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Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project Murrumbidgee River System Technical Report 2014-2019

Commonwealth Environmental Water Office Long-Term Intervention Monitoring project Murrumbidgee River system Selected Area technical report, 2014-19.

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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 (MDB). 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 2018-19. 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 (Table 2-1). 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 2-1 Summary of monitoring activities and location in the Murrumbidgee River (see Figure 2-1.

Site Name	Zone	ANAE classification	Stream metabolism	Nutrients & carbon	Microinvertebrates	Larval fish C1	Larval Fish SA	Fish community (C1)
Yarradda (River)	Carrathool	Permanent lowland streams	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								
Pevensey								
Rudds Point								X
Toganmain DS								X
Toganmain Homestead								X
Toganmain US								X
Wyreema								
The Dairy	Narrandera	Permanent lowland streams		X	X		X	
Euroley Bridge			X	X	X		X	
Narrandera				X	X		X	
Buckingbong Station								
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).

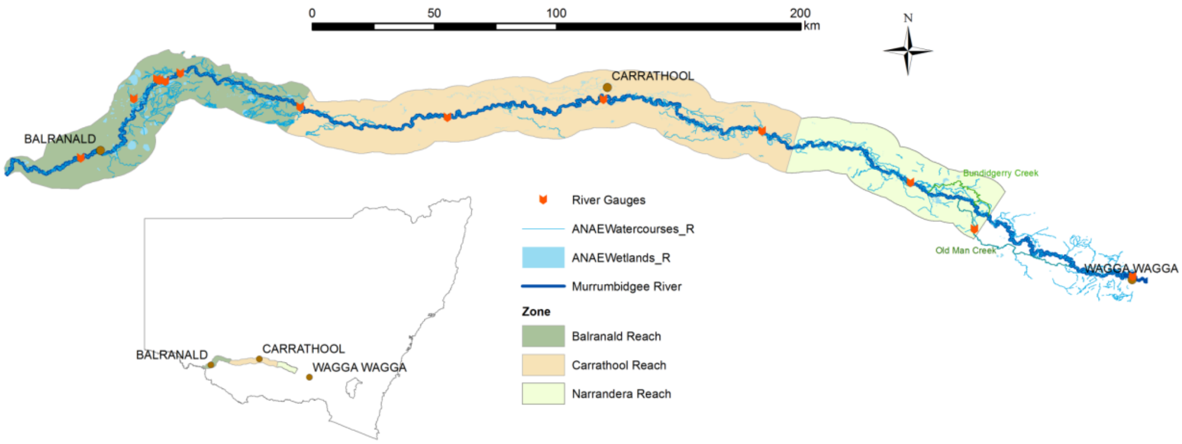


Figure 2-1 Distribution of riverine zones in the Murrumbidgee Selected Area.

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 (Table 2-2). 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 1-2 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	Microinvertebrates	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		Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Sunshower Lagoon	SUN		Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Yarradda Lagoon	YAR		Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Avalon Swamp	AVA	Nimmie-Caira	Temporary floodplain lakes	X	X	X	X	X	X
Eulimbah Swamp	EUL		Temporary floodplain wetland	X	X	X	X	X	X
Nap Nap Swamp	NAP		Intermittent River red gum floodplain swamp	X	X	X	X	X	X
Telephone Creek	TEL		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		Permanent floodplain tall emergent marshes	D	D	D	D	D	X
Two Bridges Swamp	TBR		Intermittent River red gum floodplain swamp	D	D	D	X	X	X
Waugorah Lagoon	WAG		Permanent floodplain wetland	X	X	X	X	X	X

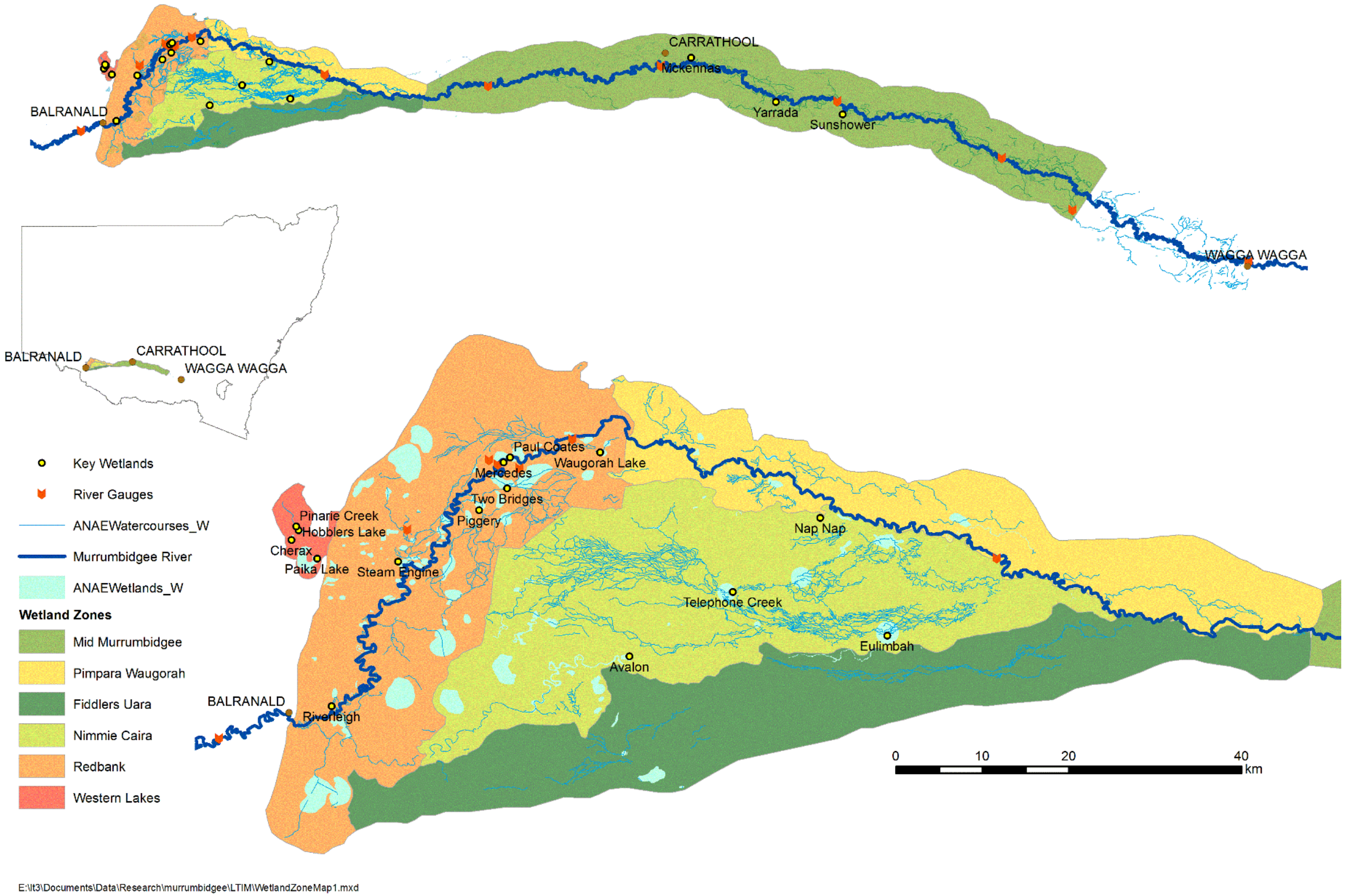


Figure 2-2 Distribution of wetland zones in the Murrumbidgee Selected Area and locations of key wetlands.

3. Environmental water delivered in 2018-19, context and expected outcomes

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 between 2010 and 2011, 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 2017-18 and 2018-19 water years, saw below average rainfall across much of the MDB. In the 2018-2019 water year, the Murrumbidgee catchment received less than 50% of the long-term average annual rainfall, however reasonable water levels in storage dams contributed to moderate water availability.

2018-19 Watering Actions

In 2018-19, the Commonwealth environmental water holder in partnership with NSW and the Murray-Darling Basin Authority delivered 61,795.9 ML of Commonwealth environmental water, 112,708 ML of NSW environmental water and 16,100 ML of The Living Murray (TLM) water allocation as part of 16 watering actions targeting rivers, wetlands, and creek line habitats in the Murrumbidgee Selected Area (Table -1). Water actions occurred throughout the year, starting in August 2018 in Yanga National Park: Yanga Lake top up and system watering action, which was delivered via the Yanga 1AS regulator and Gayini Nimmie-Caira until the end of January 2019. This action aimed to maintain water levels in Tala and Yanga Lake and increase inundation extents throughout the Yanga system of the Redbank zone. This action used the single largest volume of water (109,794 ML) (Figure 3-1).

The primary objectives of the Yanga Lake top up and systems watering actions (via 1AS and Gayini Nimmie-Caira) were to: (1) maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, and (2) avoid potential large scale fish mortality from drying or habitat degradation. Secondary objectives were to:

- Contribute to native riparian, wetland and floodplain vegetation diversity and condition;
- provide refuge habitat for waterbirds, native fish, frogs and turtles;
- improve hydrological connectivity and water quality;
- support native fish movement, spawning and recruitment; and
- improve native fish condition.

Further environmental water actions began in September 2018 and aimed to increase inundation extents in core wetlands to create aquatic refuge habitats in North Redbank, and to create refuge habitat from Nap Nap to Waugorah.

From December 2018 to the end of the water year, a series of flow deliveries targeted key refuge sites within the Nimmie-Caira zone. In response to hot climatic conditions and poor water quality during the summer months, a low dissolved oxygen (DO) management flow was delivered through the lower Murrumbidgee River and provided water quality outcomes. These watering actions raised the water levels of all four wetlands in the Redbank and Nimmie-Caira wetland systems. However, three wetlands remained dry in the mid-Murrumbidgee wetland system. In the mid-Murrumbidgee, Yarradda Lagoon was pumped with environmental water from mid-November 2018 to mid-January 2019 following a brief drying period.

Additional objectives from other watering actions (Table 3-2) in the Murrumbidgee were to:

- Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frog (e.g. Nap Nap to Waugorah and Nimmie-Caira refuge flows);
- maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18 (e.g. Yarradda Lagoon);
- contribute to improving water quality, with the aim of increasing dissolved oxygen to safe levels for native fish and other aquatic fauna and/or preventing dissolved oxygen levels dropping below critical concentrations.

Table 3-1 Summary of environmental water usage from Commonwealth and other environmental water sources in 2018-19. (Drawn from Watering Action Acquittal Report Murrumbidgee 2018-19 (Commonwealth of Australia 2019)). Shaded rows indicate flows associated with the LTIM Monitoring locations that are evaluated in this report.

Water Reference No.	Watering actions	Dates (start/end)	Commonwealth environmental water (ML)	Other environmental water (ML)	Total water use (ML)
10082-02	Yanga National Park: Yanga Lake top up and system watering (via 1AS) and then via South Caira channel)	Start: 20/08/2018 End: 31/01/2019	10,500	69,294 NSW EWA	109,794
10082-03	Yanga National Park: Yanga Lake top up (Nimmie-Caira)	Start: 19/092018 End: 25/01/2019	30,000		
NSW EWA	Nap Nap Swamp to Waugorah Lagoon	Start: 25/09/2018 End: 02/11/2018		11,419 NSW EWA	11,419
10082-04	Nimmie-Caira refuge flows	Start: 01/12/2018 End: 25/05/2019	1,505	2,795 NSW EWA	4,300
10082-05	Mainie Swamp (Junction Wetlands)	Start: 10/10/2018 End: 25/02/2019	2,000		2,000
10082-06	Toogimbie IPA Wetlands	Start: 15/10/2018 End: 22/03/2019	900		900
10082-07	Waldaira Lagoon (Junction Wetlands)	Start: 24/10/2018 End: 15/03/2019	1,700		1,700
10082-08	Yarradda Lagoon Pumping	Start: 16/11/2018 End: 18/01/2019	2,013.7		2,013.7
10082-09	Gooragool/Mantangry Lagoon Pumping	Start: 07/02/2019 End: 03/05/2019	82.7		82.7
10082-10	North Redbank refuge	Start: 18/09/2018 End: 18/01/2019	6,000	21,000 NSW EWA	27,000
10082-11	Campbell's Swamp, McCaughey's Lagoon and Turkey Flats Swamp (MIA)	Start: 08/11/2018 End: 18/02/2019	1,594		1,594
10068-12	Fivebough Swamp (MIA) Wetlands	Start: 25/10/2018 End: 22/03/2019	794		794
10068-13	Sandy Creek Wetlands	Start: 29/09/2018 End: 12/01/2019	400		400
10082-14	Tuckerbil Swamp (MIA)	Start: 24/10/2018 End: 09/05/2019	609.6		609.6
10082-15	Darlington Lagoon	Start: 20/12/2018 End: 1/05/2019	396.9		396.9
10082-16*	Lower Murrumbidgee River: Low Dissolved Oxygen management flow	Start: 30/01/2019 End: 09/04/2019	3,300	16,100 TLM 8,200 NSW EWA	27,600
		Total delivered	**61,795.9**	**128,808**	**190,603.9**

* Baldwin DS (2019) Weir stratification and hypoxic water management - Murrumbidgee River 2019. A report prepared for the Commonwealth Environmental Water Office and the Murray-Darling Basin Authority.

Table 3-1 Summary of Commonwealth environmental watering actions and objectives in 2018-19. Adapted from (Commonwealth of Australia 2019).

Water Reference No	Watering actions	Objectives (primary and secondary as at delivery)
10082-02 & 03	Yanga National Park: Yanga Lake top up and system watering (via 1AS & Gayini Nimmie-Caira)	Primary: • Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation. Secondary: • Contribute to native riparian, wetland and floodplain vegetation diversity and condition; • provide refuge habitat for waterbirds, native fish, frogs and turtles; • improve hydrological connectivity • improve water quality; • support native fish movement; spawning and recruitment; and • improve native fish condition
10082-04	Nimmie-Caira refuge flows	• Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frogs (EPBC Act).
10082-05	Mainie Swamp (Junction Wetlands)	• Prevent further decline in wetland vegetation communities; • provide refuge habitat for wetland dependent species.
10082-06	Toogimbie IPA	• Maintain wetland health and resilience; • maintain important refuge habitat for wetland dependant fauna, including for the Southern Bell frog, and; • maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18.
10082-07	Waldaira Lagoon (Junction Wetlands)	• Maintain wetland health and resilience; and • maintain refuge habitat for wetland dependant fauna, including for native frogs and waterbirds which have established populations since Commonwealth environmental water delivery began in 2015-16, natural flooding during winter-spring 2016 and the delivery of environmental water again in 2017-18.
10082-08	Yarradda Lagoon	• Maintain important refuge habitat for wetland dependant species, including for the Southern Bell frog; and • maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18.
10082-09	Gooragool/Mantangry Lagoon	• Maintain important refuge habitat for native fish, turtles and other water dependent biota. The Technical Advisory Group recommended that the majority of Gooragool Lagoon be allowed to dry in-line with then current climatic conditions, however, that the deepest part of the lagoon be maintained for refuge habitat for native fish and turtle populations that had established within the lagoon following repeat Commonwealth and NSW environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18
10082-10	North Redbank	• Maintain critical refuge habitats, and support their ecological resilience, and to support native wetland vegetation, fish, waterbirds, frogs and other aquatic vertebrate species.
10082-11	Campbells Swamp and McCaugheys Lagoon and Turkey Flats Swamp (Murrumbidgee Irrigation Area)	• Prevent further decline in wetland vegetation extent and condition Provide habitat to support survival and maintain condition of waterbirds and other native biota (including turtles, frogs and invertebrates).

10068-12	Fivebough Swamp (Ramsar site) (Murrumbidgee Irrigation Area)	• Maintain the condition and ecological character of Fivebough Swamp Ramsar sites to support survival and maintain condition of waterbirds and other water dependent species (including turtles, frogs and invertebrates).
10068-13	Sandy Creek	• Maintain refuge habitat and support their ecological resilience to support wetland vegetation, waterbirds, native, fish, frogs and other water dependent species.
10082-14	Tuckerbil Swamp (Ramsar site) (Murrumbidgee Irrigation Area)	• Maintain the condition and ecological character of Fivebough-Tuckerbil Swamp Ramsar sites to support survival and maintain condition of waterbirds and other water dependent species (including turtles, frogs and invertebrates). The dam habitat consists of an area of bog-rush known to provide Australasian Bitterns with important nesting and foraging habitat.
10082-15	Darlington Lagoon	• Improve the ecological character, condition and resilience of vegetation communities; and • support threatened species, such as superb parrots (EPBC Act vulnerable) and blue-billed and freckled ducks (NSW BC Act vulnerable).
10082- 16	Lower Murrumbidgee River: Low Dissolved Oxygen management flow	• Contribute to improving water quality, with the aim of increasing dissolve oxygen to safe levels for native fish and other aquatic fauna and/or preventing dissolved oxygen levels dropping below critical thresholds; • provision of in-channel refuge habitat; and support the movement of native fish and other aquatic animals into these refuge areas

4.Evaluation of Commonwealth Environmental Watering Actions

4.1 Wetland inundation

Prepared by Dr Rachael Thomas (DPIE) and Dr Jessica Heath (DPIE)

Introduction

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

Flooding is the most influential driver of floodplain wetland ecosystems (Bunn and Arthington 2002). Floodplain wetlands in semi-arid regions are governed by variable flow regimes, which produce diverse inundation patterns over large areas, and time scales (Thomas *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.* 1995). These inundation regime components are known to be important for vegetation (Roberts and Marsden 2011) and waterbird breeding (Kingsford and Auld 2005) in floodplain wetlands. For these reasons, targeted wetland inundation is the primary focus for environmental water managers.

Inundation extent is a useful indicator of environmental watering outcomes in floodplain wetlands where flooding from river flows varies widely in space and over time (Thomas *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.

Relevant watering actions and objectives

We report on the inundation outcomes within the surveyed wetlands of the Murrumbidgee Selected Area that were targeted for inundation by the Commonwealth and NSW environmental water actions during 2018-2019 (

and Figure 4-1b). Water actions occurred throughout the year, starting in August 2018 with the Yanga National Park water actions that were delivered via the Yanga 1AS regulator and via the Nimmie-Caira until the end of January 2019. These actions aimed to maintain water levels in Yanga Lake and increase inundation extents throughout the Yanga system of the Redbank zone (

and Figure 4-1b). Further environmental water actions began in September 2018 and aimed to increase inundation extents in core wetlands to maintain aquatic refuge habitats in North Redbank and to maintain refuge habitat from Nap Nap to Waugorah. From December 2018 to the end of the water year, a series of flow deliveries targeted key refuge sites within the Nimmie-Caira zone. In response to hot climatic conditions and poor water quality during the summer months, a Low DO management flow was delivered through the lower Murrumbidgee River and provided water quality outcomes. In the mid-Murrumbidgee, Yarradda Lagoon was pumped with environmental water from mid-November 2018 to mid-January 2019 (

and Figure 4-1).

Table 4-1 Summary of 2018-2019 Commonwealth and NSW environmental water actions with objectives providing inundation in the surveyed wetlands of the Murrumbidgee Selected Area.

Water Action Reference No.	Target Asset	Water Delivery Timing	
10082-02 & 10082-03	Yanga National Park: Yanga Lake top up and system watering (via 1AS and then via South Caira channel)	Start: End:	20/08/2018 31/01/2019
NSW EWA	Nap Nap Swamp to Waugorah Lagoon	Start: End:	25/09/2018 02/11/2018
10082-04	Nimmie-Caira refuge flows	Start: End:	01/12/2018 30/06/2019
10082-08	Yarradda Lagoon pumping	Start: End:	16/11/2018 18/01/2019
10082-09	Mantangry Lagoon pumping	Start: End:	07/02/2019 03/05/2019
10082-16	Lower Murrumbidgee River: Low Dissolved Oxygen management flow	Start: End:	30/01/2019 09/04/2019

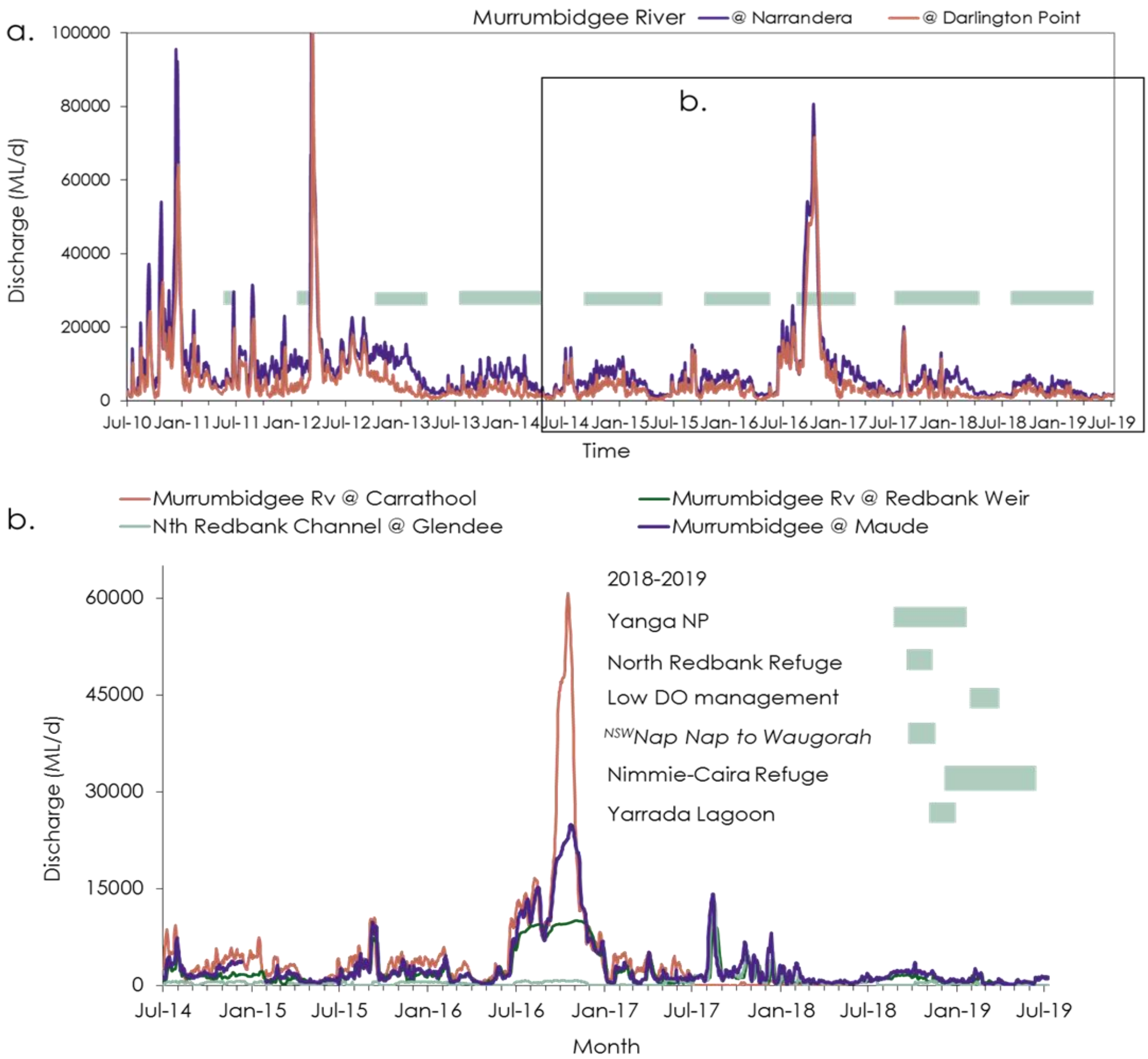


Figure 4-1a. Mean daily discharge in the Murrumbidgee River at Narrandera and Darlington Point between 1 July 2010 to 30 June 2019. The 2012 discharge peaked at 200,000 ML/d. Green horizontal bars show Commonwealth and NSW environmental water action timing for water years since 2011-12 to 2018-2019; and, b. Mean daily discharge in the Murrumbidgee River between July 2014 and June 2019 at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glendee in relation to the timing of environmental water delivery water actions (green horizontal bars) during survey period (1 July 2018 to 30 June 2019). Data downloaded from the NSW Water Info website.

