perch are more likely to be observed in wetlands during periods of reconnection and aren't expected to be found in every year of monitoring, particularly during dry years. Unspecked hardyhead have only been observed in low numbers over the past four years and their absence from the 2017-18 dataset is not evidence of decline.

The Murrumbidgee River channel is an important source of colonising individuals to wetlands, but wetland conditions, including the provision of permanent habitat and opportunities for individuals to move between the floodplain and riverine habitats can influence the establishment and persistence of populations. Any increase in wetland fish diversity in the Murrumbidgee wetlands would require either 1) recolonisation by species that are locally extinct, or 2) increased use of wetlands by species that do not typically occupy wetlands under the existing regime. The former might be achieved during very large overbank flows when connectivity is increased, provided that some permanent wetland refuges are maintained thereafter. However, following the 2017-18 water year, we found no evidence that any new species or channel-specialist species have colonised Murrumbidgee wetland sites. The latter might be achieved for wetlands that are more frequently connected to the river and, again, where watering supports permanent habitats that allow aquatic species to survive on the floodplain between water years. Both of these mechanisms are assisted by environmental water. The unregulated overbank event in 2016-17 presented opportunities for broad-scale fish movements and recolonisation, as evidenced by more native species occurring in wetlands. Subsequent drying, and no observable change in the composition of species at 'permanently' wet locations (Waugorah Lagoon, Yarradda Lagoon) following the 2016-17 unregulated event, mean the long term pattern wetland fish diversity remains unchanged.

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

The 2017-18 data shows the common, more abundant species are spawning, growing and recruiting in wetland habitats. For most species, the data suggest a single spawning event early in the year, with increasing size classes on subsequent sampling trips. Some exceptions include both common carp and goldfish, which appeared to have spawned between September and November in the mid-Murrumbidgee and Redbank zones. Although not tested, it appears that more adult carp comprised wetland populations in 2017-18 despite this spawning activity. During 2016-17 we noted that carp spawned during the early stages of the unregulated event and grew consistently across the monitoring year.

The resilience of a population or community of populations is provided by a suite of life history and behavioural attributes that have evolved alongside a regime of predictable disturbance (Hodgson *et al.* 2015; Nimmo *et al.* 2015). In regulated systems, where disturbances 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. These remnant populations are considered 'self-sustaining' and we see examples of this resilience in other species like the southern bell frog (see Frogs and turtles 4.6) 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 Telephone 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.

4.6 Frogs and turtles

Prepared by 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 to support recruitment of tadpoles and young turtles into the adult population.

Relevant watering actions and objectives

In 2017-18 the largest volume of Commonwealth environmental water was delivered to produce a water level peak capable of connecting low lying wetlands in the mid Murrumbidgee. There was limited environmental watering activity across Lowbidgee floodplain, and the majority of sites either contained residual water from unregulated flows and NSW environmental water actions undertaken in the Nimmie-Caria between April and June 2017. There was a small unregulated flow into Mercedes Swamp in the Redbank zone due to high water levels in the adjacent weir pool. The principle Commonwealth environmental watering actions that influenced the hydrological regime of LTIM monitoring sites are outlined in Table 4-10.

In the mid-Murrumbidgee all four monitored wetlands connected during the 2017-18 environmental watering action, although McKenna's Lagoon only partially filled, two wetlands (Yarradda Lagoon and Gooragool Lagoons) received additional top-up flow prior to the reconnection to minimise losses during the reconnection (Figure 4-37). Both of these wetlands also benefited from environmental watering in 2014-15 and 2015-16 and received unregulated flow in 2016-17. Sunshower and McKennas lagoons had previously filled in 2016-17 but were dry prior to the 2017-18 reconnection flow.

Table 4-10 Summary of environmental watering actions that influence the hydrological regimes of the 12 monitored wetlands during the survey period

WAR	Event	L:TIM monitoring sites receiving environmental water	Expected outcomes
WAR 10062-01	mid-Murrumbidgee wetlands reconnection	Gooragool Sunshower McKenna Yarradda	-support reproduction and improved condition vegetation, waterbirds, native fish and other biota
WAR 10062-02 (additional water delivered under 10068-06)	Yarradda Lagoon Pumping	Yarradda	-support the breeding, recruitment and habitat requirements of birds and native aquatic biota, including frogs, turtles and invertebrates; - support the habitat requirements of waterbirds, native fish and other aquatic animals.
WAR10062-03-11	Gooragool Lagoon Pumping and offset	Gooragool	-support the breeding, recruitment and habitat requirements of birds and native aquatic biota, including frogs, turtles and invertebrates;
MBG16/17-15*	Nimmie-Caira Refuge	Eulimbah, Telephone (commenced 01/04/2017)	

Evaluation Questions

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

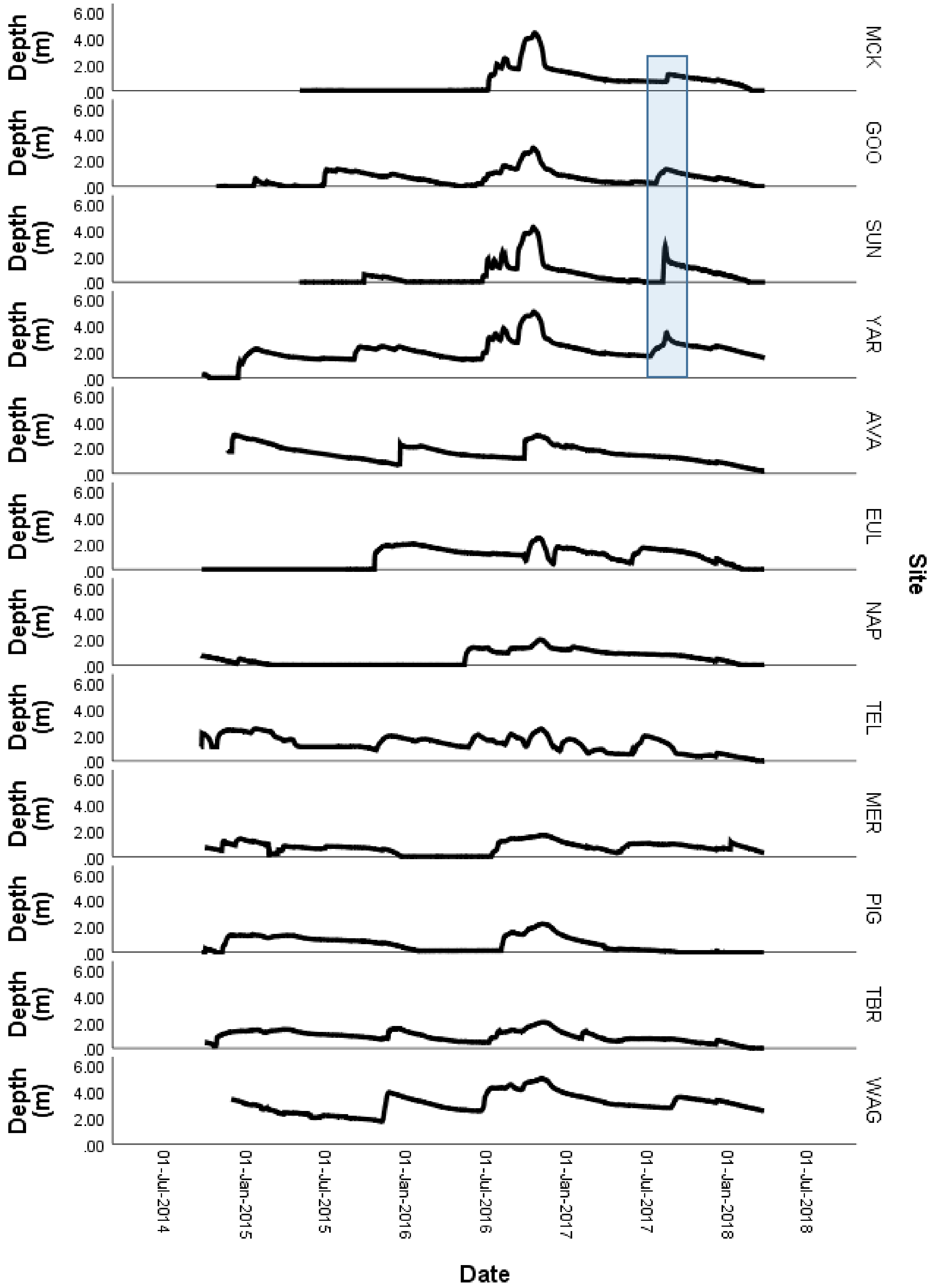

Figure 4-37 Hydrographs of the 12 LTIM monitoring wetlands 2014 to 2018. Blue shading shows approximate timing for the environmental watering actions in the mid-Murrumbidgee zone in 2017-18 (top four rows)

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 *et al.* (2014a). 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 2018 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 four water years at wetlands receiving environmental water was tested using Generalised Linear Models with wetland zone and water year as fixed factors.

Results

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

Frog species richness

Six frog species were recorded in 2017-18, the plains froglet (*Crinia parinsignfera*), barking marsh frog (*Limnodynastes fletcheri),* spotted marsh frog (*Limnodynastes tasmaniensis*), inland banjo frog (*Limnodynastes interioris*), Peron's tree frog (*Litoria peronii*) and southern bell frog (*Litoria raniformis*), which is the same as in previous years. Environmental watering actions targeting the mid-Murrumbidgee wetlands, supported five species, including the southern bell frog. However, the inland banjo frog which was identified at McKennas and Sunshower lagoons in 2016-17 was absent in the 2017-18 surveys (Figure 4-38). There was limited environmental watering actions in the Nimmie-Caira in 2017-18 and the majority of sites were drying, as a result there were declines in the number of surveys were each species were detected, but total species richness remained largely unchanged except at Nap Nap Swamp where only two frog species were recorded in 2017-18. Likewise the number of surveys in which each frog species was detected was lower at the three Redbank sites that did not receive any water in 2017-18, while total species richness remained higher at Mercedes Swamp which received unregulated flows from the adjacent weir pool.

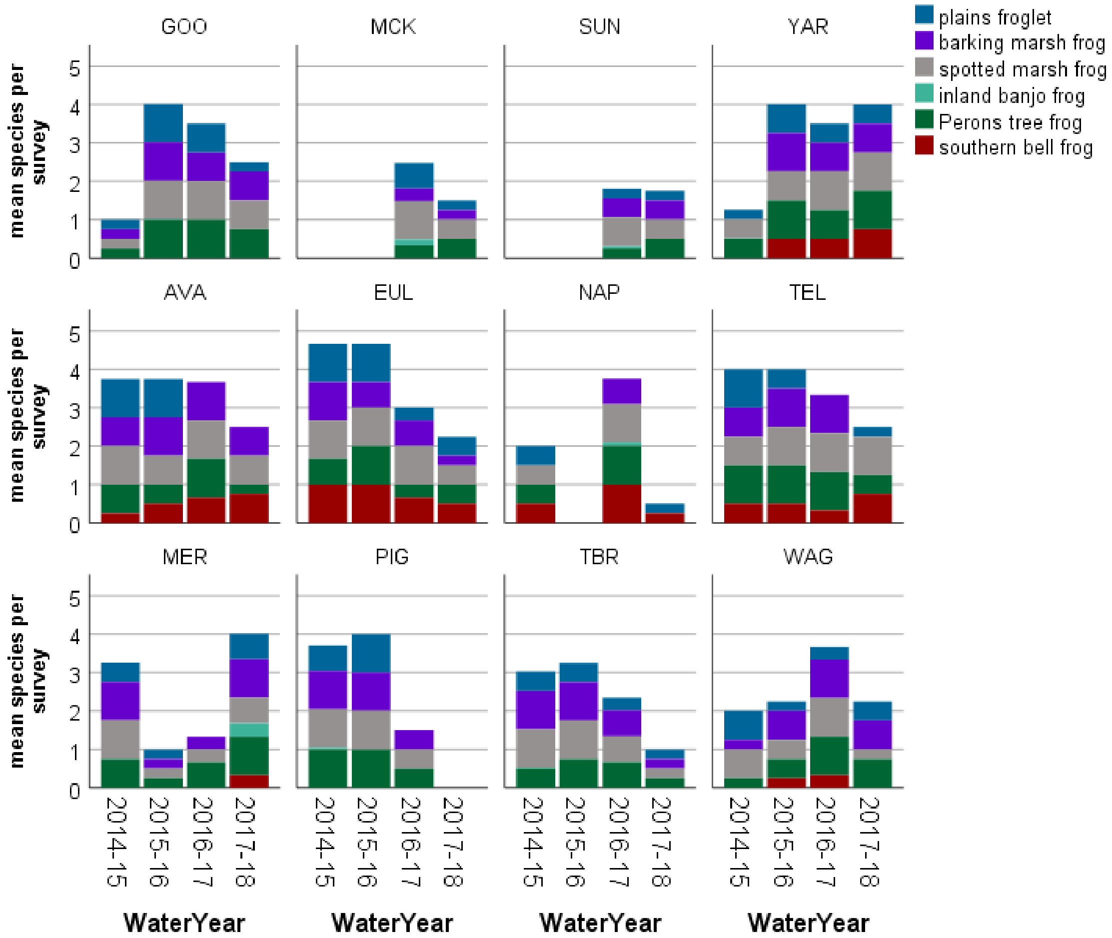

Figure 4-38 Species diversity outcomes at each of the 12 LTIM monitoring wetland in the mid-Murrumbidgee wetlands. (top row) (GOO Gooragool, MCK McKennas, SUN Sunshower, YAR Yarradda), Nimmie-Caira (middle row) (AVA Avalon, EUL Eulimbah, Nap Nap Nap, TEL, Telephone Creek). Redbank (bottom row) (MER Mercedes, PIG Piggery, TBR Two Bridges, WAG Wagourah Lagoon).

Frog abundance

The overall abundance of adult frogs was lower in 2017-18 compared to previous years, with significant differences abundance between water years for the barking marsh frog (*Limnodynastes fletcheri*) (GLM f = 3.866, p=0.011) (Figure 4-39), spotted marsh frog (*Limnodynastes tasmaniensis*)((GLM f = 7.233, p<0.001) (Figure 4-40) and Peron's tree frog (*Litoria peronii*)(GLM f=3.643, P=0.014) (Figure 4-41). This was largely driven by very high abundances for all three species during extensive floodplain inundation in 2016-17 compared with years before and after this natural event. The abundance of barking marsh frog declined significantly between 2016-17 and 2017-18 (Post Hoc contrast p = 0.05). The abundance of spotted marsh frog adults in 2017-18 was similar to those recorded in 2014-15 and 2015-16 but all three years had lower abundance than in 2016-17 (Post Hoc contrast 2016-17: 2014-15 p = 0.07, 2015-16 p = 0.01, 2017-18; p = 0.01). Differences in Peron's tree frog adult abundance was likewise driven by high abundance in 2016-17 (Post Hoc contrast 2016-17: 2015-16 p = 0.026, 2017-18; p = 0.064). While the remaining three species plains froglet, inland banjo frog and southern bell frog underwent similar trends in abundance, lower numbers and greater variability in abundance between sites meant that these differences were not significant.

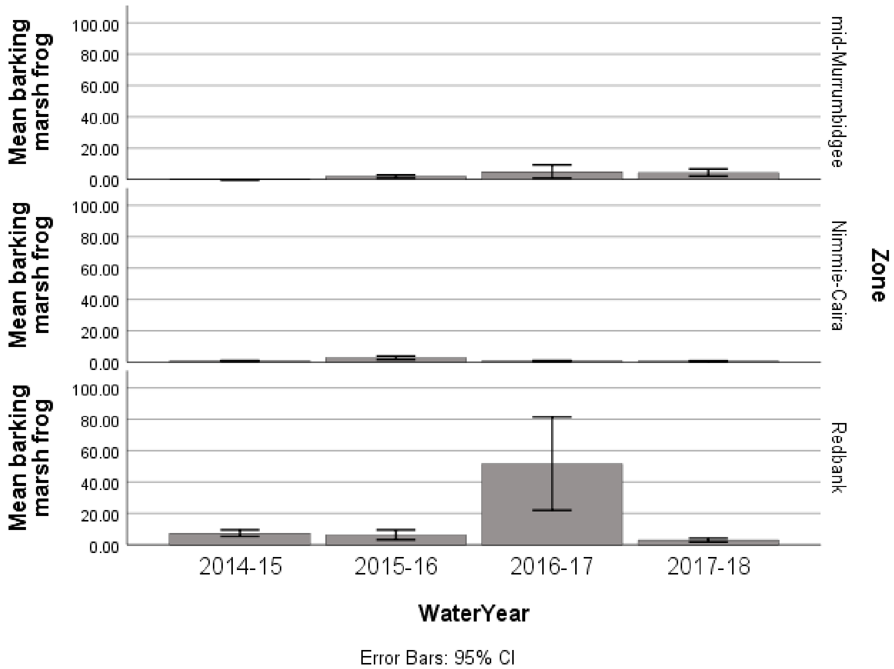

Figure 4-39 Overall trends in barking marsh frog observations (individuals per 40 survey minutes) within each monitoring zones between 2014-15 and 2017-18.

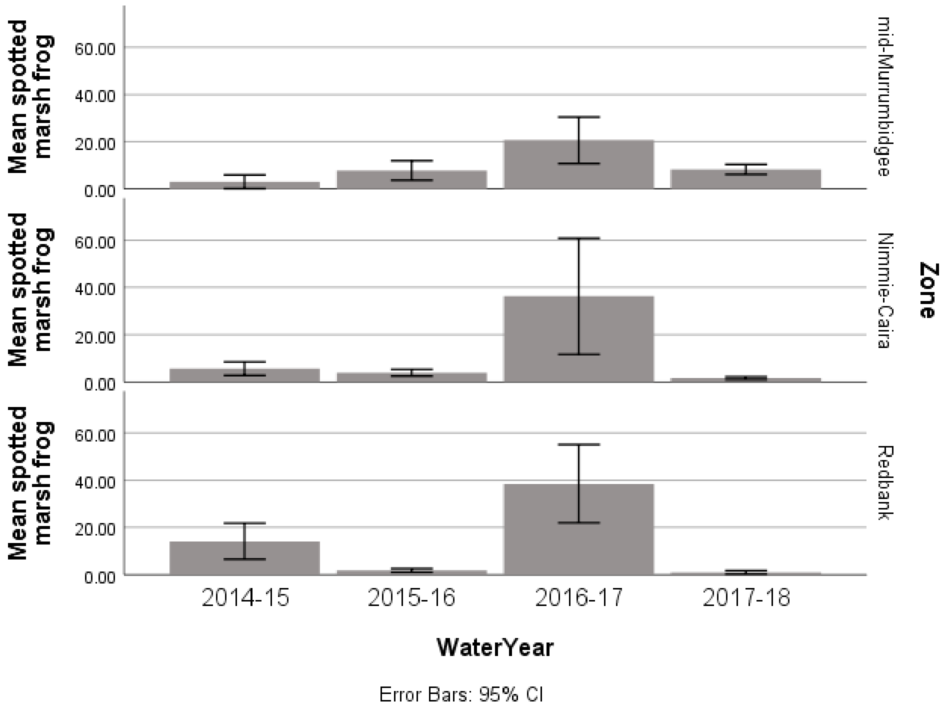

Figure 4-40 Overall trends in spotted marsh frog observations (individuals per 40 survey minutes) within each monitoring zones between 2014-15 and 2017-18.

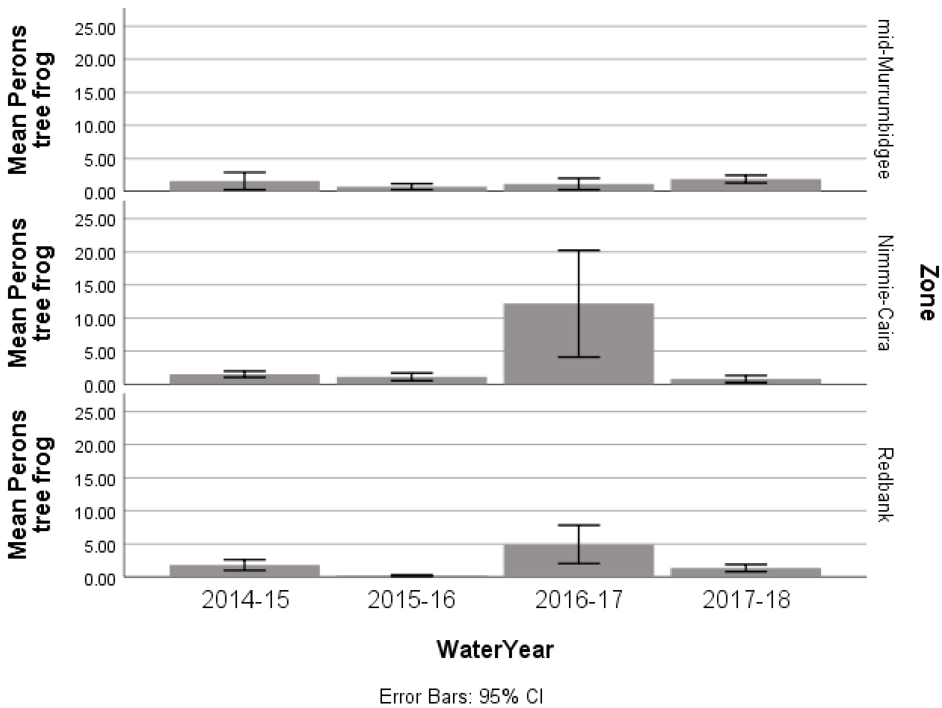

Figure 4-41 Overall trends in Peron's tree frog observations (individuals per 40 survey minutes) within each monitoring zones between 2014-15 and 2017-18.

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

Frog breeding response

The mid-Murrumbidgee reconnection flow occurred in August 2017 and is associated with an increase in calling activity in September 2017, with spring breeding species spotted marsh frogs and plains froglet the most active during September. Small numbers of southern bell frogs were recorded calling at Yarradda Lagoon in September 2017. As in previous years calling activity decreased in summer at all sites except Yarradda Lagoon where calling by spotted marsh frogs and plains froglet continued to call into November 2017.

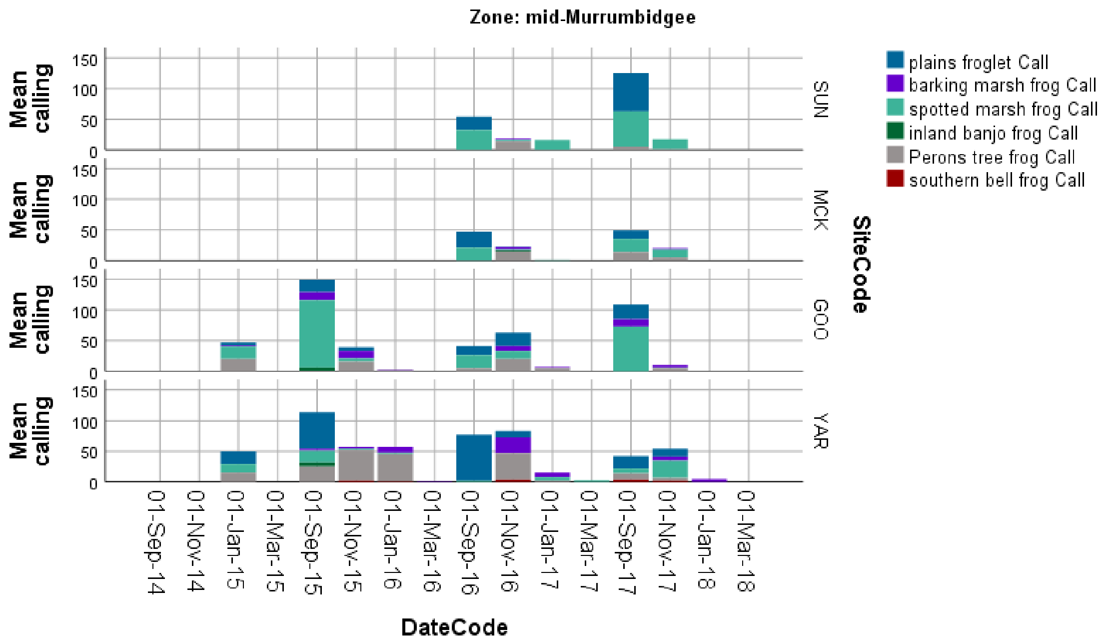

Figure 4-42 Calling activity (mean count) of resident frog species across in the four wetlands in the mid-Murrumbidgee influenced by Commonwealth environmental watering actions in 2017-18.

When considered across all water years, calling activity was positively correlated with water depth for all species except the inland banjo frog (Table 4-11). Calling activity typically decreased with declining water quality (increasing conductivity, turbidity and pH) and increasing water temperatures, not that these factors are also correlated with water depth, that is, conductivity, turbidity and pH tends to increase as the wetlands begin to dry. But not that many of these parameters were also correlated with water depth so the results need to be treated with caution.

Relationships between water depth and tadpole abundance was less clear with only march frog (barking and spotted marsh frog) tadpoles having a significant positive association with water depth, Peron's tree frog tadpoles were most abundant in warmer water reflecting. Interestingly three of the five frog species had positive associations between tadpole abundance and exotic fish abundance (Table 4-11).

Table 4-11 Spearman's rank correlations (Correlation Coefficient and Significance. (2-tailed)) between water quality and hydrology and calling activity and tadpole CPUE for resident frog species.

	Water depth	Water temp	Cond	pH	NTU	Native fish	Exotic fish
Calling activity							
Plains Froglet	**0.309** 0.000**	**-0.501** 0.000**	**-0.392** 0.000**	**-0.288** 0.001**	**-0.212* 0.018**	**0.269** 0.000**	0.074 0.329
Barking marsh frog	**0.280** 0.000**	0.133 0.141	-0.204* 0.023	-0.239** 0.008	-0.224* 0.013	**0.306** 0.000**	**0.388** 0.000**
Spotted marsh frog	**0.312** 0.000**	**-0.260** 0.004**	**-0.239** 0.008**	-0.134 0.138	-0.094 0.300	**0.241** 0.001**	**0.181* 0.017**
Inland banjo frog	0.051 0.505	**-.244** 0.007**	-0.093 0.305	**-0.218* 0.015**	**-0.272** 0.002**	-0.049 0.522	-0.011 0.884
Peron's tree frog	**0.330** 0.000**	0.001 0.992	**-0.259** 0.004**	-0.141 0.120	**-0.270** 0.003**	**0.293** 0.000**	**0.271** 0.000**
Southern bell frog	**0.224** 0.003**	-0.095 0.296	-0.159 0.079	0.024 0.792	-0.040 0.657	0.079 0.300	0.142 0.062
Tadpole abundance							
Plains froglet	0.025 0.748	-0.006 0.943	**-0.213* 0.018**	-0.120 0.186	-0.219* 0.015	-0.075 0.328	0.029 0.706
marsh frog	**0.260** 0.001**	0.014 0.881	-0.213 0.018	**-0.241** 0.007**	**-0.314** 0.000**	**0.210** 0.005**	**0.354** 0.000**
Inland banjo frog	0.127 0.096	0.047 0.602	-0.092 0.309	-0.111 0.223	**-0.314** 0.000**	-0.029 0.706	**0.249** 0.001**
Peron's tree frog	0.149 0.051	**0.207* 0.021**	0.006 0.950	0.012 0.897	-0.078 0.393	0.142 0.061	**0.234** 0.002**
Southern bell frog	0.078 0.309	-0.053 0.559	0.076 0.402	0.041 0.649	0.047 0.603	0.078 0.307	0.130 0.088

Tadpoles were recorded for all resident frog species in 2017-18, but abundances were lower overall for all species compared to previous years, but there was considerable variability in breeding response at individual wetland (

Figure 4-43). Very small numbers of southern bell frog tadpoles were recorded at Yarradda Lagoon following the environmental water actions, but few individuals of other species were recorded at this wetland. Peron's tree frog responded strongly to the environment watering actions at McKennas Lagoon and to a lesser extent at Sunshower Lagoon, but were not recorded at other wetlands in 2017-18. Inland banjo frog responded to unregulated flow into Mercedes Swamp, with comparatively high numbers of individuals recorded in 2017-18. No southern bell frog tadpoles were recorded in the Nimmie-Caira wetlands in 2017-18 reflecting unsuitable breeding conditions in key wetlands.

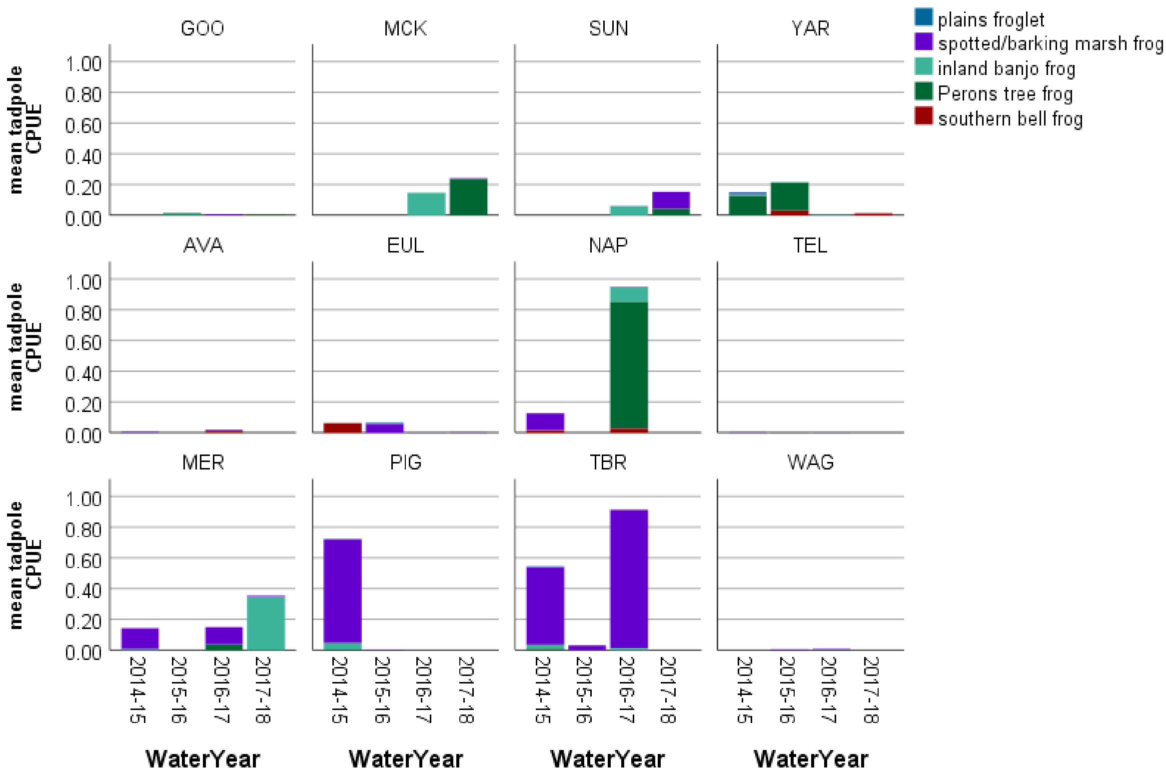

Figure 4-43 Tadpole abundance (mean Catch Per Unit Effort) averaged for each water year between 2014-15 and 2017-18.

Turtle breeding response

Turtles are a long-lived animal and breeding success is influenced to some extent by food availability in the wetland during preceding years, and also rates of fox predation, with foxes taking over 90% of eggs in some areas. Some juvenile turtles were recorded in 2017-18. Hatching Macquarie River turtles sand a single broad-shell turtle were collected from the mid-Murrumbidgee wetlands at Yarradda Lagoon following the environmental watering actions (Figure 4-44).

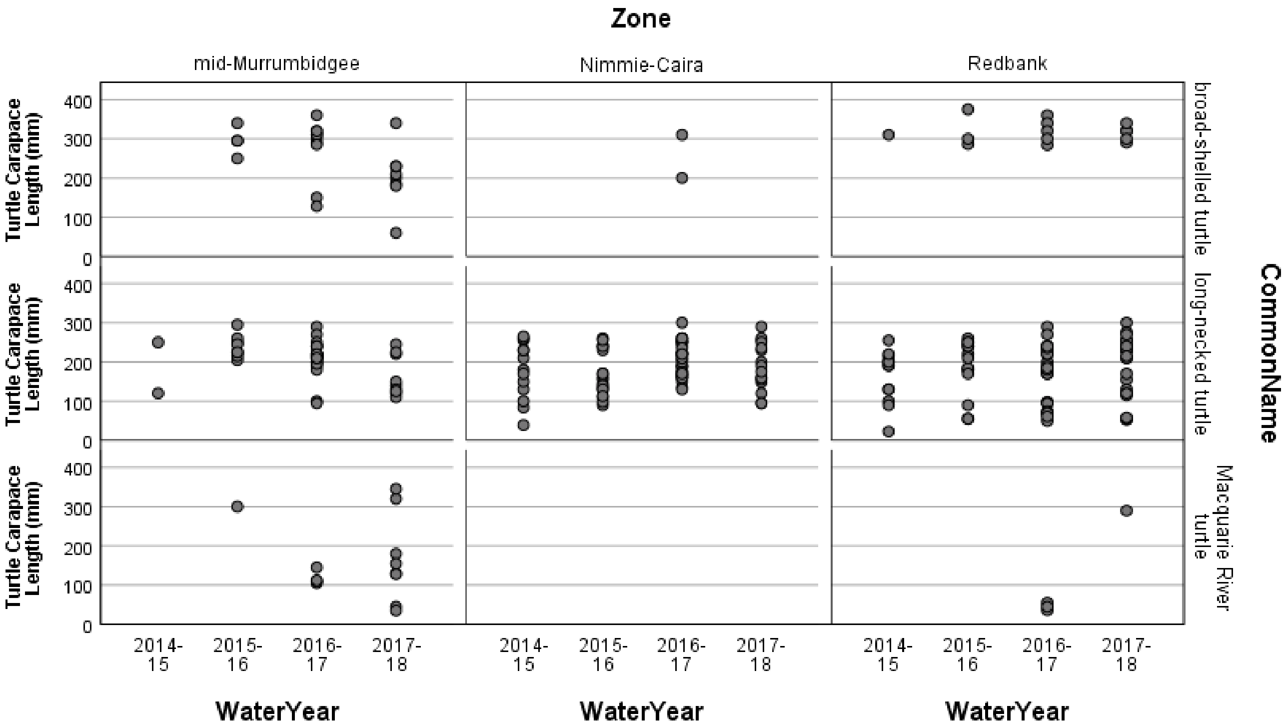

Figure 4-44 Size distribution of individual turtles caught between 2014 and 2018 in each wetland zone.

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 a role in maintaining populations during dry periods. Three of the 12 monitoring sites are considered to be refuges habitats, these are Yarradda Lagoon in the mid-Murrumbidgee, Telephone Creek in the Nimmie-Caira and Wagourah Lagoon in the Redbank system. In 2017-18 environmental watering actions targeted Yarradda Lagoon in the mid-Murrumbidgee with a combination of pumping and river reconnection flows. Water levels in Telephone Creek and Wagourah lagoon declined over the year but these wetlands did not dry out completely, Commonwealth environmental watering actions targeting refuge habitat in the Nimmie-Caira including Telephone Creek were undertaken in autumn 2018 after the 2017-18 surveys were complete. The outcomes of those actions will be considered in the 2018-19 water year.

The long-term watering strategy of maintaining persistent refuge habitats is particularly important for long-lived species including turtles, large bodied native fish and southern bell frogs. The refuge wetlands support a higher diversity of turtles compared to the non-permanent wetlands, Yarradda and Wagourah lagoons support all three species, while Telephone Creek is an important refuge for broad-shelled turtles in the Nimmie-Caira (Figure 4-45).

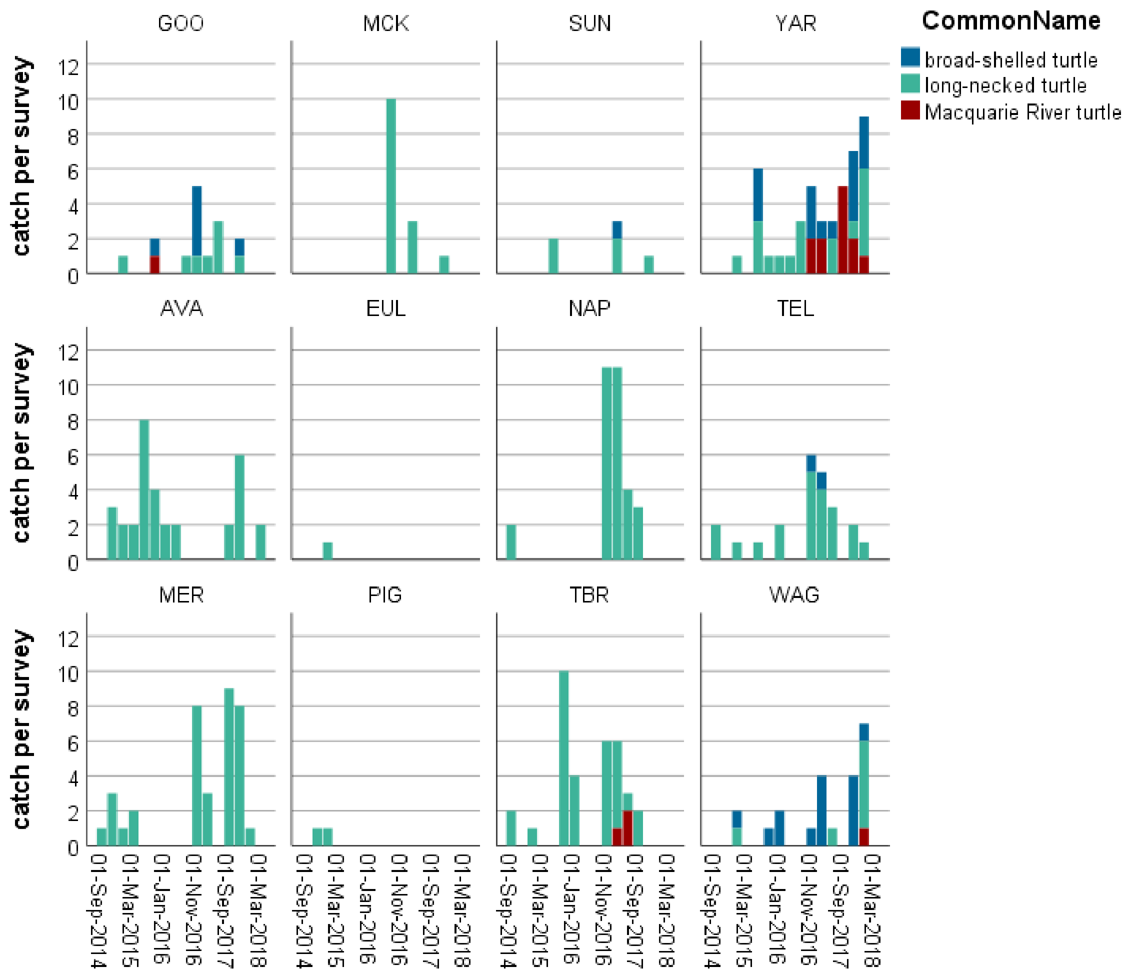

Figure 4-45 Turtle abundance across the four water years at each monitoring location (mid-Murrumbidgee wetlands (upper), Nimmie-Caira (mid) and Redbank (lower) zones).

Discussion

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

The focus of Commonwealth environmental watering actions in 2017-18 was the inundation of wetlands in the mid-Murrumbidgee. These actions had clear benefits for frogs and turtles in targeted wetlands and were successful in achieving objective of supporting breeding and habitat requirements. However, limited volumes of water available meant that there were no water deliveries to monitoring wetlands in the Nimmie-Caira or Redbank wetlands and the extent of floodplain inundation was lower overall then previous years. As a result of limited environmental watering there was a notable decline in the abundance and breeding activity of resident frogs, with key southern bell frog populations failing to breed for the first time since the monitoring program began in 2014. However, the provision of refuge flows in autumn 2018 is expected to have secured refuge habitats, as this action fell outside of the scheduled monitoring program, the success of this action in securing key populations will be evaluated in the 2018-19 monitoring year.

The overall numbers of adult frogs was lower in 2017-18 compared to previous monitoring years, with significant differences in abundance between water years for the barking marsh frog, spotted marsh frog, and Peron's tree frog. This is partly explained by the very high abundances for all three species during extensive floodplain inundation in 2016-17, with numbers in 2017-18 similar to those recorded in 2014-15 and 2015-16. This outcome does, however, highlight the critical importance of large-scale inundation in driving large recruitment and population booms, which may increase the resilience of frog and turtle populations in the longer term. As demonstrated in 2016-17 watering actions that inundate continuous areas of floodplain habitat increases hydrological diversity and the availability of breeding habitats for frogs, turtles and waterbirds. In 2017-18 the limited area of inundation and declining water levels at the monitoring sites limited breeding opportunities for frogs and turtles. There were no tadpoles detected in monitored wetlands in the Nimmie-Caira zone, or in three of the Redbank wetlands. Small numbers of tadpoles were recorded in Mercedes Swamp following unregulated flows in summer 2017. No breeding by the endangered southern bell frog was detected in the Lowbidgee floodplain, and a very small number of tadpoles were recorded in Yarradda Lagoon following Commonwealth environmental watering actions in the mid-Murrumbidgee. The limited breeding opportunities and declines in abundance highlights the critical role that Commonwealth environmental water plays in sustaining frog populations through the Lowbidgee floodplain.

In the mid-Murrumbidgee outcomes for frogs varied considerably among survey sites. Interestingly, McKennas and Sunshower lagoons supported higher abundances of tadpoles, but had lower diversity of frogs and smaller adult populations overall. Frog and tadpole abundance have declined at Yarradda Lagoon over the past four years. With notable declines occurring once the wetland reconnected with the main river channel in 2016-17 and 2017-18. Increasing densities of adult carp may have contributed to the reduced breeding by resident frogs. Although it is noted that the abundance of carp was similar in 2015-16 prior to the unregulated flows and in 2017-18 following the Commonwealth environmental watering actions. As noted in in our previous reports, studies are limited on the relationship between common carp and tadpoles, but there is a growing body of evidence that high carp numbers suppress the breeding response of frogs (Kloskowski 2009; Kloskowski 2011; Kaemingk *et al.* 2017) and may be a factor influencing outcomes of Commonwealth environmental watering actions, but these relationships are complex as the timing of inundation, wetting and drying patterns can also have a strong influence on frog breeding outcomes. However, management actions to remove carp prior to pumping are likely to have positive benefits for frogs and vegetation although this needs to be considered in the context of possible negative impacts of drying on resident turtle populations.

Evidence for successful maintenance of refuge habitats was also noted for turtles. Maintenance of an area of persistent water at Yarradda Lagoon, Telephone Creek and Wagourah Lagoon was associated with an increase in species richness and would have contributed to the support of the less common broad-shelled turtle and Macquarie River turtle.

Table 4-12 Summary of watering actions with outcomes targeting frog and turtle habitat and responses

Events	*Expected outcomes*	*Measured outcomes*	*Was the objective achieved*
mid-Murrumbidgee wetlands reconnection	support reproduction and improved condition vegetation, waterbirds, native fish and other biota	*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.* *Breeding activity for all six frog species known to occur across the monitoring sites was recorded in response to Commonwealth environmental water.*	*Yes*
Yarradda Lagoon Pumping	support the breeding, recruitment and habitat requirements of birds and native aquatic biota, including frogs, turtles and invertebrates;		
Gooragool Lagoon Pumping	- support the habitat requirements of waterbirds, native fish and other aquatic animals.		

4.7 Waterbird Diversity

Prepared by Jennifer Spencer, Joanne Ocock and Carmen Amos (NSW OEH)

Introduction

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 Murray-Darling Basin (MDBA 2014). The total number of waterbird species, their breeding activity and total number of individuals can change rapidly in response to flows, specifically increases in total wetland area and the diversity of wetland habitats inundated.

When inundated, floodplain habitats can provide feeding and breeding opportunities for a range of waterbird species. Waterbird species richness is greatest when there are varying water depths across a range of wetland types (Taft *et al.* 2002). Where there is a mosaic of inundated wetland types, this can provide deeper wetlands for fish-eating waterbirds and diving ducks, and vegetated shallower wetlands that provide feeding habitat for dabbling ducks and large waders. Inundated emergent aquatic vegetation also provides habitat for cryptic crakes, rails and bitterns. As wetlands dry down, exposed mudflats on the edges of open waterbodies can provide feeding habitat for resident and migratory shorebird species.

Relevant watering actions and objectives

There were six watering actions in the Murrumbidgee Selected Area which targeted waterbird habitat in 2017-18 (see Table 4-13). Four of these watering actions were focused on the mid-Murrumbidgee zone over the July – December 2017 period. The aim of these watering events was to benefit wetland-dependent species including supporting the habitat requirements of waterbirds. The remaining watering actions focused on North Redbank wetlands in October 2017, but this region was not monitored as part of the LTIM program, and parts of the Nimmie-Caira in December 2017 and April/May 2018, but again these actions fell outside of the monitoring period. The Nimmie-Caira watering action target was refuge habitats to ensure there was some habitat for wetland-dependent species, primarily the threatened southern bell frog, over summer 2017-18.

Table 4-13. Summary of 2017-18 Commonwealth and NSW environmental water actions in the Murrumbidgee Selected Area that had objectives for providing waterbird habitat.

LTIM zone	Watering action		Timing of environmental water delivery
mid-Murrumbidgee	10062-02	Yarradda Lagoon Pumping	4 July – 1 August 2017
	10062-03	Gooragool Lagoon Pumping	18 July – 11 August 2017
	10062-01	mid-Murrumbidgee Wetlands Reconnection Flow	24 July – 1 September 2017
	10068-06	Yarradda Lagoon	20 – 27 November 2017
Redbank	10068-02	North Redbank	9 – 19 October 2017
Nimmie-Caira	10034-13	Nimmie-Caira refuge habitat	15 – 18 December 2017
	10068-10	Nimmie-Caira refuge habitat	15 April – 28 May 2018

Evaluation Questions

The responses of waterbirds to environmental watering actions across the Murrumbidgee Selected Area were assessed against four key evaluation questions to determine the extent to which the expected outcomes were achieved.

- Did Commonwealth environmental water contribute to waterbird species diversity?
- Did Commonwealth environmental water contribute to waterbird abundance?
- Did Commonwealth environmental water contribute to waterbird species of conservation significance?
- Did Commonwealth environmental water contribute to waterbird breeding?

Methods

Ground surveys to assess waterbird species richness, maximum abundance and breeding activity were conducted at the 12 LTIM wetland survey sites spread across the mid-Murrumbidgee, Nimmie-Caira and Redbank wetland zones (four sites per zone). Waterbird ground surveys were carried out on four occasions bimonthly between September and March in the four water years from 2014-18. Methods followed those employed previously to survey waterbirds in the Murrumbidgee Catchment and are documented in Wassens *et al.* (2014).

Complementary waterbird monitoring was also undertaken by NSW OEH across the Murrumbidgee Selected Area (Spencer *et al.* 2018). UNSW also completed aerial surveys of the Lowbidgee floodplain in mid-October as part of long-term Aerial Waterbird Surveys of Eastern Australia (AWSEA program) and MDBA funded Specified Environmental Asset Surveys (Porter *et al.* 2017; Kingsford *et al.* 2018). In the 2017-18 surveys, OEH monitoring included ground surveys of known waterbird colony sites. Repeat visits were conducted at five colony sites which were active in the Murrumbidgee Selected Area over the October 2017 – March 2018 period (Spencer *et al.* 2018). The colony ground surveys were conducted on foot, or using a large canoe or small boat, to estimate colony size (ha), total number of nests for each species, stage of nesting, evidence of mortality and collect information on water depths across each colony (see detailed methods in (Wassens *et al.* 2014a).

In order to determine the extent to which the Commonwealth environmental watering actions achieved their objectives with respect to waterbird communities in the Murrumbidgee Selected Area, we considered three key aspects of the waterbird response: 1) species richness (number of species), 2) number of functional groups, 3) maximum abundance recorded in each surveyed wetland in each survey period and 4) waterbird breeding activity (number of breeding species, number of broods/nests, number of active colonies).

Data analysis

Multivariate analyses (PRIMER 2002) were used to investigate differences in waterbird guild assemblages among the survey sites as per Wassens *et al.* (2014a). Waterbird species were separated into eight functional groups as per Hale *et al.* (2014) (see Appendix 1) to investigate differences in bird assemblages among the surveyed wetlands. Note that bird species belonging to two wetland-dependent guilds identified by (Hale *et al.* 2014), raptors and reed-inhabiting passerines, were also recorded during the surveys, but as these species were recorded in low abundance, and these groups are not targeted with environmental water, they are not analysed in detail. The total abundance of each functional group was calculated per hectare for each survey based on known coverage of each site in relation to the wetland boundaries (Wassens *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.

We also used Generalised Linear Modelling (GLM) with a binomial distribution (R Development Core Team 2014) to investigate waterbird responses (total number of species 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 2014-18 monitoring period. The inundation status of each site during each survey period was determined using a combination of on-ground observations and flooded area estimates from inundation mapping. Inundated sites were defined as survey sites that were more than 10% inundated during the time of the survey (sites that were dry were <10% inundated).

Results

What did Commonwealth environmental water contribute to waterbird species richness and abundance?

In total 64 wetland-dependent bird species (included raptors and reed-inhabiting passerines) were recorded in the 2014-18 period in the Murrumbidgee Selected Area (see Appendix 1 and 2). Over the four years of surveys, the total number of waterbird species peaked in the 2016-17 water year (48 species in total) in respond to widespread natural flooding in each wetland zone in spring 2016. The number of waterbird species observed in the 2017-18 water year was comparatively low (33 species in total) in response to reduced habitat availability (Figure 4-46). The total number of waterbird species in each wetland zone declined over the 2017-18 survey period, with sites drawing down in each of the wetland zones over the water year (Figure 4-47).

Four species of conservation significance were detected during the 2017-18 LTIM and complementary NSW OEH surveys. This included the endangered Australasian bittern (*Botaurus poiciloptilus)* (Commonwealth Environmental Protection and Biodiversity (EPBC Act 1999), vulnerable freckled duck (*Stictonetta naevosa)* and white-bellied sea-eagle (*Haliaeetus leucogaster)* (NSW Biodiversity Conservation (BC) Act 2016) and the migratory Latham's snipe (*Gallinago hardwickii)*, which is listed under international migratory bird agreements Australia has signed with Japan (JAMBA) and the Republic of Korea (RoKAMBA). The Australasian bittern was heard during frog surveys of Eulimbah Swamp (Nimmie-Caira zone) and Latham's snipe were detected on the edge of McKenna's Lagoon (mid-Murrumbidgee zone) in the September 2017 surveys. Australasian bitterns have been detected in the Murrumbidgee Selected Area in every year of the LTIM program.

Freckled ducks were observed in Loorica Lake (Nimmie-Caira) in NSW OEH's annual spring waterbird surveys. A pair of white-bellied sea-eagles were observed nesting in Nap Nap Swamp (Nimmie-Caira) in September 2017. There were further records of white-bellied sea-eagles at Telephone Creek (September 2017, November 2017, January 2018), Eulimbah Swamp (January 2018) in the Nimmie-Caira zone, Two Bridges Swamp, in the Redbank zone (September 2017), and Yarradda Lagoon, in the mid-Murrumbidgee zone (January 2018) over the 2017-18 LTIM surveys.

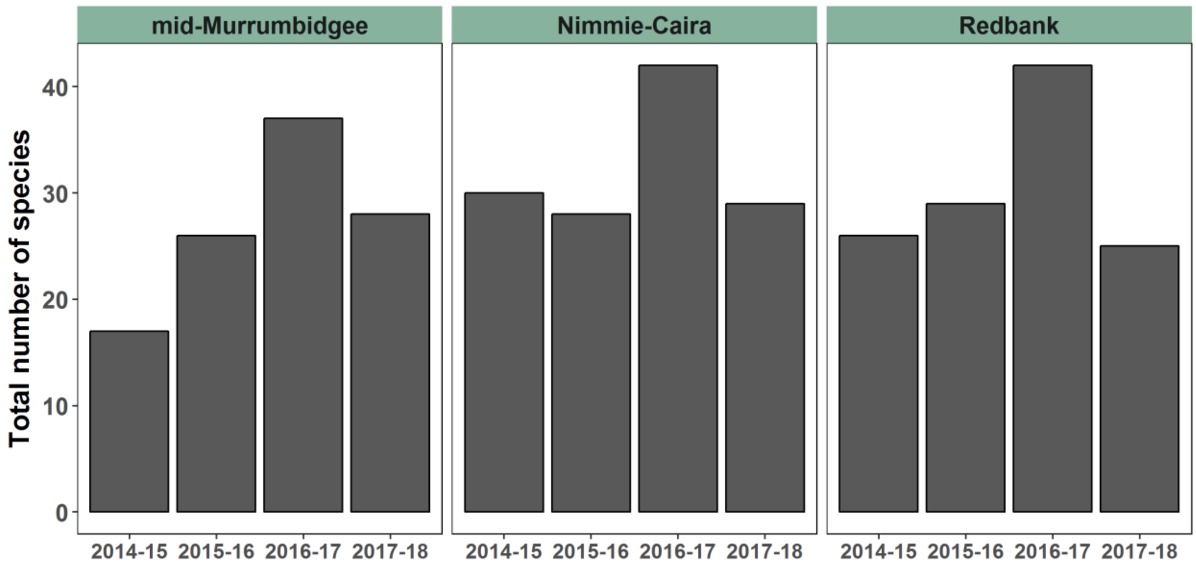

Figure 4-46: Total number of waterbird species recorded in each wetland zone in the 2014-15, 2015-16, 2016-17 and 2017-18 LTIM survey periods. (Note that reed-inhabiting passerines and raptors are not displayed here).

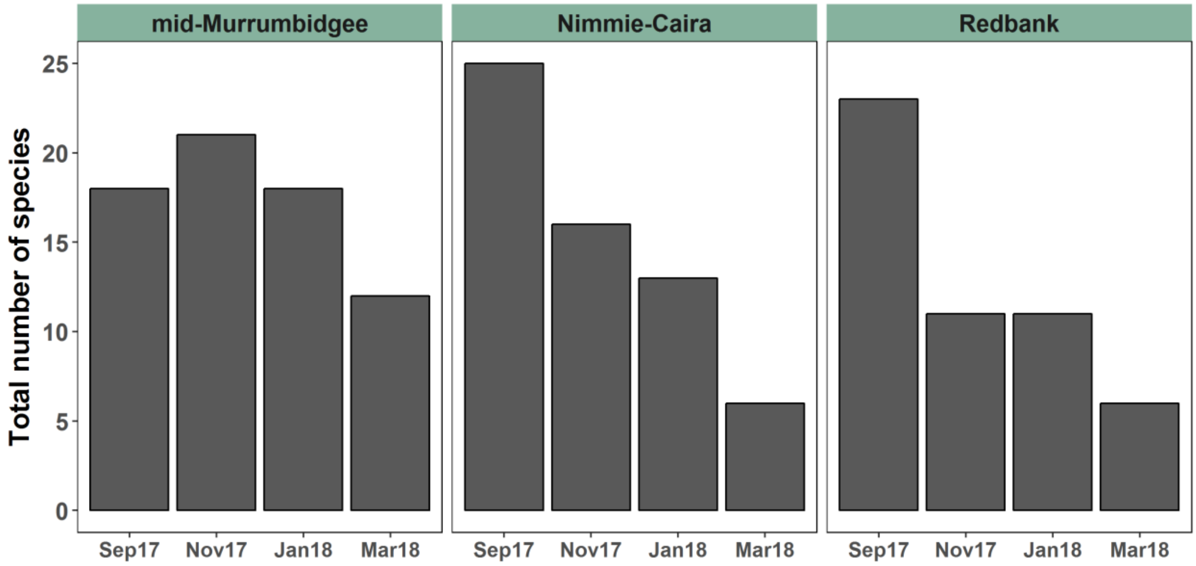

Figure 4-47: Total number of waterbird species recorded in each wetland zone in the four LTIM survey periods in the 2017-18 water year. (Note that reed-inhabiting passerines and raptors are not displayed here).

Waterbird community composition varied over the four years of LTIM surveys. Dabbling ducks (e.g. grey teal (*Anas gracilis)* and pink-eared duck (*Malacorhynchus membranaceus)) and fish-eating waterbirds* have dominated waterbird communities in each wetland zone in the survey years, including 2017-18. Large waders made up a larger proportion of total waterbirds observed in the Redbank zone in the 2017-18 surveys compared to previous surveys (Figure 4-46) but total abundance of all waterbird groups was much lower overall in the 2017-18 surveys (Figure 4-47). Rails and shoreline gallinules (e.g. waterhens) formed a larger proportion of the waterbird community in the Nimmie-Caira region in 2017-18 than in previous survey years (Figure 4-46).