Evaluation Questions

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

Methods

Inundation mapping

Using methods developed by Thomas *et al.* (2015), we mapped floodplain wetland inundation across sections of the Murrumbidgee Selected Area. We used images from the Sentinel-2 satellite, a multispectral sensor like Landsat but with increased resolution (spatial: 10 m x 10 m pixel; temporal: 5-day revisit; spectral: 13 bands). Images were automatically downloaded by NSW DPIE from the Copernicus Sentinel Open Access Hub (https://scihub.copernicus.eu/dhus/#/home) as orthorectified images. NSW DPIE processed these images to standardised surface reflectance (Flood *et al.* 2013). We used as many available image observations as possible from July 2018 to June 2019.

From each satellite image observation, NSW DPIE 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, 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.

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 (Hall *et al.* 2019) (excluding Gooragool, Mantangary and Darlington Lagoons) we estimated the percentage area inundated and plotted them over time.

We also provide an overview of the total area of Lowbidgee floodplain inundated during the 2014-2015 to 2018-2019 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

Lowbidgee Floodplain - Annual Inundation Outcome

A total of 25,655 ha of the Lowbidgee floodplain were inundated during 2018-2019, 26% more extensive than the previous water year (Figure 4-2). Most of the Lowbidgee inundation extent was distributed in the zones of Redbank (64% of the total inundated area) and Nimmie-Caira (21% of the total inundated area) covering 16,434 ha and 5,500 ha respectively (Figure 4-2 and Figure 4-3) as a result of environmental flow deliveries. Inundation in the Redbank zone was 82% more extensive than the previous year whilst inundation in the Nimmie-Caira was almost 20% more extensive than the previous year, which included the large areas of Yanga Lake (~1400 ha) and Tala Lake (~660 ha) inundated from a dry state by flows in previous years (Figure 4-2).

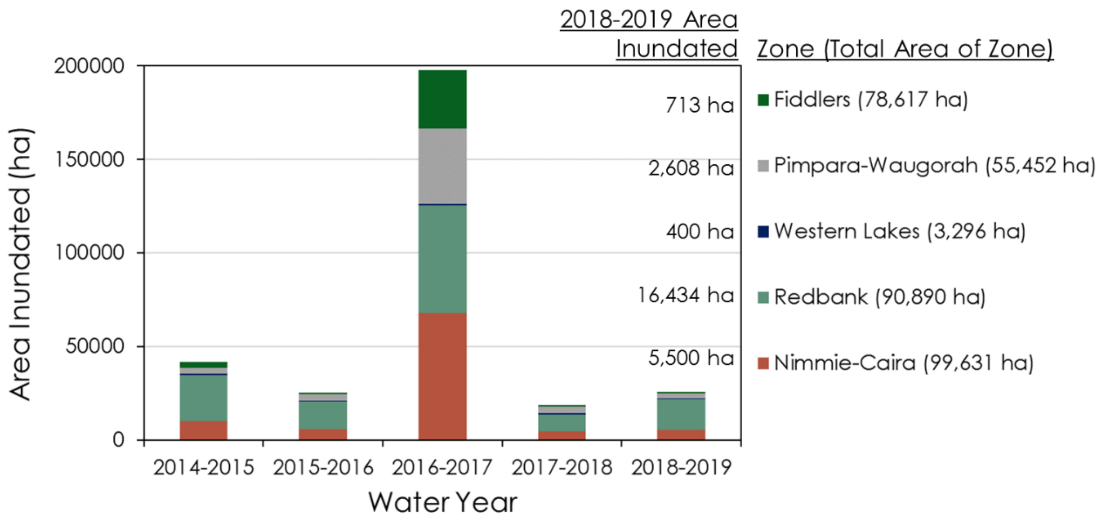


Figure 4-2 Annual cumulative total area (ha) of the floodplain inundated for the Lowbidgee floodplain and wetland zones for the water years from 2014-2015 to 2018-2019.

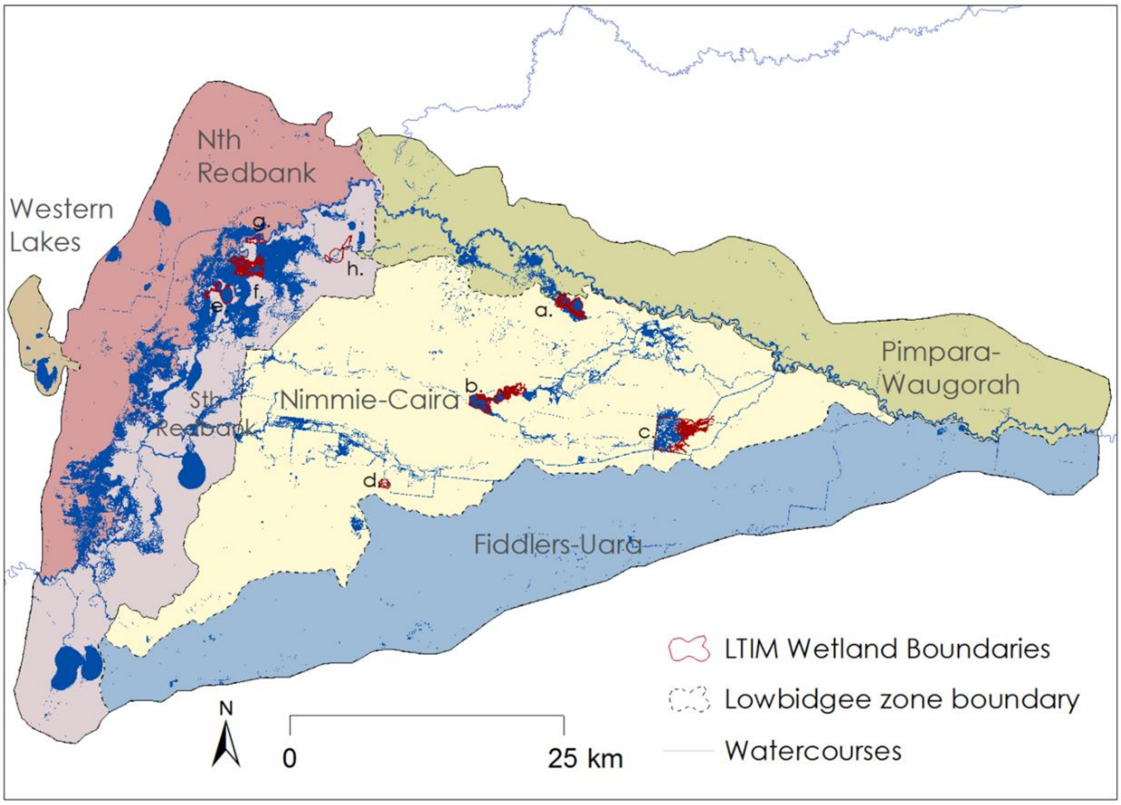


Figure 4-3 Distribution of the cumulative inundated area total across the Lowbidgee floodplain during the July 2018 and June 2019 period based on inundation maps classified from Sentinel-2 satellite images. LTIM surveyed wetlands: a. Nap Nap Swamp, b. Telephone Creek, c. Eulimbah Swamp, d. Avalon, e. Piggery Lake, f. Two Bridges Swamp, g. Mercedes Swamp (boundary includes Pocock's Swamp) and h. Waugorah Lagoon.

Inundation extent plateaued to 4,870 ha during July and August 2018 prior to the start of environmental flow deliveries (20 Aug 2018) (Figure 4-4) with the majority of water in the landscape confined to open water lakes, although there was a small NSW pre-water into Nap Nap Swamp in July 2018 (Figure 4-5). A maximum inundated area of 17,253 ha occurred in late spring (Nov 2018) with the most extensive inundation occurring in the Redbank zone as a result of flooding in South Redbank (Yanga) and North Redbank (Figure 4-4). Flood extent also peaked in the Nimmie-Caira zone and Waugorah Creek (Pimpara-Waugorah zone) during late spring (November) 2018. Over the summer months, there was general pattern of inundation contraction in all zones, except for different locations which were newly inundated from a dry state in February 2019 (Figure 4-4).

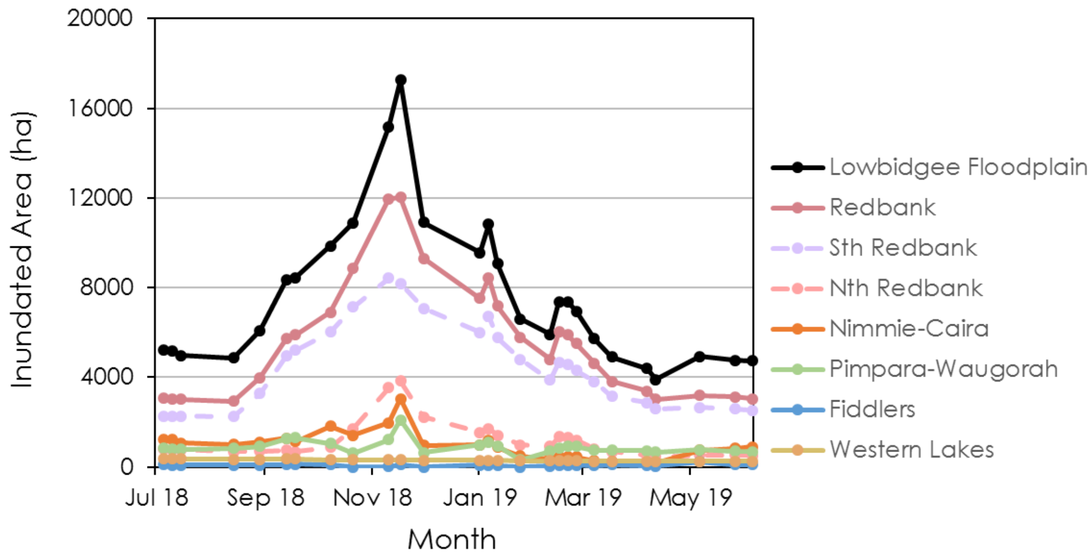


Figure 4-4 Inundated areas over time during 2018-2019 for the Lowbidgee zones including the Redbank zone sub-regions (south and north).

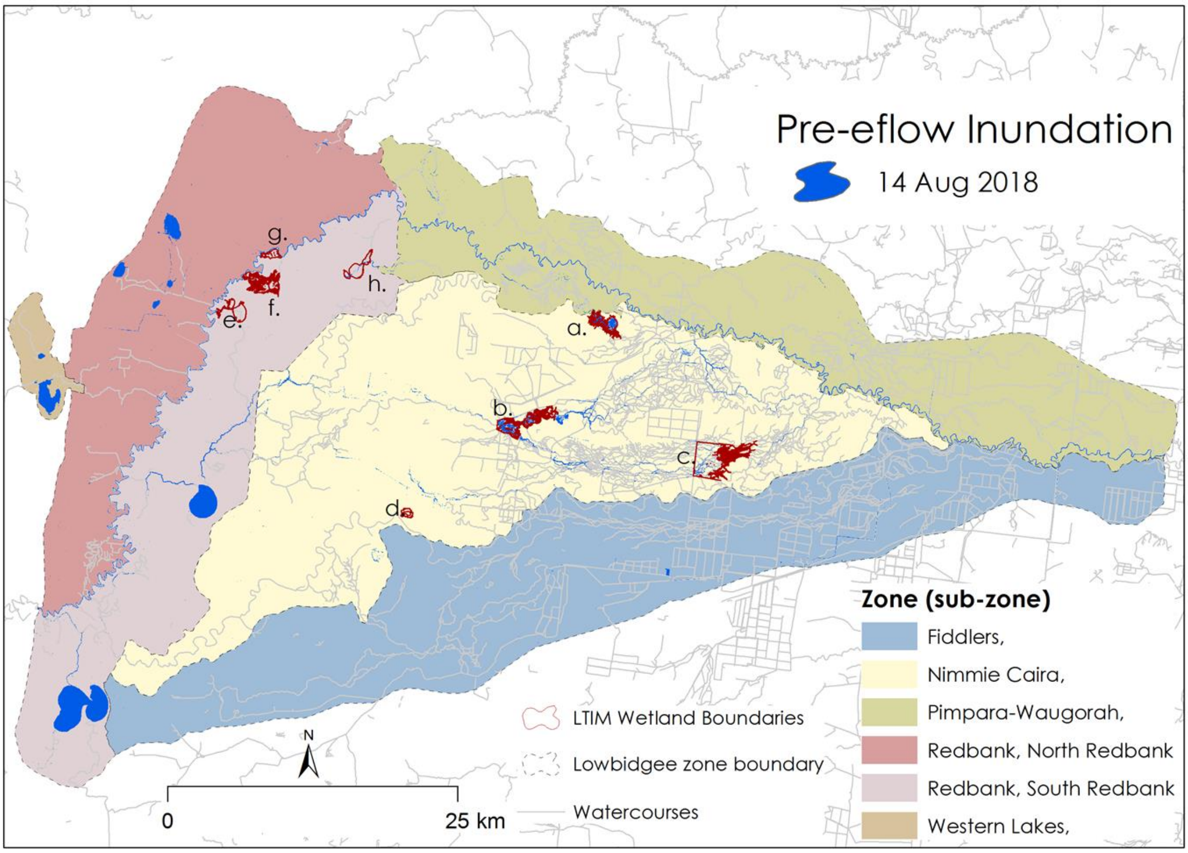


Figure 4-5 Inundation extent prior to environmental flow deliveries (14 Aug 2018) in the wetlands of the Lowbidgee zone. LTIM surveyed wetlands: a. Nap Nap Swamp, b. Telephone Creek, c. Eulimbah Swamp, d. Avalon, e. Piggery Lake, f. Two Bridges Swamp, g. Mercedes Swamp and h. Waugorah Lagoon.

Redbank Zone - Water Action Inundation Outcomes

As a result of the Yanga NP water action, an overall cumulative total of 10,345 hectares of South Redbank (Yanga) were inundated over the water action period (20 Aug 18 – 31 Jan 2019). Most of this area was attributed to the resulting inundation extent in North Yanga, which reached a maximum area of 5,699 ha in mid-November 2018. As inundation progressed south, South Yanga was inundated to a maximum area of 3,365 ha in early January 2019. The Yanga NP water action targeted LTIM surveyed wetlands in the North Yanga section of South Redbank: Mercedes Swamp (includes Pocock's Swamp), Two Bridges Swamp and Piggery Lake (Figure 4-6). Prior to the environmental flow delivery (July-mid August 2018), conditions in North Yanga were dry (Figure 4-6-i.) and so the inundated area of late August 2018 was a direct result of the water action (Figure 4-6-ii.). Maximum inundation extent in North Yanga was achieved in mid-November (10^{th}-17^{th}) (Figure 4-6-ii) contracting during the summer months and further progressing south towards South Yanga (Figure 4-6-iii). On

29 August 2018, Mercedes Swamp was inundated to almost 40% of its boundary, the maximum extent for this event, which did not include Pocock's Swamp. About 20% of Mercedes Swamp was inundated for four and a half months (Figure 4-6-g). Even though Mercedes Swamp was not inundated to 50% or more of its maximum boundary because it did not inundate Pocock's Swamp as in past years, this year's water action meant it was the fourth time the wetland was inundated from a dry state in the last five years (Figure 4-6-g). Two Bridges was inundated by the Yanga NP water action to 75% of its boundary, which then expanded to 100% inundated on 10 November 2018 after having been dry during the 2017-2018 water year (Figure 4-7-ii and Figure 4-6-f). At least fifty percent of Two Bridges Swamp was inundated for four and a half months and it was the fourth time the wetland was inundated from a dry state in the last five years (Figure 4-7-f). As inundation progressed south, Piggery Lake was 100% inundated on 13 September 2018 and at least 70% of the lake was inundated for nine months (Figure 4-6-ii and Figure 4-7-e).

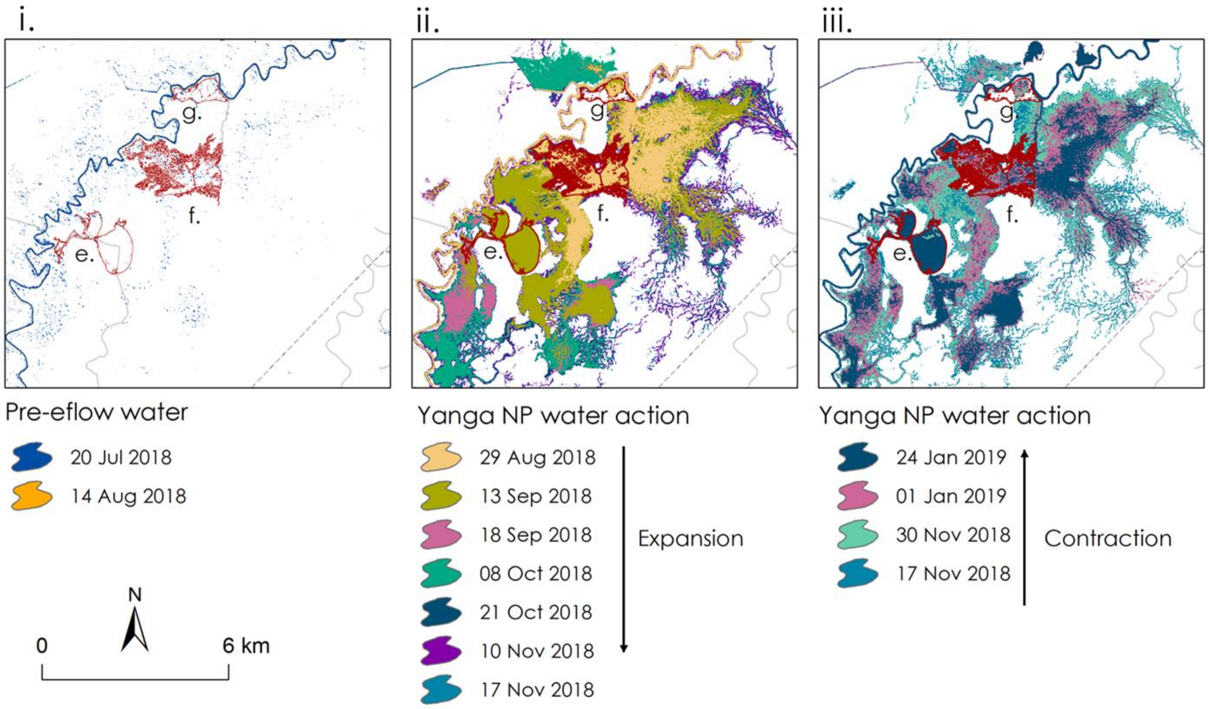


Figure 4-6 Inundation progression during the Yanga NP water action in 2018-2019 showing: i. pre-environmental flow conditions, July to August 201; ii. inundation expansion, August to November 2018; and iii. inundation contraction, November to January 2019 in wetlands within South Redbank (North Yanga). LTIM surveyed wetlands of the Redbank zone: e. Piggery Lake, f. Two Bridges Swamp, and g. Mercedes Swamp.

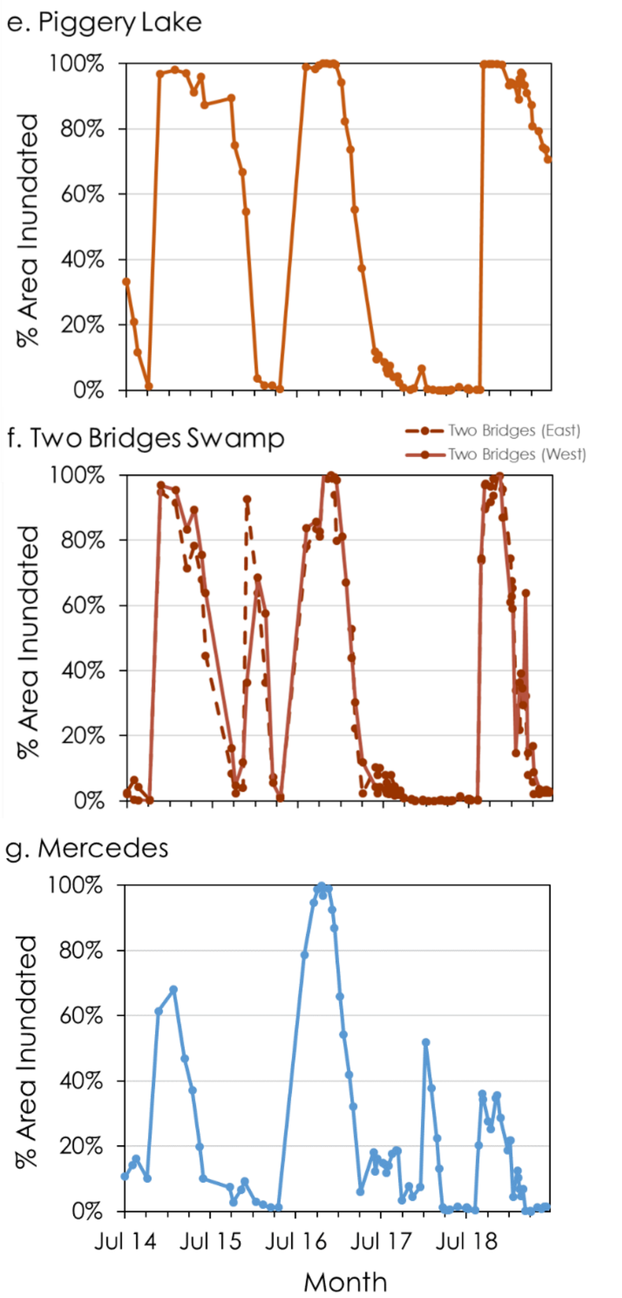


Figure 4-7 Percentage area inundated between July 2014 and June 2019 for LTIM surveyed wetland sites in South Redbank (North Yanga) of the Redbank zone: e. Piggery Lake, f. Two Bridges Swamp, and g. Mercedes Swamp.

Waugorah Lagoon, located in the North Yanga portion of South Redbank (h, Figure 4-8), received flows from the NSW EWA Nap Nap to Waugorah water action (25/09/18 – 11/18) inundating it to 16% of its boundary in January 2019 from its pre-environmental water percentage inundated of 7% (Figure 4-8-i and ii, and Figure 4-9). Inundation from the Nap Nap to Waugorah water action was laterally connected to the inundation from the Yanga NP water action through the outlet of Waugorah Lagoon on 21 October 2018 (Figure 4-8-ii).