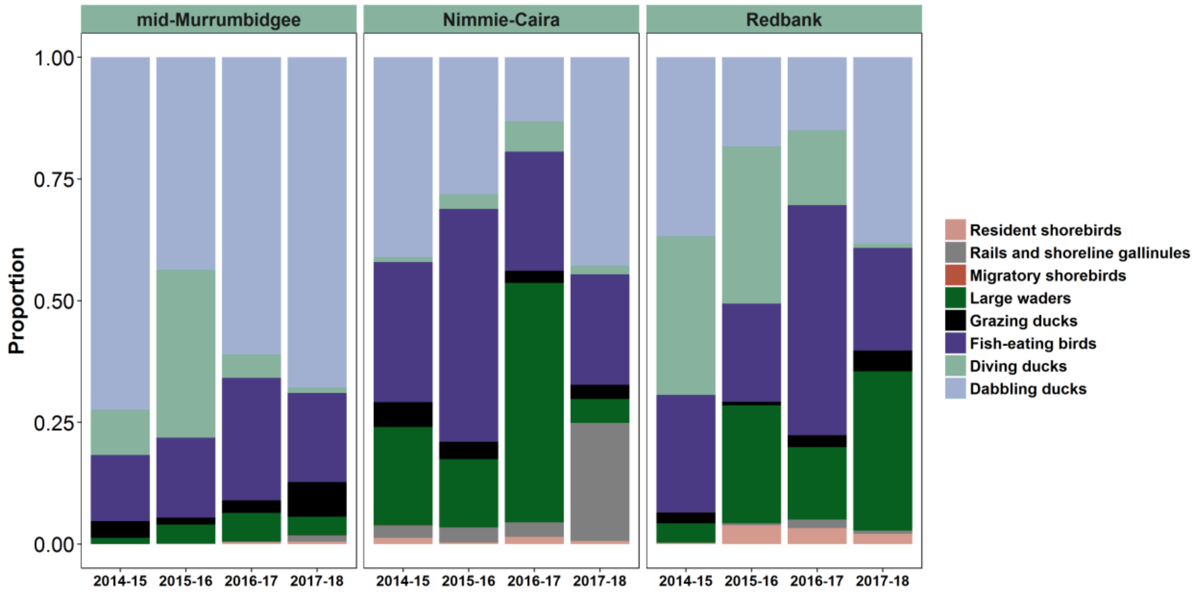

Figure 4-48: Overall waterbird community composition (max count per waterbird guild) in each wetland zone in the 2014-15 to 2017-18 LTIM survey periods.

There were significant differences in waterbird guild assemblages across the surveyed LTIM wetlands among the four water years (ANOSIM *Global R* 0.103, *p* = 0.001) and some differences among the three wetland zones (ANOSIM *Global R* 0.023, *p = 0.05*). The 2014-15 and 2015-16 water years differed from the wetter 2016-17 and relatively dry 2017-18 water years, but not from each other (Pair-wise tests 2014-15: 2015-16 *Global R -0.007*, *p* = 0.693). Overall, the waterbird assemblages in the Nimmie-Caira and Redbank zones were more similar to each other than waterbird communities observed in the mid-Murrumbidgee zone (Pair-wise tests Nimmie-Caira: Redbank *Global R* -0.013, *p* = 0.996).

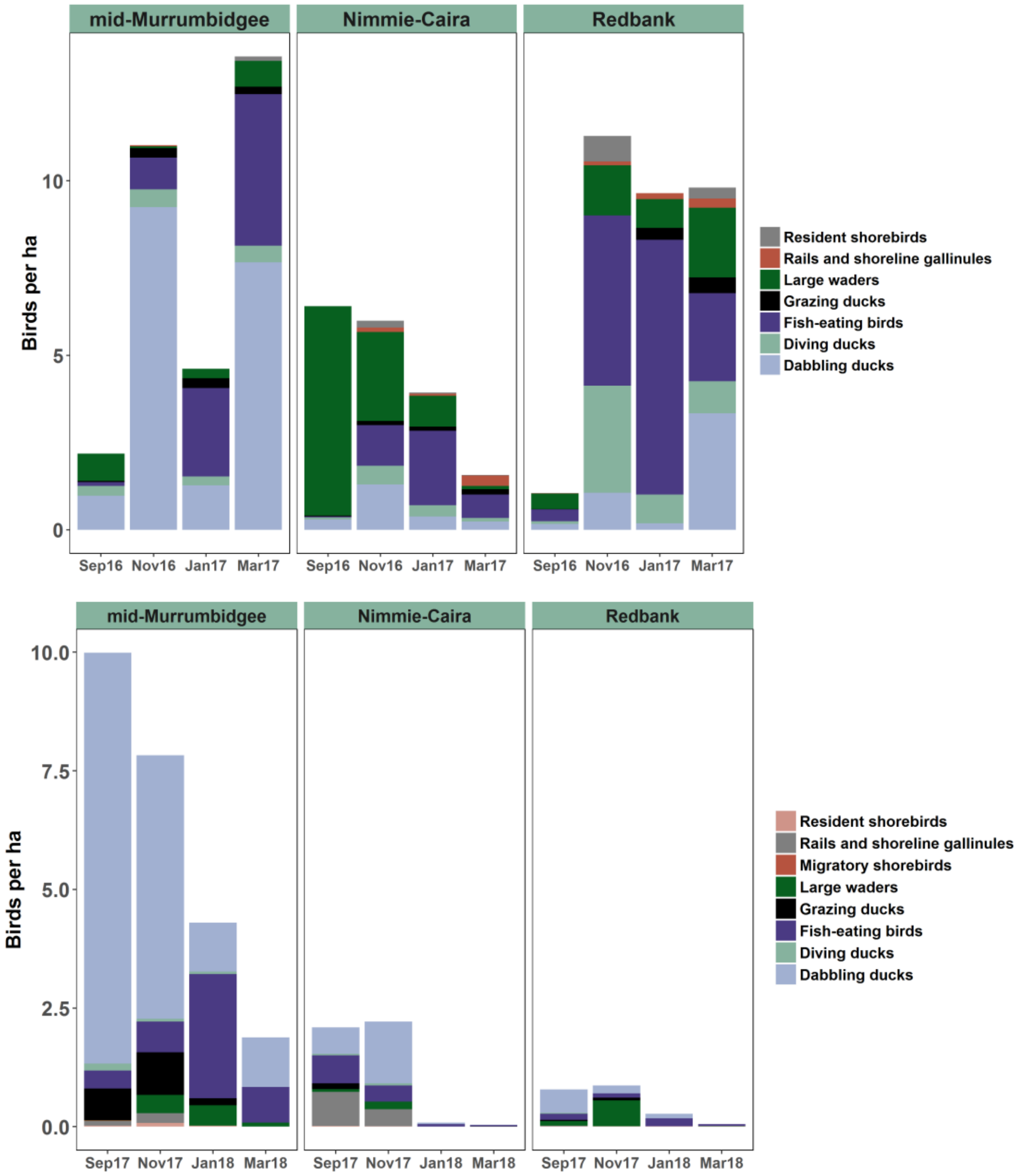

Figure 4-49 Comparison of total number of waterbirds (per ha grouped by functional guild), recorded across each wetland zone in the 2016-17 (upper) and 2017-18 (lower) LTIM survey periods. Note that reed-inhabiting passerines and raptors were not recorded in sufficiently large numbers to be displayed here. (Functional groups are described in Appendix).

Overall, we predicted that waterbird species richness and total abundance would be higher in wetland sites that were inundated in the Murrumbidgee Selected Area, and this was supported by results of LTIM surveys completed between September 2014 and March 2018. 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 = 17.0, p <0.001; abundance Z value = 11.2, p <0.001) (Figure 4-50).

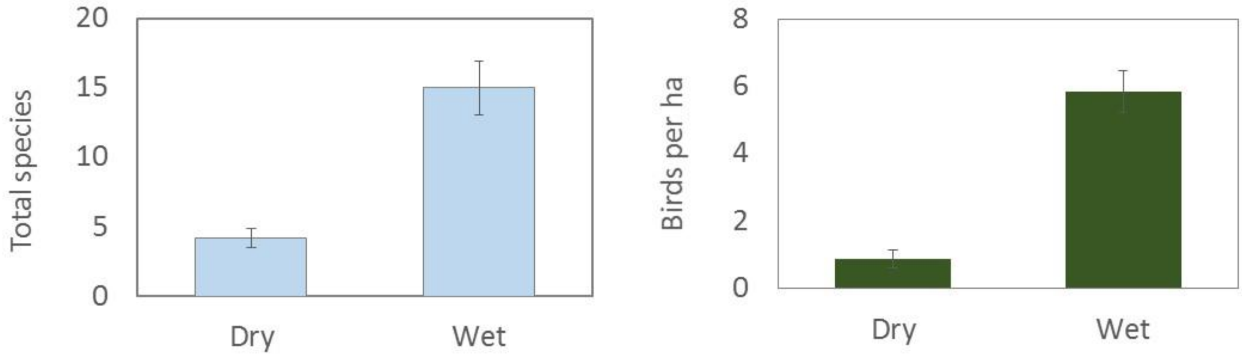

Figure 4-50 Comparison of average (+/- standard error) diversity (left) and abundance (max. count/ha) (right) recorded in inundated (>10% wet) and drier (<10% wet) LTIM wetlands surveyed from 2014-18.

Compared to the 2016-17 water year, the total numbers of waterbirds observed in each wetland zone in 2017-18 was comparatively low (Figure 4-51). There was evidence of some response of waterbirds in sites that received environmental water in the mid-Murrumbidgee zone, including Gooragool and Yarradda lagoons. In comparison few waterbirds were observed in the LTIM wetland sites in the Redbank and Nimmie-Caira zones in 2017-18 (Figure 4-49). The Nimmie-Caira and Redbank wetland regions were comparatively dry in 2017-18, with only limited inundation in these areas. The Nimmie-Caira watering action in December 2017 inundated refuge habitats only (Table 4-14).

What did Commonwealth environmental water contribute to waterbird breeding?

Waterbird breeding activity was limited in the Murrumbidgee Selected Area in 2017-18 (Figure 4-50). Eight waterbird species were confirmed breeding during the LTIM and complementary OEH ground surveys in 2017-18. This was considerably lower than in the previous three survey years (32 species were detected in 2016-17, during a large flood year, and 16 and 17 species were recorded in 2014-15 and 2015-16, respectively) (see Appendix 1 and 2).

In 2017-18 small numbers of colonially-nesting Australasian darter (*Anhinga novaehollandiae*), great cormorant (*Phalacrocorax carbo)*, little black cormorant (*Phalacrocorax sulcirostris)*, little pied cormorant (*Microcarbo melanoleucos)* and yellow-billed spoonbill (*Platalea flavipes)* were observed in the Murrumbidgee Selected Area. There was also some limited breeding activity (four species, single broods) observed in non-colonial waterbird species. This included Pacific black duck (*Anas superciliosa)*, black swan (*Cygnus atratus)*, grey teal and black-tailed native-hen (*Tribonyx ventralis)*.

There were five colony sites that had active small colonies (three to 26 nests in total per site) in the Murrumbidgee Selected Area in the October 2017 to March 2018 period Table 4-14). Australian White Ibis were thought to have started nesting in Eulimbah Swamp in mid-October 2017 but UNSW aerial surveys confirmed no activity (R. Kingsford, *pers. comm* 2017). Four colony sites received environmental water in 2017-18 including House Creek, upstream of Telephone Creek in the Nimmie-Caira zone, in December 2017, Narwie wetlands in North Redbank in October 2017, and Gooragool and Yarradda lagoons in the mid-Murrumbidgee zone. Yarradda Lagoon (Plate 4-5) received Commonwealth environmental water between July and November 2017 and environmental water was delivered to Gooragool Lagoon prior to the nesting period in July-August 2017 (see Table 4-14). Loorica Lake held residual water from the previous 2016-17 flood year.

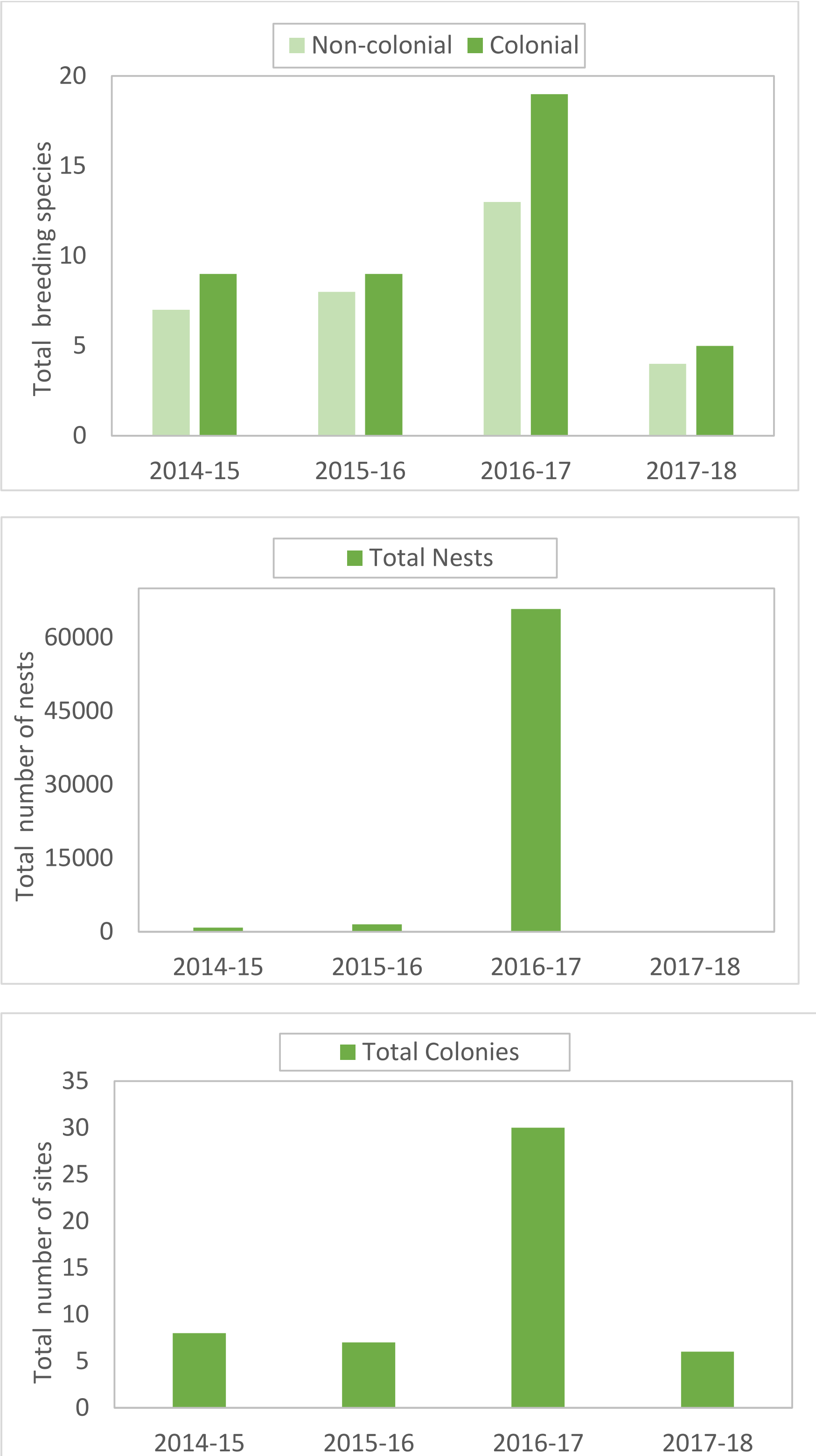

Figure 4-51 Total number of breeding non-colonial and colonial waterbird species (upper), total number of colonial-waterbird nests (mid) and total number of colony sites (lower) detected in the Murrumbidgee Selected Area in each water year from 2014-18.

Table 4-14. Summary of waterbird breeding activity recorded in the Murrumbidgee Selected Area in 2017-18 during NSW OEH ground surveys and LTIM wetland surveys.

Colony locations		Active nesting observed	Species breeding*					
			DAR	GC	LBC	LPC	YSB	Total nests
mid-Murrumbidgee	Yarradda Lagoon	Oct 2017-Mar 2018	19	7	0	0	0	26
	Gooragool Lagoon	Oct-Nov 2017	4	0	0	13	0	17
Nimmie-Caira	House Creek (US Telephone)	Nov 2017	0	0	0	0	3	3
	Loorica Lake	Oct-Nov 2017	3	0	0	0	0	3
Redbank	Narwie Wetlands (North Redbank)	Nov 2017-Jan 2018	7	0	0	6	0	13

* Species codes: DAR = Australasian Darter, GC = Great Cormorant, LBC = Little Black Cormorant, LPC = Little Pied Cormorant, YSB = Yellow-Billed Spoonbill.

Plate 4-5. Mature and recruiting river red gums regularly provide breeding habitat for cormorants and darters in Yarradda Lagoon (Murrumbidgee Valley National Park) in the mid-Murrumbidgee zone.

Discussion

What did Commonwealth environmental water contribute to waterbird species richness, abundance and breeding activity?

Monitoring results from the past four years of surveys supported our prediction that greater wetland inundation is associated with increases in waterbird species richness, including species of conservation significance, waterbird abundance and breeding activity in the Murrumbidgee Selected Area. Sites that were inundated in the four years of surveys had a higher overall species richness and abundance when compared to wetlands that were dry for extended periods during this period.

We observed an increase in waterbird species richness and abundance following widespread natural flooding and the delivery of environmental water in 2016-17, compared to the water years either side of 2016-17 when the total area of inundated wetland habitat available was much less. In the absence of natural flooding, greater habitat was available for waterbirds in the 2014-15 and 2015-16 periods, compared to the 2017-18 period, because there was greater environmental watering in 2014-17 (Wassens *et al.* 2018). Comparatively, waterbird responses were low in the 2017-18 water year in response to limited wetland inundation.

There was evidence of some response of waterbirds in sites that received environmental water in 2017-18 in the mid-Murrumbidgee zone, and this included Gooragool and Yarradda lagoons. The mid-Murrumbidgee watering actions also supported active nests of darters and cormorants in Yarradda and Goorgool lagoons (Table 0-2). The mid-Murrumbidgee reconnection event did not inundate McKenna's and Sunshower lagoons fully as expected due to complications in water delivery, and therefore, these two mid-Murrumbidgee sites did not support many waterbirds. Few waterbirds were also observed in the LTIM wetland sites in the Redbank and Nimmie-Caira zones with most drying down between September 2017 and March 2018. Eight of the 12 survey sites were dry during the January and March 2018 surveys.

Management implications

Where possible, Commonwealth environmental water should be prioritised to provide annually seasonally-flooded 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 (Scott 1997). The provision of environmental water in the years following large-scale flood events is likely to be extremely important in creating feeding habitat to support the survival of young waterbirds. Inundating floodplain habitat to create foraging habitat would benefit waterbird populations in the Murray-Darling Basin by promoting the survival of juvenile and adult waterbirds.

4.8 Riverine Hydrology

The hydrology of the Murrumbidgee River was influenced by the delivery water for the mid-Murrumbidgee reconnection in July and August 2017. The flow peaked at 22,862ML/day (4.1 m) at Wagga Wagga and attenuated downstream to reach 14159ML/day at Carrathool (Figure 4-52). At this height the flow connected low-lying wetlands while remaining within its banks and well below minor flood level which is 7.3m at Wagga Wagga. Once the reconnection flow had been completed, the hydrology of the river at both Wagga Wagga and Carrathool was similar to those observed in 2014-15 and 2015-16, and lower than in 2016-17when heavy rain through the catchment resulted in a large unregulated flow peak (see Figure 4-52).

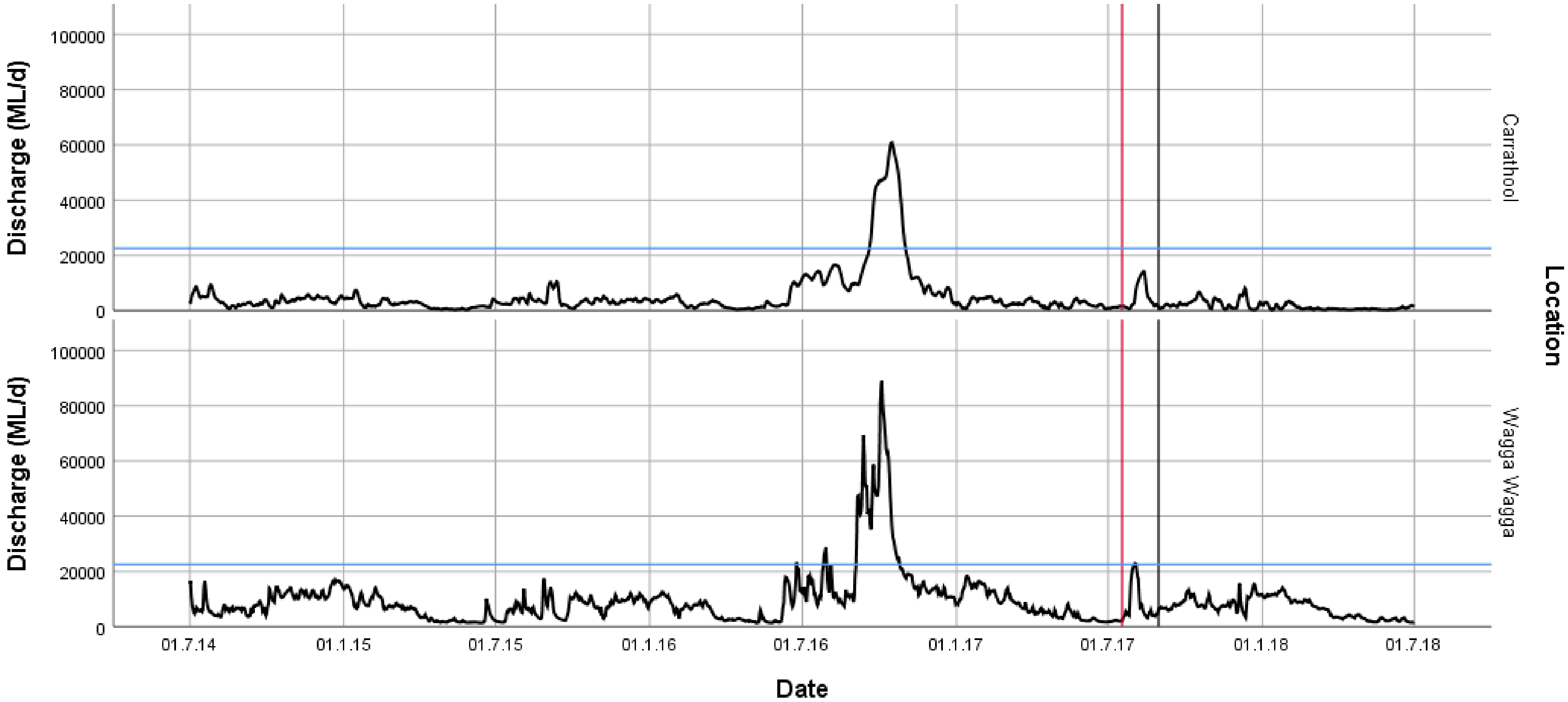

Figure 4-52: a. Mean daily discharge in the Murrumbidgee River at Wagga Wagga and Carrathool between 1 July 2014 to 30 June 2018. Vertical bars indicate the approximate start and finish of the mid-Murrumbidgee reconnection flow. Horizontal blue line shows desired flow target of 22000 ML/d at Wagga Wagga

4.9 Riverine water quality

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

Introduction

In rivers, water quality (the physicochemical environment and concentrations of dissolved nutrients and carbon) contributes to habitat suitability and biota are generally adapted to its variation (Poff *et al.* 1997). High flows, low flows, and variability in flows can contribute to changes in physicochemical parameters and nutrient concentrations (Watts *et al.* 2009). Large perturbations that have widespread negative impacts for riverine biota, such as hypoxic blackwater events (McCarthy *et al.* 2014) or in-stream algal blooms, are infrequent and can sometimes be offset with timed deliveries of environmental water.

Relevant watering actions and objectives

Between June and October 2017, a total of 236,205 ML of environmental water (159,283 ML of Commonwealth environmental water) was delivered in channel to inundate low-lying wetlands in the mid-Murrumbidgee zone as part of the mid-Murrumbidgee wetlands reconnection. River flows peaked at Narrandera at approximately 20,200 ML/d on 6 August 2017, and 14,300 ML/day at Carrathool on 13 August 2017 (see Figure 4-1). While there were no specific objectives related to riverine water quality an objective of the mid-Murrumbidgee wetland reconnection was to "*support hydrological connectivity and biotic and nutrient dispersal*". At these discharges river flows entered low-lying wetlands along the mid-Murrumbidgee, returning floodplain-derived nutrients and materials to the river as flows receded. We examined potential flow-on effects from this broad-scale delivery of environmental water by investigating differences in water quality among LTIM monitoring years. 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 to published water quality guidelines for lowland streams in south-eastern Australia (ANZECC 2000).

Evaluation Questions

- Did Commonwealth environmental water affect the cycling of nutrients and carbon in the Murrumbidgee River during 2017-18?

Methods

River water quality was monitored six times between October and December in each monitoring year (2014-15, 2015-16, 2016-17 and 2017-18). Sampling coincided with microinvertebrate and larval fish monitoring programs (see sections 4.11 and 4.12 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 4.10). 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 *et al.* 2015).

Data analysis

To test for differences between river zones and water years, data were analysed using a linear mixed effects model. Zone (n=2), sample trip (n=6) water year (n=4) 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 TripNo). Results were considered significant at $P<0.05$. Linear mixed effect models were produced using the lme4 package in R (Bates *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 4-15).

*Table 4-15 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 µg L^{-1}	FRP µg L^{-1}	Chl-a µg 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

During 2017-18, physicochemical conditions (Figure 4-53) were similar to the two years before the 2016-17 flood year (2014-15 and 2015-16). Overall, there was a high degree of variation among sample occasions within monitoring years, and little variation among replicate sites within hydrological zones, meaning high-order interaction terms were significant for all measured variables. There was a temporary decrease in pH and dissolved oxygen, and an increase across other measured water quality variables during late November / early December that coincided with heavy local rainfall (see section 4.1) and a brief fresh that was observed at both sites (peaking at 14,077 ML per day at Narrandera on 8 December 2017 and 8,230 at Carrathool on 11 December 2017).

On the second sampling occasion (late October) in 2017-18, pH exceeded the reference data across both sites (Figure 4-53) and subsequently declined to within the normal range (neither of these changes in pH were significant; Table 4-16). Turbidity temporarily increased to above the reference range during late-November and early December in response to the natural rainfall event (also not significant). During 2017-18, DOC was initially lower than previous LTIM-monitored years and reference data across both Zones (Figure 4-54), averaging 1.71 ± 0.08 mg L^{-1} between early-October and late-November compared with the LTIM average for 2014-15 and 2015-16 of 2.70

±0.14 mg L^{-1}. DOC later increased to within the normal range, following the small natural flow. Ammonia remained unexpectedly high throughout the 2017-18 study (average 7.06 ±0.86 µg L^{-1}), exceeding the average ammonia concentration for 2014-15 and 2015-16 (2.40 ±0.14 µg L^{-1}) (Figure 4-55). Values exceeded the pre-LTIM reference during early December 2017. Data for early October, where we might expect to have seen an impact from the July/August environmental flow, did not differ significantly from results in previous years (except for 2016 when the system was in flood).