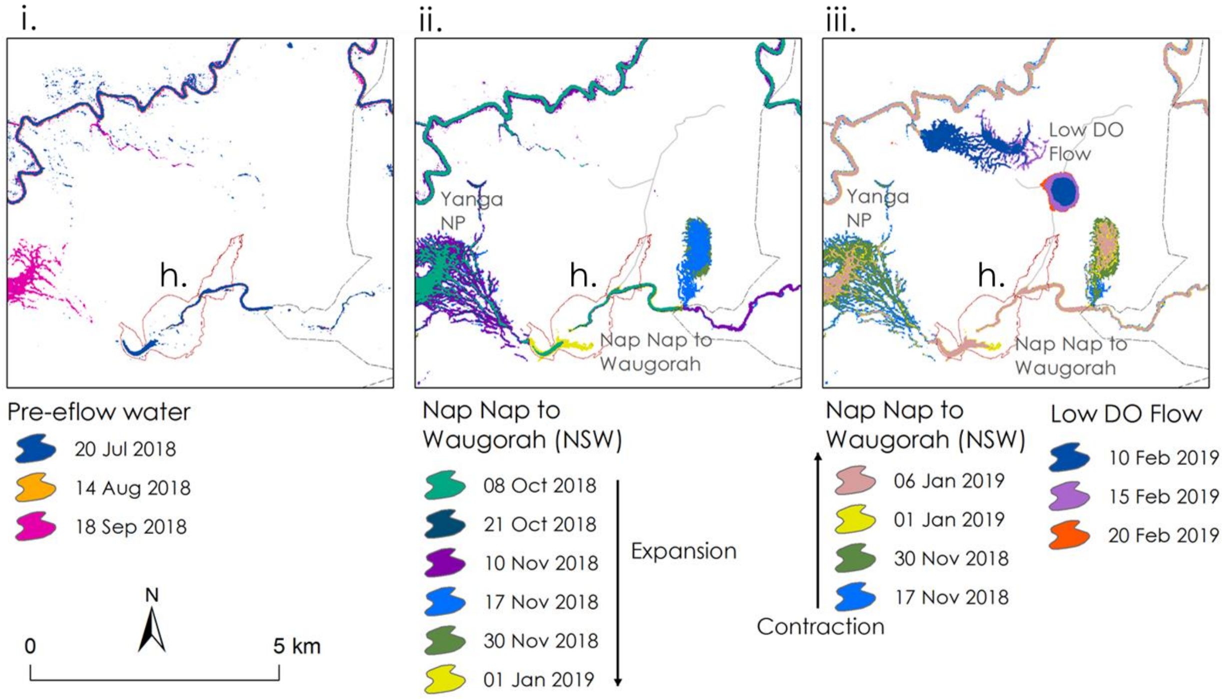


Figure 4-8 Inundation progression in and around Waugorah Lagoon (h.) in Yanga NP showing: i. pre-environmental flow conditions, July to September 2018; ii. inundation expansion, October 2018 to January 2019; and iii. inundation contraction, November to January 2019 as a result of the NSW Nap Nap to Waugorah Lagoon water action. Panels ii. and iii. indicate areas in nearby locations independently inundated by different water actions: Yanga NP and the Low DO fish flow.

Whilst most of the inundated area in North Yanga was contracting in December-January, new locations (Shaw's Swamp and Waugorah Lake) were independently inundated by the Low DO native fish flow water action increasing the inundated area of 1,481 ha on the 10 February to 2,138 ha on 15 February 2019 (Figure 4-8-iii).

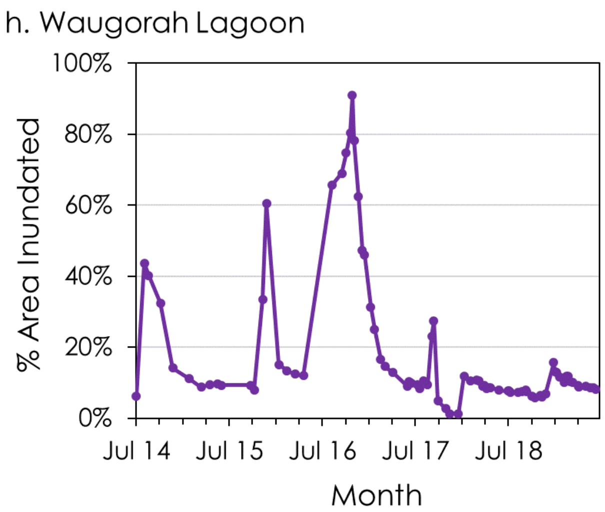


Figure 4-9 Percentage area inundated between July 2014 and June 2019 for the LTIM surveyed wetland site h. Waugorah Lagoon, in South Redbank (North Yanga).

North Redbank inundation extent increased from dry conditions as a result of the North Redbank refuge flow, which began in mid-September 2018. A cumulative total of 3,645 hectares of the floodplain were inundated by the North Redbank refuge flow (Figure 4-10-i.). A maximum area of 3,230 ha occurred on 17 November, first inundating a small areas in the north around Lake Marimley Swamp, then inundating the region from Athen to Murrundi and then progressing south from Murrundi towards Balranald Common, although the latter location was not inundated by the water action (Figure 4-10-i). In February 2019, inundation extent of North Redbank also increased from dry conditions due to flooding of different targeted wetland areas in the North Redbank region (Marimley Swamp) as a result of the Low DO management flow (Figure 4-10-ii).

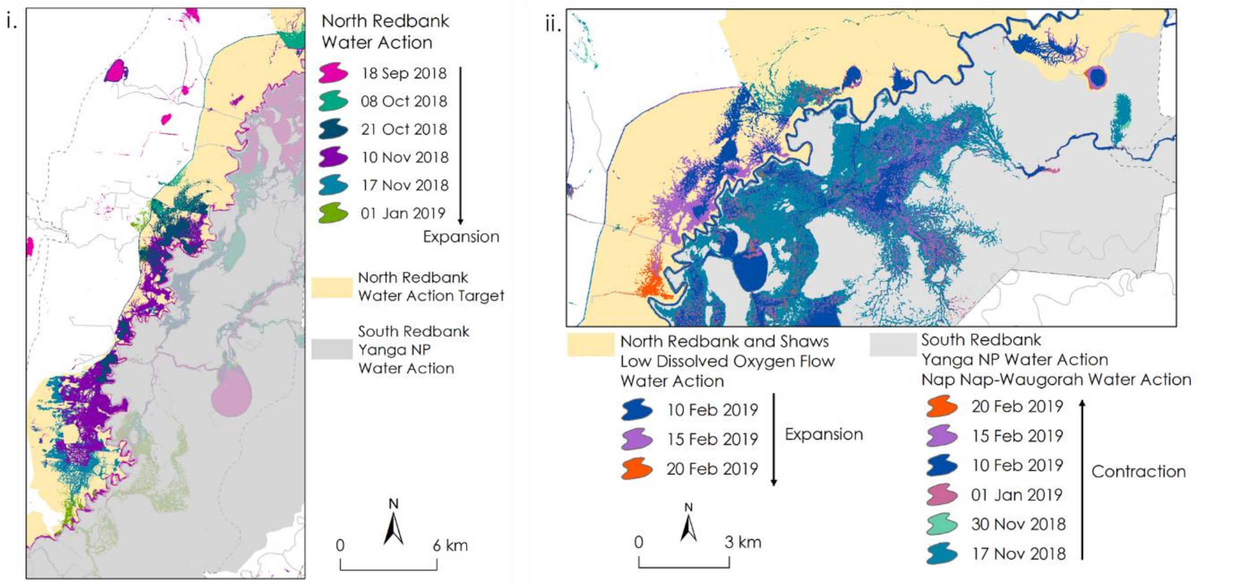


Figure 4-10 Inundation progression and expansion outcomes in the targeted areas of North Redbank region (beige shading) from i. the North Redbank water action, and ii. the Low DO flow water action. Inundation progression outcomes from other water actions occur in the South Redbank (Yanga) region (grey shading).

Nimmie-Caira Zone - Water Action Inundation Outcomes

Nap Nap Swamp in the Nimmie-Caira Zone was pre-watered in July 2018 to about 60% (Figure 4-11-i) after having dried out the previous water year (Figure 4-12). Environmental water from the NSW EWA Nap Nap to Waugorah Lagoon water action increased inundation extent to almost 100% of its boundary in early October 2018 and was full by mid-November 2018 (Figure 4-11-ii and Figure 4-12). In the last few weeks of November 2018, there was rapid contraction to 57% but at least 50% of Nap Nap Swamp was inundated for about 6 months (Figure 4-11-iii and Figure 4-12). This year was the third time Nap Nap Swamp was inundated in the last five years after being in a dry state (Figure 4-12).

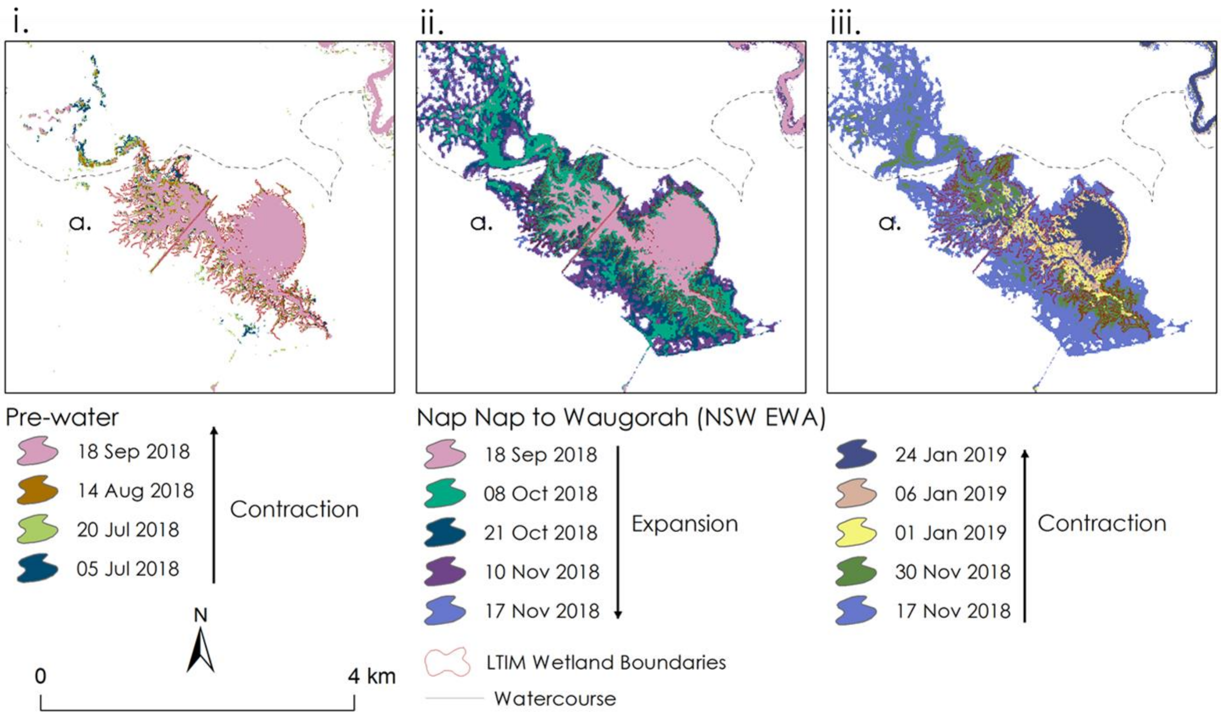


Figure 4-11 Inundation progression in Nap Nap Swamp (a.) in the Nimmie-Caira Zone during: i. pre-environmental flow conditions, July to September 2018; ii. inundation expansion, October 2018 to January 2019; and iii. inundation contraction, November to January 2019 as a result of the NSW EWA Nap Nap to Waugorah Lagoon water action. The date at the top of the legend represents the smallest extent in the inundation sequence.

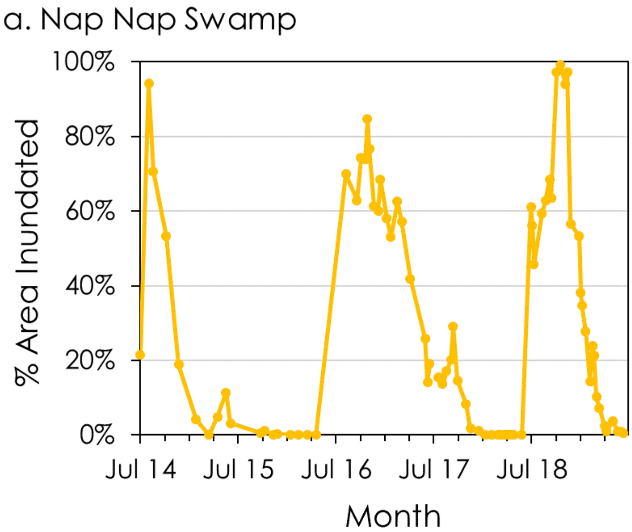


Figure 4-12 Percentage area inundated between July 2014 and June 2019 for the LTIM surveyed wetland site a. Nap Nap Swamp in located in the Nimmie-Caira Zone.

Telephone Creek in the Nimmie-Caira Zone received flows prior to environmental water deliveries between July and September 2018 (Figure 4-13) inundating almost 70% in September 2018 after having dried out the previous water year (Figure 4-14). There was rapid contraction in October 2018 due to water spilling out onto the Pollen Creek floodplain upstream. However, flows via Eulimbah Swamp combined with environmental water from the NSW EWA Nap Nap to Waugorah Lagoon water action provided untargeted flows to Telephone Creek increasing inundation extent back to 70% of its boundary by mid-November 2018 (Figure 4-13 and Figure 4-14). During the summer months, there was rapid contraction to about 10% at the end of February 2019. At least 40% of Telephone Creek was inundated for about 7 months since May 2018 (Figure 4-13 and Figure 4-14). The 2018-2019 water year was the first time Telephone Creek was inundated after having almost completely drying out in the last five years (Figure 4-14).

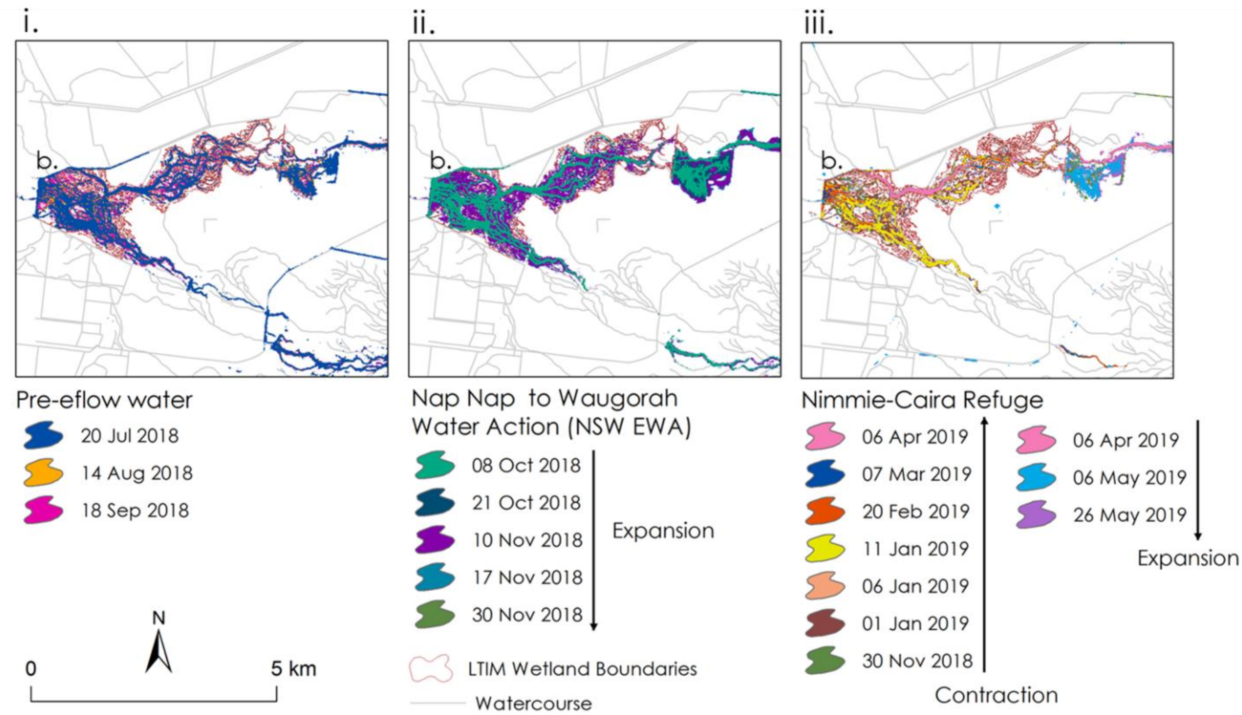


Figure 4-13 Inundation progression in Telephone Creek (b.) in the Nimmie-Caira Zone during: i. pre-environmental flow conditions, July to September 2018; ii. inundation expansion, October 2018 to November 2018 as a result of the untargeted watering from the NSW EWA Nap Nap to Waugorah Lagoon water action; and iii. inundation contraction, November to April 2019 during the Nimmie-Caira refuge flow. The date at the top of the legend represents the smallest extent in the inundation sequence.

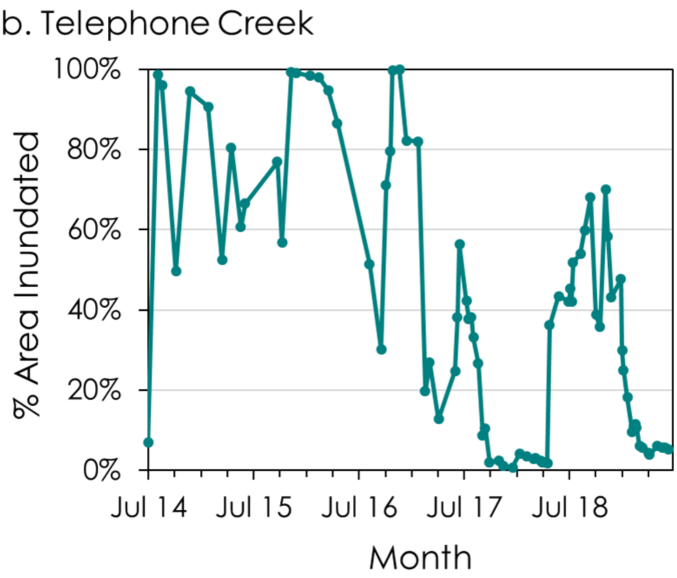


Figure 4-14 Percentage area inundated between July 2014 and June 2019 for the LTIM surveyed wetland site b. Telephone Creek located in the Nimmie-Caira Zone.

Inundation extent in Eulimbah Swamp continued to contract between July and September after the NSW environmental water action in April-May 2018 (Figure 4-15-i. and Figure 4-16). Eulimbah Swamp received a small volume of water in early October 2018, which was confined to the braided channel network and quickly contracted during the summer months until some environmental water from the Nimmie-Caira refuge action provided some wetting (Figure 4-15-ii. and Figure 4-16). In May 2019, Eulimbah Swamp received environmental water increasing inundation extents to 50% of the boundary and spilling into the floodplain to the north in June 2019 (Figure 4-15-iii. and Figure 4-16).

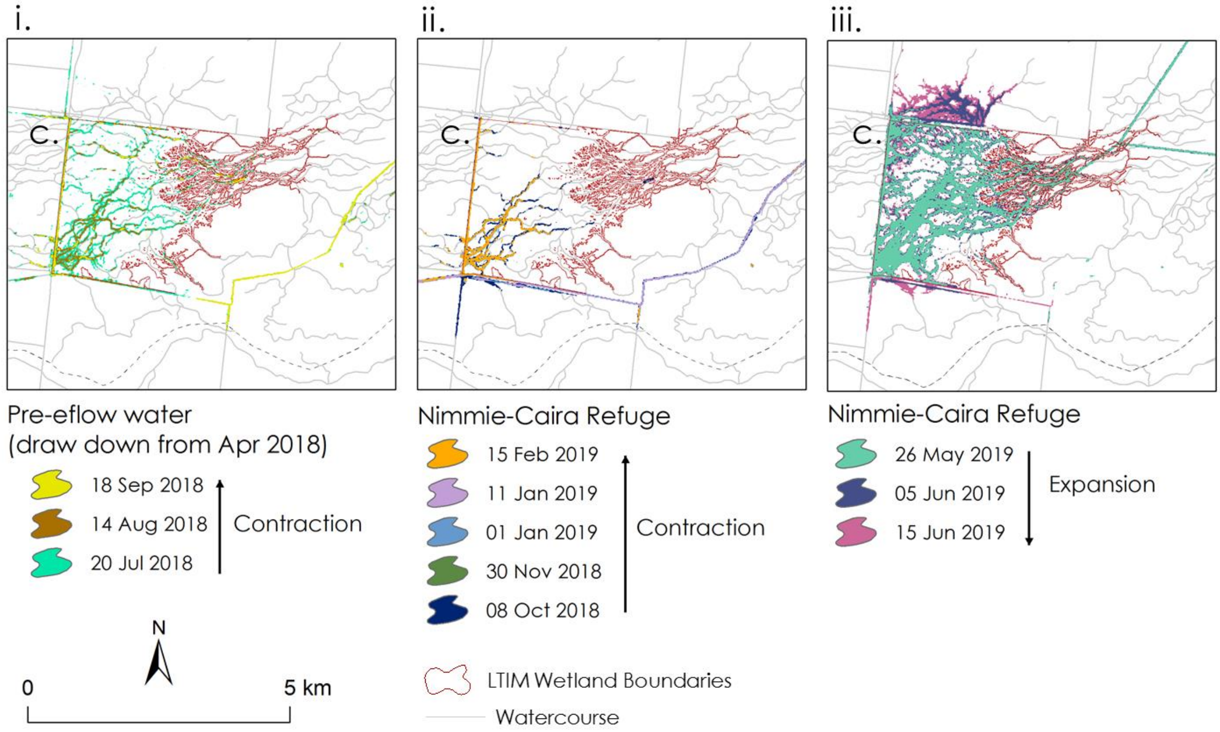


Figure 4-15 Inundation progression in Eulimbah Swamp (c.) in the Nimmie-Caira Zone during: i. pre-environmental flow conditions (draw down from April 2018), July to September 2018; ii. inundation contraction from 8 October 2018 to February 2019 during Nimmie-Caira refuge flow; and iii. inundation expansion, May to Jun 2019 during the Nimmie-Caira refuge flow. The date at the top of the legend represents the smallest extent in the inundation sequence.

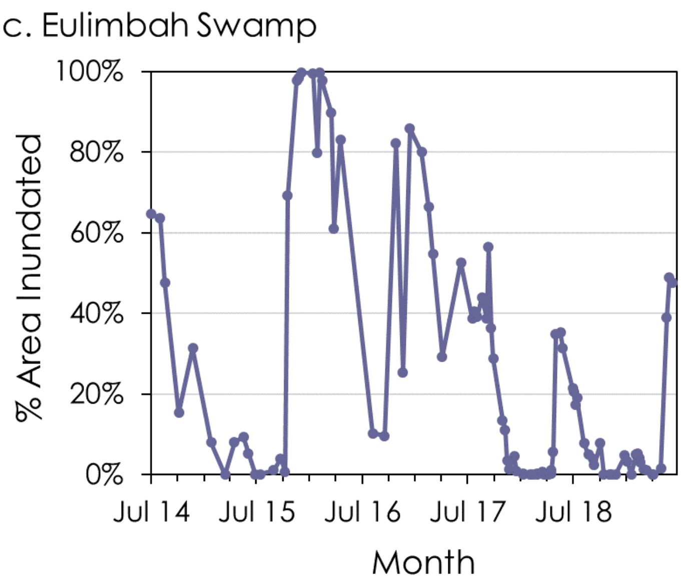


Figure 4-16 Percentage area inundated between July 2014 and June 2019 for the LTIM surveyed wetland site c. Eulimbah Swamp located in the Nimmie-Caira Zone.