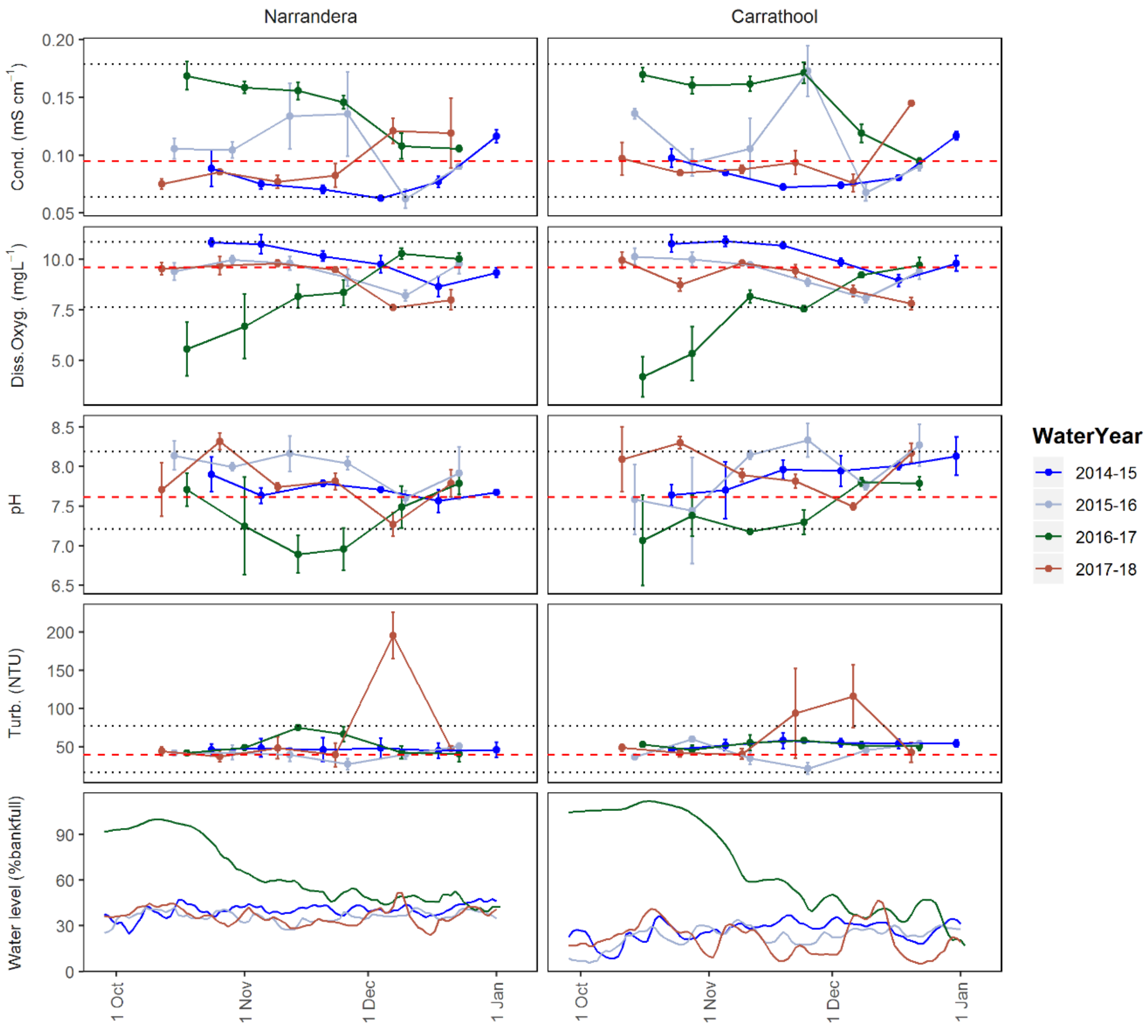

Figure 4-53 Mean ± standard error for physicochemical parameters (turbidity, pH, dissolved oxygen and conductivity) measured on six occasions between October and December during 2014-15, 2015-16, 2016-17 and 2017-18.

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/). Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

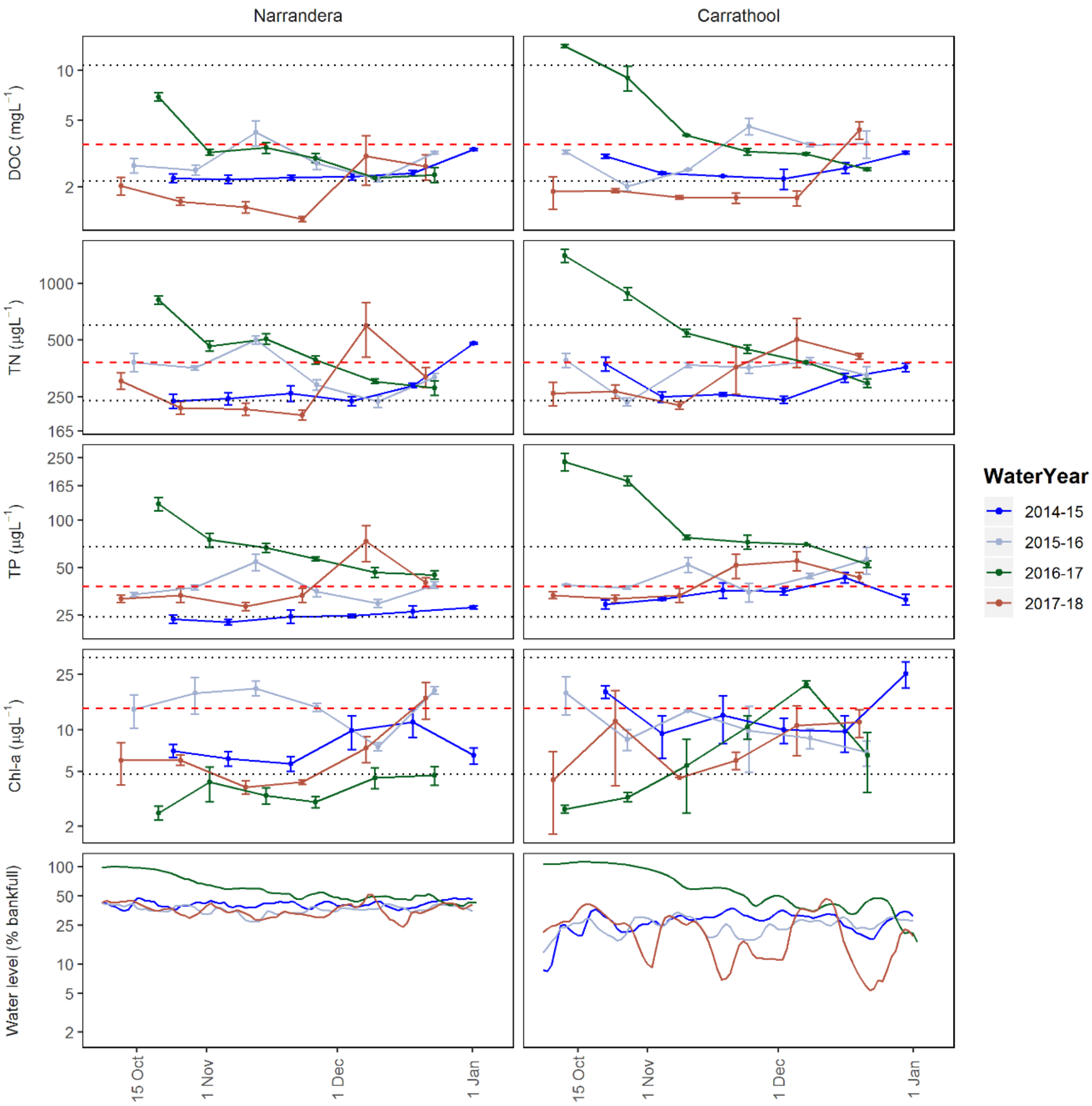

Figure 4-54 Concentrations of dissolved organic carbon (DOC), total nitrogen (TN), total phosphorous (TP), and chlorophyll-a (Chl-a) in water samples collected on six occasions between October and December during each of 2014-15, 2015-16, 2016-17 and 2017-18.

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/) and calculated as a proportion of estimated bankfull height. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

*Table 4-16 LMER results for water quality data collected for the Narrandera and Carrathool Zones for the 2014-15, 2015-16, 2016-17 and 2017-18 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 R^2(m)
	WaterYear(WY)	Zone(Zo)	TripNo(TN)	WY*Zo	WY*TN	Zp*TN	WY*Zo*TN	
df	*3*	*1*	*5*	*3*	*15*	*5*	*15*	
Total N	47.615***	10.889	6.134***	2.592	14.016***	2.550*	3.545***	0.83
Total P	258.092***	44.880*	5.512***	12.511***	25.062***	1.855	4.846***	0.93
NH3	325.171***	0.254	35.604***	15.757***	57.778***	4.317**	4.842***	0.96
NOx	57.11***	56.343*	2.493*	2.872*	7.831***	2.53*	4.363***	0.80
FRP	474.135***	55.211*	6.868***	40.250***	24.294***	4.490**	3.905***	0.96
Chl-a	44.773***	19.697*	4.612**	12.543***	4.384***	1.669	2.947**	0.78
DOC	87.14***	30.851*	11.430***	8.736***	19.490***	4.415**	6.469***	0.89
Cond.	172.851***	25.724*	15.125***	1.207	26.935***	18.861***	14.626***	0.93
pH	8.442***	0.123	1.217	1.343	2.441*	3.203*	1.372	0.53
DO	144.093***	79.375*	13.586***	43.959***	47.645***	11.503***	9.528***	0.94
Turb.	5.257**	3.899	3.283*	1.188	5.046***	0.678	2.491*	0.66

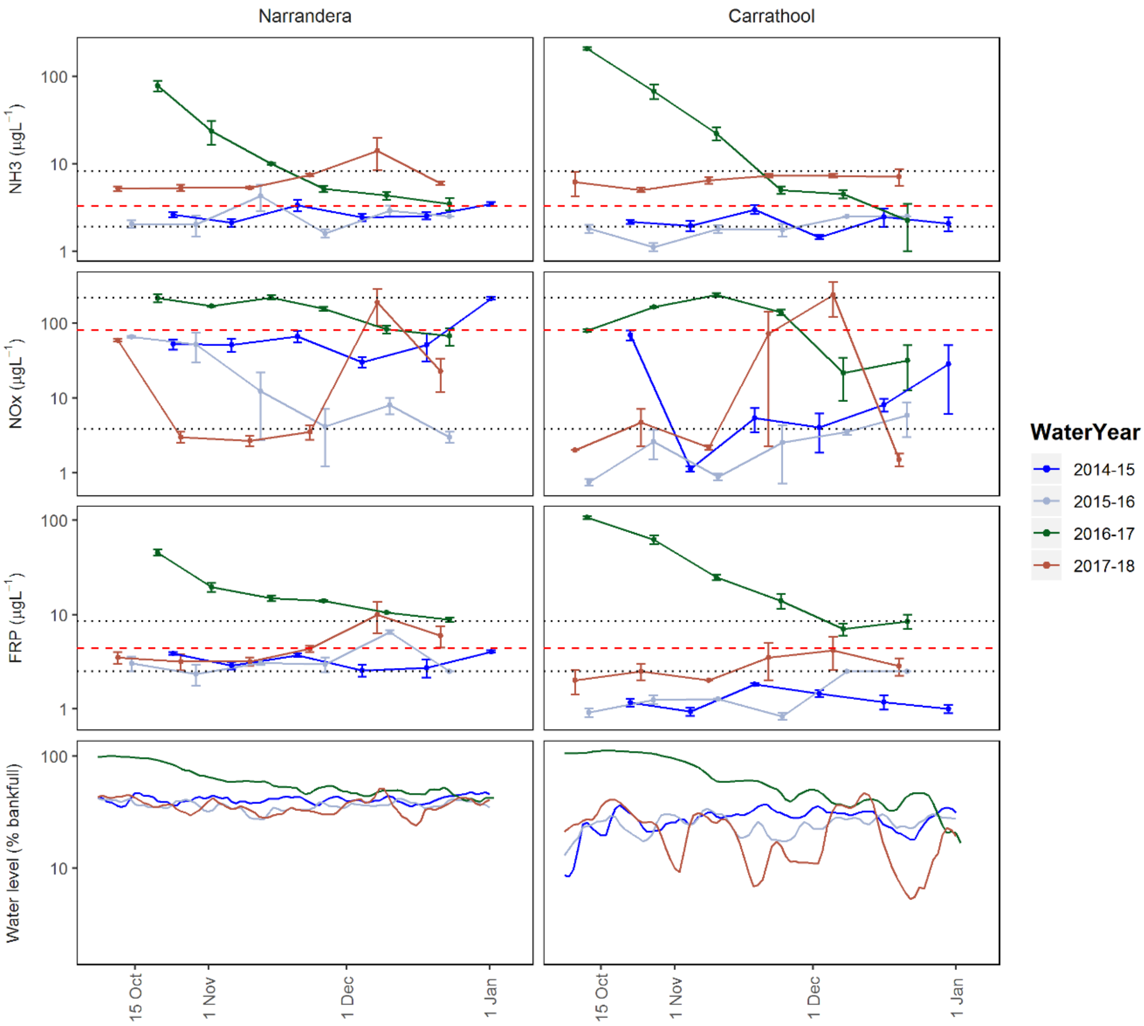

Figure 4-55 Concentrations of bioavailable nutrients (filterable reactive phosphorus – FRP; oxidised nitrate/nitrite – NO_x; and ammonia – NH_3), dissolved organic carbon (DOC) and chlorophyll-a (Chl-a) in water samples collected on six occasions between October and December during each of 2014-15, 2015-16, 2016-17 and 2017-18.

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

How did Commonwealth environmental water affect the cycling of nutrients and carbon in the Murrumbidgee River during 2017-18?

Early in 2017-18 there was a large environmental watering event that aimed to inundate riparian habitat and low-lying wetland in the mid-Murrumbidgee zone (see Section 4.1). While there were no specific objectives related to riverine water quality an objective of the mid-Murrumbidgee wetland reconnection was to "*support hydrological connectivity and biotic and nutrient dispersal*". The action peaked between 6 and 13 August 2017, ceasing on approximately 1 September 2017. It is not known when or how much floodplain water drained back into the main stem, although we estimate that return flows could have occurred until 17 August, ceasing at least six weeks before monitoring commenced. Potential flow-on effects from this water use include elevated water column nutrients, similar to those observed during the 2016-17 unregulated event, and associated increases in chlorophyll-a. However, during 2017-18 we found no evidence of a lasting impact of the reconnection flow on water quality in the river in either zone. Rather, riverine nutrient concentrations were unexpectedly low during 2017-18.

Overbank inundation that flows across large areas of floodplain carries floodplain-derived nutrients and energy that augment in-channel processes (Puckridge *et al.* 1998). 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 *et al.* 2000; Knowles *et al.* 2012) and transporting nutrients into the river channel with water returning to the river. Nutrients are subsequently used in-channel, supporting increased production that results in increased algal and/or microbial biomass) that is then available to consumers in food webs. Lower concentrations of nutrients and carbon could indicate that during the early part of the 2017-18 monitoring these resources were taken up into biomass, however, the LTIM monitoring dataset does not measure the biomass of plants or animals and this cannot be confirmed.

The 2017-18 dataset shows a disproportionately large impact of local heavy rainfall on water quality dynamics in the Murrumbidgee River. Up to 60mm of rain fell within 24 hours across most of the monitoring area, creating a small fresh in the river. Water quality responded strongly to this event, with most measured variables increasing (or in some cases decreasing: DO and pH). Filtered reactive phosphorous (i.e. the readily bioavailable proportion of phosphorous in the water column) increased to levels seen during the 2016-17 flood. Like other rivers in the Murray-Darling Basin, the Murrumbidgee River contains lower median concentrations of nutrients compared to other floodplain rivers across the world (Grace 2016) and this is particularly true throughout much of 2017-18. Rainfall runoff, especially when rain coincides with low-river flows, could have the potential to temporarily augment nutrient loadings and support increased production. The role of rainfall runoff and tributary inflows as drivers of enhanced productivity are not well understood. Large areas of floodplain in the Murrumbidgee catchment are developed for agriculture (Kingsford *et al.* 2004). Agricultural activities that augment available nutrients in soils can be an important source of nutrients e.g. (Brodie *et al.* 2005). However, river red gum leaves also rapidly leach highly bioavailable orthophosphate upon inundation (Baldwin 1999)

4.10 Stream metabolism

Prepared by Ben Wolfenden (CSU) and 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 *et al.* 2008). As the master variable controlling these drivers (Poff *et al.* 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 *et al.* 2008) with flow-on effects to food web dynamics and water quality (Marcarelli *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.

Between June and October 2017 a total of 236,205 ML of environmental water (159,283 ML of Commonwealth environmental water) was delivered along the Murrumbidgee River channel to water low-lying wetlands in the mid-Murrumbidgee. Flows peaked at Narrandera at approximately 20,200 ML/d on 6 August 2017, and 14,300 ML/day at Carrathool on 13 August 2017. While there were no specific objectives related to riverine water quality an objective of the mid-Murrumbidgee wetland reconnection was to *"support hydrological connectivity and biotic and nutrient dispersal"*. At these discharges river flows entered low-lying wetlands, returning floodplain-derived nutrients to the river as flows receded. A small fresh, caused by heavy local rainfall during early December, coincided with a period relatively low-flows across both monitoring zones. Although environmental water was delivered in previous water years, none of these actions fell within the monitoring period. Long-term watering plans for the Murrumbidgee River forecast in-channel deliveries of Commonwealth environmental water to support habitat and riverine productivity for fish.

We investigated the relationship between stream metabolism and river flows during 2014-15, 2015-16, 2016-17 and 2017-18 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 *et al.* 2015) modified to incorporate improvements proposed by (Song *et al.* 2016) and packaged in R (Bond et al. 2018). Rates of stream metabolism can change with river discharge, time of year and channel geomorphology. We used a simple linear regression to explore potential dependencies of metabolism rate on river discharge. All models were checked for normality by examining plots of residuals and log (x+1)-transformed where necessary. All statistical analyses were performed using the statistical-computing environment 'R' (R Development Core Team 2014).

Results

Overall 95% of the data extracted from the Narrandera Zone logger and 93% of the data extracted from the Carrathool Zone logger was of suitable quality to be included in the evaluation (Table 4-17). 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 (Table 4-17). The highest metabolic rates recorded for 2017-18 occurred at both sites in early December, coinciding with a small fresh and subsequent rainfall rejection created by heavy local rainfall. Median river discharge was lower in 2017-18 than previous years, particularly in the Carrathool reach (Table 4-17).

At the Narrandera and Carrathool sites, median net daily metabolism (NDM; GPP-ER) was > 0 during the 2017-18 water year, suggesting metabolism was net autotrophic (i.e. more carbon was produced by photosynthetic organisms than was consumed overall), however, the data also shows that this trend was highly variable across time (Figure 4-57). During previous LTIM monitoring years, production has been net heterotrophic (except for the Narrandera site during 2015-16 when production was net autotrophic).

During 2017-18, river discharge was negatively related to both GPP and ER (Figure 4-58, Table 4-18). Analysis for individual years shows the influence of discharge on metabolism rates varies across space and time. At Narrandera, simple linear regression found significant negative relationships between water level vs GPP and water level vs ER for all four water years (Table 4-18). However, at the Carrathool site, significant negative relationships were only found for 2014-15 and 2017-18. When scaled-up to a daily loading (Figure 4-59) the overall total production loading for both ecosystem respiration and gross primary production shows that increased water volume achieves a greater overall increased in energy flux that outweighs the lower overall rate at higher discharge.

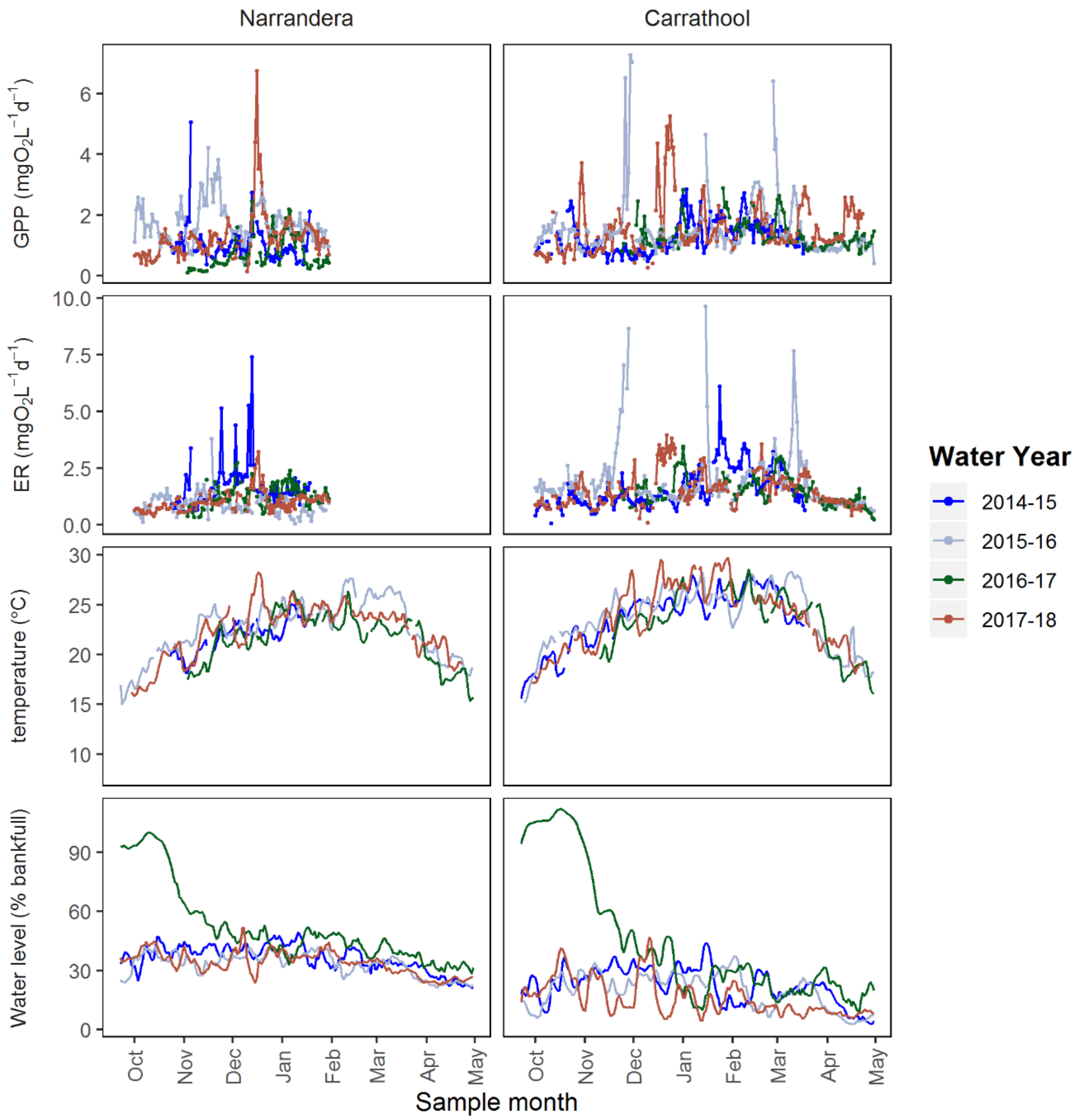

Figure 4-56 Metabolism results (GPP.mean – gross primary production; ER.mean – ecosystem respiration; PR_ratio – the ratio of GPP:ER) measured continuously at the Narrandera Cat 3 (October to January) and Carrathool Cat 1 (October to April) sites. The P:R ratio of 1 is indicated by the dotted line. Data are shown for 2014-15, 2015-16, 2016-17 and 2017-18 using ordinal date on the x-axis. Mean daily water temperature (wtemp) was monitored continuously.

Table 4-17 Summary statistics for stream metabolism at Narrandera and Carrathool in the Murrumbidgee River (GPP: Gross Primary Productivity; ER: Ecosystem Respiration). Note these data are calculated with the revised BASE function.

	Narrandera				Carrathool			
Water Year	2014-15	2015-16	2016-17	**2017-18**	2014-15	2015-16	2016-17	**2017-18**
	24/10/14 – 18/1/15	1/10/15 – 31/1/16	2/11/16 – 31/1/17	**31/1/18 – 1/10/17**	1/10/14 – 18/3/15	1/10/15 – 30/4/16	23/11/16 – 1/5/17	**25/10/17 – 23/4/18**
Number of available observations (number of missing observations)	82 (3)	112 (7)	79 (10)	**133 (7)**	151 (14)	195 (12)	117 (33)	**178 (14)**
GPP (mg O_2 L^{-1} d^{-1}) median [range]	0.87 [0.37-5.07]	1.64 [0.47-4.22]	0.53 [0.11-2.45]	**1.19 [0.14-6.75]**	1.14 [0.42-2.85]	1.28 [0.41-13.45]	1.24 [0.71-2.88]	**1.33 [0.26-5.25]**
ER (mg O_2 L^{-1} d^{-1}) median [range]	1.50 [0.64-7.40]	0.85 [0.07-3.81]	1.34 [0.34-3.23]	**0.94 [0.41-3.23]**	1.31 [0.09-6.12]	1.58 [0.59-26.82]	1.49 [0.26-3.47]	**1.53 [0.11-3.96]**
Water level (m) median [range]	7,845 [2,205 - 11,865]	6,331 [2,891-8,588]	11,259 [4,180-81,862]	**6,500 [1,876-13,108]**	3,126 [383-7,361]	3,069 [373-5,892]	4,399 [551-60,737]	**1,056 [223-8,148]**

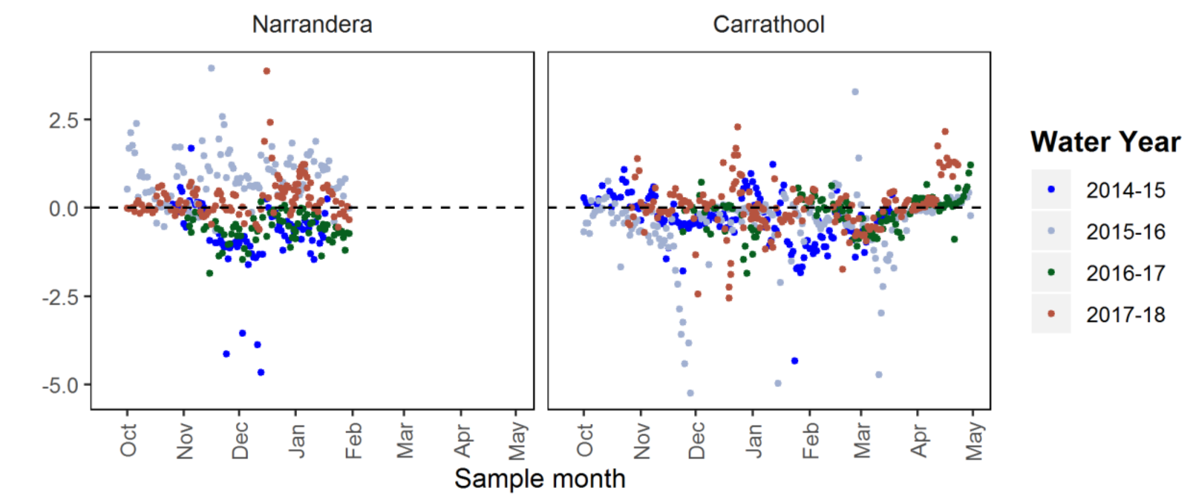

Figure 4-57 Metabolism results (NDM = net daily metabolism) measured continuously at the Narrandera Cat 3 (October to January) and Carrathool Cat 1 (October to April) sites. The NDM of 0 is indicated by the dotted line. Data are shown for 2014-15, 2015-16, 2016-17 and 2017-18 using ordinal date on the x-axis.

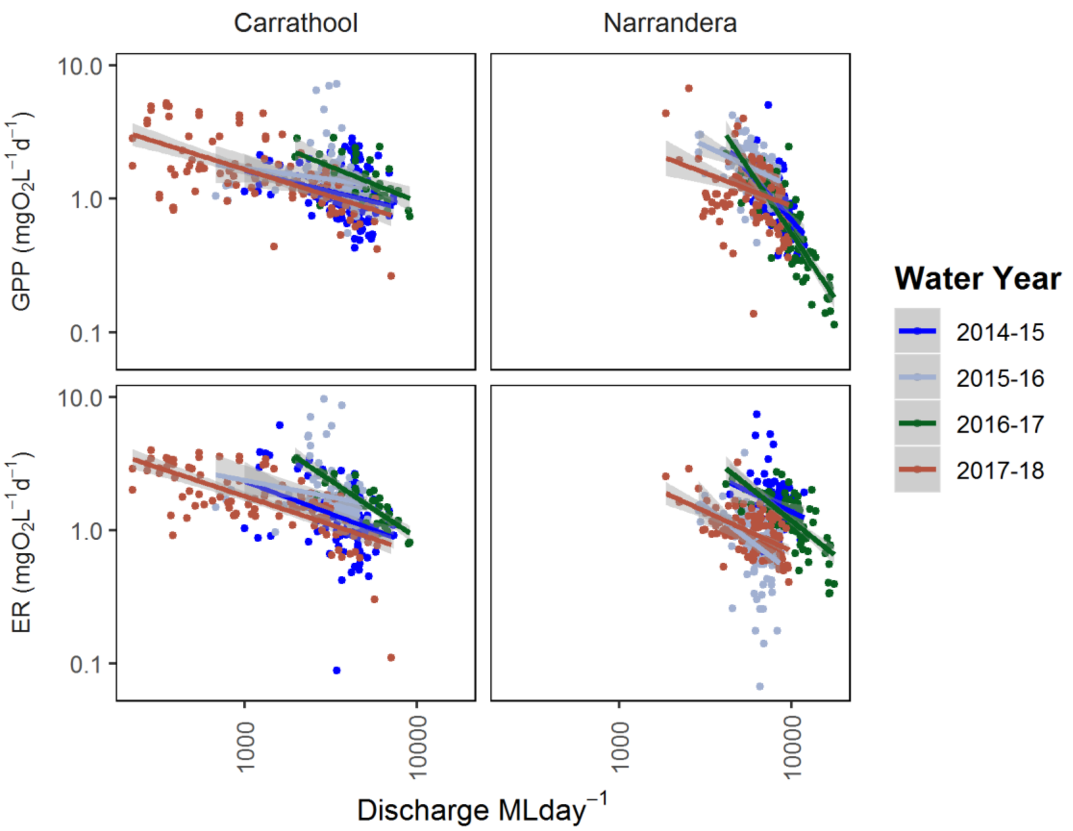

Figure 4-58 Observed values of gross primary productivity (GPP, mgO_2 L^{-1} d^{-1}) and ecosystem respiration (ER, mgO_2 L^{-1} d^{-1}) at the Carrathool Cat 3 site for the water years 2014-15, 2015-16 and 2016-17, based on linear regression model with autoregressive errors of a lag-1, using mean daily 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.