During the Nimmie-Caira refuge flow, Avalon Dam was full on 17 November 2018 with a shallow overflow extending south into part of Avalon Swamp (Figure 4-17-ii and Figure 4-18). This then contracted back to the dam by 1 Jan 2019 before expanding again in mid-February 2019 to 13% of Avalon Swamp's boundary (Figure 4-17iii and Figure 4-18).

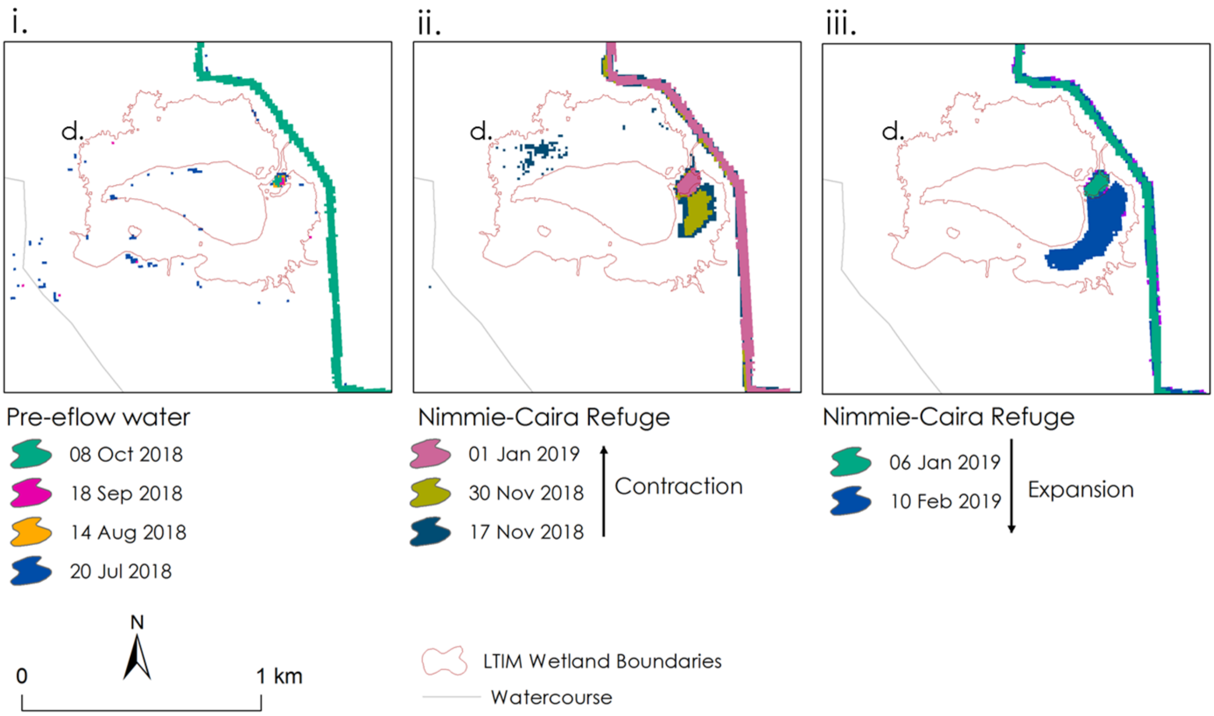


Figure 4-17 Inundation progression in Avalon Swamp (d.) in the Nimmie-Caira Zone during: i. pre-environmental flow conditions, July to October 2018; ii. inundation expansion on 17 November 2018 and then contraction through to January 2019; and iii. inundation expansion, in February 2019 during the Nimmie-Caira refuge flow. The date at the top of the legend represents the smallest extent in the inundation sequence.

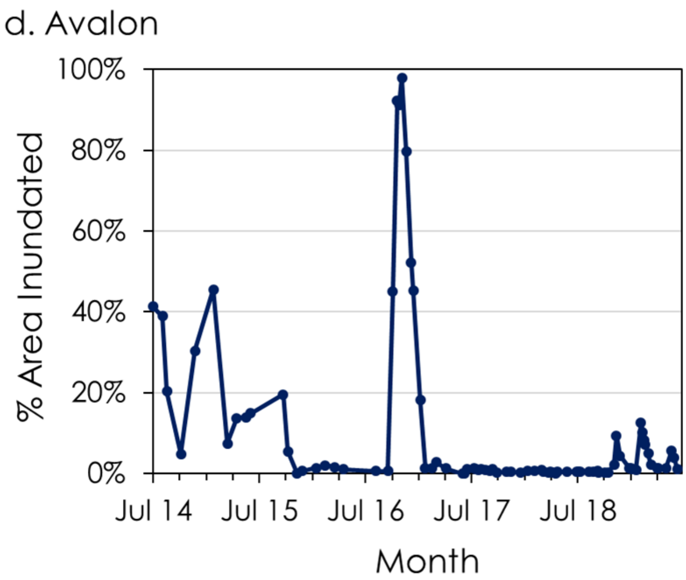


Figure 4-18 Percentage area inundated between July 2014 and June 2019 for the LTIM surveyed wetland site b. Telephone Creek located in the Nimmie-Caira Zone.

Mid-Murrumbidgee Zone – Water Action Inundation Outcomes

Yarradda Lagoon in the mid-Murrumbidgee Zone, after having almost dried out by mid-November 2018 from previous year's inundation, filled to 50% of its boundary by late December 2018 as a result of the pumping water action (Figure 4-19-i-ii and Figure 4-20). Inundation extent peaked at almost 60% of its boundary in mid-January 2019, which meant that 50-60% of Yarradda Lagoon was inundated for about 1.5 months (Figure 4-20). Inundation extents began to contract in mid-February allowing at least 35% of the lagoon to be inundation for about 6 months (Figure 4-19-iii and Figure 4-20). This was the fourth year in a row that Yarradda Lagoon was inundated to at least 50% of its boundary (Figure 4-20-a). McKenna's and Sunshower Lagoons were not targeted for inundation by environmental flows in the 2018-2019 water year and so they have been dry for 17 months, since mid-February 2018 (**Error! Reference source not found.**-b and c). For other mid-Murrumbidgee lagoons that received environmental water but did not have a wetland boundary delineated by the LTIM project (Gooragool, Mantangary and Darlington Lagoons) the inundation outcomes are documented in Thomas *et al.* (2019).

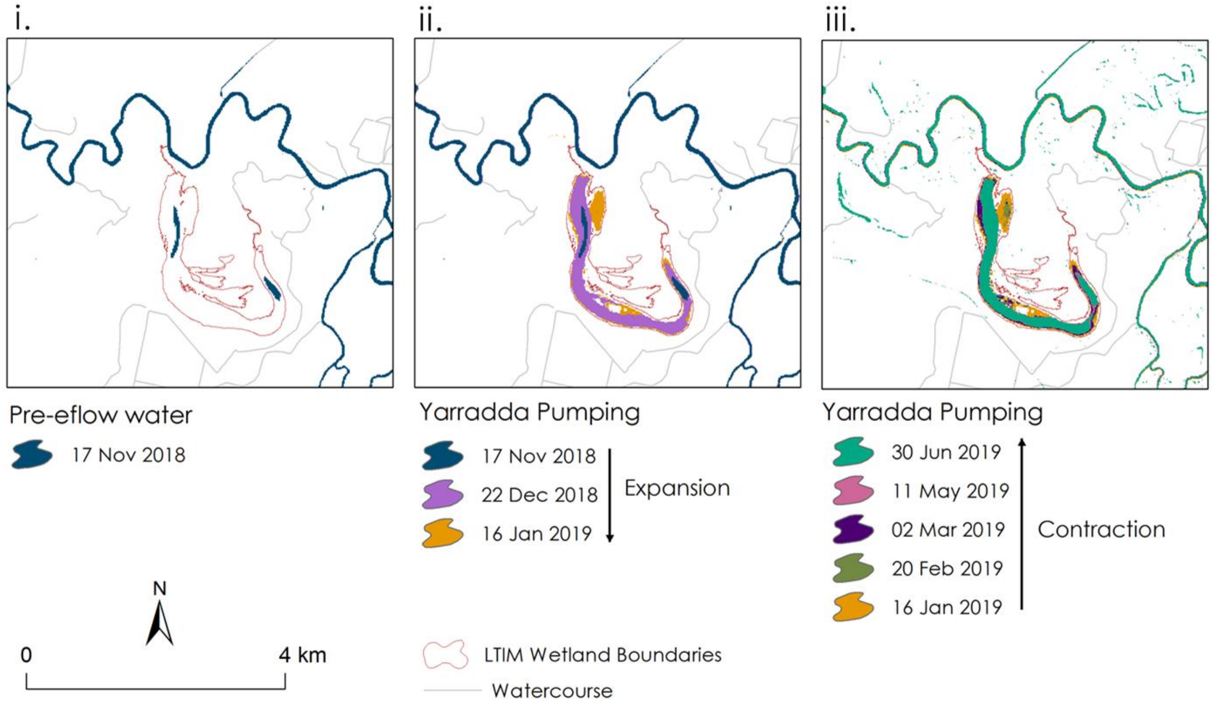


Figure 4-19 Inundation progression in Yarradda Lagoon of the mid-Murrumbidgee zone during i. pre-environmental flow conditions, in mid-November 2018; ii. inundation expansion from 17 November 2018 to 16 January 2019 as a result of the Yarradda pumping water action; and iii. inundation expansion, in February 2019 during the Nimmie-Caira refuge flow. The date at the top of the legend represents the smallest extent in the inundation sequence.

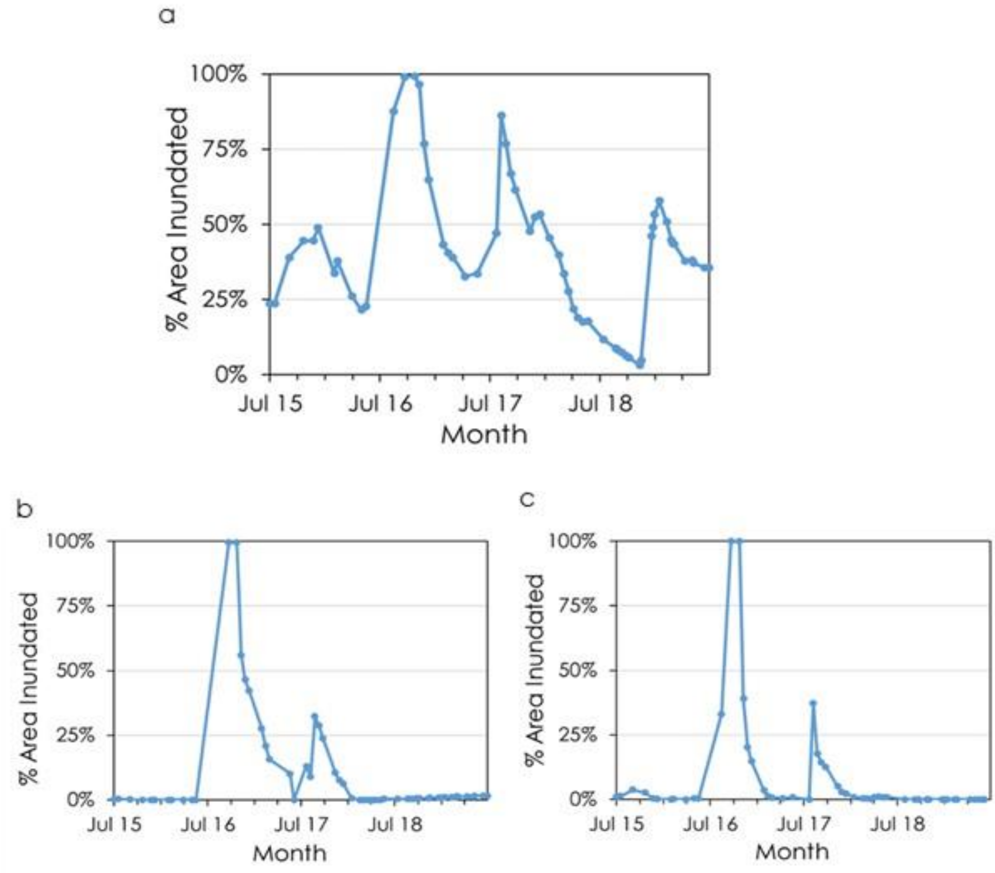


Figure 4-20 Percentage area inundated for (a) Yarradda Lagoon, (b) McKennas Lagoon and (c)Sunshower Lagoon in the mid-Murrumbidgee zone between July 2015 and June 2019.

Hydrology at monitoring sites

In 2018-19, eight of the 12 monitoring sites contained water (Figure 4-21). The wetlands evaluated in this program represent a range of hydrological regimes from permanent lagoons to infrequently inundated wetlands with long dry periods. Commonwealth and NSW environmental water sources influenced the hydrological regimes of wetlands in all years, except 2016-17 when some wetlands received only unregulated flows while others received a mix of unregulated and regulated flows throughout that year. In order to evaluate the role of hydrological regime maintained by CEWO, we used logger data to calculated proportion of days that each was dry between September 2014 and April 2019.

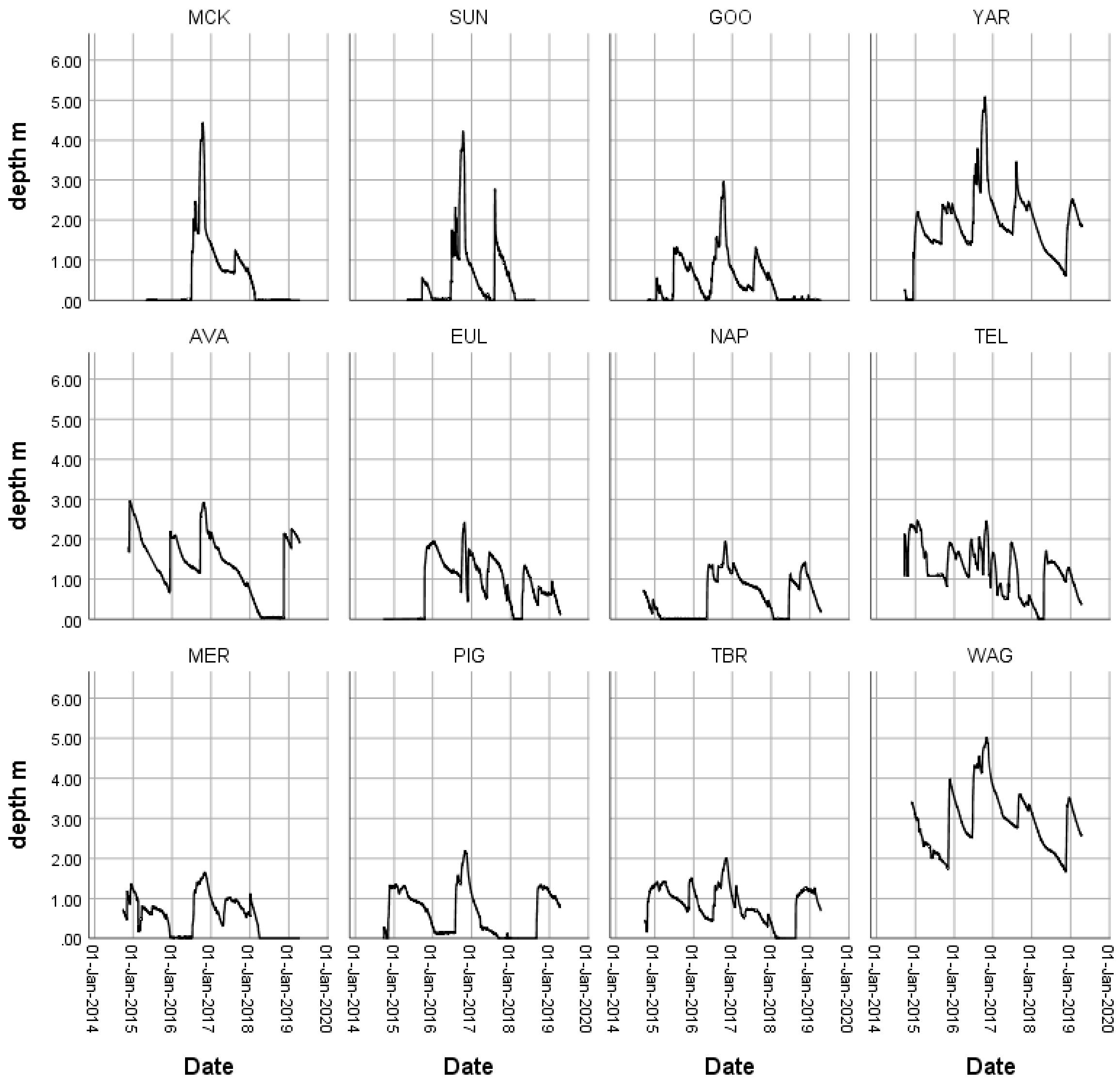


Figure 4-21 Water depth profiles of twelve monitored wetlands in the Murrumbidgee Selected Area between June 2014 and July 2019.

Discussion

What did Commonwealth environmental water contribute to wetland inundation extent?

Commonwealth environmental water actions combined with NSW environmental water achieved inundation outcomes in targeted core wetlands in the mid-Murrumbidgee zone, and the Nimmie-Caira and Redbank zones of the Murrumbidgee Selected Area.

Environmental flows were successfully used to increase inundation extent in core wetlands to create aquatic refuge habitat critical for biota during the forecasted hot and dry conditions of 2018-2019. Inundation from environmental flows increased lateral connectivity with the river and between the core wetlands that are distributed across the large Lowbidgee floodplain. Whilst the wetland area inundated was small compared to the entire floodplain, there were good outcomes because a high proportional area (>50%) of the individual core wetlands was inundated when they would otherwise have been dry without environmental flows.

Due to levee blowouts and regulator leakages there were unforeseen inundation outcomes in untargeted wetlands. For example, in Telephone Creek and Eulimbah Swamp in the Nimmie-Caira zone the timing of increased inundation extent was not always as planned. Furthermore, for some areas inundation was delayed to hotter and drier months (e.g. the Yanga NP water action delivered through the Nimmie-Caira). For other core wetland areas, inundation extent was less than expected as it did not progress as planned (e.g. in North Yanga because flooding did not reach Balranald Common as expected). Other wetlands in the North Redbank region, namely Marimley Swamps, were targeted for inundation in February 2019 by the Low DO management flow, which occurred in response to a hypoxic event. If this hypoxic event did not occur, these wetlands would not have been a target for inundation and most likely would have remained dry.

Many of the wetlands within the Murrumbidgee Selected Area require seasonal inundation of sufficient duration to maintain a diverse mosaic of plant communities that transition between a characteristic wet and dry phase in response to the flooding regime. Historically, many of these floodplain wetlands would have been connected to the river annually but could possibly have remained partially or fully inundated for up to a year or more. The water actions delivered in 2018-2019 contributed to maintaining the required seasonal inundation regime within only small areas of core wetlands by targeting them after they had dried out over the winter of 2018. For the LTIM survey sites being the fourth or fifth year of inundation after drying in as many years, environmental flows contributed to a more natural wetting and drying cycle required for their long-term persistence. However, inundation duration is also critical for the completion of the life history stages of flora and fauna. During the 2018-2019 water year, inundation duration was achieved for periods of between three and nine months in some wetlands, for example, at least 70% of Piggery Lake was inundated for nine months. Yet for some of the LTIM surveyed wetlands these inundated lengths of time were maintained for only a small proportional area (<50%) of the wetland. For example, in Mercedes Swamp between 20-35% of the wetland boundary was inundated for 4.5 months. In Nap Nap Swamp, after about 3 months of increased inundation extent, 100% of the wetland was inundated, but this lasted for just over one month with a rapid draw down to 50% in less than a month. In the mid-Murrumbidgee, whilst up to 50-60% of Yarradda Lagoon was inundated, this lasted for only 1.5 months. Whilst different groups of floodplain wetlands are sensitive to variable flooding regimes, based on current our knowledge most wetland plants require at least three month of inundation duration to maintain vigorous growth (Roberts and Marston 2011).

For wetlands that do not receive flooding, the character of the wetland is likely to change from aquatic species to rainfall dependent species and/or woody plant species (Thomas *et al.* 2010, Bino *et al.* 2011, Capon and Reid 2016; Wassens *et al.* 2017). For example, whilst Yarradda Lagoon has been inundated from almost a dry state four times in the last 5 years, only two of these inundation events increased inundation extent to 75-100% of its area. This may make it vulnerable to river red gum encroachment from saplings that most likely established after the large flood of 2012. To avoid river red gum encroachment, inundation of river red gum seedling needs to occur very early in seeding life (soon after germination or within three months), with sufficient water depth to ensure it overtops the seedling height and for a sufficient length of time (at least two months) (Campbell *et al.* in prep.).

Our capacity to restore the required inundation regime across the entire Murrumbidgee Selected Area with only environmental flows is limited because the volumes of environmental water available are relatively small compared to those required to inundate the full extent of all floodplain and wetland habitats, frequently and for long periods. Despite this, environmental flows may provide the only opportunity for primary productivity, nutrient and carbon cycling, and biotic dispersal and movement. Inundation from environmental flows will therefore be critical for maintaining core refuge habitats in localised areas and to avoid their ecological degradation during dry periods. With the forecasted persistence of hotter and drier than average conditions into 2019-2020, the importance of environmental flows cannot be overstated.

4.2 Wetland water quality

Prepared by Dr Damian Michael (CSU), Dr Ben Wolfenden (NSW DPIE) and Dr Yoshi Kobayashi (NSW DPIE)

Introduction

Water quality is naturally variable over time, reflecting changes in air temperature, discharge, patterns of wetting and drying, salinisation and aquatic photosynthesis. The biota found in ephemeral wetlands can 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). Very hot conditions, limited water movement (stratification) and wetland drying can lead to poor water quality.

In 2018-19, five deliveries of Commonwealth environmental water contributed to water quality outcomes in the twelve LTIM monitored wetlands. These watering actions targeted Yarradda Lagoon in the mid-Murrumbidgee zone, and the majority of wetlands in the Nimmie-Caira and Redbank zones, with a combination of pumping and refuge flows (see Table). A pulse of environmental water released via the 1AS regulator reached Yanga National Park after passing through Piggery Swamp and Two Bridges Swamp.

There were no specific watering objectives related to wetland 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 (prior to 2014) data and against other wetlands in the Murrumbidgee catchment between September 2014 and March 2019.

Commonwealth environmental water is evaluated against the following criteria:

What did Commonwealth environmental water contribute to wetland water quality?

Methods

Wetland water quality monitoring began in September 2014 and was completed in March 2019, monitoring is undertaken four times per year (September, November, January and March) on all occasions when water level is above 10 cm of surface water. Sampling includes 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. Correlations between wetland water depth and water quality measurements are presented.

Results

Physicochemical measurements collected from wetland sites in 2018-19 were largely consistent with data collected during the previous five years and remained within the upper and lower ranges of pre-2014 measurements (Table 2). In 2018-19, mean conductivity at most sites remained consistent with previous years, although values for some wetlands were consistently above the average (Figure 4-22). Maximum dissolved oxygen (Figure 4-23), pH (Figure 4-24) and turbidity (Figure 4-25) also varied among wetlands sites and between years, but overall remained consistent with pre-2014 values. Notable exceptions included above average turbidity readings at Avalon and Eulimbah during the 2014-2015 and 2018-19 water years, and Telephone Creek (Nimmie-Caira zone) during the 2017-2018 water year. Readings at these wetland sites often exceeded the calibrated range of field instruments (>1000 NTU) primarily due to some of these wetlands being in a drying phase.

Carbon (Figure 4-26), phosphorous (Figure 4-27), nitrogen (Figure 4-28) and chlorophyll-a (Figure 4-29) concentrations measured in 2018-19 were also generally within the pre-2014 reference range (Table 2). The only exception was Avalon Swamp, which had above average chlorophyll-a readings in 2018-19, again likely due to this wetland being in a drying phase.

Table 2-2 Pre-2014 and 2018-19 median, 5th and 95th percentiles and number of samples for water quality measurements collected across all wetlands in the Murrumbidgee Selected Area.

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
Pre-2014 Median (5th – 95th)	1483.5 (444-13,719)	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
2018-19 Median (min-max)	1600.0 (257-23,250)	192.5 (37-1900)	31.5 (2-1044)	15.5 (22.35-60)	0.18 (0.07-0.85)	8.04 (5.83-10.05)	94.33 (4.40-940.00)	9.44 (1.74-9.44)
#samples	29	29	29	29	29	29	29	29

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

*Table 4-3 Correlations (2-tailed) between water quality measurements and wetland depth for composited water quality data collected between September 2014 and March 2019 (*significant at P <0.05, ** signiciant at P <0.001).*

Indicator	Chl-a µg L-1	DOC mg L-1	TN mg L-1	TP mg L-1	C mS cm-1ond	pH	Turb. NTU	DO mg L-1
Coefficient	-0.290**	-0.250**	-0.227**	-.246**	-0.190*	-.027	-0.292**	-0.110
Significance	0.000	0.001	0.003	0.001	0.018	0.740	0.000	0.176
N	173	172	172	172	154	154	154	154

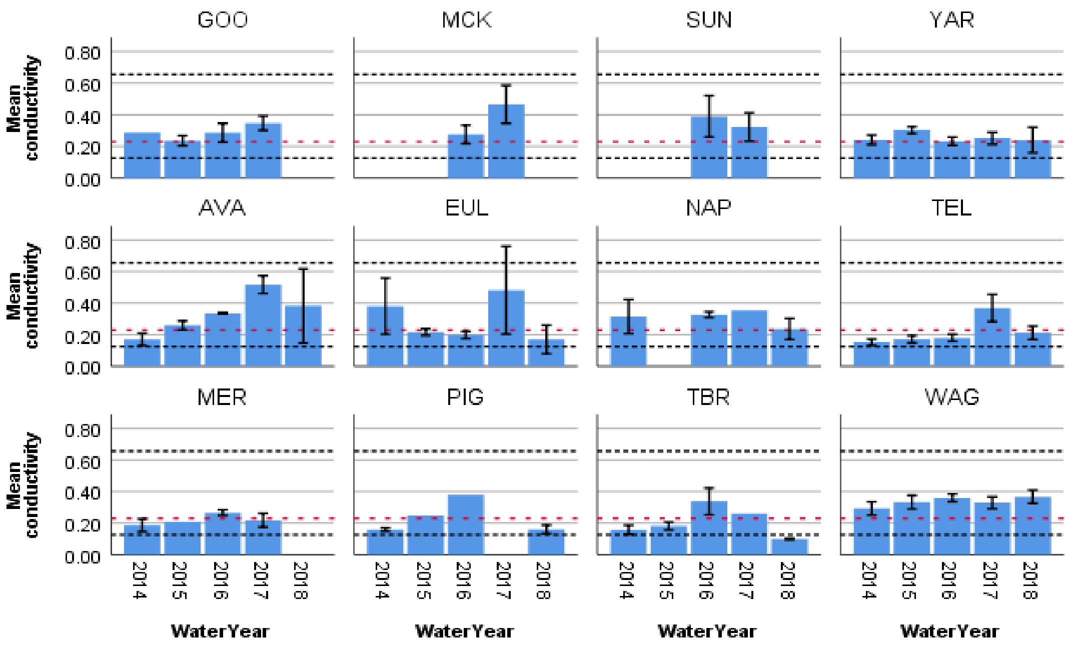


Figure 4-22 Mean ± standard error for water conductivity (mS cm⁻¹) for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014. Samples are averaged across three sites at each wetland. Missing error bars indicate wetlands that were surveyed on one occasion for that respective watering year due to low water levels.

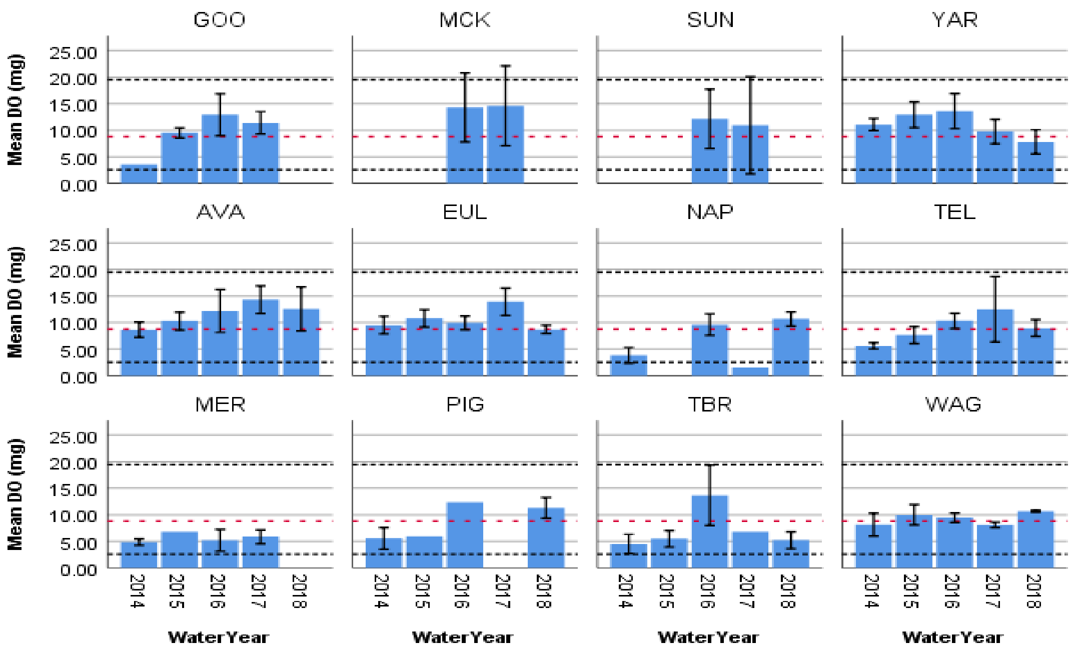


Figure 4-23 Mean ± standard error for dissolved oxygen (mg) for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014. Missing error bars indicate wetlands that were surveyed on one occasion for that respective watering year due to low water levels.

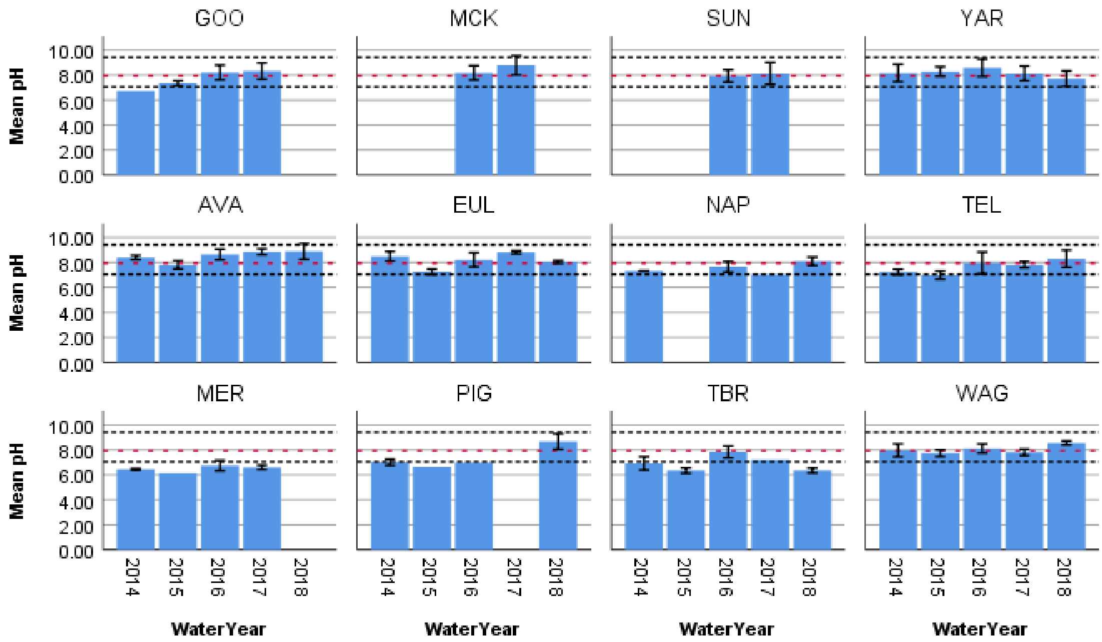


Figure 4-24 Mean ± standard error for pH for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014. Missing error bars indicate wetlands that were surveyed on one occasion for that respective watering year due to low water levels.

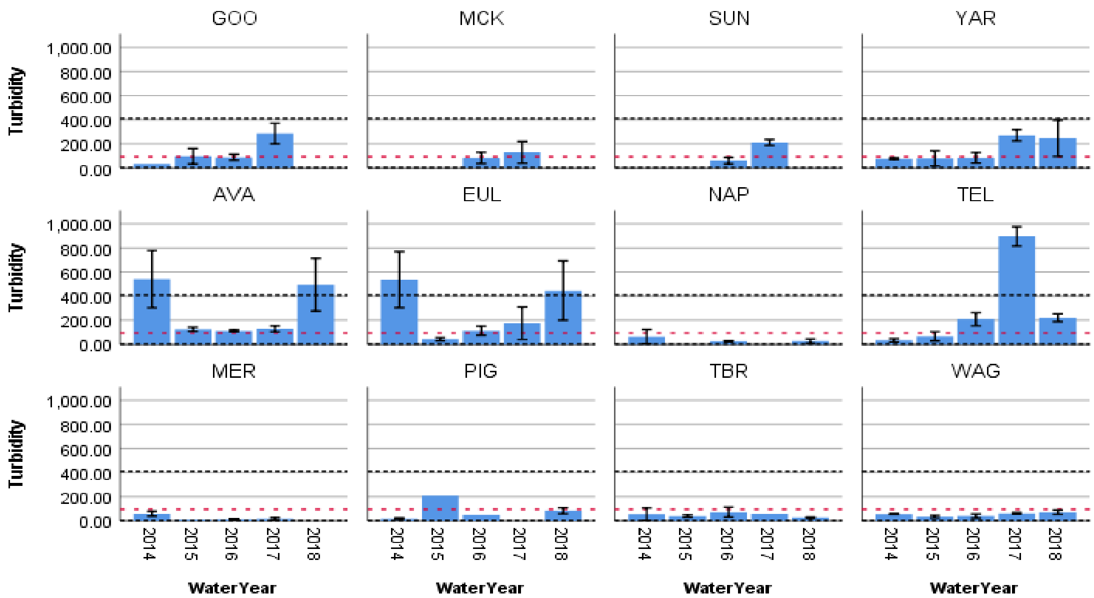


Figure 4-25 Mean ± standard error for turbidity for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014. Missing error bars indicate wetlands that were surveyed on one occasion for that respective watering year due to low water levels.

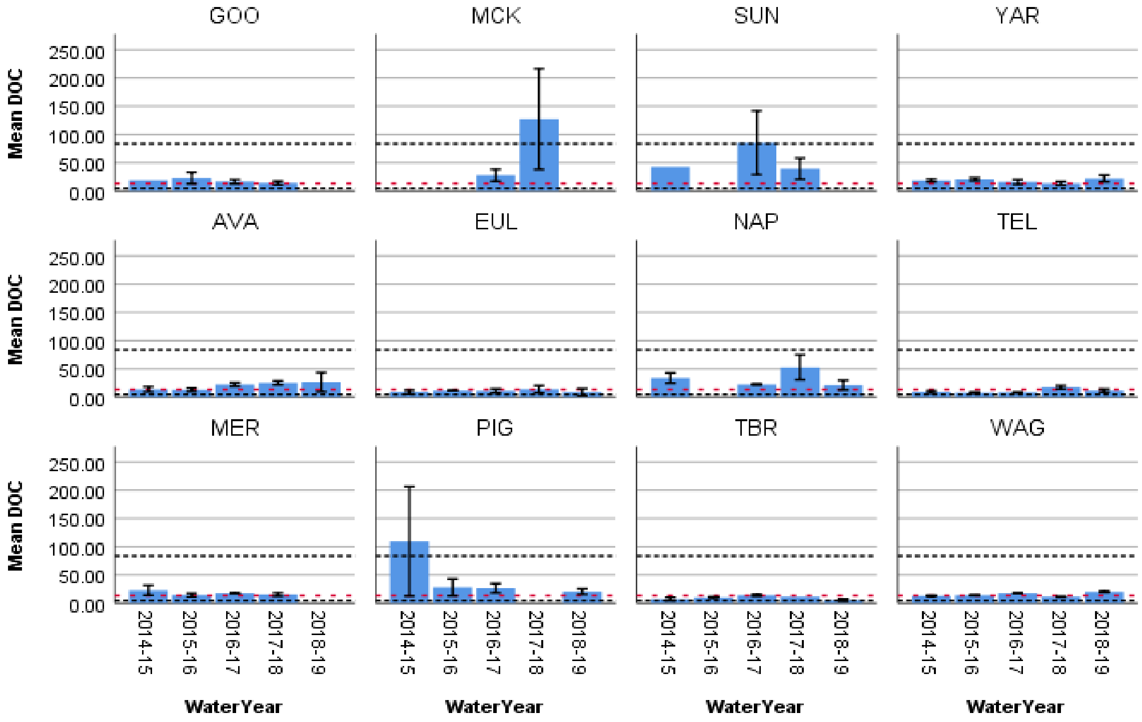


Figure 4-26 Mean ± standard error for dissolved organic carbon (DOC mg L^{-1}) for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014. Samples are averaged across three sites at each wetland.

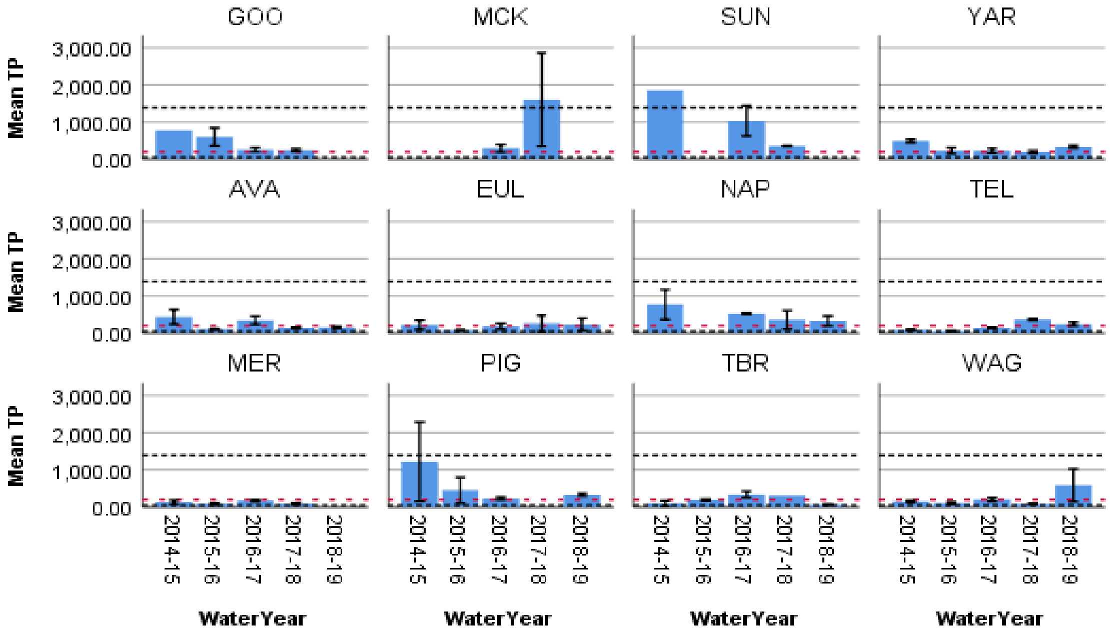


Figure 4-27 Mean ± standard error for total phosphorous for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014.Samples are averaged across three sites at each wetland.

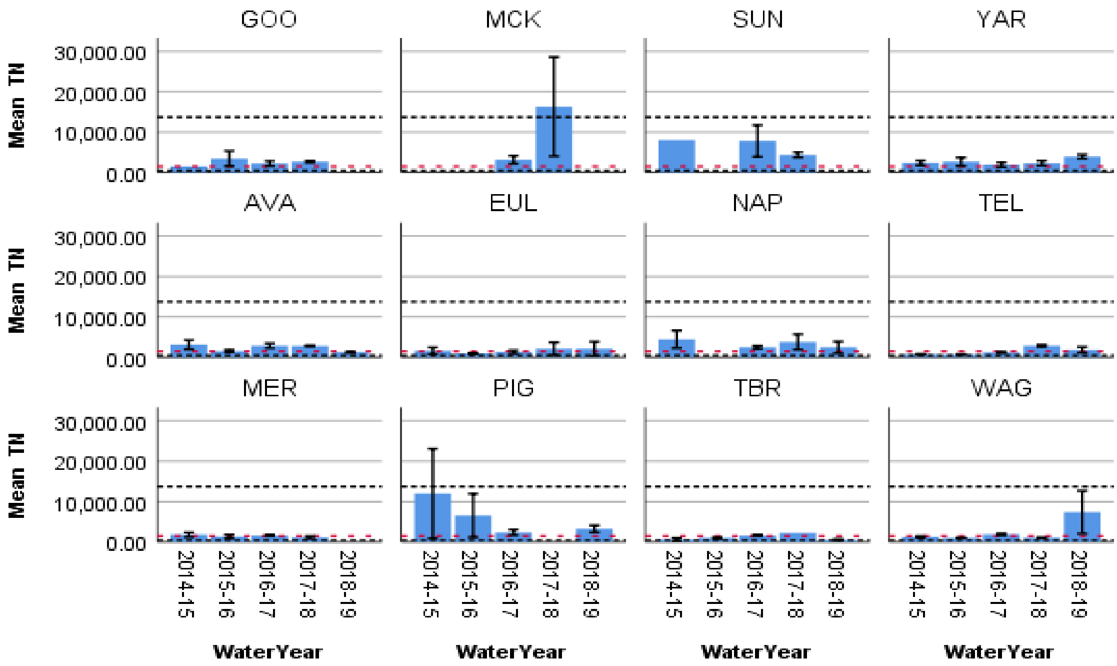


Figure 4-28 Mean ± standard error for total nitrogen for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014. Samples are averaged across three sites at each wetland.

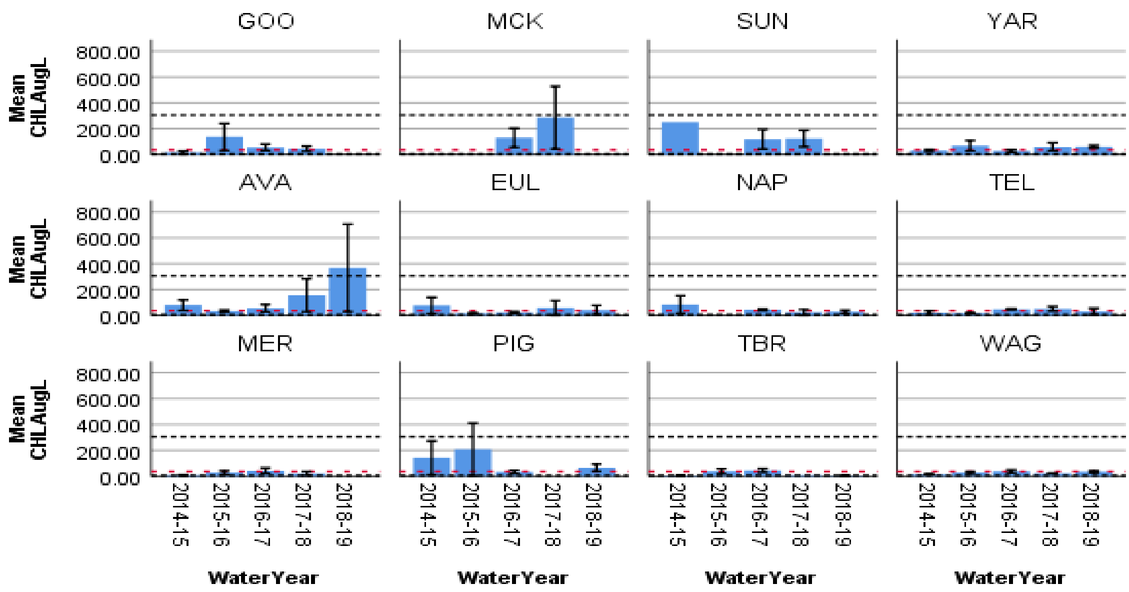


Figure 4-29 Mean ± standard error for chlorophyll for each wetland between September 2014 and March 2019. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 .Samples are averaged across three sites at each wetland. Missing error bars indicate wetlands that were surveyed on one occasion for that respective watering year due to low water levels.

Discussion

What did Commonwealth environmental water contribute to wetland water quality?

Declining water quality with wetland drying is a feature of ephemeral wetlands that is an expected part of the hydrological cycle and is seen on an annual basis across 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 during the wetland-drying phase. Low water levels in some wetlands across the five year monitoring period have resulted in some poor water quality events, however, there has been no net decline in water quality over time. Pumping actions to Yarradda Lagoon during the later stages of the monitoring program (post 2017) have also increased water levels, ensuring a longer period of good water quality.

4.3 Wetland microinvertebrates

Prepared by Dr Kim Jenkins (CSU), Dr Ben Wolfenden (NSW DPIE), Sylvia Hay (UNSW), Claire Sives (UNSW), Gilad Bino (UNSW), Kendal Krause (CSU) 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, 2017-18 and 2018-19 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) (outcome from the Monitoring and Evaluation Plan, Wassens *et al.* 2014). 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 2018-19, there were five deliveries of Commonwealth environmental water that contributed to water quality outcomes in the twelve LTIM monitored wetlands across the Murrumbidgee catchment. These watering actions targeted Yarradda Lagoon in the mid-Murrumbidgee zone, and the majority of wetlands in the Nimmie-Caira and Redbank zones, with a combination of pumping and refuge flows (see Table). A pulse of environmental water released via the 1AS regulator reached Yanga National Park after passing through Piggery Swamp and Two Bridges Swamp.