Table 4-18 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	Water Year	F-statistic	adjusted R^2
Narrandera	GPP.mean	2014-15	38.22***	0.31
		2015-16	21.71***	0.16
		2016-17	166.78***	0.68
		2017-18	**19.62*****	**0.12**
	ER.mean	2014-15	6.51*	0.06
		2015-16	26.38***	0.19
		2016-17	79.02***	0.50
		2017-18	**50.44*****	**0.27**
Carrathool	GPP.mean	2014-15	20.02***	0.11
		2015-16	0.01	-0.01
		2016-17	0.05	-0.01
		2017-18	**69.25*****	**0.28**
	ER.mean	2014-15	64.53***	0.30
		2015-16	6.53*	0.03
		2016-17	2.82	0.02
		2017-18	**45.86*****	**0.20**

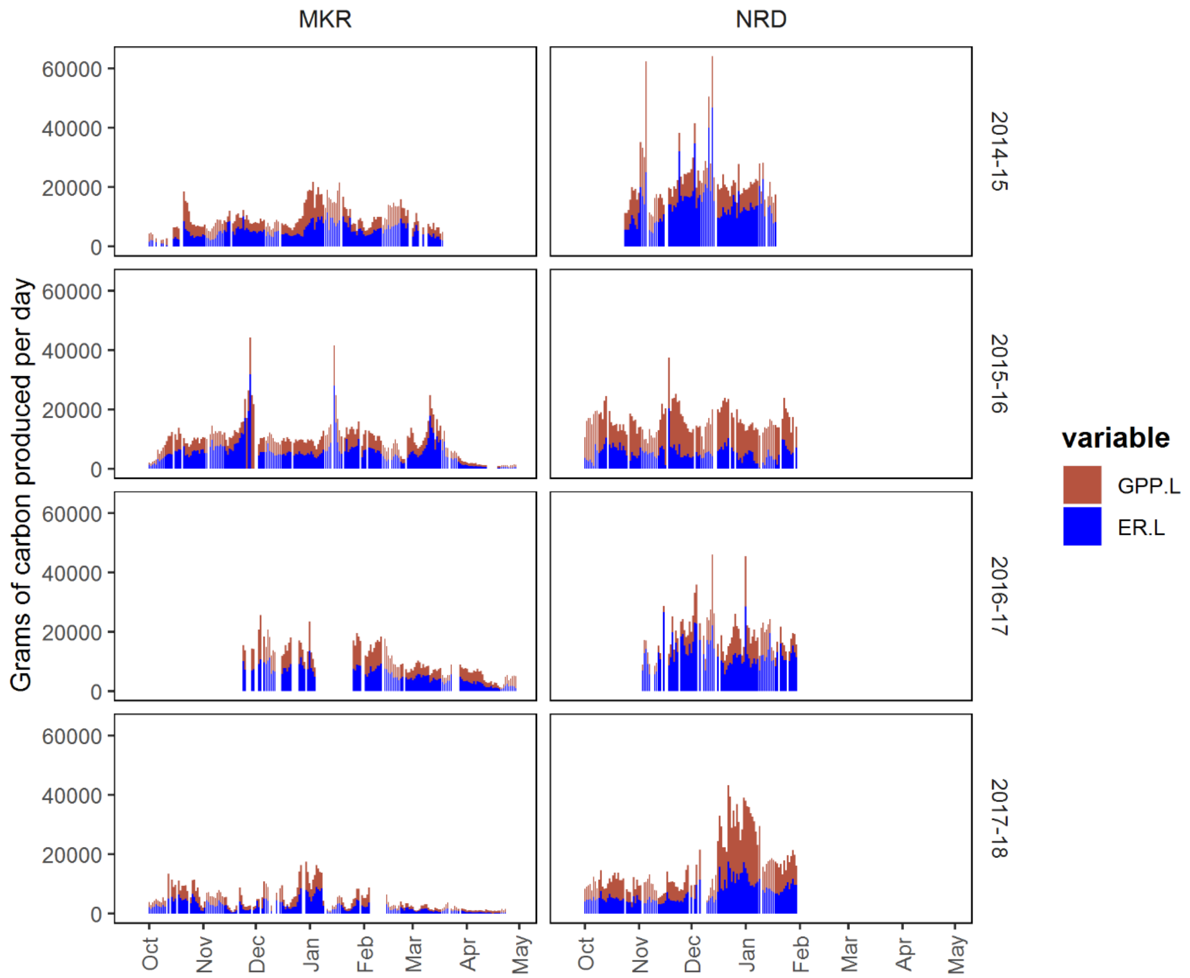

Figure 4-59 A stacked bar plot showing metabolism results (GPP.L – gross primary production load; ER.L – ecosystem respiration load) measured continuously at the Narrandera Cat 3 (October to January) (NRD)and Carrathool Cat 1 (October to April) (MKR) sites. Data are shown for 2014-15, 2015-16, 2016-17 and 2017-18 using ordinal date on the x-axis. Data are the product of per-litre metabolism rate and river discharge.

Discussion

Did Commonwealth environmental water have a measurable impact on the metabolism regime of the Murrumbidgee River during 2017-18?

236 GL of environmental water, including 159 GL of CEW, was delivered in the months leading up to the 2017-18 stream metabolism monitoring program. One of the key objectives relating to water quality and metabolism was to "*support hydrological connectivity and biotic and nutrient dispersal*". It is expected that during reconnections between the river and low lying wetlands there will be an increase in nutrient and carbon concentrations when environmental returns to the river as flows recede. This temporary increase in resource availability is expected to accelerate

rates of ecosystem metabolism. During 2017-18, we found no evidence that rates of ecosystem metabolism differed between the previous water years (2014-15 and 2015-16). During the previous water years, environmental water was delivered through the Murrumbidgee River system to supply water for floodplain inundation without creating a peak within the river channel or reconnecting low lying wetlands. The prediction that metabolism will increase following floodplain to riverine reconnection hinges on the expectation that rates of production are limited by the availability of resources (nutrients and carbon) which are needed for algal and microbial metabolism (Grace 2016). As noted previously (Wassens *et al.* 2018), rates of production in the Murrumbidgee River are low, corresponding with apparently low nutrient availability. This pattern was seen again in 2017-18. In a study of the drivers of metabolism in the Murrumbidgee River, Vink (2005) found evidence that algal production was limited by the availability of phosphate, and that low overall rates of production that were thought to be caused by reduced floodplain connectivity. However, it has also been shown that river biofilms, which are a key site of production in rivers, respond slowly to changes in flow height and variability (e.g. (Ryder 2004). Moreover, rates of ecosystem metabolism are known to scale with temperature (Siders *et al.* 2017; Heffernan 2018). Presumably, rates of production, biofilm growth and nutrient uptake are slower during colder months. This means we are more likely to see floodplain nutrients move downstream before being taken up, with a more diffuse, de-localised response in production during winter than during warmer months.

4.11 Riverine microinvertebrates

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

Introduction

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).

Microinvertebrate outcomes for 2017-18 are considered in the context of 2014-15, 2015-16 and 2016-17 outcomes. Commonwealth environmental water was not directly targeted at in-channel watering outcomes for microinvertebrates during 2014-15, 2015-16, 2016-17 or 2017-18. Across all years, river flows were lower in the Carrathool zone which is less impacted by the delivery of irrigation flows.

Relevant watering actions and objectives

During 2017-18 significant volumes of Commonwealth environmental water were delivered to the mid-Murrumbidgee wetlands as part of the mid-Murrumbidgee wetland reconnection flow. While not specifically targeting microinvertebrate responses, did have an objective related “support hydrological connectivity and biotic and nutrient dispersal” and “to support reproduction and improved condition vegetation, waterbirds, native fish and other biota”. A total of 236,205 ML of environmental water (159,283 ML of Commonwealth environmental water) were delivered in channel to water low-lying wetlands in the mid-Murrumbidgee between June and October 2017. Flows peaked at Narrandera at approximately 20,200 ML/d on 6 August 2017, and at Carrathool at approximately 14,200 ML/day. At these discharges river flows entered low-lying wetlands along the mid-Murrumbidgee, returning floodplain-derived resources on the flow recession. Monitoring is aligned with larval fish surveys which commenced in mid-October 2017 and commenced after the mid-Murrumbidgee reconnection flow. A small fresh caused by heavy local rainfall during early December 2017 also occurred within a period of relatively low-flows across both monitoring zones.

Evaluation Questions

We predicted that a peak in river heights would inundate previously dry sediments in rivers (i.e. wetlands, 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 we address the following evaluation question with respect to riverine microinvertebrate communities.

- Did Commonwealth environmental water contribute to densities of benthic and pelagic microinvertebrates

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. Sampling was undertaken fortnightly from 9 October until 21 December 2017 in the fourth year of sampling. 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, *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 *et al.* 1983; Shiel *et al.* 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., Carrathool or Narrandera) along with trip by fitting a linear mixed-effects model (LMM) using the lmer function in the lme4 package in R (Bates *et al.* 2014); R version 3.2.1, (R Development Core Team 2014). 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

Between 2014 and 2018 densities of microinvertebrates have consistently been at least two orders of magnitude higher in benthic (<3000/L) than pelagic (<10/L) habitats within the Murrumbidgee River (Figure 4-60). Pelagic densities were consistently an order of magnitude below the lowest prey density threshold suggested for successful feeding by larval fish (Figure 4-60). Communities of microinvertebrates were also strikingly different between benthic and pelagic habitats (Figure 4-61).

Densities of microinvertebrates were lower in both 2017-18 and 2016-17 compared to 2014-15 and 2015-16 sampling periods (

Figure 4-62). In 2016-17 the low densities coincided with high water levels and fast flows during flooding, while in the 2017-18 sampling period, water levels in the Carrathool and Narrandera zones were the lowest observed during the LTIM project (see section 4.1). A wetland reconnection event in August 2017 produced a peak in river flows, lower than peak flows during floods the year before, and was slightly higher than similar winter peaks observed in the first two years.

Overall, densities of microinvertebrates were higher in the Carrathool than Narrandera zone (Figure 4-60). Model estimates of total microinvertebrate density indicate the higher densities in the Carrathool zone compared to the Narrandera zone were not significant but were consistent between years (Figure 4-63). Water levels in the Carrathool zone during the 2017-18 sampling period showed greater variation than in the first two years of the project.

In benthic habitats in both the Narrandera and Carrathool zones, microinvertebrate densities generally increased in the last three trips in 2014-15 and 2015-16 and the last two trips in 2017-18 (Figure 4-64). In contrast, microinvertebrate densities were lower in the last four trips in 2016-17 (Figure 4-64). 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 2017-18 and 2016-17 (and Figure 4-64), were reflected in a different taxa composition compared to 2014-15 and 2015-16 (Figure 4-64). In both the recent years there were lower densities of key microinvertebrate taxa including; *Macrothix* sp., *Neothrix armata*, ostracods and a number of chydorids (Figure 4-64). In 2017-18, compared to other years, higher densities of *Macrothrix spinosa* and a chydorid Alona sp. were observed (Figure 4-64).

Total microinvertebrate density did not show a relationship with either flow rate (Figure 4-65) or water level (Figure 4-66) for both benthic and pelagic habitats. Small clusters of points at both low and high flows drive the shape of the fitted curves, whereas the majority of data revealed both low (2017-18) and high (2014-16) densities coinciding with lower flows/water levels and low densities observed with high flows (2016-17). The benthic densities in Narrandera zone at the highest flows and water levels were not as high as observed in the Carrathool zone (Figure 4-66).

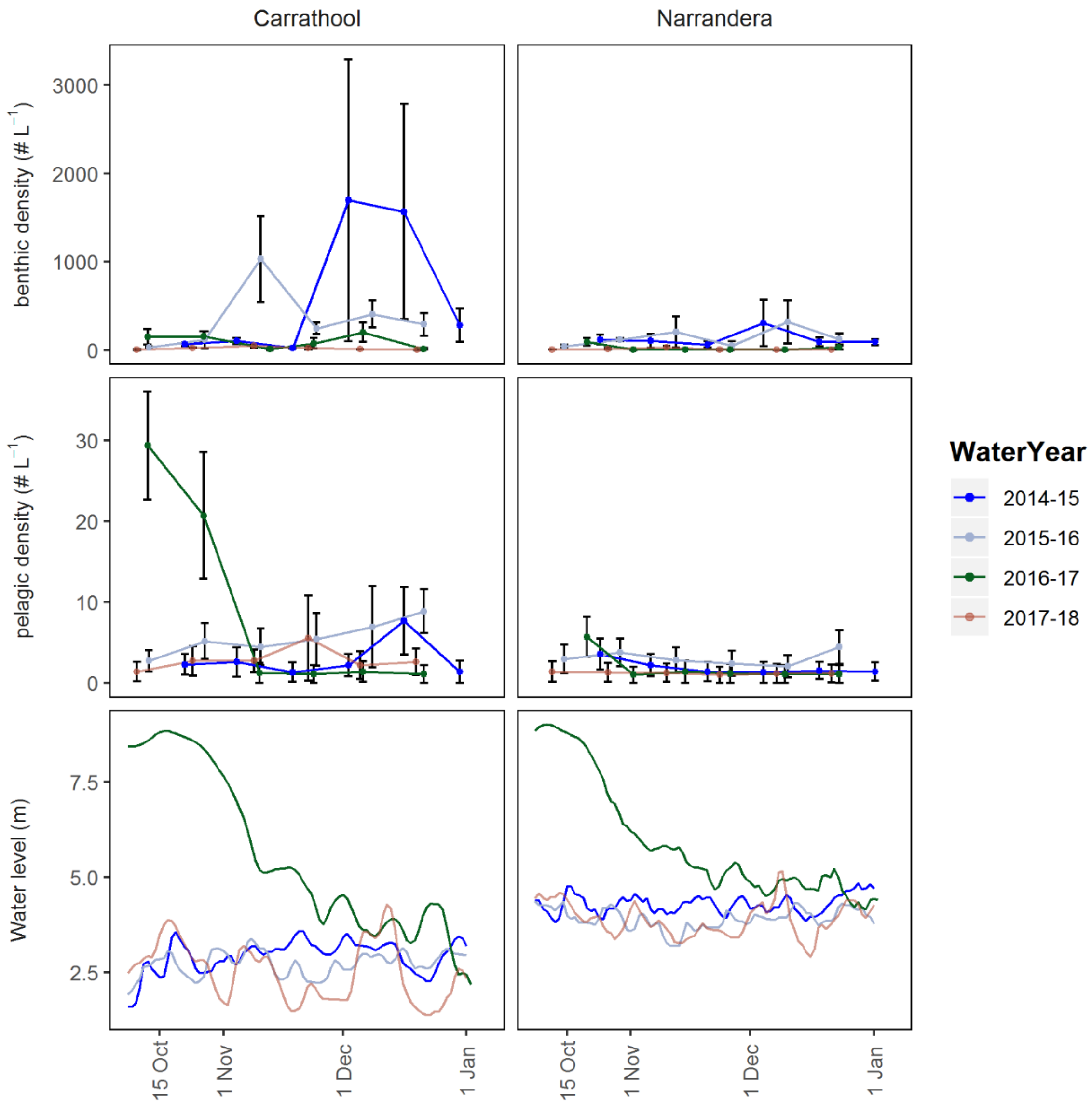

Figure 4-60 Benthic (upper row) and pelagic (second row) microinvertebrate densities (L-1) for 3 sites in the Carrathool zone (left graphs) and 3 sites in the Narrandera zone (right graphs) of the Murrumbidgee River sampled from October 2014 to January 2018.

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/). Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

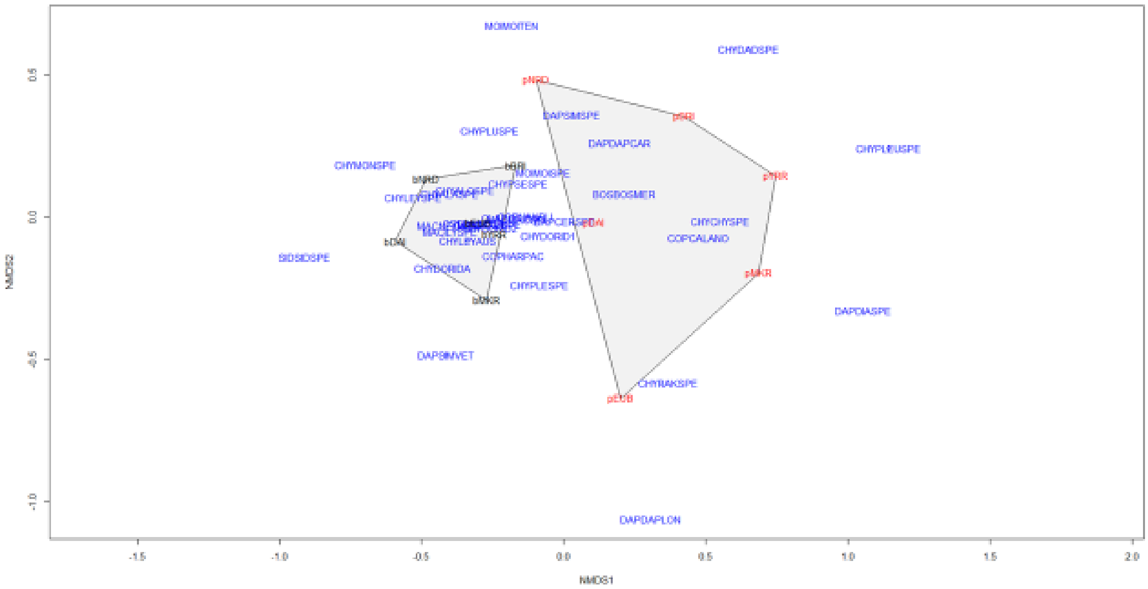

Figure 4-61 Benthic (left cluster) and pelagic (right cluster) microinvertebrate species composition shown in multi-dimensional space including 3 sites in the Carrathool zone and 3 sites in the Narrandera zone of the Murrumbidgee River sampled from October 2014 to January 2018.

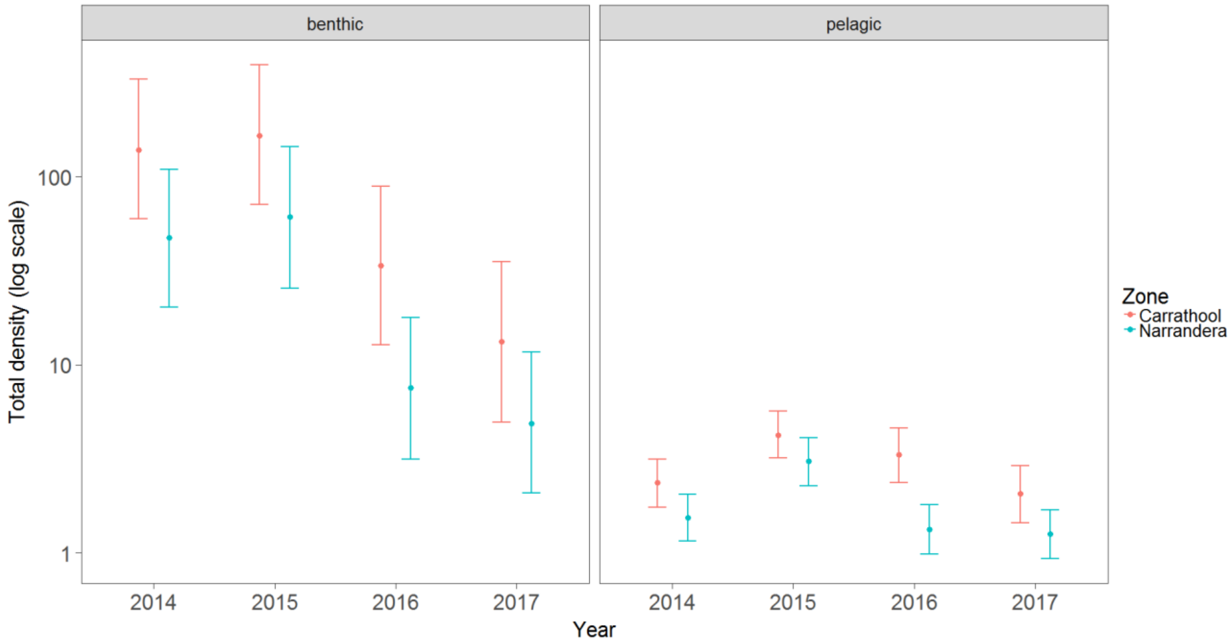

Figure 4-62 Model estimates of total microinvertebrate density (log scale) in three sites each from the Carrathool and Narrandera zones in both benthic (left graph) and pelagic (right graph) habitats sampled in 2014-15, 2015-16, 2016-17 and 2017-18.

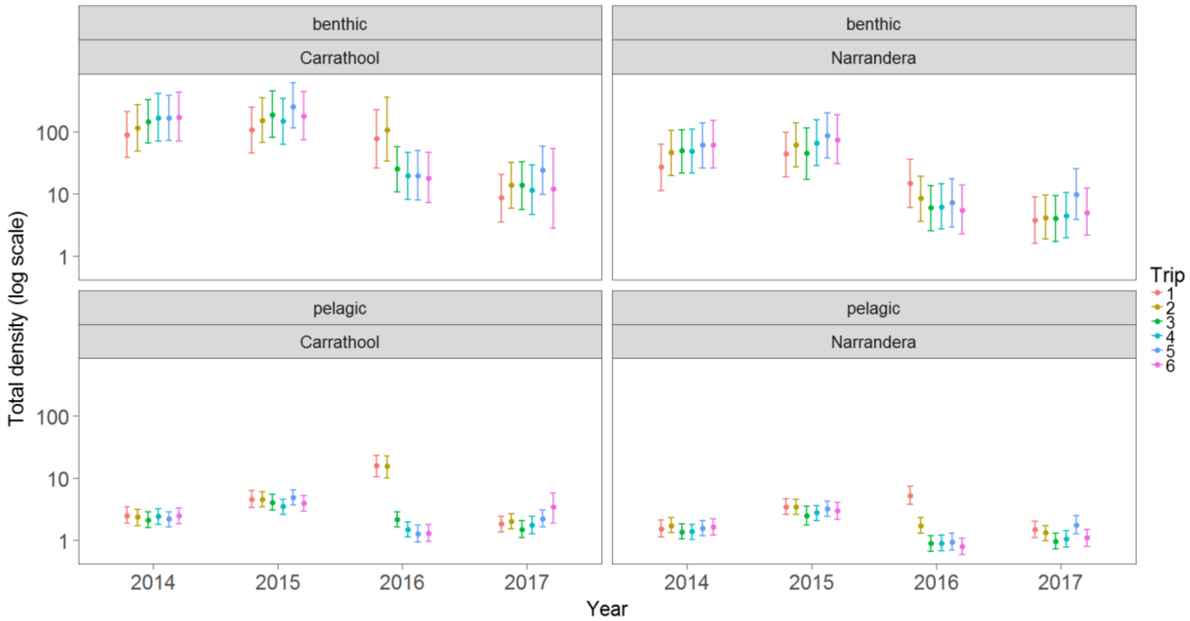

Figure 4-63 Model estimates of total microinvertebrate density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic (upper graphs) and pelagic (lower graphs) habitats sampled over 6 trips in 2014-15, 2015-16, 2016-17 and 2017-18.

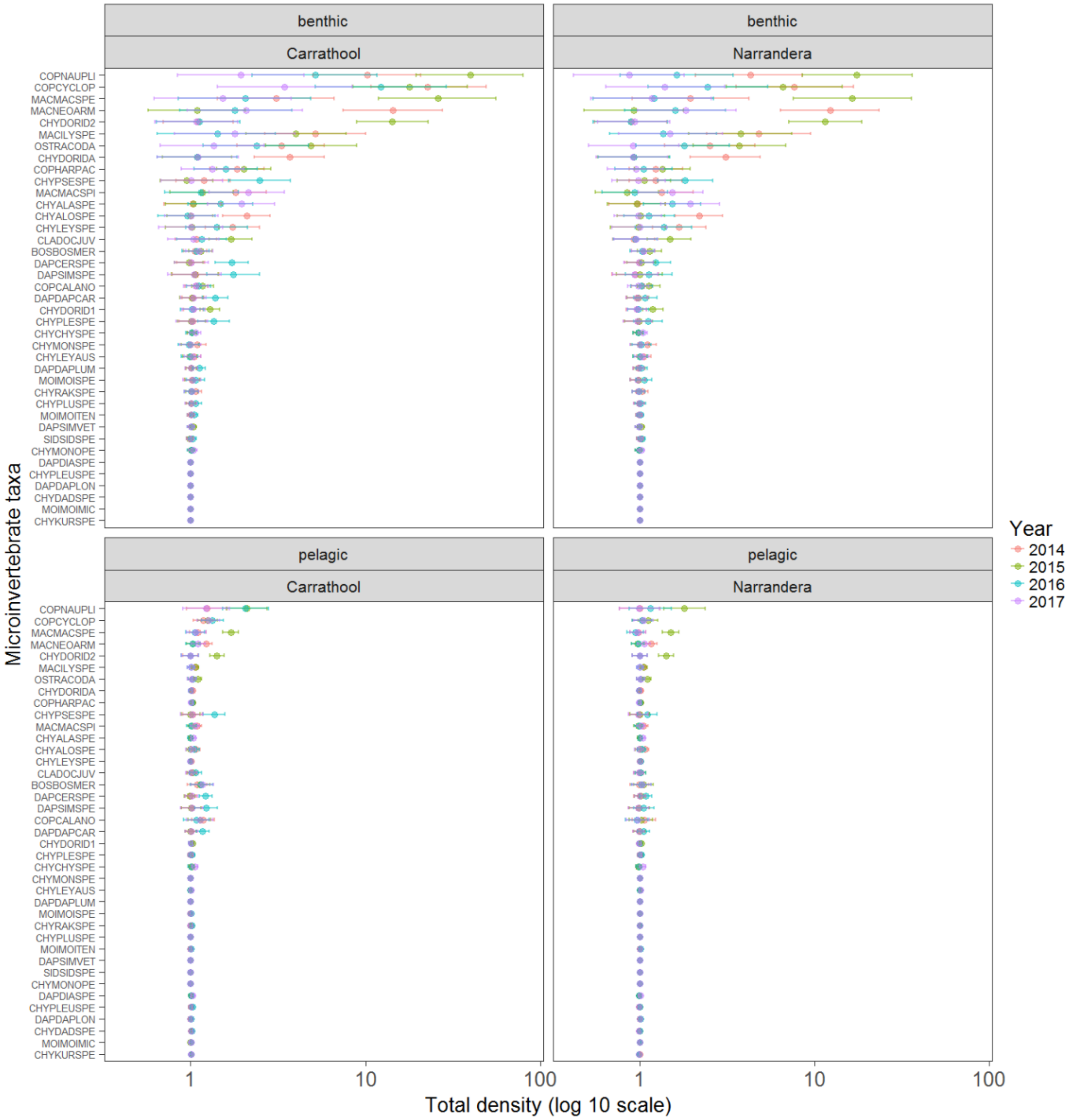

Figure 4-64 Model estimates of total microinvertebrate taxa density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic (upper row) and pelagic (lower row) habitats sampled in 2014-15, 2015-16, 2016-17 and 2017-18.