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.

Evaluation Question

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 2019. Microinvertebrate samples are not collected when the wetland is dry or was less than 10 cm of surface water. Benthic and pelagic samples were collected following the methods described by Wassens *et al.* (2014). Laboratory methods follow those reported in the riverine microinvertebrate section.

Data analysis

To determine differences in microinvertebrate density between zones (Narrandera and Carrathool) and years (2014-15, 2015-16, 2016-17, 2017-18 and 2018-19), 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) using the vegan package (Oksanen *et al.* 2011) in R version 3.6.1 (R Development Core Team 2019). Raw data were initially log transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$.

Results

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

Over the past 5 years, the inundation of wetlands in the mid-Murrumbidgee, Nimmie Caira and Redbank zones with Commonwealth environmental water has contributed to high levels of secondary productivity with densities of microinvertebrates between 500-1000/L throughout spring and summer from 2014 to 2019 (**Error! Reference source not found.**). The highest benthic microinvertebrate densities recorded in the LTIM project were observed in September and November 2018 in the mid-Murrumbidgee. Densities of microinvertebrates were higher in benthic than pelagic habitats and although wetland pelagic densities were mostly less than 500/L (100-400/L), they were considerably higher than pelagic densities in riverine habitats (< 100/L) (Figure 4-29).

There were significant differences among zones in densities of benthic and pelagic microinvertebrates (PERMANOVA p<0.002, **Error! Reference source not found.**). The mid-Murrumbidgee and Nimmie-Caira zones generally supported higher densities of microinvertebrates than the Redbank zone in both benthic and pelagic habitats. Benthic microinvertebrate densities were consistently above 100/L and often exceeded 500 to 1000/L (Figure **Error! Reference source not found.**).

There was no significant difference between years in densities of microinvertebrates (Figure 29). High densities were observed in all five years of the LTIM sampling. There was no consistent difference in microinvertebrate densities between trips. Densities in the mid-Murrumbidgee were high in September 2018 with densities around 1000 /L falling below 100/L by March 2019 (Figure 29).

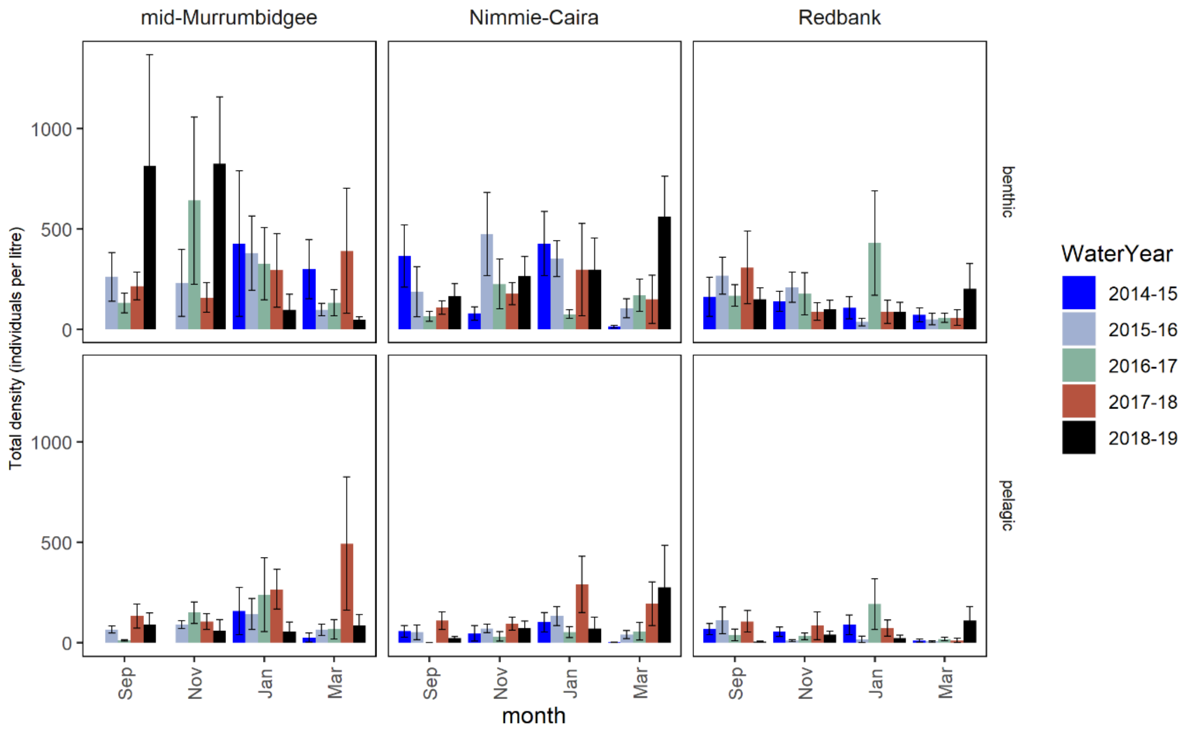


Figure 4-29 Mean densities of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) , 2015-16 (light blue), 2016-17 (green), 2017-18 (brown) and 2018-19 (black). Errors are standard errors.

Copepods, particularly cyclopoids and nauplii (with lower numbers of harpacticoids and calanoids), dominated benthic assemblages in all five years and across the three zones (Figure 30**Error! Reference source not found.**). This pattern was reflected in the less productive pelagic habitats (not shown here for simplicity). Densities of copepods were typically greater than 1-200/L in the Mid-Murrumbidgee and Nimmie-Caira zones with peaks from 500 to 1000/L. Cladocerans were common in samples from all zones and were dominant in September and November 2018 in the mid-Murrumbidgee and were abundant in the Nimmie Caira in September 2014 and January 2015 and also in March in both 2018 and 2019 (Figure 30). Cladoceran taxa included Moinids, Chydorids, Daphnids, Bosminids and Macrothricids. In 2018-19, the dominant cladocerans were Macrothricids (*Macrothrix spinosa* and *Ilyocryptus* sp.), Moinids (*Moina micrura) and chydorids (Alona* sp.). This was a slight shift from 2017-18 when the dominant benthic cladoceran taxa were; Bosminids (*Bosmina meriodonalis)*, Moinid (*Moina micrura),* Macrothricid (*Macrothrix* sp.) and the Chydorids (*Alona* sp., *Chydorus* sp, *Leydigia australis)*.

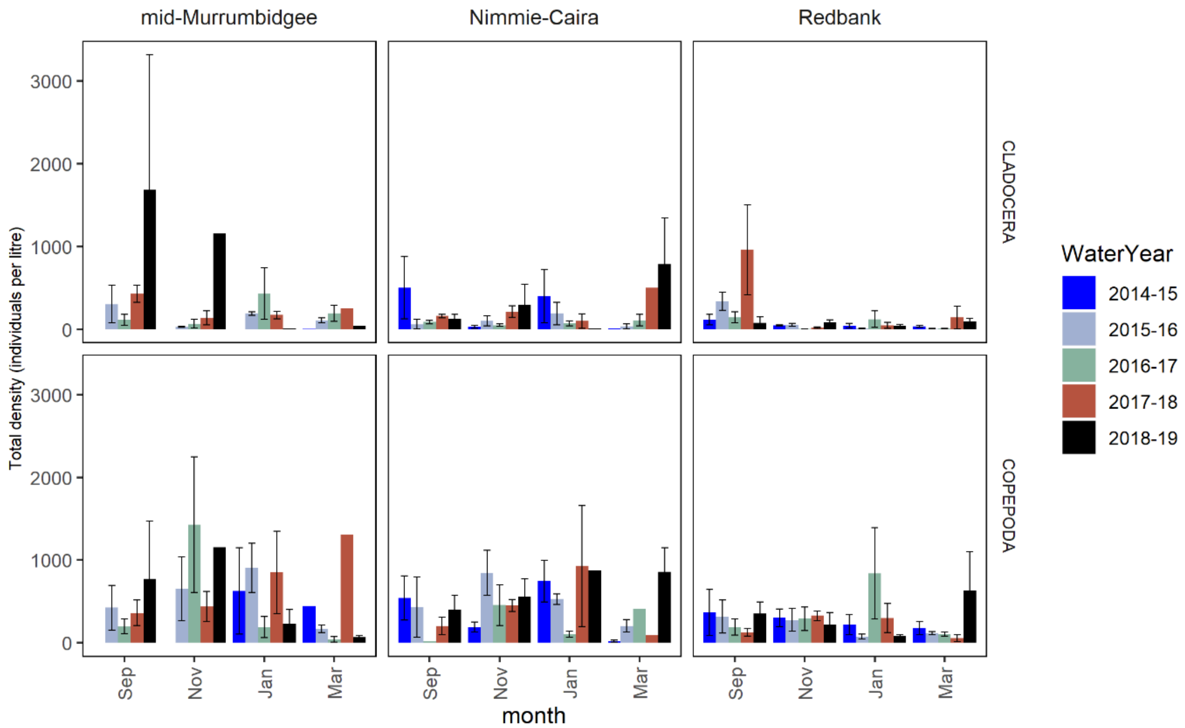


Figure 4-30 Mean densities of benthic cladocera (first row) and benthic copepods (second row) across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) , 2015-16 (light blue), 2016-17 (green), 2017-18 (brown) and 2018-19 (black). Errors are standard errors.

Ostracods occurred in densities greater than 100/L a number of times from 2014 to 2019 (Figure 1). The highest densities of ostracods were recorded in the mid-Murrumbidgee in March 2015 (>400/L) and in Redbank in November 2015 (>300/L). Densities greater than 100/L occurred three times in 2018-19; in November 2018 in the mid-Murrumbidgee and in November 2018 and March 2019 in the Nimmie-Caira (Figure 1).

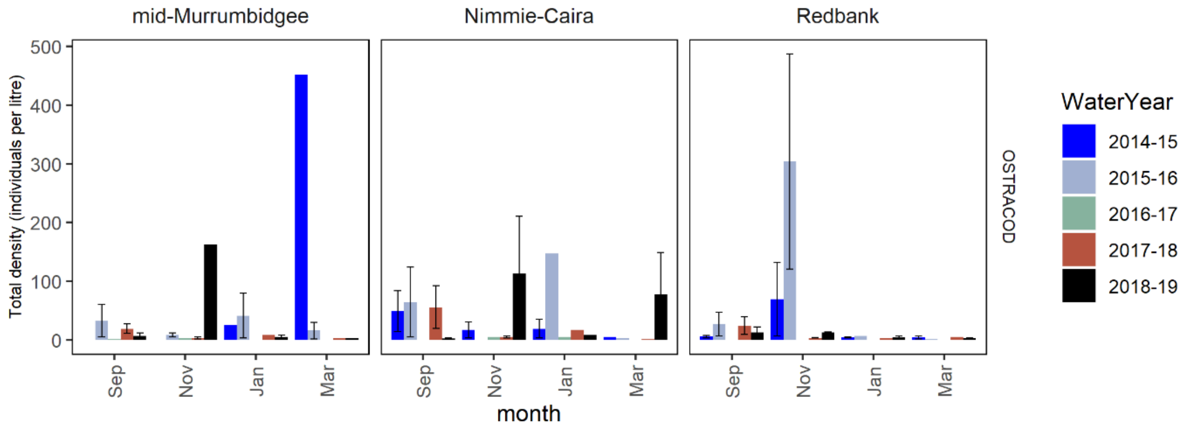


Figure 4-31 Mean densities of benthic ostracods across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) , 2015-16 (light blue), 2016-17 (green), 2017-18 (brown) and 2018-19 (black). Errors are standard errors.

Environmental watering in the Nimmie-Caira system from September 2018 through to autumn 2019 was associated with high productivity at Nap Nap Swamp in 2018-19 (Figure 32). Densities between 500 to 1000/L occurred in September 2018 and January 2019, with more than 2000/L in March 2019 (Figure 32). Waugorah Lagoon supported modest densities (100 – 500/L) throughout the 2018-19 water year (Figure). Piggery Lake and Two Bridges supported densities of benthic microinvertebrates around 400 - 600/L in September 2018 after watering commenced in August 2018, with densities around 100 - 200/L sustained until densities peaked at 1000 - 2000/L in Piggery Lake in March 2019. Yarradda Lagoon had benthic densities higher than 3000/L in September 2018 when the residual pool was sampled. After water was pumped into this wetland, from November 2018, densities remained high (>1000/L), falling to around 100/L by March 2019 (Figure).

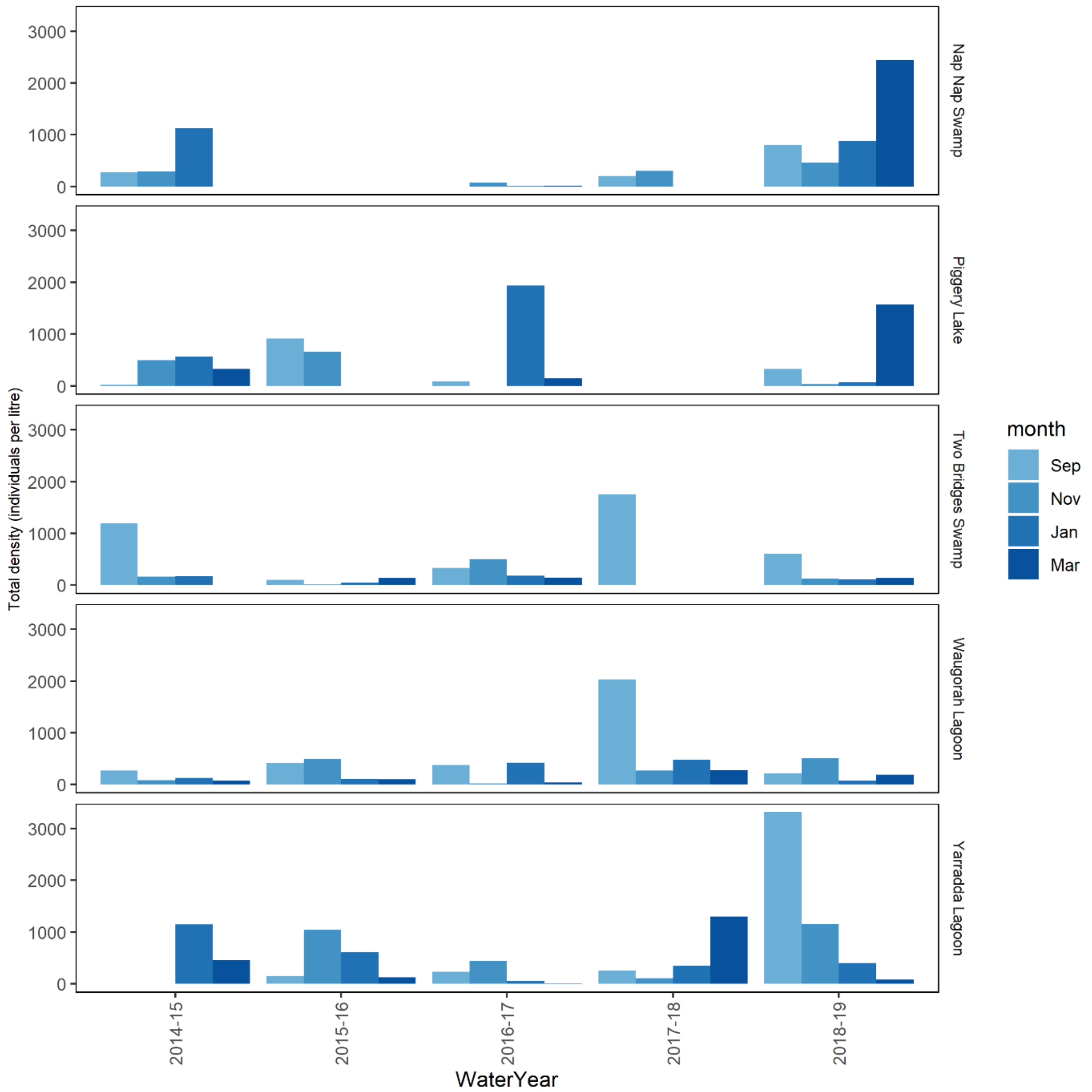


Figure 4-32 Mean densities of benthic microinvertebrates in wetlands targeted by watering action in 2018-19. Data are shown for all water years and for trips within water year. Data are shown for Nap Nap Swamp (first row) Piggery Lake (second row), Two Bridges Swamp (third row), Waugorah Lake (fourth row) and Yarradda Lagoon (fifth row).

Discussion

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

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee to support habitat, food resources and breeding requirements of waterbirds, native fish and other vertebrates. Over the past five years, inundation of these wetlands has consistently triggered a rapid and productive response of microinvertebrates in all zones with high densities throughout September, November, January and March. Benthic densities were very productive with densities 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*,).

The peak benthic densities (>1000/L) recorded across the five years of LTIM sampling were in the mid-Murrumbidgee in September and November 2018, November 2016, and January 2015 (see Figure **Error! Reference source not found.**). Differences in benthic and pelagic densities between zones is likely due to differences in water temperature. Generally, low densities were observed in March in all zones in all study years, apart from the mid-Murrumbidgee in 2014-15 and 2017-18 and the Nimmie-Caira in March 2019 (see Figure 29). In March, temperatures and water levels are falling, making conditions less than ideal for microinvertebrates. In addition, after at least six months of inundation, nutrients may become depleted, compared to the initial high flush of nutrients, and productivity falls.

Environmental watering of the mid-Murrumbidgee and Lowbidgee over the past five years facilitated ecosystem functioning, enhancing habitat suitability for high ecological value species that rely on wetland food-webs. Responses of microinvertebrates to inundation were consistently high across years and zones 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.

The current water regime supported by Commonwealth and NSW environmental water is yielding productive feeding habitats for filter-feeding waterbirds, fish, larval fish and tadpoles in terms of microinvertebrate densities. Based on information from fisheries research, microinvertebrate densities between 100-1000/L support larval fish and adult fish that predate on microinvertebrates (King 2004).

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).

In 2018-19, the largest volume of Commonwealth environmental water was delivered through the south Redbank system (Yanga National Park) and from Nap Nap Swamp to Waugorah Lagoon. The principle Commonwealth environmental watering actions that were monitored and influenced the hydrological regime of LTIM vegetation monitoring sites are outlined in Table 4-4.

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

Water Action Reference	Event	Objectives
10082-02 &10082-03	Yanga National Park: Yanga Lake top up and system watering (via 1AS)	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
NSW EWA	Nap Nap to Waugorah Lagoon (NSW EWA) 25/09/2018 - 2/11/2018	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
10082-04	Nimmie-Caira refuge flows Avalon Dam, Eulimbah, Telephone Creek	Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frogs (EPBC Act).
10082-08	Yarradda Lagoon Pumping	Maintain important refuge habitat for wetland dependant species, including for the Southern Bell frog; and maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18.
10082-09	Gooragool Lagoon Pumping	Maintain important refuge habitat for native fish, turtles and other water dependent biota.

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

Despite some variability in the composition of overstory species (which consist of a mix of river red gum and black box), understory communities across the 12 wetlands broadly fall into three key groups (Figure 4-). These include lignum-black box-red gum wetlands (Nap Nap, Telephone Creek, Avalon in the Gayini Nimmie-Caria and Waugorah Lagoon in the Redbank zone); tall emergent aquatic wetlands characterised by an understory of spike rush (*Eleocharis* species) and fringing river red gum (Mercedes, Two Bridges and Piggery Swamp in the Redbank Zone). All four of the wetlands in the mid-Murrumbidgee are classified as river red gum woodland with deeper open ox-bow lagoons and fringing river red gum (Sunshower, Gooragool, Yarradda, McKennas). Data square root transformed aggregated by quadrat and transect to give a single value for each site-survey combination. Tests for differences between unordered Community groups ANOSIM Global R 0.551, $p<0.001$) (pairwise test Lignum-Black Box - Tall Emergent R 0.483, $p <0.001$, Lignum-Black Box- oxbow lagoon R 0.591 $p<0.001$, oxbow lagoon - tall emergent R 0.753, $p <0.001$).

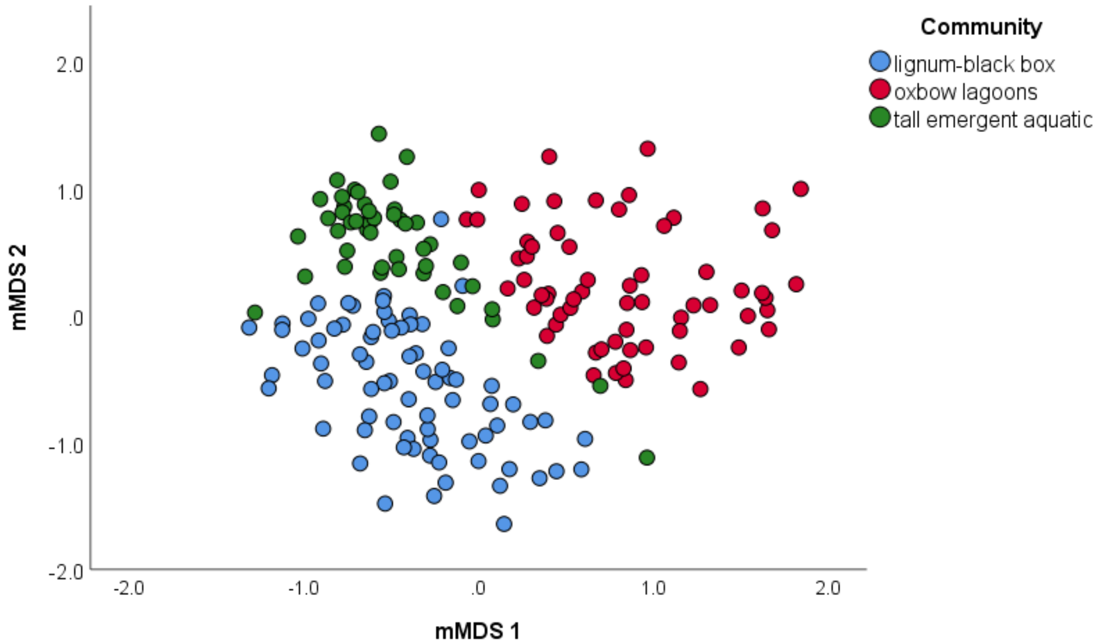


Figure 4-33 Threshold metric MDS plot showing groupings of site-surveys into the three broad vegetation community types. Each circle represents a single survey of a wetland site with all quadrat and transect data averaged to give a single value for species percentage cover on each site-survey occasion. Analysis includes all discrete species records. Circles that are close together share more species in common relative to those that are further away. Data is squere root transformed.

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 as per the standard methods outlined in the Murrumbidgee Monitoring and Evaluation Plan (Wassens *et al.* 2014), 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 metre quadrats depending on transect length. Data on the percentage cover of each species, open water, bare ground, leaf litter, and logs > 10 cm, tree canopy crown cover, water depth (cm) and soil moisture (Categorical dry (0)– soil completely dry and powdery, damp (1)- soil shows evidence of moisture staining, waterlogged (2) – soil surface shiny, visible water when soil surface is depressed, and submerged (3) - visible standing water over soil surface) are also collected at each site.