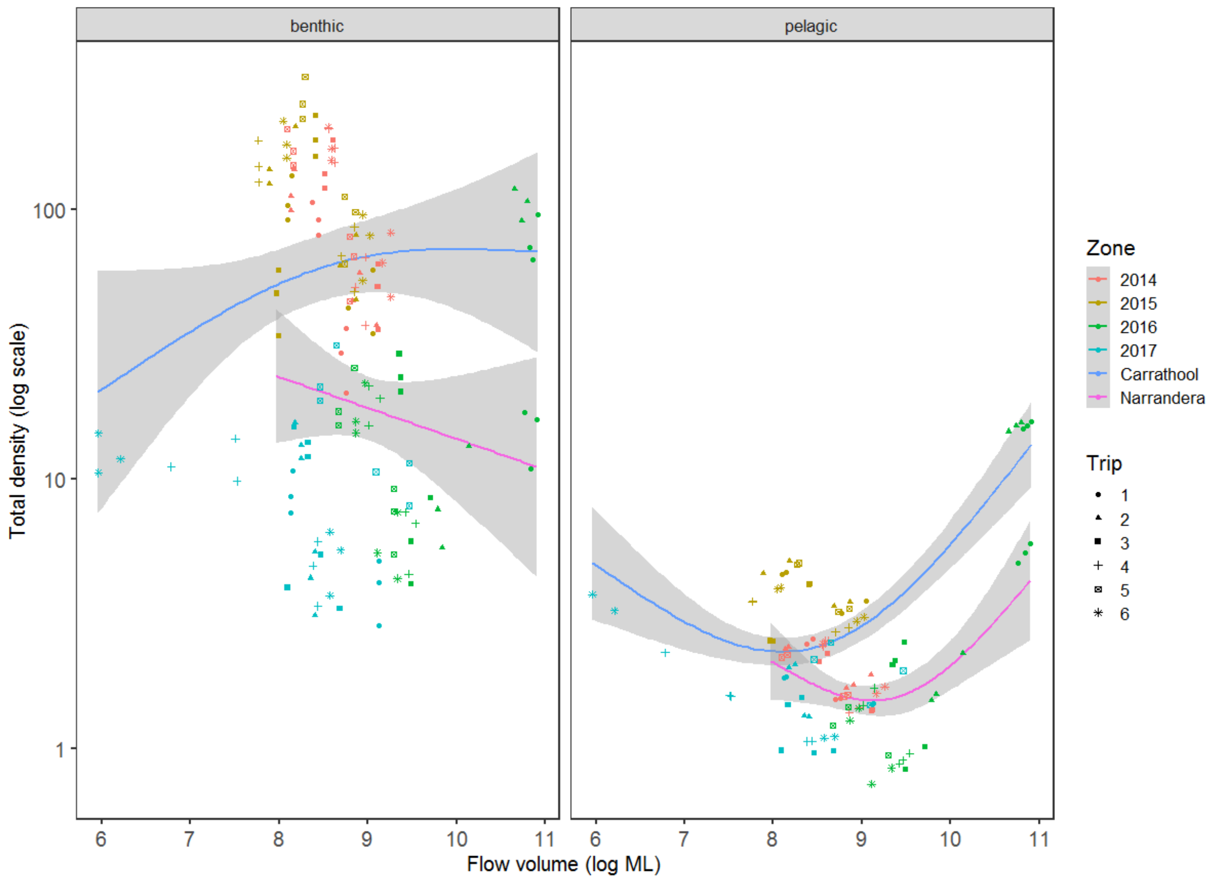

Figure 4-65 Model estimates of flow(ML/day) (log scale) versus total microinvertebrate density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic and pelagic habitats sampled in 2014-15, 2015-16, 2016-17 and 2017-18

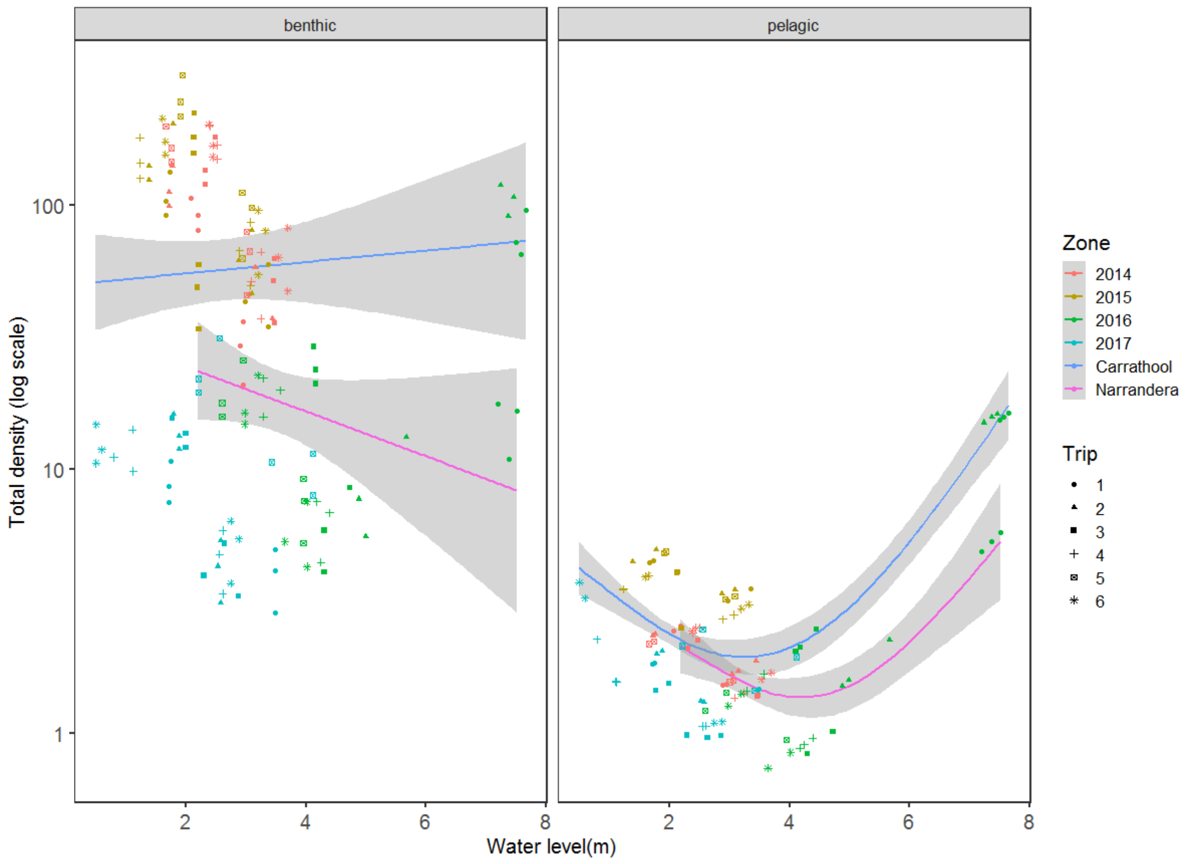

Figure 4-66 Model estimates of water level versus total microinvertebrate density (log scale) in three sites each from the Carrathool (left graphs) and Narrandera (right graphs) zones in both benthic and pelagic habitats sampled in 2014-15, 2015-16, 2016-17 and 2017-18

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-Murrumbidgee may have contributed to peaks in flow within the Murrumbidgee River in the Carrathool Zone and to a lesser extent in the Narrandera Zone. In 2017-18, flows in both zones during the sampling period were lower overall than in previous years, and the variation in flow between peaks and troughs was greater. Peaks in benthic microinvertebrate densities in the Carrathool Zone in the first three years of LTIM were recorded 7-10 days after river levels peaked as water levels were falling. 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 conditions in the Murrumbidgee River. Despite lower flows in 2017-18, benthic microinvertebrate densities remained low throughout the sampling period, increasing slightly in the last two trips in December 2017.

Overall, densities of pelagic microinvertebrates were two to three orders of magnitude lower than benthic densities throughout the four-year study period. This is likely due to the fast-flowing nature of the Murrumbidgee 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 Carrathool zone than Narrandera zone across the four years of monitoring (see Figure 4-60). River levels in the Narrandera zone are higher in the Narrandera than in the Carrathool zone, except for 2017-18 where variability was high in both zones (See Figure 4-60). 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, sometimes more variable river levels with pronounced peaks in microinvertebrate densities were recorded in 2 of the 4 monitoring years (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. It is not clear why this pattern was not observed in 2017-18, but perhaps the greater variability in flows disrupted formation of a productive benthic community. Furthermore, the low densities observed in 2017-18 coincide with low levels of carbon and nitrate and high levels of ammonia at these sites compared to other years. A significant rainfall event in early December 2017 triggered a recovery in nutrient levels in the river to those observed in earlier years and it is possible that the slight increase in microinvertebrate densities was a response to rising nutrients.

Although densities of microinvertebrates were lower when sampling returned to the high flowing river sites from trip 3 (see Figure 4-63), densities of benthic riverine microinvertebrate were the lowest observed in the project in 2017-18.

The relationships between flow (at the time of sampling) and microinvertebrate densities indicates a complex relationship that interacts with water quality. The relationship between these variables, including analysis of lags in flow, will be further investigated in the final report in 2019.

4.12 Larval fish

Prepared by Jason Thiem and Tom Davis (NSW DPI Fisheries) and Gilad Bino (UNSW)

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 *et al.* 2016). The larvae stage is the most critical and vulnerable part of a fish's life history, with larval fish survival highly dependent on hydrology, which influences habitat availability (Copp 1992), water temperature (Rolls *et al.* 2013), larval dispersal (Gilligan *et al.* 2003) and microinvertebrate abundance for first feed (King 2004). Commonwealth environmental water deliveries that target native fish responses, has the capacity to positively influence reproductive opportunities and enhance larval survival, thereby increasing recruitment to the wider population. Understanding the critical links between flows, fish spawning and larval fish survival can, therefore, assist with the management of environmental water to support and enhance native fish populations.

Use of a specifically designed hydrograph that targets groups of fish species, with similar reproductive strategies, could benefit a range of species in a given water year (Baumgartner *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 *et al.* 1998). Alternatively flow peaks may be used to trigger reproduction directly in flow-dependant species, such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (King *et al.* 2009; King *et al.* 2016). In this monitoring program we 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 to 2016-2017 (LTIM Years 1- 3 (Wassens *et al.* 2018) are included for comparison. Category 1 fish community sampling data collected from the Carrathool zone only in 2014-15 to 2016-17 (Wassens *et al.* 2015; Wassens *et al.* 2016; Wassens *et al.* 2018) and 2017-18 are also included to provide some information on the translation of spawning into young-of-year recruitment.

Relevant watering actions and objectives

In 2017-18 the Murrumbidgee River experienced no flows specifically targeting native fish in-channel spawning, however the hydrology in the sampling zone was heavily impacted by Commonwealth environmental water actions targeting the mid-Murrumbidgee wetlands in from late July into August 2017, as well as irrigation releases and downstream delivery targets. In this section we describe the range of fish responses observed during 2017-18, and contrast these with the responses from previous years of monitoring.

Evaluation Questions

This monitoring program is also required to address the following evaluation questions related to Commonwealth environmental watering actions:

- Did Commonwealth environmental water contribute to native fish populations?
- Did Commonwealth environmental water contribute to native fish reproduction?

Methods

Larval fish were collected using methods described by (Wassens *et al.* 2014a). Larval fish sampling was undertaken at six riverine sites, with three sites selected within each of two hydrological zones (

Figure 4-67). 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 *et al.* 2014), with the exception being that five additional larval drift nets were set at each site to adequately sample commonly encountered larvae such as Murray cod (*Maccullochella peelii*). Sampling was undertaken fortnightly from 9 October until 21 December 2017, 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 to 2016-17 (Wassens *et al.* 2015; Wassens, 2018; Wassens *et al.* 2016). Where possible, 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. The remaining samples collected from both light traps and drift nets were preserved in 90% ethanol for later laboratory identification using keys described in (Serafini *et al.* 2004).

A sub-sample of larvae hatched from live-picked eggs as well as preserved eggs, comprising both golden perch 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 Polymerase Chain Reaction (PCR) amplification. Genetic assignment of golden perch and silver perch was generally consistent with 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 *et al.* 2013; Wassens *et al.* 2014b).

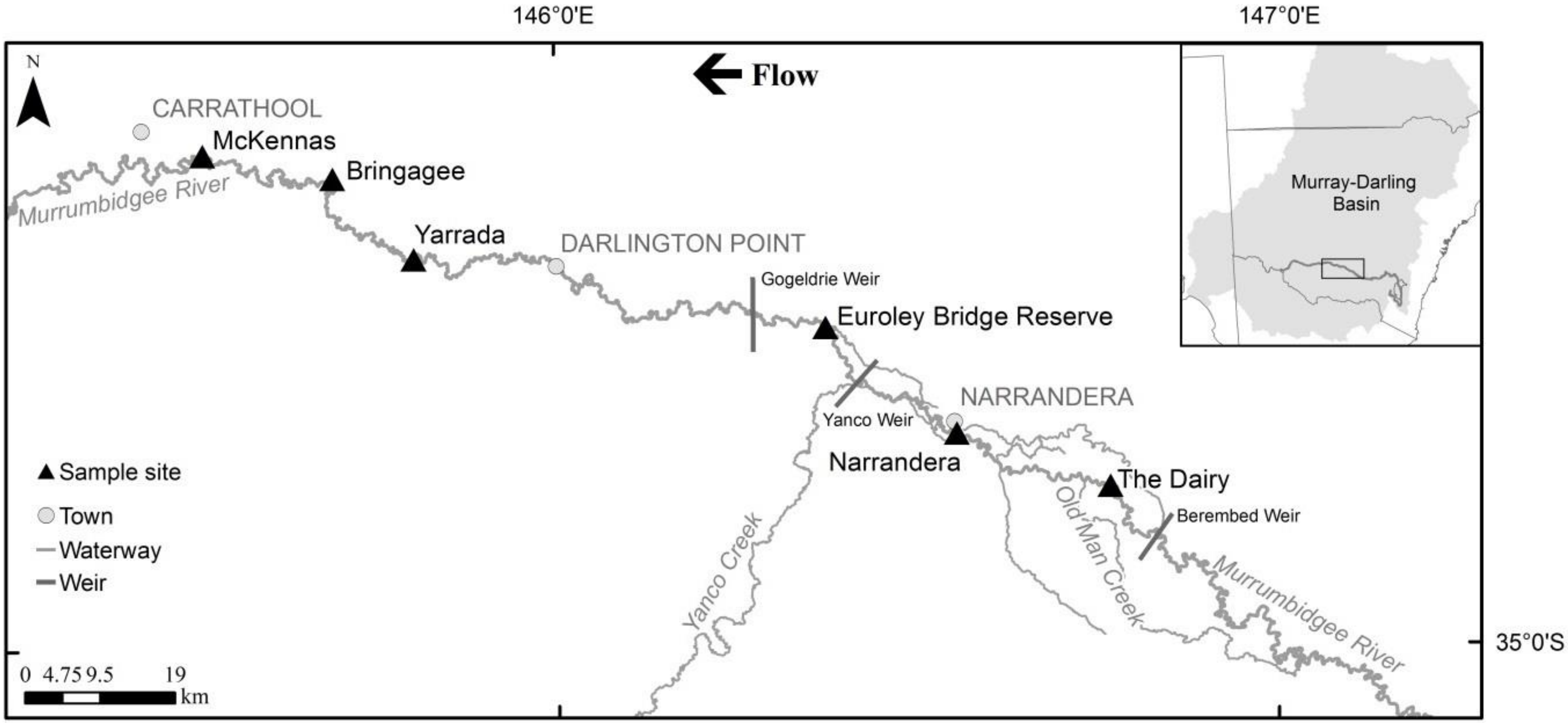

Figure 4-67 Locations of larval fish in-channel sampling sites on the Murrumbidgee River, encompassing Narrandera (The Dairy (DAI), Narrandera (NRD) and Euroley Bridge (EUB)) and Carrathool (Yarradda (YRR), Bringagee (BRI) and McKennas (MKR)) hydrological zones.

Data analysis

Data were standardised to a single value per species for each combination of site, sampling event and method (i.e. total catch for each species from a site was pooled by sampling method for each sampling event), with species data represented by 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 sampling effort was not consistent for these groups and numbers were too low to allow further analysis. Daily stream gauging data from Narrandera (NSW Office of Water gauge 410005) and Carrathool (gauge 410078) were 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, 2016-17 and 2017-18), data were analysed using a two-way fixed factor (with zone and year as factors) Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson *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 (for golden perch and silver perch) in response to abiotic factors (hydrology and temperature). Model-selection was undertaken by examining a suite of standardised hydrological variables (proportion of bankfull height, change in proportion of bankfull height) and climatic variables (water temperature, change in water temperature), over 1, 10- and 20-day periods, for each hydrological zone, during each of the sampling events within watering years. Silver and golden perch spawning was analysed 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 *et al.* 2014); R version 3.2.1, (R Development Core Team 2014). A model averaging method was then employed to generate a summary model from subset models based on the corrected Akaike information criterion (AICc; Grueber *et al.* (2011), using the dredge and model.avg functions in the MuMIn package (Barton 2015). A cutoff of 2AICc was used to generate the submodel set that was averaged in the summary model (Burnham *et al.* 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 *et al.* 2011).

Category 1 fish community data (as per Hale *et al.* (2014)), collected from the focal zone in March 2015 (2014-15), 2016 (2015-16) and 2017 (2016-17) and 2018 (2017-18) (encompassing Yarradda, Bringagee and McKennas larval sampling sites), were examined to determine whether spawning in any watering year translated into young-of-year recruitment. Specifically, length-frequency plots were used to indicate the presence of new recruits as a proportion of the sampled populations.

Results

A combined total of 4,614 eggs and larvae were collected during the 2017-18 sampling. sampling. Seven native fish species (Australian smelt *Retropinna semoni*, bony herring *Nematalosa erebi*, carp gudgeon *Hypseleotris* spp., flat-headed gudgeon *Philypnodon Philypnodon grandiceps*, golden perch, Murray cod, silver perch) and one alien species species (common carp *Cyprinus carpio*) were detected spawning in the Murrumbidgee Murrumbidgee River in 2017-18 (

Table 4-19). Additionally, early stage juvenile Murray River crayfish and freshwater yabby were captured in drift nets (

Table 4-19).

Golden perch eggs (n=1426), cod larvae (n=1063), flat-headed gudgeon larvae (n=998) and (n=998) and Australian smelt larvae (n=828) were captured in the highest abundances. abundances. Golden perch eggs, cod larvae and Australian smelt larvae were abundant in abundant in both zones, whereas flat-headed gudgeon larvae were only abundant in the in the Carrathool zone (

Table 4-19). Although both golden perch and silver perch eggs were captured, golden perch larvae (n=4) were only captured at one site within the Narrandera zone and no silver perch larvae were captured.

Catch per unit effort of larvae and eggs differed significantly among years ($Pseudo\text{-}F_{3,132}$ = 3.124, P<0.001) and between hydrological zones ($Pseudo\text{-}F_{1,132}$ = 6.379, P<0.001), with a significant interaction between year and zone ($Pseudo\text{-}F_{3,132}$ =1.805, P =0.041). Pair-wise comparisons indicated that there were significant differences in CPUE between 2017-18 and 2015-16 (t=1.972, P=0.003), as well as 2017-18 and 2014-15 (t=1.820, P=0.010), but not between 2017-18 and 2016-17 (t=1.028, P=0.382). Differences between zones were primarily driven by higher CPUE of Australian smelt, cod species and carp gudgeon in the Carrathool zone (Table 4-20).

Table 4-19 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	eggs			1			3
	larvae	277	38	120	148	109	136
Bony herring	larvae				9	11	16
Carp gudgeon	larvae				30	4	50
Cod species	larvae	77	65	138	69	215	499
Flat-headed gudgeon	larvae				11	558	429
Golden perch	eggs	172	1065	33	2	19	132
	larvae	4					
Silver perch	eggs	21	98	1	3	3	2
Unidentified	eggs		2				
Alien fish species							
Common carp							
Other							
Murray River crayfish	juvenile	1	4	1			
Freshwater yabby	juvenile				1	2	12

Table 4-20 Contributions of fish larvae CPUE (Catch per unit effort) to variability among years (2014-15, 2015-16, 2016-17 and 2017-18) 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 2014-15 and 2015-16, and between 2016-17 and 2017-18, are not included as there were no significant pair-wise differences in CPUE.

Comparison	Species	Contribution to difference (%)	Greatest CPUE
2014-15 and 2016-17	Australian smelt	28	2016-17
	cod species	27	2014-15
	common carp	13	2016-17
	carp gudgeon	11	2014-15
2014-15 and 2017-18	Australian smelt	26	2014-15
	cod species	24	2014-15
	common carp	11	2017-18
	silver perch	10	2014-15
	carp gudgeon	10	2014-15
2015-16 and 2016-17	Australian smelt	28	2016-17
	cod species	25	2015-16
	common carp	12	2016-17
	carp gudgeon	12	2015-16
	silver perch	11	2015-16
2015-16 and 2017-18	Australian smelt	26	-
	cod species	23	2015-16
	carp gudgeon	11	2015-16
	silver perch	11	2015-16
Carrathool-Narrandera	Australian smelt	26	Carrathool
	cod species	24	Carrathool
	carp gudgeon	14	Carrathool
	silver perch	10	Narrandera
	common carp	10	-

Distinct peaks were evident in the abundance of larvae and eggs captured, for most fish fish species, in 2017-18, with the seasonal timing of reproduction of native fish species within within the Murrumbidgee Selected Area varying amongst species (

,

). Australian smelt and carp gudgeon larvae were found to be less abundant in 2017-18 than in previous years, with larvae of Australian smelt captured over an extended period, from late October to early December, while captures of carp gudgeon peaked in late December as per previous years (

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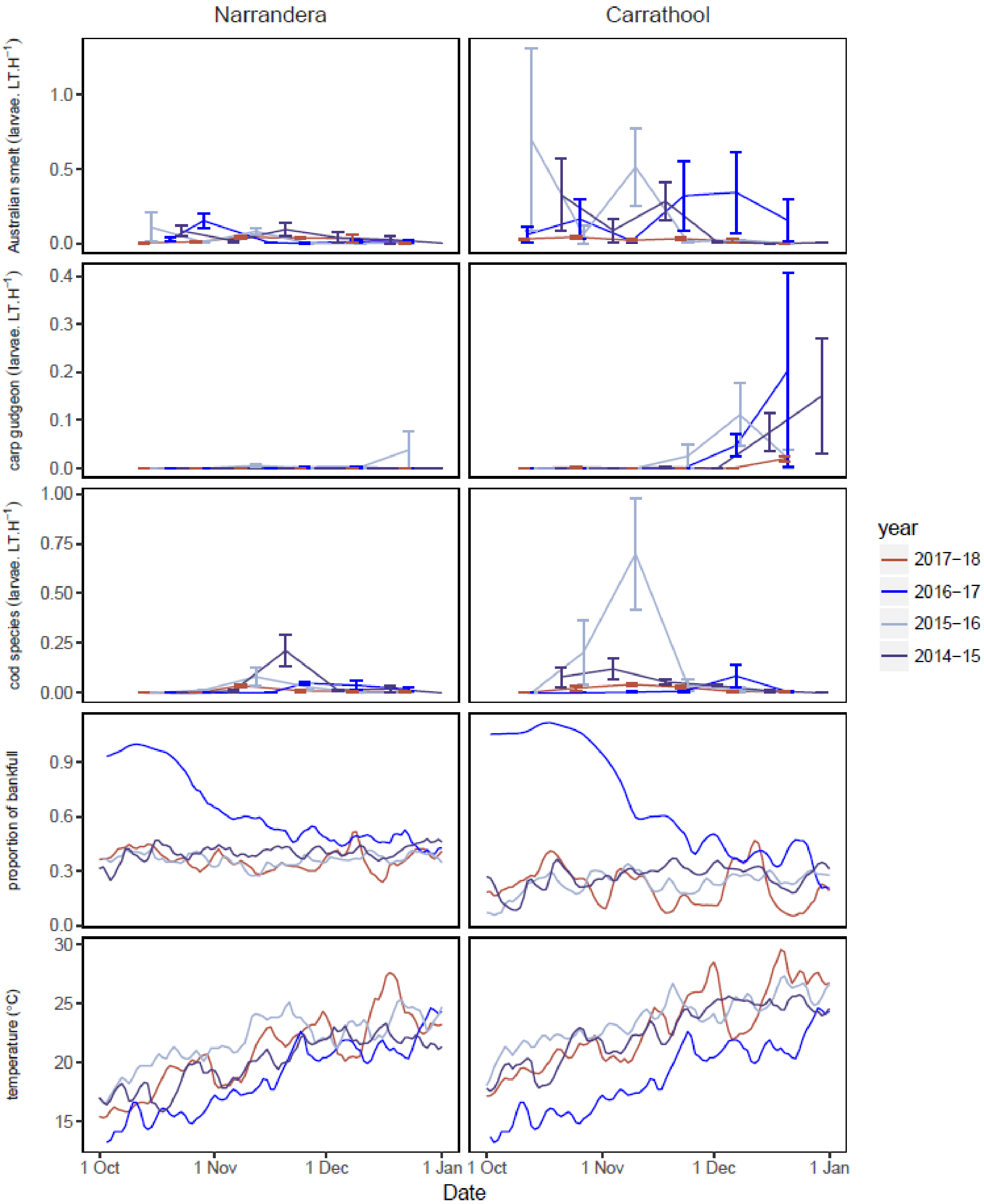

Figure 4-68 Larval light trap catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the

associated water level and water temperatures for these zones in 2014-15, 2015-16, 2016-17 and 2017-18. Only captures of the three most abundant species larvae are represented.

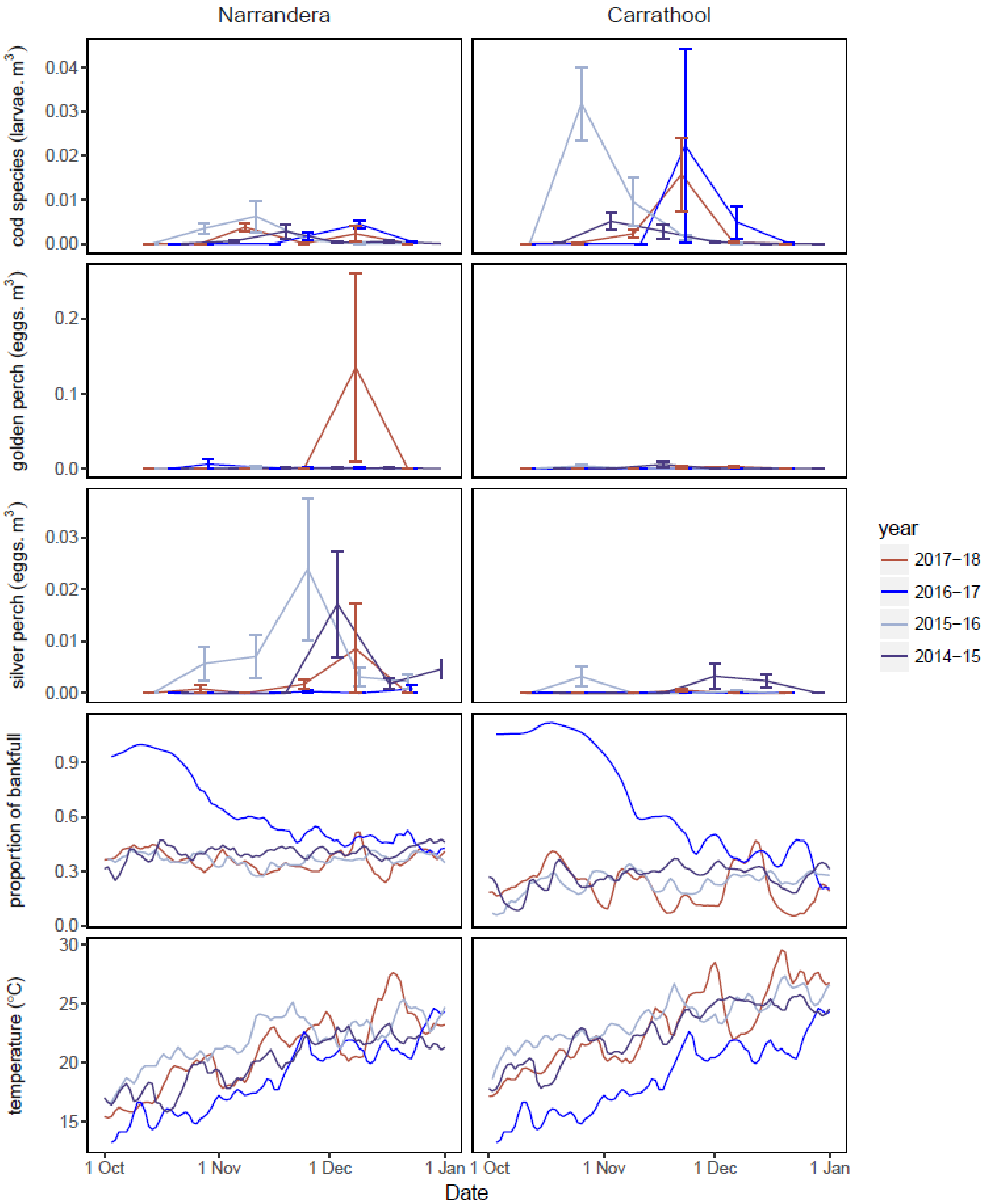

Figure 4-69 Larval drift net catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones in 2014-15, 2015-16, 2016-17 and 2017-18. The three most abundant species are represented, with captures of cod species represented by larvae, and golden and silver perch by eggs.