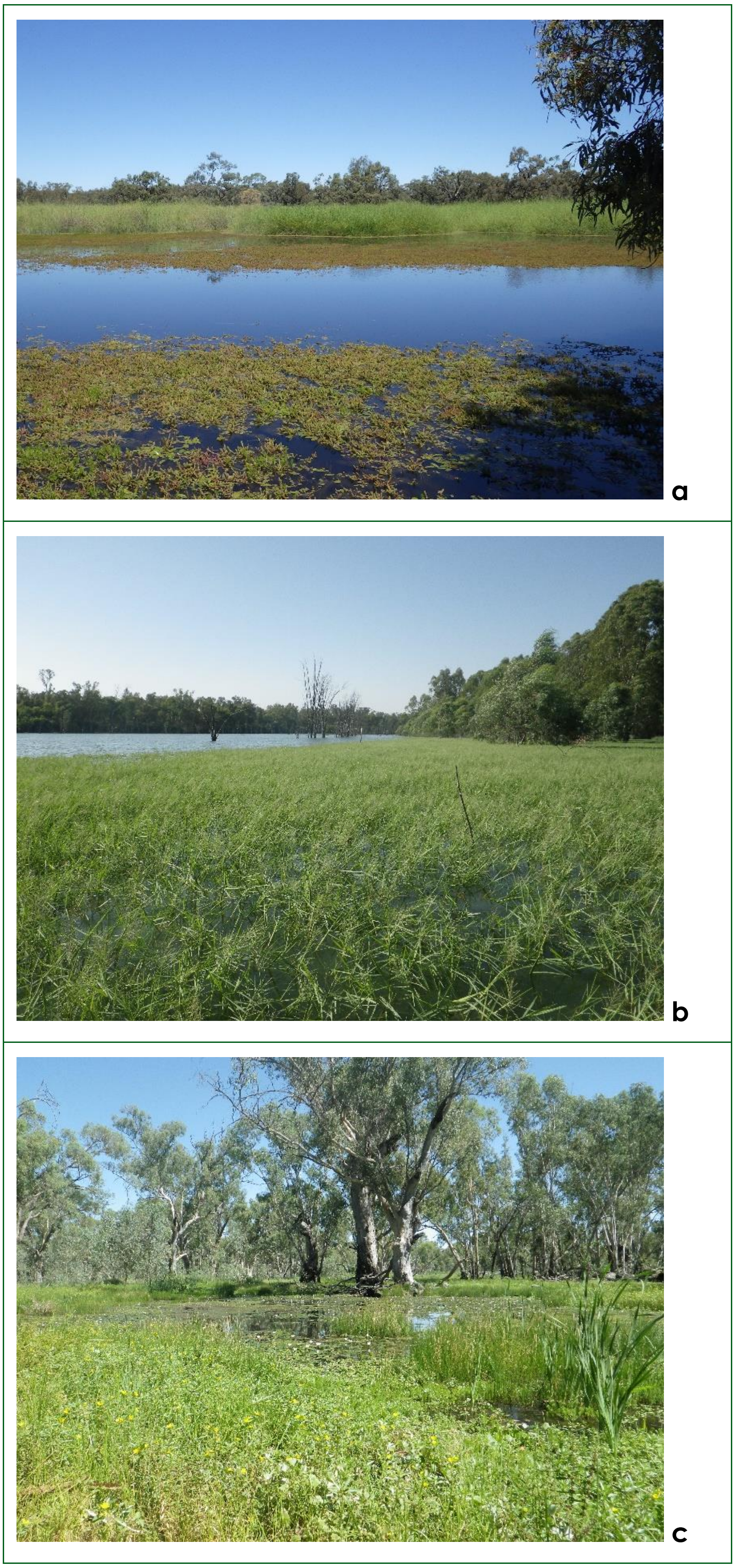


Plate 4-4 Examples of the three dominant vegetation communities: (a) Avalon Dam - lignum-black box-red gum, (b) Yarradda Lagoon - oxbow lagoon with fringing river red gum, (c) Two Bridges Swamp - tall emergent spike rush communities with fringing river red gum.

Data analysis

Comparisons of community structure and species diversity were undertaken using Primer version 6 (Clarke *et al.* 2006). Prior to analysis data from individual quadrats and transects were aggregated to give a single percent cover for each species for each site-survey combination (12 sites, 4 survey occasions giving an n of The percentage cover of each species was Square Root 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 five year monitoring period. Spearman's RHO tests were used to describe the relationship between species richness and wetland water regime. Comparisons of community composition between each vegetation community during its wet and dry phase were undertaken using PERMANOVA with Bray Curtis dissimilarity (site treated as a random factor). High numbers of zero counts were standardised using by adding 0.1 to all values prior to 4^{th} root transformation.

Sites were classified as dry when then were no standing water when one or less of the nine or 10 quadrats surveyed at the site contained standing water (less than 10%) of survey quadrats, and when then more than 10% of quadrats contained standing water.

All species were assigned functional groups according to Brock and Casanova (1997) for analysis species that fell into the terrestrial dry and terrestrial damp categorises were assigned into the terrestrial group, while those that fell into the amphibious groups were assigned as water dependant. The native or introduced status of each species was assigned based on the NSW Plantnet status classification.

Results

Commonwealth environmental water contribution to vegetation species diversity

Overall, environmental water contributed to a significant increase in the number of water dependent (Kruskal-Wallis 41.295, $p<0.001$) and native (KW 6.928, $p=0.008$) flora species, while contributing to a decrease in the species richness of exotic (KW 14.915, $P<0.001$) and terrestrial species (KW 18.987, $p<0.001$) (Figure 4-34).

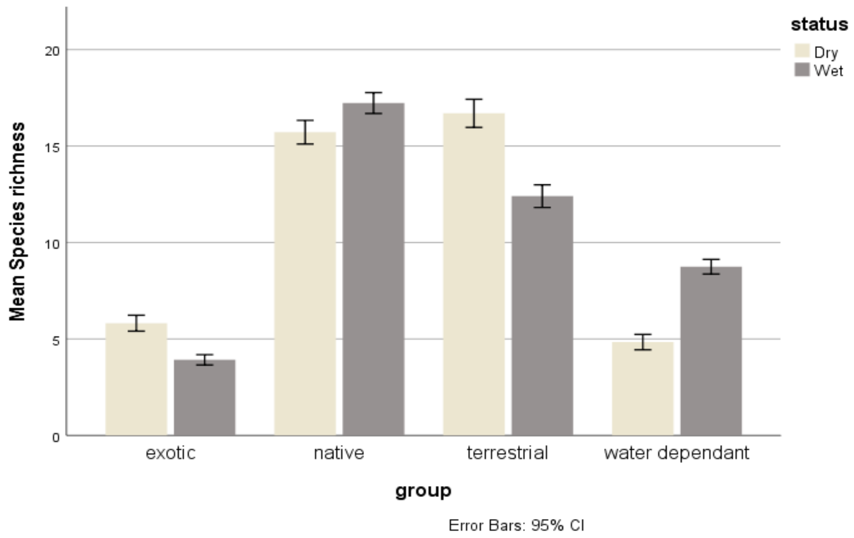


Figure 4-34 Mean differences in species richness during wet and dry phases between four main plant groups.

Commonwealth environmental water increased the availability of wetted soils and the species richness of water dependent species was significantly higher in areas where soil was either water logged or submerged, compared to areas where it was dry or damp (Jonckheere-Terpstra test 5.741, p =<0.001) (Figure 4-305). Terrestrial species richness declined (JT -7.469, p =<0.001), exotic species richness declined (JT -7.573, p =<0.001), whereas native species richness did not differ between soil moisture classes.

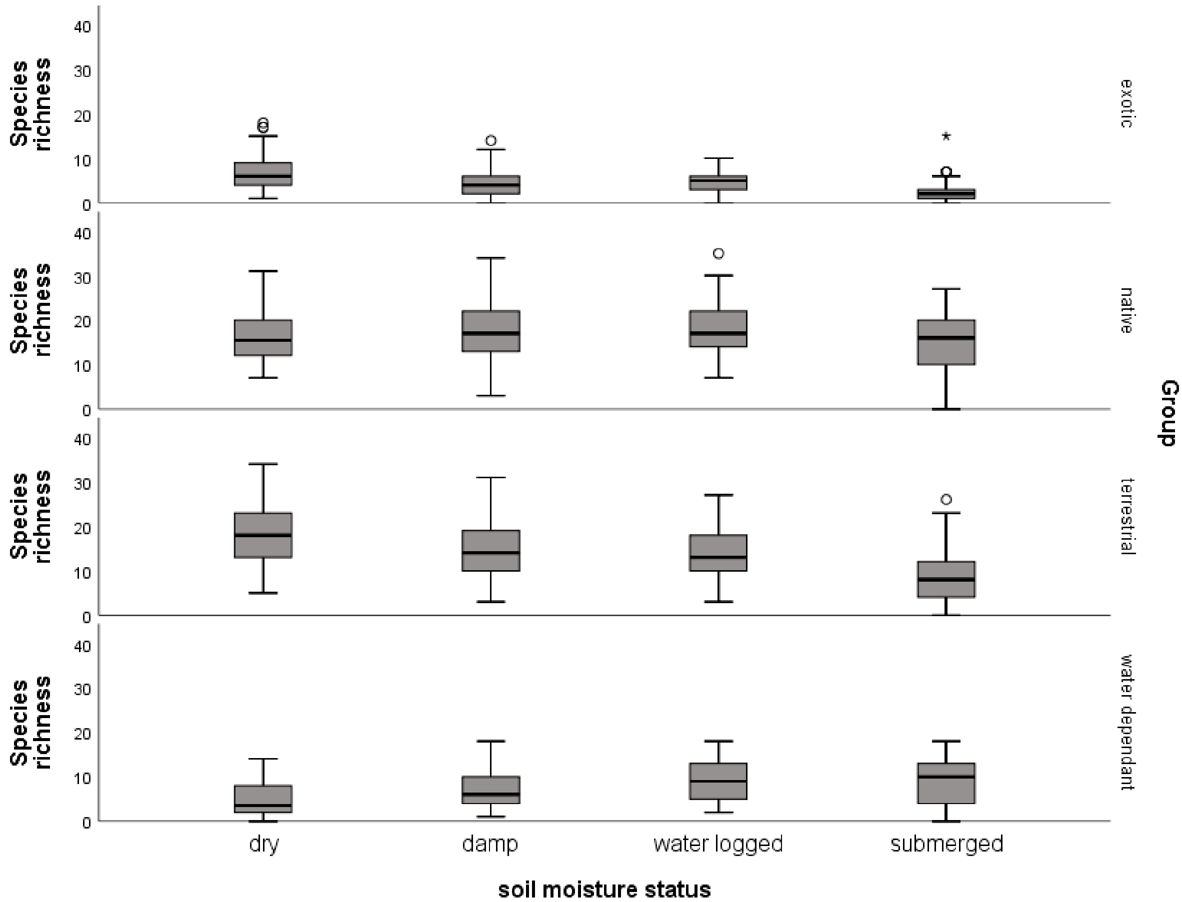


Figure 4-30 Mean species richness of the four plant groups across the four soil moisture classes.

This link between diversity and the availability of water means that water dependent species is lowest when larger numbers of sites are dry and increases with an increasing number of wet sites. As a result, care needs to be taken when interpreting the broader patterns of species richness across the five-year monitoring period, since differing diversity tends reflect both the number of monitored wetlands inundated in a given year, and the general community composition of those wetlands.

However, it is worth commenting on some specific trends related to management intervention in the Redbank system and the mid-Murrumbidgee. In 2017-18, all three of the monitored tall emergent spike rush wetlands in the Redbank system received a managed draw down with the aim of allowing for litter breakdown. In 2018-19, two of the three wetlands received extended duration watering as part of the Golden Perch to Tala Lake Flow, while the third wetland Mercedes swamp remained dry throughout the year. There was a subsequent increase in species richness between 2017-18 and 2018-19 following the Golden perch flow through these wetlands.

Long term relationships between CEWO watering regimes and species richness

Water regime relates to the number of times that a wetland receives water over time. In this instance, we considered the role of Commonwealth environmental water in creating a water regime that contributed to increased species richness of desirable plant groups – namely water dependent and native species. Water regime was calculated as a proportion based on the average number of times that each quadrat was wet divided by the total number of surveys over the five years. Species richness was calculated the mean value for each site across all survey occasions. Overall, wetlands that received water most frequently had higher species richness than those that rarely received environmental water, with species richness of water dependent species increasing with increasing watering frequency although this relationship was not significant to 95% ($r = 0.503$, $p = 0.095$). Terrestrial species showed the opposite trend with species richness declining with increased watering frequency (r -6.92, $p = 0.013$). The species richness of exotic species also decreased with increasing frequency of watering (r -6.50, $p = 0.022$) while the richness of native species did not change in response to increased watering frequency ($r = 0.182$, $p = 0.572$)(Figure 4-6).

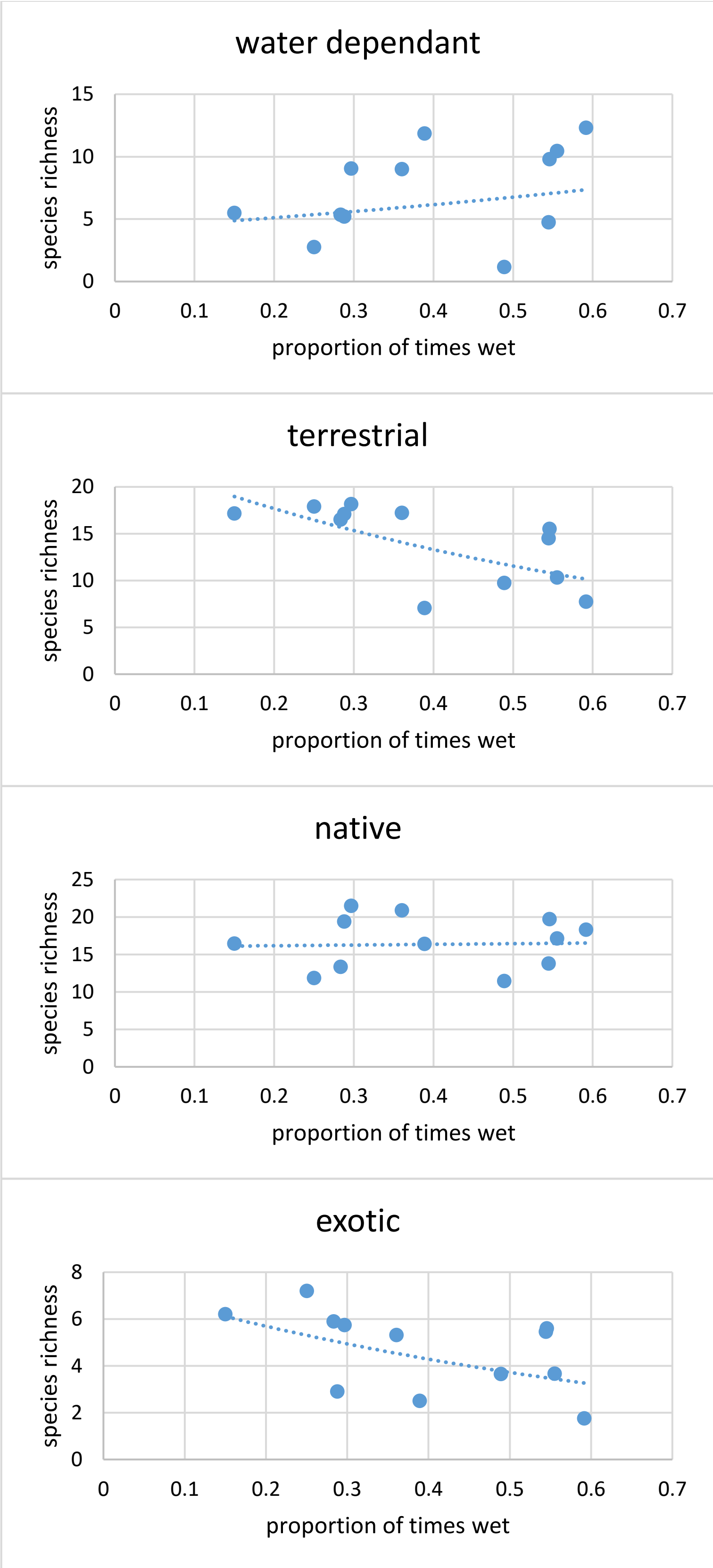


Figure 4-36 Scatter plots of mean species richness for water dependent, terrestrial, native and exotic species relative to the mean proportion of times that survey transects received managed environmental water between 2014 and 2019.

Cumulative species richness mid-Murrumbidgee wetland recovery

Since 2014, Commonwealth environmental water has been used to restore the natural seasonal inundation regime in Yarradda and Gooragool Lagoons. These actions were aimed at re-establishing key water dependent species which were lost from these wetlands during the millennium drought (Wassens *et al.* 2016). Over the five year period, Yarradda and Gooragool Lagoons received environmental water in four of the five years, with an unregulated flow filling the wetlands in 2016. By contrast, Sunshower and McKennas Lagoons received environmental water on only one occasion (2017) as well as unregulated flow in 2016. Wetlands that received environmental water multiple times between 2014 and 2019 (e.g. Yarradda and Gooragool Lagoons) had higher overall diversity of native water dependent species and native water dependant species established at a higher rate when compared to wetlands that received environmental water on just one occasion (Figure 4-3137). 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 in 2017, while curly pondweed (*P. crispus*) was also identified at Sunshower for the first time. However, no additional species were identified in these wetlands in 2018-19. Yarradda Lagoon has shown a steady increase in the number of aquatic species being recorded with two additional species identified following Commonwealth environmental watering, water primrose (*Ludwigia peploides* ssp. *montevidensis*) and nardoo (*Marsilea drummondii*) in 2017-18 and water wort (*Elatine gratioloides*) and slender knotweed (*Persicaria decipiens*) recorded in 2018-19. Gooragool Lagoon had a high diversity of aquatic species overall, but there were no new species identified in 2017-18 or 2018-19.

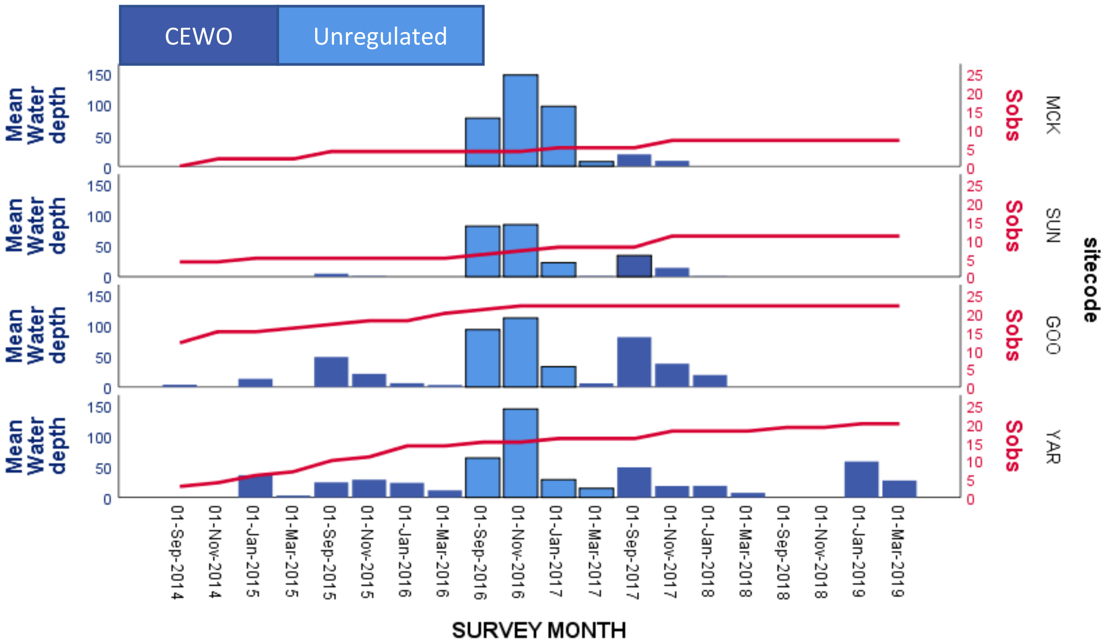


Figure 4-317 Species accumulation curve for water dependent species in wetlands in the mid-Murrumbidgee relative to mean water depth (cm) between September 2014 and March 2019 (Site codes: MCK = McKennas Lagoon, SUN = Sunshower Lagoon, GOO = Gooragool Lagoon, YAR = Yarradda Lagoon).

Did Commonwealth environmental water contribute to vegetation community diversity?

Environmental water contributed to significant differences in the types of species present within individual wetlands and across different community types during the wet (environmental water and unregulated flows) and dry phases (Permanova F 2.4756, P<0.001)(Figure 4-328).

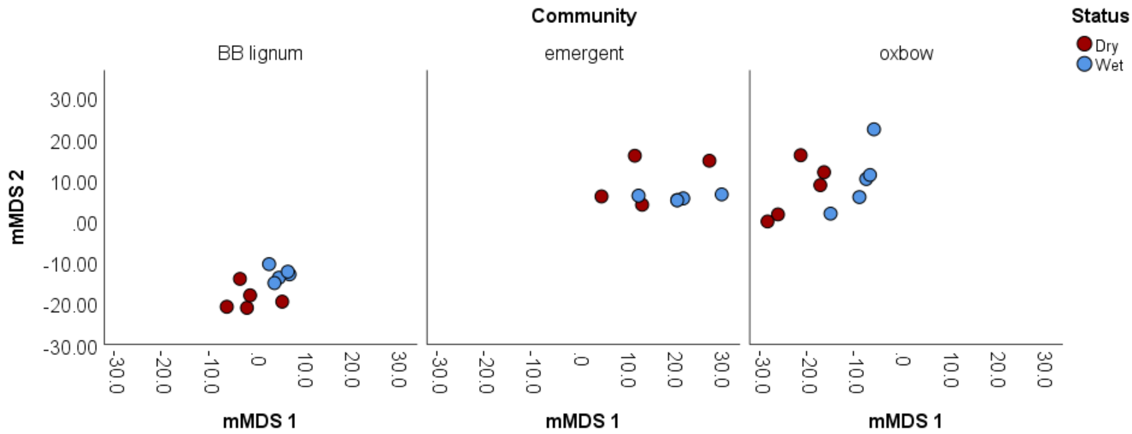


Figure 4-328 Metric multidimensional scaling plot of wetland vegetation community structure within the three water management zones during wet and dry phases between September 2014 and March 2019. The greater the overlap the more similar the wet and dry phases are between vegetation communities (BB lignum = Nimmie-Caira wetlands, emergent = Redbank wetlands, and oxbow = mid-Murrumbidgee wetlands).

Species composition

Based on SIMPER analysis, native water dependant species contributed highly to vegetation communities following environmental water. In particular, old man weed (*Centipeda cunninghamii*), lesser joyweed (*Alternanthera denticulata*), common spike rush (*Eleocharis acuta*), tall spike rush (*Eleocharis sphacelata*), nardoo (*Marsilea drummondii*), water primrose (*Ludwigia peploides*), and common water milfoil (*Myriophyllum papillosum*) (Table 5Table). While a mix of native water dependent and terrestrial species contributed most to the composition of wetlands during their dry phase, including crumb weed (*Dysphania pumilio*), caustic weed (*Chamaesyce drummondii*). Old man weed was also relatively abundant at dry sites, particularly in the months following environmental watering.