Captures of cod larvae peaked in early-mid December in 2017-18 in the Carrathool zone, similar to 2016-17, with the peak in larval capture occurring later than in 2014-15 and 2015-16 (Figure 4-68, Figure 4-69). In contrast, larval captures in the Narrandera zone were spread over a more extended period, from early November to early December 2017, and were lower than in the Carrathool zone (Figure 4-68, Figure 4-69). Golden perch eggs were collected from all sites in both zones in 2017-18, from late November to early December 2017 (Figure 4-70). A high abundance of golden perch eggs were captured at Narrandera in early December 2017, with four larvae captured at 'The Dairy' site in the same week. As the probability of golden perch spawning differed significantly between zones (Figure 4-70a, b), predictive relationships for golden perch spawning were established separately for each zone. Golden perch exhibited little evidence of a spawning association with water temperature or with absolute values of water level within the sampling periods, although there was a strong positive association with daily changes in water level (Figure 4-71a, b; Table 4-21).

Silver perch eggs were collected from all three sites in the Carrathool zone on one sampling trip in late November 2017 and from three sampling trips in the Narrandera zone in 2017-18 (Figure 4-69). Captures of silver perch eggs, in the Carrathool zone, were lower than in 2014-15 and 2015-16, and occurred later in the season than in these years. However, captures of silver perch eggs in 2017-18 were substantially higher than in 2016-17 (Figure 4-69).

Predictive relationships, for silver perch spawning, were established separately for each zone, due to the significant zone differences (Table 4-22, Figure 4-70). There was little association between silver perch spawning and either absolute values of water level, or changes in water level, although a strong positive association occurred between 10- and 20-day mean water temperatures and silver perch spawning (Table 4-22; Figure 4-71, Figure 4-72).

All fish captured as eggs and/or larvae in the Carrathool zone during 2017-18 were represented in the fish community sampling undertaken in March 2017. Three additional species were also captured in the fish community sampling; Murray-Darling rainbowfish, eastern gambusia and goldfish (Table 4-23). New recruits of the most abundant species were generally present in the river, with the exception of golden perch and eastern gambusia (

Figure 4-73 and

Figure 4-74), and the proportion of new recruits, for large bodied species, were generally lower than in previous years.

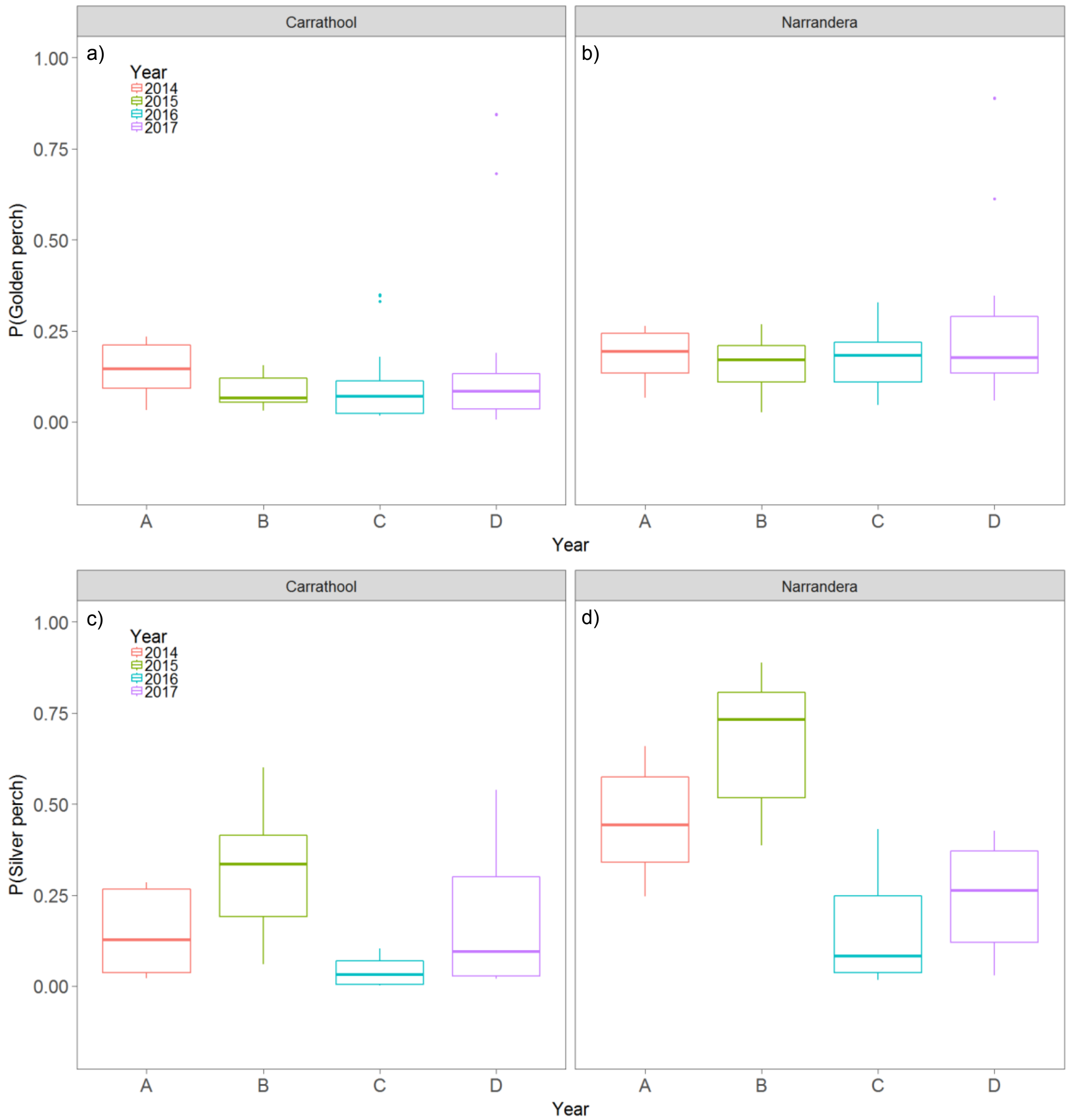

Figure 4-70. Variation in the spawning of golden perch (a and b) and silver perch (c and d) among sampling years and between hydrological zones in the Murrumbidgee River. A=2014-15, B=2015-16, C=2016-17, D=2017-18.

Table 4-21 Model-averaged parameter estimates explaining the probability of golden perch spawning in relation to water temperature (1, 10 and 20 day averages; xx.temp), changes in water temperature over the same time periods (d.xx.temp), water level as a proportion of bankfull height (1, 10, and 20 day averages; xx.proplev) and changes in proportion of bankfull height over the same time periods (d.xx.proplev).

Parameter	Estimate	Std. Error	Adjusted SE	z value	p
(Intercept)	-1.66	1.37	1.38	1.20	0.23
d.10.temp	-2.98	1.55	1.56	1.90	0.06
d.01.proplev	31.19	11.57	11.67	2.67	0.01
Zone. Narrandera	0.94	0.55	0.55	1.70	0.09
d.01.temp	-0.68	0.44	0.45	1.51	0.13
20.temp	-0.07	0.10	0.10	0.69	0.49
01.temp	-0.07	0.10	0.10	0.67	0.50
20.proplev	0.70	1.29	1.30	0.54	0.59
10.temp	-0.06	0.10	0.10	0.57	0.57
10.proplev	0.59	1.33	1.34	0.44	0.66

Table 4-22 Model-averaged parameter estimates explaining the probability of silver perch spawning in relation to water temperature (1, 10 and 20 day averages; xx.temp), changes in water temperature over the same time periods (d.xx.temp), water level as a proportion of bankfull height (1, 10, and 20 day averages; xx.proplev) and changes in proportion of bankfull height over the same time periods (d.xx.proplev).

Parameter	Estimate	Std. Error	Adjusted SE	z value	p
(Intercept)	-12.68	3.18	3.20	3.96	0.00
d.01.temp	1.00	0.50	0.50	2.01	0.04
10.temp	0.51	0.14	0.14	3.66	0.00
Year2015-16	0.15	0.61	0.61	0.25	0.80
Year2016-17	-0.92	0.79	0.80	1.15	0.25
Year2017-18	-1.48	0.74	0.74	2.00	0.05
Zone. Narrandera	1.85	0.55	0.55	3.35	0.00
d.01.proplev	13.05	10.22	10.31	1.27	0.21
d.20.temp	4.41	3.05	3.08	1.43	0.15
20.temp	0.52	0.14	0.14	3.62	0.00

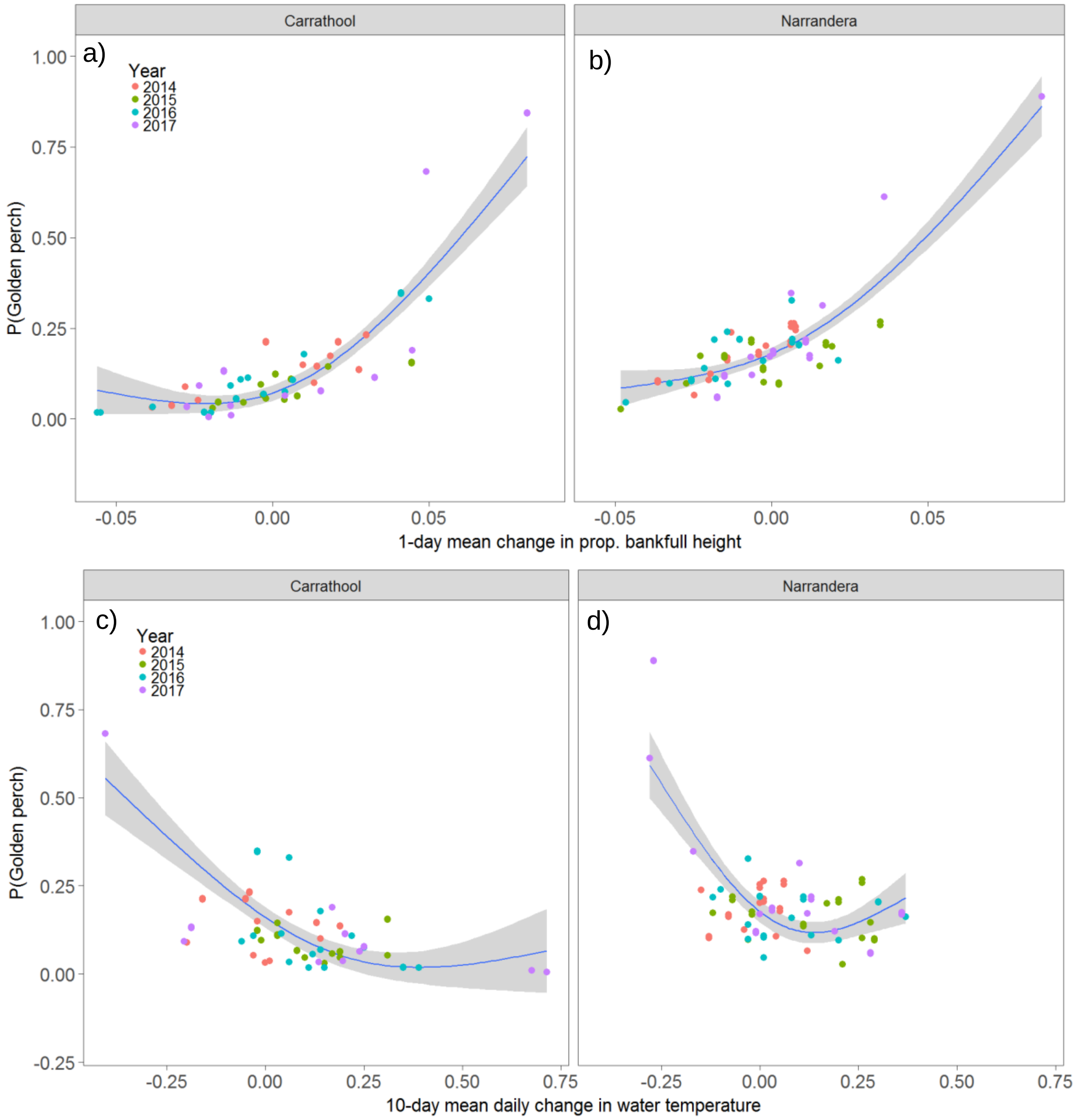

Figure 4-71 Predictive relationships generated from model-averaged parameter estimates (Table 4-21) describing the spawning probably (p; y-axis) for golden perch in relation to changes in bankfull height and changes in water temperature for the Narrandera and Carrathool reaches. Data were collected over four watering years (2014-15 to 2017-18) using larval drift nets in the Murrumbidgee River and probabilities are based on the presence/absence of drifting egg captures.

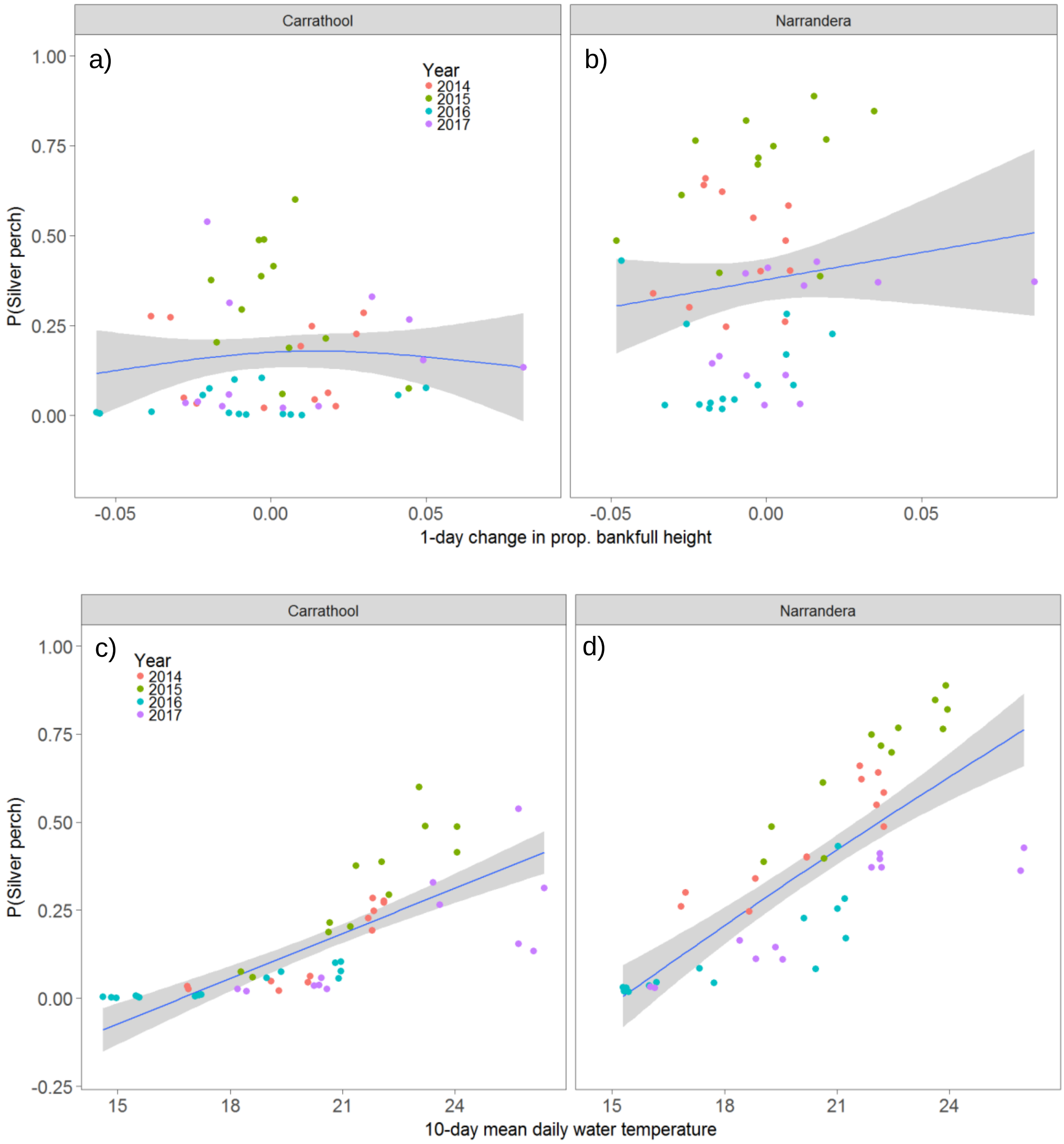

Figure 4-72 Predictive relationships generated from model-averaged parameter estimates (Table 4-22) describing the spawning probably (p; y-axis) for silver perch in relation to changes in bankfull height and water temperature for the Narrandera and Carrathool reaches. Data were collected over four watering years (2014-15 to 2017-18) using larval drift nets in the Murrumbidgee River and probabilities are based on the presence/absence of drifting egg captures.

Table 4-23 Summary of fish captured during Category 1 standardised sampling in 2014-15, 2015-16, 2016-17 and 2017-18 in the Murrumbidgee LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	**2014-15**				**2015-16**				**2016-17**				**2017-18**			
	BE	SFN	BT	**Total**	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**	41	3		**44**
bony herring	438	2		**440**	360			**360**	170	2		**172**	737			**737**
carp gudgeon	9	205	18	**232**	22	704	39	**765**	13	567	40	**620**	9	1173	5	**1187**
flatheaded gudgeon				**0**				**0**		2		**2**	3	22		**25**
golden perch	39			**39**	28			**28**	37			**37**	38			**38**
Murray cod	126	5		**131**	155			**155**	68	1		**69**	153	1		**154**
Murray-Darling rainbowfish	162	401		**563**	131	136		**267**	86	61		**147**	41	133		**174**
silver perch	1			**1**				**0**	3			**3**	2			**2**
un-specked hardyhead	4	2		**6**	4			**4**	1	2		**3**				
alien species																
common carp	112			**112**	63			**63**	313	1	6	**320**	162			**162**
eastern gambusia	8	735	1	**744**	11	493	1	**505**	6	371		**377**		440	2	**442**
goldfish	11			**11**	3			**3**	6			**6**	5	1		**6**
redfin perch				**0**				**0**	1			**1**				

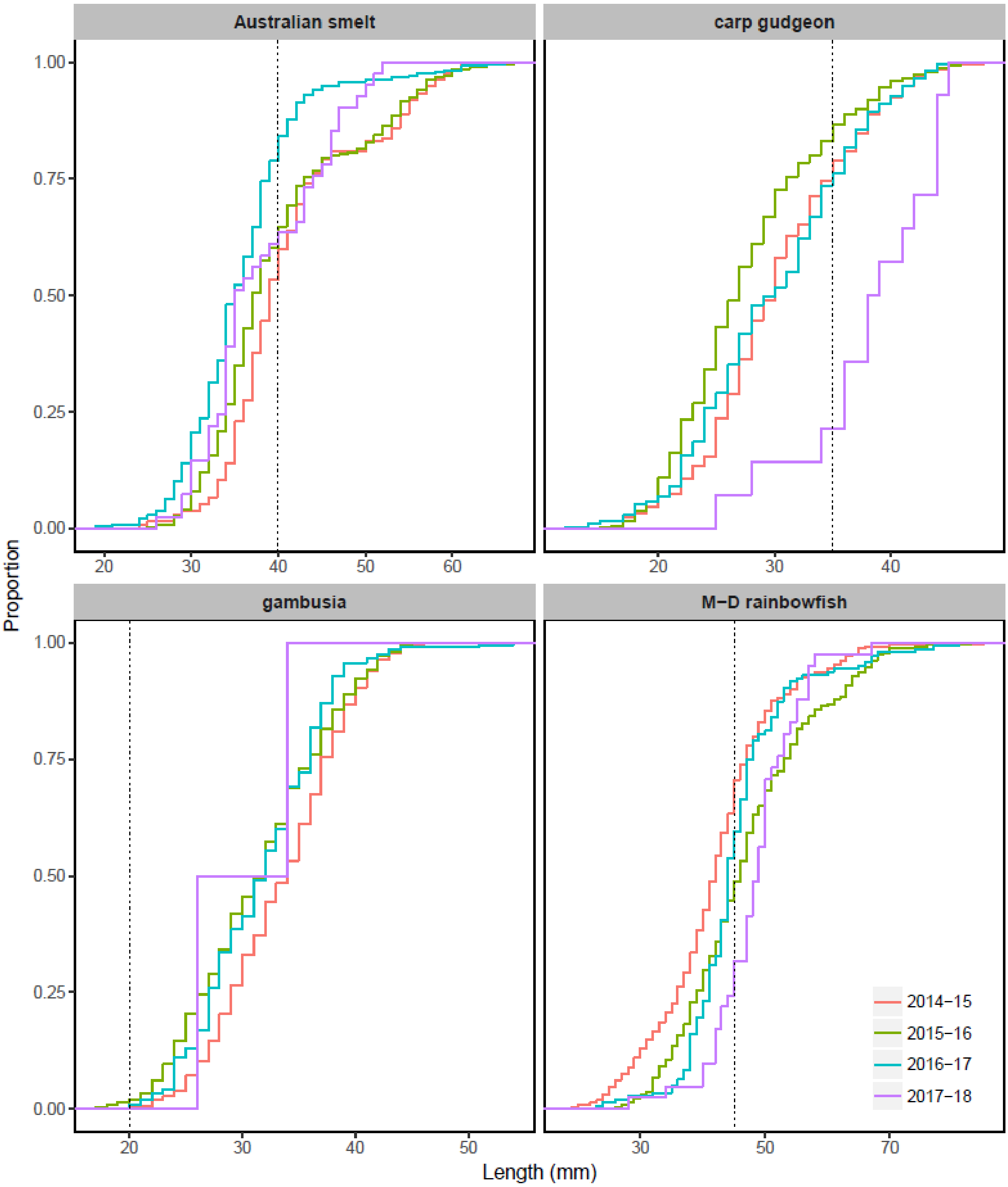

Figure 4-73 Length-frequency comparison among years (2014-15, 2015-16, 2016-17 and 2017-18) of the four most abundant small-bodied fish species captured during Category 1 fish community sampling in the Murrumbidgee River. The dashed line indicates approximate size at sexual maturity.

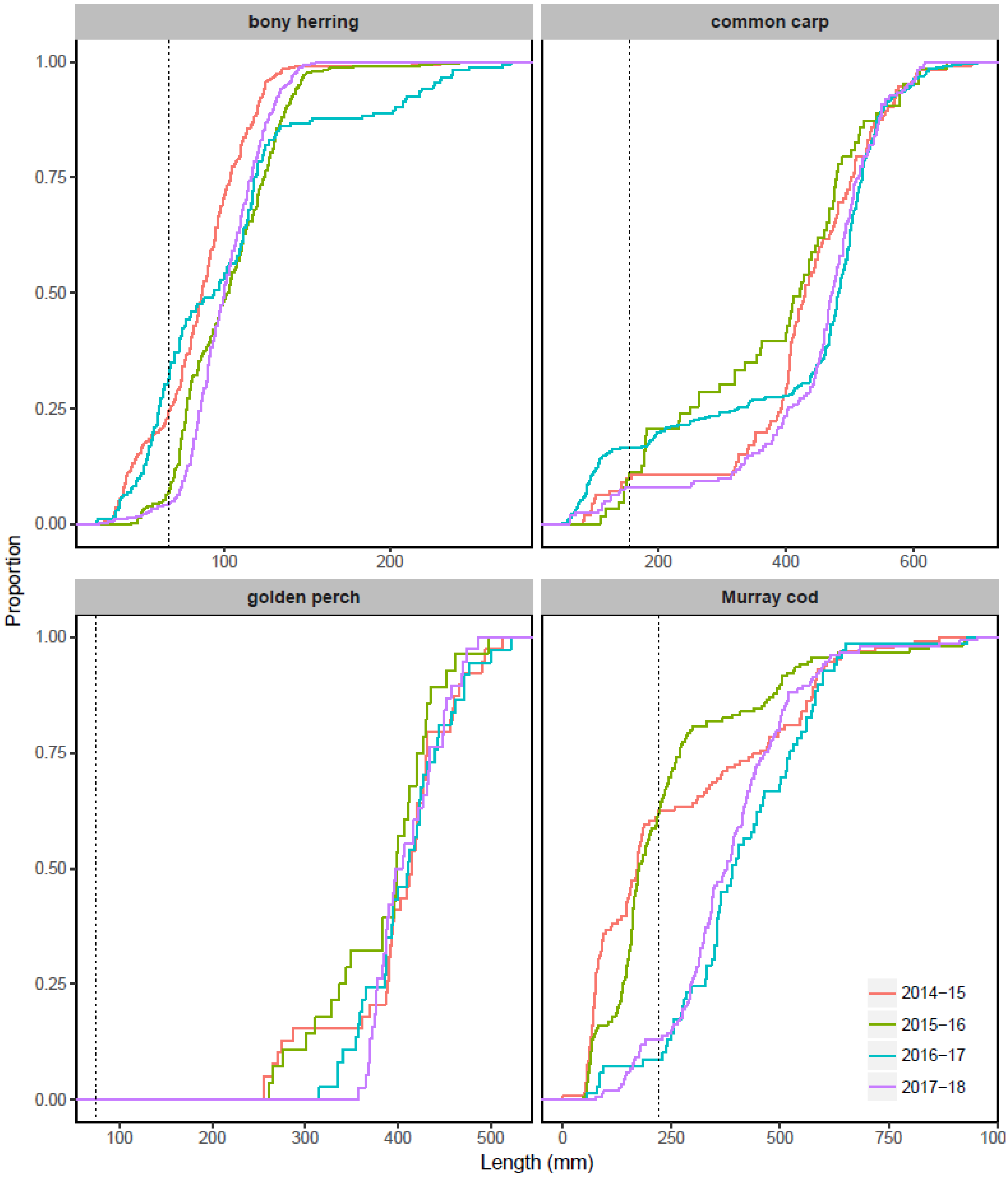

Figure 4-74 Length-frequency comparison among years (2014-15, 2015-16, 2016-17 and 2017-18) of the four most abundant medium-large bodied fish species captured during Category 1 fish community sampling in the Murrumbidgee River. The dashed line indicates approximate size at one-year of age.

Discussion

What did Commonwealth environmental water contribute to native fish reproduction?

Commonwealth environmental water was not specifically delivered to support native fish in-channel spawning outcomes in the focal zone during 2017-18, however Commonwealth environmental watering actions influenced the hydrology of the Murrumbidgee River through August and created connectivity between the river and low-lying floodplain wetlands in the mid-Murrumbidgee. Under the observed flows, in 2017-18, we identified spawning of seven native and one alien fish species across the two monitored hydrological zones. Predictive relationships were further developed for the flow-cued spawning species, golden perch and silver perch. Spawning of both golden perch and silver perch were detected, in both the Narrandera and Carrathool zone in 2017-18, however we did not detect any evidence of recruitment in the Carrathool zone, for either species, following these spawning events. Further, Murray cod young-of-year (YOY) proportional abundance was reduced compared with 2014-15 and 2015-16, being at very low levels, similar to those seen in 2016-17.

The mechanisms contributing to the poor YOY recruitment response exhibited by Murray cod, remain unknown. In addition, the spawning observed in golden perch and silver perch in both zones in the 2017-18, and in previous years, does not appear to be translating to recruitment for either of these species. For the fourth continuous year no juvenile golden perch were captured within the selected area during annual community sampling. Furthermore, while one juvenile silver perch was captured in 2014-15, none were captured from 2015-16 to 2017-18. Interesting large numbers of golden perch YOY have been recorded in floodplain wetlands and lakes following Commonwealth environmental watering actions in previous years. 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 *et al.* 2016). Stocking of silver perch does not occur within the Murrumbidgee River. We can therefore assume that the adult population, which is contributing to spawning in both species, is comprised of wild adults and that these adults were spawned and recruited locally, given the number of impassable barriers within the system. It follows, therefore, that successful recruitment of silver perch and golden perch must have occurred at some time in the past, within the Murrumbidgee River, in order to generate the adult populations of both these species. However, the drivers of successful recruitment, the key locations which support juveniles and the causes for the recent failures in recruitment, remain unknown and these data represent important knowledge gaps that require further investigation.

Prior to commencing the current monitoring program, it was predicted that in-channel freshes would promote spawning in golden perch and silver perch. However, model predictions, based on four years of monitoring in the Murrumbidgee Selected Area, indicate that spawning for silver perch was more strongly associated with temperatures than with flows, with little evidence to support predicted increased probability of spawning with increasing river levels. Results from the current study, therefore, are not entirely consistent with recent findings by King *et al.* (2016) who also identified that spawning of silver perch was positively influenced by temperatures, but, in contrast to the current study, found that spawning was associated with increasing flows in the Murray River.

In the case of golden perch, spawning was found to be most closely associated with daily changes in water levels, indicating that appropriate in-channel hydraulic conditions, to trigger spawning responses, are available within the mid-Murrumbidgee river channel throughout much of the watering season, due to the frequent fluctuations in flow that occur in the river as a result of irrigation releases. Spawning of golden perch in the current study, however, was not strongly associated with either flow levels or temperatures, a result inconsistent with recent findings by King *et al.* (2016) who identified that spawning, in the Murray river, was positively influenced by these factors.

It is worthwhile noting that spawning, of both silver perch and golden perch, has occurred independently of any discernible river level rise and at stable bankfull summer irrigation flows in the Murray River e.g. (Gilligan *et al.* 2003; King *et al.* 2005; Koster *et al.* 2014). Further, golden perch have been observed to exhibit substantial flexibility in both spawning and recruitment responses (Mallen-Cooper *et al.* 2003; Balcombe *et al.* 2006a; Balcombe *et al.* 2009). The evidence presented to date, therefore, 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. In the Murrumbidgee and mid-Murray rivers, for example, the broad definition of in-channel freshes is generally met all summer as a result of irrigation releases. Therefore, appropriate hydraulic conditions for spawning may be present for protracted periods, rather than during discrete events, such as delivered 'rises' from environmental water releases. In the absence of high irrigation flows, however, it may be that delivered 'rises' would be required to meet the threshold requirements for spawning. We anticipate that continued monitoring of flow-cued spawning responses will strengthen the predictive relationships, established here, for the Murrumbidgee Selected Area. This will, in turn, facilitate development of transferable information, for management of spawning of native freshwater species, applicable to other un-monitored sections of the Murrumbidgee River.

4.13 Evaluation of the 2017-18 Watering actions - Conclusions and management implications

Apart from the 2016-17 water year (June 30-July 1st) where very heavy rainfall resulted in significant unregulated floodplain inundation and high allocations for water users, the volumes of water used have been of similar magnitude during the 2014-15, 2015-16, and 2017-18 water years (Figure 4-75). However, the watering objective in 2017-18 was to support reconnections between the river and the low-lying wetlands in the mid-Murrumbidgee in conjunction with smaller volumes of water to maintain refuge habitats across the Lowbidgee floodplain. Overall, the general riverine and wetland outcomes were broadly similar to 2014-15 and 2015-16, with generally lower numbers in southern bell frog breeding and abundance, likely due to limited habitat availability in the Nimmie-Caira.

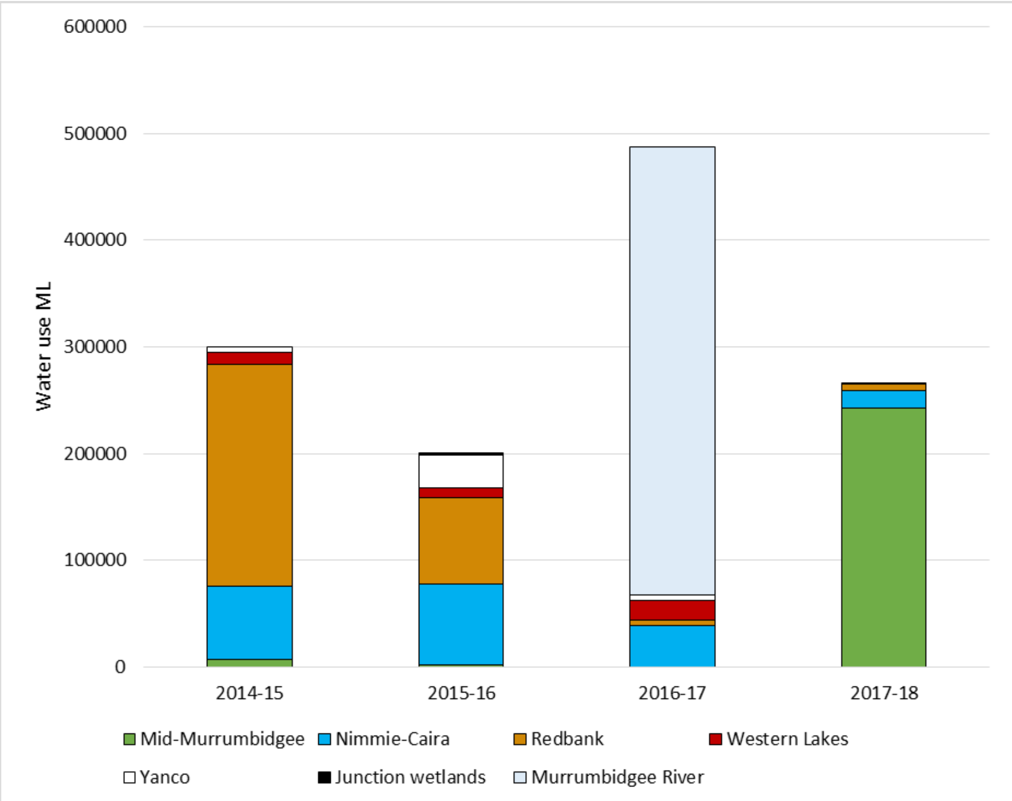

Figure 4-75 Summary of the principle NSW and Commonwealths environmental watering actions by volume in key management zone in the Murrumbidgee between 2014 and 2018. Note that there was also substantial unregulated floodplain inundation during 2016-17

Riverine outcomes

Water quality in the Murrumbidgee River remained stable and were similar to those reported during normal river operations in 2014-15 and 2015-16. As in 2014-15 and 2015-16 (and with the exception of 2016-17 when there was a large unregulated flow due to heavy rainfall), there was little evidence that flows influenced the concentration of dissolved organic carbon, nitrogen or phosphorus or the rates of primary or secondary productivity in the main river channel. The relationship between flow and primary and secondary productivity are complex and may be heavily influenced by hydrogeometry, especially the availability of warm, slow flowing habitat. While smaller creek and river systems in the Murray-Darling Basin may exhibit increases in the availability of nutrients and subsequent increases in primary and secondary productivity during environmental releases, the watering actions for the Murrumbidgee frequently occur in the context of an already full river during periods of low water temperatures and with limited availability of shallow, slow flowing habitat. Higher rates of metabolism and secondary productivity are often observed during periods of either very low flow (as is often the case in the Carrathool zone during summer) or very high flows which inundate substantial area of floodplain and wetland habitat (as was the case in 2016-17). There seems to be limited capacity for Commonwealth environmental water to have a significant influence on rates of stream metabolism and nutrient availability via manipulation of river water levels in the Murrumbidgee River within the existing capacity constrains under normal flow conditions. However, previous work has shown that managed return flows do have the capacity to influence riverine nutrient availability at more local scales, as was the case of the Redbank return flows undertaken in 2014-15 (Wolfenden *et al.* 2017).

Riverine fish continue to spawn in the Murrumbidgee River with spawning closely linked to water temperature. To date we have identified little evidence to suggest that managing for discrete flow peaks within the monitored reaches of the mid-Murrumbidgee influenced native fish spawning. This might be in part due to the already higher water flows occurring in the mid-Murrumbidgee, with irrigation deliveries creating conditions suitable for spawning throughout the breeding season. Despite slightly more variable flow levels in Carrathool reach in 2017-18 spawning by golden perch and silver perch was similar to previous years. However, we did not detect any evidence of recruitment by golden or silver perch in the Carrathool zone following these spawning events. Further, Murray cod young-of-year proportional abundance was considerably lower compared with 2014-15 and 2015-16, similar to those recorded in 2016-17. The mechanisms contributing to the poor young-of-year recruitment response exhibited by Murray cod, remain unknown.

Table 4-24 Summary of key riverine outcomes and implications for management of environmental water

Riverine monitoring indicator	Key riverine outcomes	Implications for future riverine water actions
Water quality	Nutrient, carbon and chlorophyll-a concentrations were consistent with previous years, Nutrient concentrations remain low in the river. We expected that the mid-Murrumbidgee wetland reconnection flow would mobilise carbon and nitrogen and increase concentrations in the river. The timing of the flow was outside of the set monitoring period.	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.
Stream metabolism	Rates of metabolism were low compared with other river systems monitored under the LTIM program.	Rates of metabolism have remained relatively stable over the past 4 years despite considerable variability in flow volume. 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. 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.
Microinvertebrates	Microinvertebrate densities exceeded levels needed to support larval fish during October in the Carrathool 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 monitoring indicator	Key riverine outcomes	Implications for future riverine water actions
Fish Spawning	Silver perch and golden perch spawning occurs at distinct water temperatures but is largely independent of river levels. Under the observed flows, in 2017-18, we identified spawning of seven native and one alien fish species across the two monitored hydrological zones. Spawning of both golden perch and silver perch were detected, in the Narrandera and Carrathool zone.	In some smaller river systems, spawning by golden and silver perch has been linked to the rate of river rise, however in larger rivers including the mid-Murrumbidgee and mid-Murray spawning often occurs under normal summer irrigation delivery flows. The evidence presented to date, therefore, 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. In the mid-Murrumbidgee, suitable conditions for spawning generally occur through summer as a result of irrigation releases. The mid-Murrumbidgee wetland reconnection (July-August) occurred prior to the spawning period for perch and cod and was therefore not expected to directly contribute to larval fish abundance
Fish Community	Fish communities were similar to previous years in terms of both species richness and species abundances. Key native species included Australian smelt, bony herring, carp gudgeon, flatheaded gudgeon, golden perch, Murray cod, silver perch and Murray-Darling rainbowfish. Size structure of large bodied native fish were typically skewed towards larger individuals with few young of year recorded	As in previous years there was limited evidence of recruitment (young-of-year fish). Although small numbers of young-of-year golden perch were recorded in floodplain wetlands and lakes through the Murrumbidgee

Wetland outcomes

A number of environmental watering actions targeting floodplain and wetland habitats were undertaken in 2017-18. Monitoring as part of this program was focused on evaluating outcomes in the mid-Murrumbidgee where four related actions were taken to support a reconnection of low-lying wetlands along the mid-Murrumbidgee floodplain. This included pumping actions and offsets to prime larger lagoons (Yarradda and Gooragool) prior to the reconnection flow, and the generation of a small (approximately 22000 ML per day at Wagga Wagga) managed peak in the Murrumbidgee River during August 2017.

While complete mapping of inundation during the flow was not possible, the reconnection flow was successful in raising water levels at the four monitored wetlands (Gooragool, Sunshower, Yarradda, and McKennas), although less water than expected entered McKennas lagoon due to some channel obstructions. Overall, the mid-Murrumbidgee reconnection achieved its primary objectives related to supporting habitat for wetland taxa and improving vegetation condition. Wetland water quality remained within the normal bounds for floodplain wetlands and the action contributed to high levels of primary (Chlorophyll a) and secondary (microinvertebrates) productivity. There were some positive responses by aquatic plant diversity and good breeding outcomes for frogs particularly at Sunshower and McKennas lagoons. Waterbirds, particularly dabbling ducks responded positively to the action and small number of waterbirds were observed nesting at Gooragool.

Results through the remaining monitoring sites in the Nimmie-Caira and Redbank systems which did not receive Commonwealth environmental water during the monitoring period (September-March) were mixed. NSW watering actions during June and July contributed to inundation across the Nimmie-Caira and supported refuge habitats for key vertebrates including the southern bell frog, native fish and turtles. However, there was limited breeding by southern bell frogs, lower diversity of waterbirds and slightly lower cover of aquatic plant species, compared to 2014-15 and 2015-16 where similar volumes of water were used. These outcomes are not unexpected given that large areas of floodplain remained dry throughout the monitoring period and highlights the critical role that Commonwealth environmental water plays in supporting floodplain plants and animals in the Murrumbidgee. Refuge watering actions undertaken in April 2018 are expected to support important floodplain populations through to 2018-19 and positive outcomes are expected in response to Commonwealth and NSW environmental watering actions being undertake in 2018-19.

Table 4-25 Summary of key wetland outcomes and implications for management of environmental water

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Hydrology	Commonwealth environmental water actions, combined with NSW environmental water, achieved inundation objectives in the mid-Murrumbidgee, the Nimmie-Caira and Redbank zones of the Murrumbidgee Selected Area. Inundation extent was confined to core wetlands and so whilst the area inundated was small, for some of these wetlands the proportional area of the wetland inundated was high (over 50%).	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.
Water quality	Carbon, nutrient and chlorophyll-a concentrations seen in 2017-18 typically fell within the expected range. Exceptions were McKennas which had high Carbon, nutrient and chlorophyll-a in January. Water quality in wetland sites that received Commonwealth environmental water improved due to increased water depth	Water quality in floodplain wetlands follows a natural cycle that involves initially low levels of conductivity, pH and turbidity when the wetland first fills, with water quality parameters increasing over time as the wetland dries out.
Microinvertebrates	As in previous years microinvertebrate densities were above 1000 individuals/litre across all monitoring sites and contained relatively high diversity of microcrustacea including copepods and cladocerans.	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.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Vegetation diversity	Species diversity and cover of key aquatic species was maintained at Gooragool and increased in wetlands in the mid-Murrumbidgee following environmental watering actions. The hydrological regimes created wetlands receiving environmental water was sufficient to allow resident native aquatic plant species to achieve seed set. The wetting and drying cycle for Gooragool and Yarradda have been maintained close to their long-term average since 2014. Inundation frequency at McKenna's and Sunshower is lower than the long-term average and this is reflected in lower diversity and cover of aquatic species at these wetlands.	The majority of monitored wetlands have received environmental water at least once over the past 4 years and vegetation communities remain in very good condition. This is consistent with predictions that restoring a more natural inundation frequency through environmental watering will support the establishment and persistence of water dependent species to a far greater extent than unregulated flows alone. River red gum encroachment remains a concern in the mid-Murrumbidgee wetlands, particularly at McKennas lagoon.
Fish	The diversity of native fish in floodplain wetlands was slightly lower in 2017-18. The 2017-18 data shows that small bodied native fish are spawning, growing and recruiting in wetland habitats.	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 and/or connection to the river channel. However, there are trade-offs in the maintenance of refuge habitat. In some instances, high densities of invasive fish species including carp can occur. Carp densities at Yarradda lagoon have increased over time in conjunction with declines in the abundance of frogs and tadpoles. As this wetland can be refilled via pumping which reduced carp entering the wetland, it is recommended that this system be allowed to dry to remove adult carp. Invasive fish densities in remaining permanent creek systems (e.g. Telephone Creek and Wagourah Lagoon) remain stable, and retaining water in these wetlands is recommended.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Frogs and Turtles	Six native 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. Breeding activity (calling) by all six frog species known to occur across the monitoring sites was recorded in response to environmental water. Environmental water actions in the mid-Murrumbidgee supported frog breeding with McKennas and Sunshower lagoons supporting inland banjo frog, spotted/barking marsh frog and Peron's tree frog tadpoles Small numbers of southern bell frog tadpoles were recorded at Yarradda, however fewer tadpoles of the southern bell frog were recorded overall in 2017-18	There were some declines overall in frog and tadpole abundances in 2017-18, this is partly due to limited availability of suitable habitats in the Lowbidgee floodplain during spring and summer, and also increasing densities of carp in Yarradda lagoon in the mid-Murrumbidgee. Breeding by important floodplain species, including the southern bell frog is triggered by rising wetland water levels during October and November. Watering action undertaken from late summer through to winter are important for providing refuge but are unlikely to provide suitable conditions for breeding. This was noted in the Lowbidgee floodplain during 2017-18 where few tadpoles were recorded. Evidence for successful maintenance of refuge habitats was also noted for turtles. Maintenance of an area of persistent water at Yarradda Lagoon, Telephone Creek and Wagourah Lagoon was associated with an increase in turtle species richness and would have contributed to the support of the less common broad-shelled turtle and Macquarie River turtle.
Waterbirds	Eight waterbird species were confirmed breeding during the LTIM and complementary OEH surveys in 2017-18. This was considerably lower than in the previous three survey years (32 species were detected in 2016-17, during a large flood year, and 16 and 17 species were recorded in 2014-15 and 2015-16, respectively) Few waterbirds were also observed in the LTIM wetland sites in the Redbank and Nimmie-Caira zones with most drying down between September 2017 and March 2018. Eight of the 12 survey sites were dry during the January and March 2018 surveys.	Sites that were inundated in the four years of surveys had a higher overall species richness and abundance when compared to wetlands that were dry for extended periods during this period. Breeding activity is linked to the area of floodplain inundation during spring and summer, in 2017-18 there was limited breeding habitat availably at key rookery sites in the Lowbidgee. As in 2014-15 and 2015-16 breeding activity can be increased by inundating larger areas of continuous floodplain habitat through spring and summer.

Management implications

The mid-Murrumbidgee floodplain presents significant management challengers. The natural inundation regime of these wetlands has been highly altered as a result of river regulation and given the modest volumes of environmental water available in the Murrumbidgee relative to the extent of riverine, floodplain and wetland assets there is limited capacity to restore the natural inundation regime via managed reconnections, which historically occurred annually for low lying wetlands with small freshes occurring multiple times in winter and spring. The current water management approach centres on managed pumping to key wetlands with occasional river to wetland reconnections (there have been two managed and two unregulated reconnections since 2010). In terms of ecological outcomes per megalitre of water used, pumping has very high ratio of positive outcomes relative to water volume, but these benefits are highly localised. Reconnection flows may have comparatively fewer immediate positive outcomes relative to the volumes of water used because large volumes of water are required to generate a flow peak in the river relative to the amount of floodplain and wetland habitat that is inundated. While immediate positive outcomes of reconnection flows within the main river channel might not be evident within the reporting period, time-lags in ecosystem recovery are expected (Lindenmayer *et al.* 2008). Reconnection flows might also support dispersal and recolonization of wetlands by native plant species, as noted by several previously unrecorded aquatic species being added to McKennas lagoon following reconnections in 2016-17 and 2017-18. The relationship between reconnections and fish is far more complex, while reconnection flows allow movement of native fish into and out of wetlands, they also allow for colonisation of wetlands by introduced species. The colonisation of Yarradda lagoon by carp during the unregulated flows in 2016-17 is likely to have contributed to substantial declines frog and tadpole abundances in 2017-18.

While it might usually be expected that a flow peak in the river would create benefits for in channel habitat, capacity constraints and water demand from other users mean that flows are restricted to winter months when low water temperatures limit primary and secondary productivity and fall outside spawning periods for native fish.

Prioritisation – balancing competing water use

Management and restoration of the landscapes are inevitability complex, comprising of both temporal and spatial interactions between a multitude of ecological components (Lindenmayer *et al.* 2008). In many such instances, ecosystem components have differing resource requirements that may temporally and spatially vary. Under such complexities, restoration management operating with limited resources and constraints such as volume and timing of environment water must balance competing restoration objectives. In certain situations, prioritization may be required to evaluate trade-offs between different conservation objectives (Possingham 2001). Preferably, prioritisation of competing objectives should be grounded on a good understanding of the ecosystem and its components to develop predicted outcomes of management actions and thereby prioritise conservation outcomes. This requires developing robust long-term objectives that consider the limitation of management and the complex and often lagged restoration of a degraded system such as the Murrumbidgee. We therefore recommend developing tools in support of the existing adaptable management framework (e.g., multicriteria decision analysis)(Linkov *et al.* 2005), that can deal with such complexities and uncertainties and will enable identifying achievable objectives that optimise restoration outcomes. This approach would align with the Basin Evaluation Plan's adaptive management framework used to identify the desired states and associated objectives hierarchy with clear cycles of monitoring and evaluation through adaptive governance.

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6. Appendices

Appendix 1 Wetland-dependent bird species recorded from 2014-18.

Functional Group	Common Name	Scientific Name	CAVS Code
Dabbling 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	black swan	*Cygnus atratus*	203
	dusky moorhen	*Gallinula tenebrosa*	56
	Eurasian coot	*Fulica atra*	59
	hardhead	*Aythya australis*	215
	musk duck	*Biziura lobata*	217
Fish-eating birds	Australasian bittern	*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	*Bubulcus ibis*	977
	eastern great egret	*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
Grazing ducks	Australian shelduck	*Tadorna tadornoides*	207
	Australian wood duck	*Chenonetta jubata*	202
	magpie goose	*Anseranas semipalmata*	199
	plumed whistling-duck	*Dendrocygna eytoni*	205
Large waders	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
Migratory shorebirds	Latham's snipe	*Gallinago hardwickii*	168
	sharp-tailed sandpiper	*Calidris acuminata*	163
Rails and shoreline gallinules	Australian spotted crake	*Porzana fluminea*	49
	Baillon's crake	*Porzana pusilla*	50
	black-tailed native-hen	*Tribonyx ventralis*	55
	buff-banded rail	*Gallirallus philippensis*	46
	purple swamphen	*Porphyrio porphyrio*	58
Raptor	Australian Hobby	*Falco longipennis*	235
	black-shouldered kite	*Elanus axillaris*	232
	black kite	*Milvus migrans*	229
	brown falcon	*Falco berigora*	239
	nankeen kestrel	*Falco cenchroides*	240
	swamp harrier	*Circus approximans*	219
	wedge-tailed eagle	*Aquila audax*	224
	whistling kite	*Haliastur sphenurus*	228
	white-bellied sea-eagle	*Haliaeetus leucogaster*	226
Reed-inhabiting passerines	Australian reed-warbler	*Acrocephalus australis*	524
	golden-headed cisticola	*Cisticola exilis*	525
	little grassbird	*Megalurus gramineus*	522
Resident 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

Functional groups as described by (Hale *et al.* 2014). Nomenclature follows (Christidis *et al.* 2008)

Appendix 2 Maximum count of each wetland-dependent bird species

Species recorded in each of the Murrumbidgee wetland zones during the LTIM 2014-18 surveys (*indicates breeding detected). MM - mid-Murrumbidgee, NC - Nimmie-Caira, RB - Redbank

	2014-15			2015-16			2016-17			2017-18		
Common Name^	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***
Australasian bittern Ee	0	0	0	0	2	0	0	1	0	0	0#	0
Australasian darter	0	8	2	31*	14	2	23*	26*	11*	21*	1	1
Australasian grebe	45	0	4	20	11	73	25	8	2	10	3	2
Australasian shoveler	6	0	0	0	0	8	4	5	2	0	0	0
Australian gull-billed tern	0	0	0	0	0	0	15	0	0	0	0	0
Australian hobby	0	0	0	0	0	0	0	0	1	0	1	0
Australian pelican	0	75	64	80	20	131	0	16	60	48	49	4
Australian reed-warbler	0	1	0	1	1	6	6	9	17	2	22	9
Australian shelduck	0	3	2	2	0	6	2	6	20	2	2	2
Australian spotted crake	0	0	0	0	0	0	0	6*	0	0	0	0
Australian white ibis	9	39	10	8	24	135	9	27	76	7	19	84
Australian wood duck	38	16	17	23	15	12	20	31	34	70	30	8
Baillon's crake	0	0	0	0	0	0	0	5	0	0	0	0
Black-fronted dotterel	0	7	0	0	0	0	3	2	2	4	2	0
Black-shouldered kite	0	0	0	0	0	0	0	0	0	0	22	0
Black-tailed native-hen	0	23	0	0	36	0	0	67	2	20	173	2
Black-winged stilt	0	4	0	0	2	101	7	42	119	0	0	0
Black kite	0	0	0	0	0	0	2	2	0	7	1	0
Black swan	0	8	57	31	6	245*	5*	13*	80*	0	4	1
Brown falcon	0	0	0	0	0	0	1	0	0	0	3	0
Buff-banded rail	0	0	0	0	0	0	0	0	1	0	0	0
Cattle egret	0	0	0	0	0	0	0	0	1	0	0	0
Chestnut teal	0	0	0	0	0	0	4	0	0	0	0	0
Dusky moorhen	0	0	0	0	0	3	2	1	5	7	4	0
Eastern great egret	2	17	4	2	32	38	45	18	80	3	5	3
Eurasian coot	65	4	204	575	8	710	26*	88*	353*	7	0	1
Glossy ibis	0	0	0	0	0	270	0	6	120	0	0	0
Golden-headed cisticola	0	0	0	0	0	1	2	0	0	1	2	0
Great cormorant	38	2	12	65	58	20	15*	36	85*	17*	17	5

	2014-15			2015-16			2016-17			2017-18		
Great crested grebe	0	0	0	0	0	0	4	0	155*	0	0	0
Grey teal	215	202*	312	383*	99	422	497*	112*	474*	445	255	58
Hardhead	32	0	15	110	0	10	3	12	7	0	12	0
Hoary-headed grebe	58	0	110	24	2	0	1	11	22	0	0	0
Intermediate egret	0	1	7	6	12	61	19	12	252	1	0	1
Latham's snipe J,R	0	0	0	0	0	0	0	0	0	1	0	0
Little black cormorant	5	100	21	7	75	12	88*	66	65*	93	28	1
Little egret	0	5	0	0	4	7	4	1	14	0	1	0
Little grassbird	0	0	0	0	1	1	2	4	5	1	5	2
Little pied cormorant	4	7	17	56*	50	24	21*	52*	127*	60	18	7
Masked lapwing	0	2	2	2	2	5	0	13	6	2	0	2
Musk duck	0	1	0	0	0	0	1	4*	0	0	2	0
Nankeen kestrel	0	0	0	1	0	2	0	0	1	1	4	1
Nankeen night-heron	0	0	5	0	0	0	16	94*	137*	22	0	1
Pacific black duck	48*	55	52	100*	50*	18*	170*	16*	65*	184*	96	10
Pied cormorant	0	0	0	6	1	0	2*	1	2	1	1	4
Pied heron	0	0	0	0	0	0	0	0	3	0	0	0
Pink-eared duck	259	18	125	16	0	0	75*	29*	2	3	0	0
Plumed whistling-duck	0	35	0	0	0	0	10	5	0	0	0	0
Purple swamphen	0	0	0	0	0	8	4	4	34	1	1	0
Red-capped plover	0	2	0	0	0	0	0	0	0	0	0	0
Red-kneed dotterel	0	0	0	0	0	0	0	1	21	0	2	0
Red-necked avocet	0	0	0	0	0	0	0	0	20	0	0	0
Royal spoonbill	0	7	0	22*	6	12	4	14	94	17	22	2
Sacred kingfisher	0	1	1	2	1	0	3	2	6	4	4	3
Sharp-tailed sandpiper J,C,R	0	2	0	0	0	0	0	0	0	0	0	0
Straw-necked ibis	4	200	40	0	28	15	80	1104*	75	0	0	2
Swamp harrier	0	0	0	1	3	0	0	2	1	0	2	0
Unidentified duck	0	0	0	0	0	0	10	7	157	25	0	0
Unidentified egret	0	0	0	0	2	0	1	0	188	3	2	0
Unidentified small grebe	0	0	0	0	0	0	0	0	0	2	0	0
Unidentified small migratory wader	0	0	0	1	0	0	0	0	0	0	0	0
Unidentified spoonbill	0	0	0	0	0	0	0	0	10	0	0	0
Unidentified tern	0	0	0	0	0	0	1	0	0	0	0	0
Wedge-tailed eagle	0	0	0	0	0	0	0	0	0	0	0	3
Whiskered tern	0	0	0	0	120	0	4	68	20	0	0	0
Whistling kite	2	0	4	1	4	3	4	4	2	5	4	2
White-bellied sea-eagle v	0	2	2	1	1	2	1	1	1	2	1	1

	2014-15			2015-16			2016-17			2017-18		
White-faced heron	3	19	2	7	4	4	6	6	42	16	6	4
White-necked heron	0	3	9	5	1	9	33	16	48	4	2	1
Yellow-billed spoonbill	2	25	4	51	16	210	420*	18	26*	25	5	4

^ Status: J = JAMBA, C = CAMBA, R = RoKAMBA (listed under international migratory bird agreements Australia has with Japan, China and Republic of 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, and complementary monitoring undertaken by NSW OEH (see Spencer *et al.* 2018).
# An Australasian bittern was detected calling during LTIM frog surveys of Eulimbah Swamp in September 2017.