Table 4-5 SIMPER comparisons of vegetation communities while wetlands are wet (environmental water and unregulated flows) and dry in each vegetation community. Only species with contributions greater the 4% have been included.

Species supported by environmental water	**Av. Abundance**	**% contribution**	**Species occurring during dry phases**	**Av. Abundance**	**% contribution**
Redbank - Tall spike rush community					
Eleocharis sphacelata_AN	1.76	14.47	*Centipeda cunninghamii_AN*	1.06	11.13
Eleocharis acuta_AN	1.47	13.71	*Eleocharis acuta_AN*	1.15	9.74
Marsilea drummondii_AN	1.12	10.31	*Ludwigia peploides_AN*	0.91	9.22
Ludwigia peploides_AN	1.06	7.97	*Eleocharis sphacelata_AN*	0.96	8.26
Myriophyllum papillosum_AN	0.8	4.56	*Marsilea drummondii_AN*	0.8	7.31
Pratia concolor_TN	0.68	4.34	*Persicaria decipiens_AN*	0.74	6.64
Azolla filiculoides_AN	0.85	4.28	*Alternanthera denticulata_TN*	0.59	4.81
			Marrubium vulgare_TI	0.6	4.77
			Chamaesyce drummondii_TN	0.58	4.68
			Eucalyptus camaldulensis_TN	0.46	4.52
Mid-Murrumbidgee - Oxbow lagoons					
Eucalyptus camaldulensis_TN	0.99	20.59	*Eucalyptus camaldulensis_TN*	1.04	13.13
Eleocharis acuta_AN	0.93	13.23	*Cirsium vulgare_TI*	0.9	8.72
Centipeda cunninghamii_AN	0.81	9.69	*Calotis scapigera_TN*	0.83	8.52
Alternanthera denticulata_TN	0.66	7.33	*Atriplex semibaccata_TN*	0.69	6.82
Atriplex semibaccata_TN	0.54	5.88	*Centipeda cunninghamii_AN*	0.68	6.39
Pseudoraphis spinescens_AN	0.66	4.9	*Polygonum aviculare_TI*	0.71	6.21
			Dysphania pumilio_TN	0.66	4.8
			Cynodon dactylon_TN	0.56	4.79
			Chamaesyce drummondii_TN	0.54	4.65
Nimmie – Caira - Lignum-Black Box communities					
Duma florulenta_AN	1.55	20.01	*Duma florulenta_AN*	1.29	19.26
Marsilea drummondii_AN	0.76	6.73	*Centipeda cunninghamii_AN*	0.95	10.66
Centipeda cunninghamii_AN	0.81	6.72	*Chenopodium nitrariaceum_TN*	0.7	7.89
Eleocharis pusilla_AN	0.84	6.33	*Heliotropium europaeum_TI*	0.82	6.57
Eleocharis acuta_AN	0.78	6.32	*Marsilea drummondii_AN*	0.8	6.28
Ludwigia peploides_AN	0.75	5.16	*Alternanthera denticulata_TN*	0.66	5.99
			Dysphania pumilio_TN	0.62	5.32

TN = terrestrial native species, TI = Terrestrial introduced species, AN = water dependent native species

Discussion

There were five key watering actions undertaken in 2018-19 that influenced the hydrology of nine of the 12 monitored wetlands. Overall, these watering actions were successful in achieving the stated objectives with respect to vegetation, but outcomes varied between individual wetlands. Species richness of water dependant and native species was higher in wetlands receiving Commonwealth environmental water compared to, and following on from, 2017-18 where monitored wetlands in the Nimmie-Caira and Redbank were largely dry during the September to March monitoring period. In the Redbank system, the wetlands that had undergone a short dry period quickly re-established water dependent communities following Commonwealth environmental watering with little change in community composition. Allowing for an occasional short drying period can have a positive impact on vegetation communities in some seasonally inundated wetlands and in 2017-18 we predicted that 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. This prediction was largely supported in the tall spike rush wetlands of the Redbank systems with species richness increasing slightly in 2018-19 compared to 2016-17 and 2017-18 but these differences was not statistically significant. While some watering actions were undertaken in the Gayini Nimmie-Caria in 2018-19, with the exception of Nap Nap Lagoon, these actions largely targeted the permanent refuge pools and there was limited inundation of the wetland margins where the majority of water dependant vegetation species occur.

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. Despite the high level of natural variability between wetlands, there were clear trends with respect to species and community diversity occurring as a result of Commonwealth environmental water. In general, wetlands receiving environmental water more frequently over the past five years support higher species richness of water dependent species and lower numbers of exotic species. This demonstrates the role of long-term water planning in creating water regimes that support the establishment and maintenance of water dependent communities.

From a management perspective it can be useful to consider general trends within individual wetlands when developing longer term watering strategies. Two key wetlands, Avalon (Plate 4-1) and Telephone Creek in the Gayini Nimmie-Caria, while receiving some top up flows from the permanent dam and creek line, have received limited inundation of the larger wetland area which typically supports the greatest diversity of water dependent species. Avalon Swamp wetland was historically flooded in most years, but due to concerns about water stress to fringing black box, there has been a more cautious approach to watering since 2014, with Commonwealth environmental water mainly used to maintain water in the associated dam. The larger lignum wetland complex has contained water on only 20% of survey occasions. This is likely to have contributed to the decline in the number of water dependant species recorded and generally lower diversity during unregulated flows. Likewise, the creek line of Telephone Creek has been continually wet, but the surrounding lignum wetland has contained water on 30% of surveys with a general decrease in the number of water dependent species detected over the five years. Increasing the frequency and duration of spring-summer inundation in these two wetlands may be required to assist in the reestablishment of native plant species and maintain water dependent vegetation communities.

Plate 4-1 Avalon swamp after environmental watering in 2008 (top) and after partial watering in 2019.

4.5 Wetland fish

Prepared by Skye Wassens (CSU)

Introduction

Native fish communities in the Murrumbidgee catchment are severely degraded, exhibiting declines in abundance, distribution and species richness (Gilligan 2005). Floodplain fish communities are particularly degraded and many of the small-bodied floodplain species that were historically abundant throughout the Murrumbidgee River wetland habitats, including the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis agassizii*) are now considered locally extinct (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.

In 2018-19, Commonwealth environmental water was delivered to LTIM monitored wetlands in the mid-Murrumbidgee, Nimmie-Caira and Redbank (Table 4-6).

Table 4-6 Summary of environmental watering actions that influenced wetland fish diversity during the monitoring period.

Water Action Reference	Event	Objectives
10082-02 &10082-03	Yanga National Park: Yanga Lake top up and system watering (via 1AS)	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
NSW EWA	Nap Nap to Waugorah Lagoon (NSW EWA) 25/09/2018 - 2/11/2018	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
10082-04	Nimmie-Caira refuge flows Avalon Dam, Eulimbah, Telephone Creek	Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frogs (EPBC Act).
10082-08	Yarradda Lagoon Pumping	Maintain important refuge habitat for wetland dependant species, including for the Southern Bell frog; and maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18.
10082-09	Gooragool Lagoon Pumping	Maintain important refuge habitat for native fish, turtles and other water dependent biota.

Evaluation Questions

- 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 *et al.* (2014). Wetland fish are surveyed using a combination of two large and two small fyke nets which are set overnight. The fish Catch-Per-Unit Effort (CPUE) is based on the number of fish collected standardised by net soak time 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 using a three way permutational analysis of variance (PERMANOVA) with Water Year (n=5) and Zone (n=3) as fixed factors and site (n=12) as a random factor.

To determine differences in fish communities among years and zones, abundance data were analysed using two-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson *et al*. 2008) in Primer Version 7. 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 $p<0.10$. 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 nested within zone.

Recruitment

The proportion of the total catch represented by recruits was estimated for each site survey using the following criteria: Large-bodied and generally longer-lived species (max. age >3 years) were considered recruits when length was less than that of a one-year-old. Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature, or by expert opinion when literature was not available (Table 4-7Table 3).

Table 4-7 Size limits used to distinguish new recruits for each species. Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)
Native species	
Australian smelt	40 mm (Pusey *et al.* 2004)
bony herring	67 mm (Cadwallader 1977)
carp gudgeon	35 mm (Pusey *et al.* 2004)
river blackfish	80 mm
golden perch	75 mm (Mallen-Cooper 1996)
Murray cod	222 mm (Gavin Butler, *Unpublished data*)
Murray-Darling rainbowfish	45 mm (Pusey *et al.* 2004: for *M. duboulayi*)
silver perch	75 mm (Mallen-Cooper 1996)
trout cod	150 mm
un-specked hardyhead	38 mm (Pusey *et al.* 2004)
Alien species	
common carp	155 mm (Vilizzi and Walker 1999)
Gambusia	20 mm (McDowall 1996)
Goldfish	127 mm (Lorenzoni *et al.* 2007)
oriental weather loach	76 mm (Wang *et al.* 2009)

Relationship between the proportions of recruits within the catch of each species, overall diversity of native species, and the diversity of native and exotic species with recruits and the wetland water regime (proportion of days wet) was described using Spearman's Rank Correlation.

Results

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

Between 2014 and 2019 nine native and six exotic fish species were captured across the 12 LTIM wetland sites (Table 8). Notable species recorded included golden perch, which occurred across wetlands in the mid-Murrumbidgee and Nimmie-Caira, Murray Cod recorded at Eulimbah and Avalon swamps, and silver perch recorded in Yarradda Lagoon. Other native fish species included carp gudgeon, which was widespread, and very abundant, Australian smelt, bony herring and Murray-Darling rainbowfish were relatively widespread, while un-specked hardyhead and flat-headed gudgeon were infrequently recorded. Of the introduced species, carp, gambusia, oriental weatherloach and goldfish were all widespread and abundant across all wetlands, while red find perch was recorded in frequently and in low abundance. Native species diversity was highest in wetlands that have an area of permanent water, including Avalon swamp, Telephone creek and Waugorah Lagoon (Figure 4-40).

Across the five year period the diversity of native species was positively correlated with increasing water permanence (measured here as the proportion of days that the wetland contained water (from all sources) across the five year period) (Spearman's RHO 0.636, p = 0.026)(Figure 4-441). While the diversity of exotic species showed no relationship with wetland permanence (Spearman's -0.112, p = 0.729)(see Figure 4-4-41). The composition of fish communities also varied significantly between water years (Figure 4-42).

Table 4-8 Total number of individuals recorded across the five years at each of the 12 monitoring sites.

	Gooragool Lagoon	McKennas Lagoon	Sunshower Lgoon	Yarradda Lagoon	Avalon Swamp	Eulimbah Swamp	Nap Nap Swamp	Telephone Creek	Mercedes Swamp	Piggery Lake	Two Bridges Swamp	Waugorah Lagoon
Murray cod					2	4						
golden perch	2	3	7	4		1		3				
silver perch				7								
Australian smelt	27	4	257	161	5	118	15	166			2	19
bony herring	112			366	293	346	7	390		4	137	136
carp gudgeon	7698	393	376	16017	12949	3811	3121	8466	358	6595	15330	25559
flat-headed gudgeon	1			91	1	8				2		
Murray-Darling rainbowfish		22	49	285	1	47		125	4	63	19	85
un-specked hardyhead			1	6		22				1		
common carp	1269	4032	3702	5172	6112	16304	9846	4840	3312	5125	33342	13514
gambusia	4931	961	739	7361	3545	925	1978	8639	4877	5221	31344	708
goldfish	404	28	33	594	149	547	125	355	19	230	1675	921
oriental weatherloach	12	2	2	3	51	61	48	47	224	949	3877	35
redfin perch	2	1		1								

Key

(lightest shading)	1-100
(medium shading)	101-1000
(darkest shading)	>1000

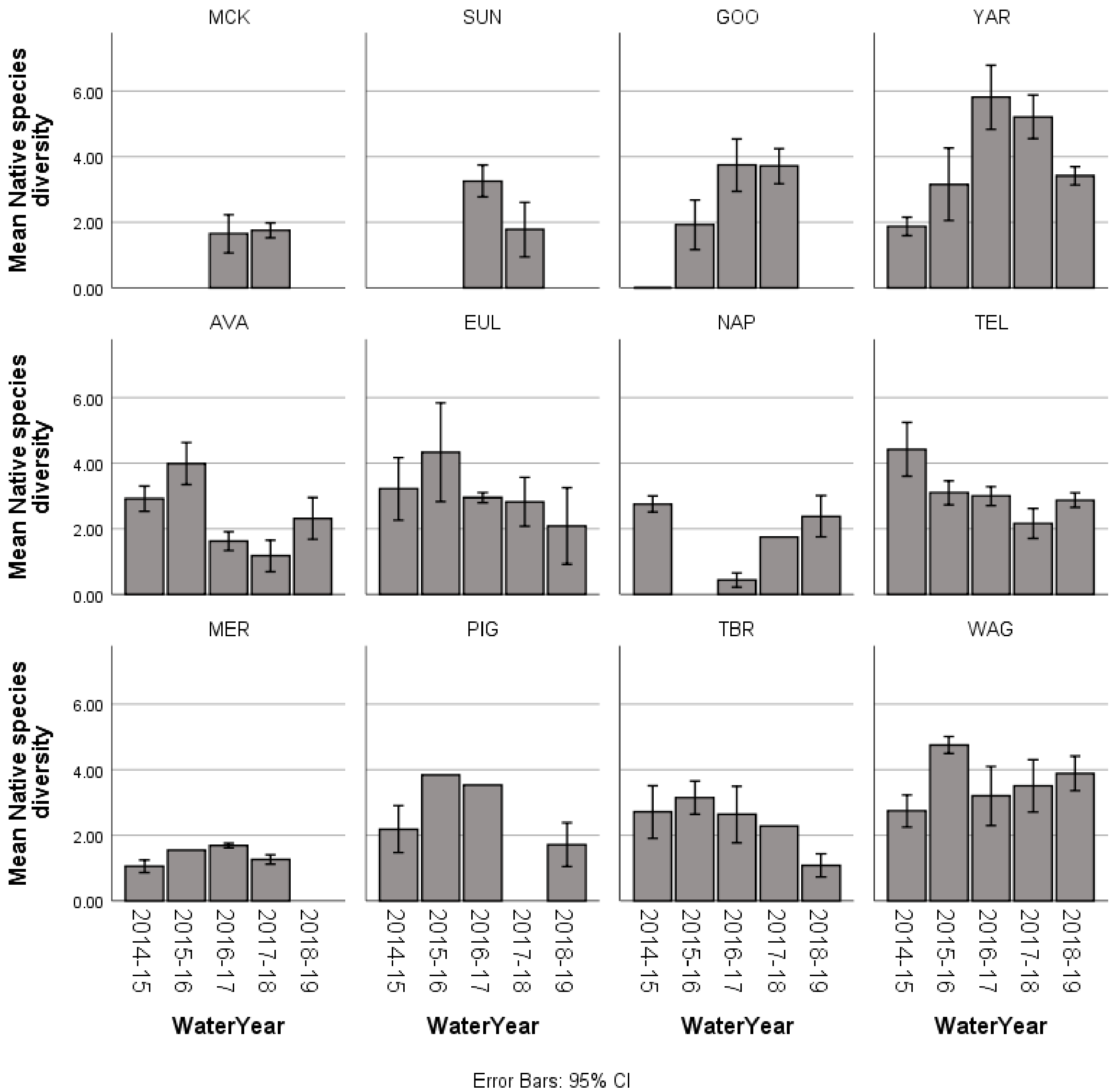


Figure 4-40 Native fish diversity between 2014 and 2019 at the 12 monitored wetlands (blank value indicates that the wetland did not hold water during that year.

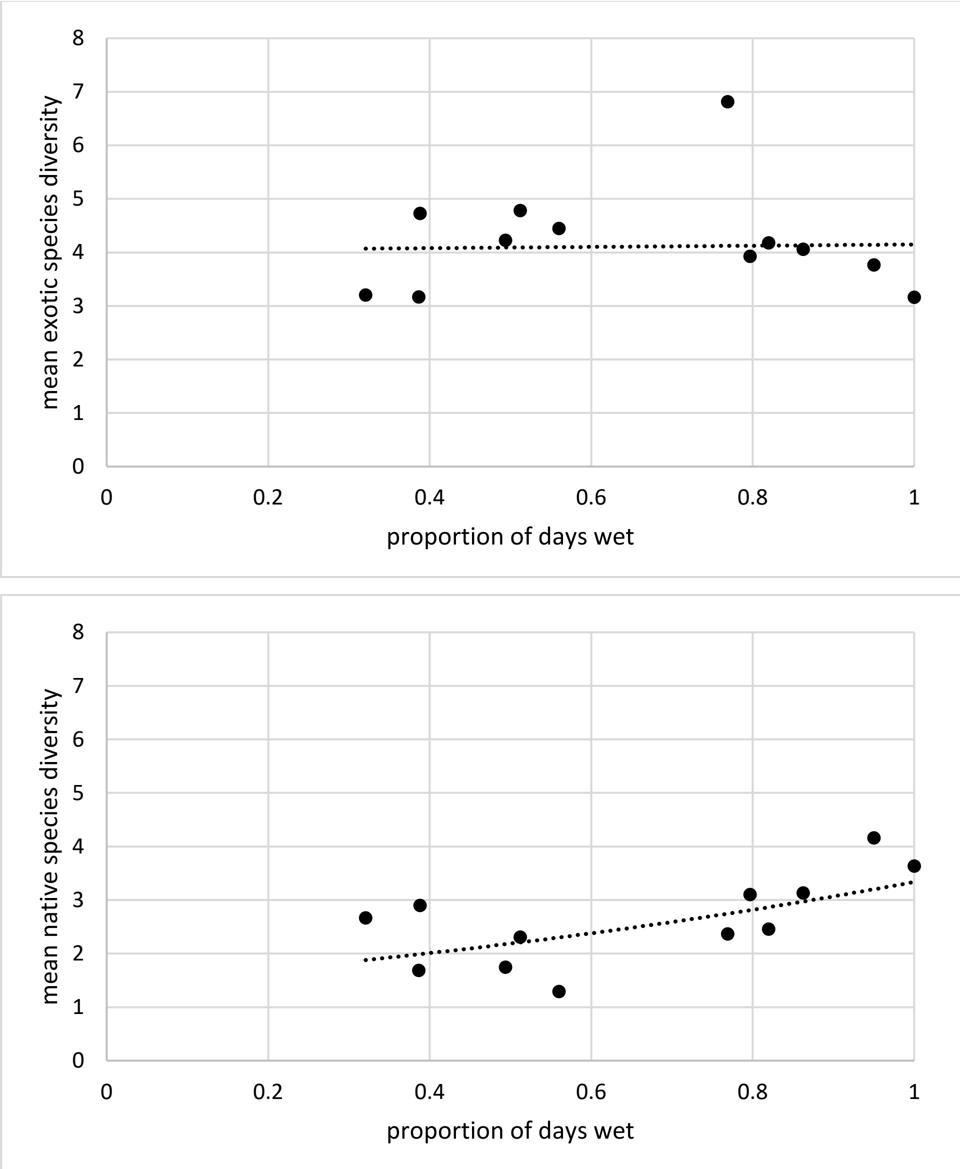


Figure 4-41 Relationship between species diversity of native (bottom) and exotic (top) species at each wetland relative to the proportion of days the wetland contained water between September 2014 and April 2019.

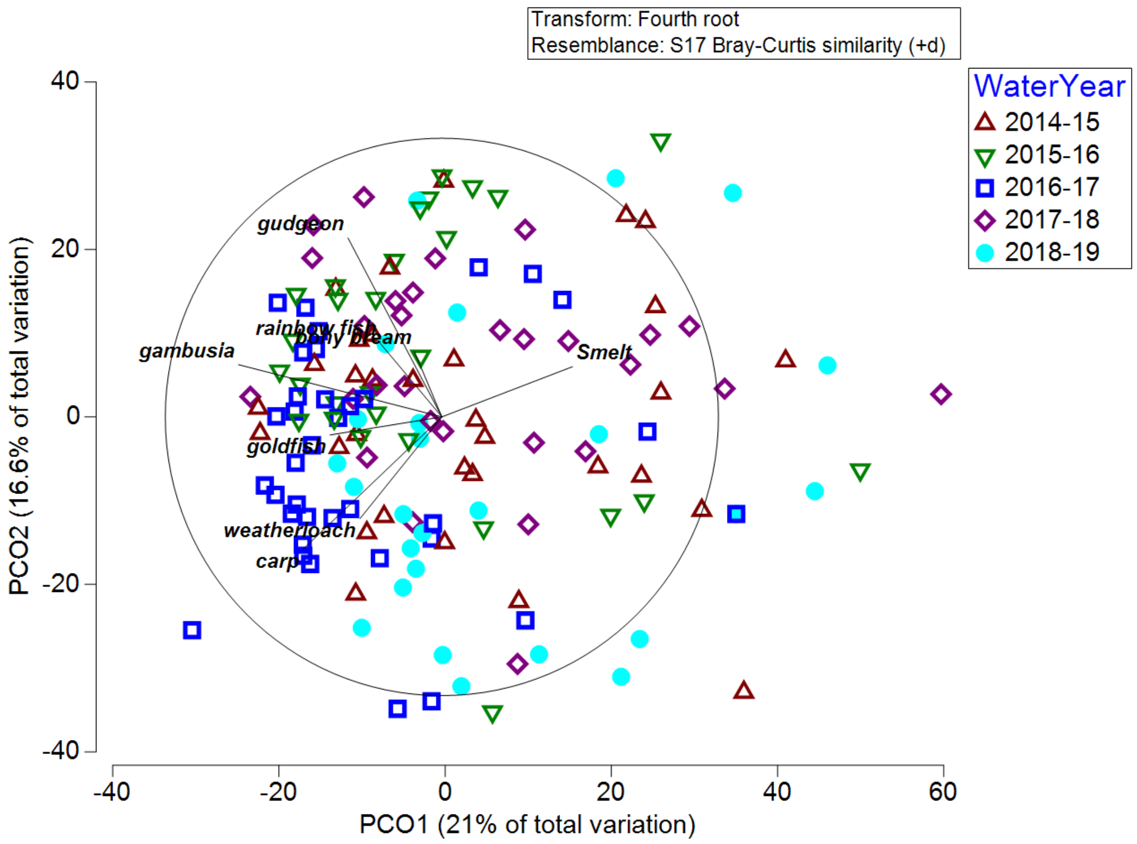


Figure 4-42 Results of a Permutational Multivariate Analysis of Variance for fish communities by water year.

Yarradda Lagoon pumping

Management of water levels at Yarradda Lagoon involves the use of pumping infrastructure in 2014-15, 2015-16, followed by unregulated inflows in 2016-17, then pumping and regulated river to wetland connections in 2017-18 and finally a draw down and refilling using pumps in November 2018. Given this unique combination of pumping and riverine reconnections allows us to investigate the influence of different water management approaches on native fish communities.

Overall native fish diversity peaked at Yarradda Lagoon following unregulated wetland reconnection in 2016-17 with silver and golden perch both entering the lagoon (Figure). Following the draw down in November 2018, native fish diversity declined from the 2016-17 levels, but was still slightly higher then 2014-15 and 2015-16 following previous CEWO pumping actions. Australian smelt, bony herring, carp gudgeon, flat-headed gudgeon and Murray-Darling rainbowfish all recorded after pumping, suggesting that these small bodied native species may be able to enter wetlands via pumping infrastructure.

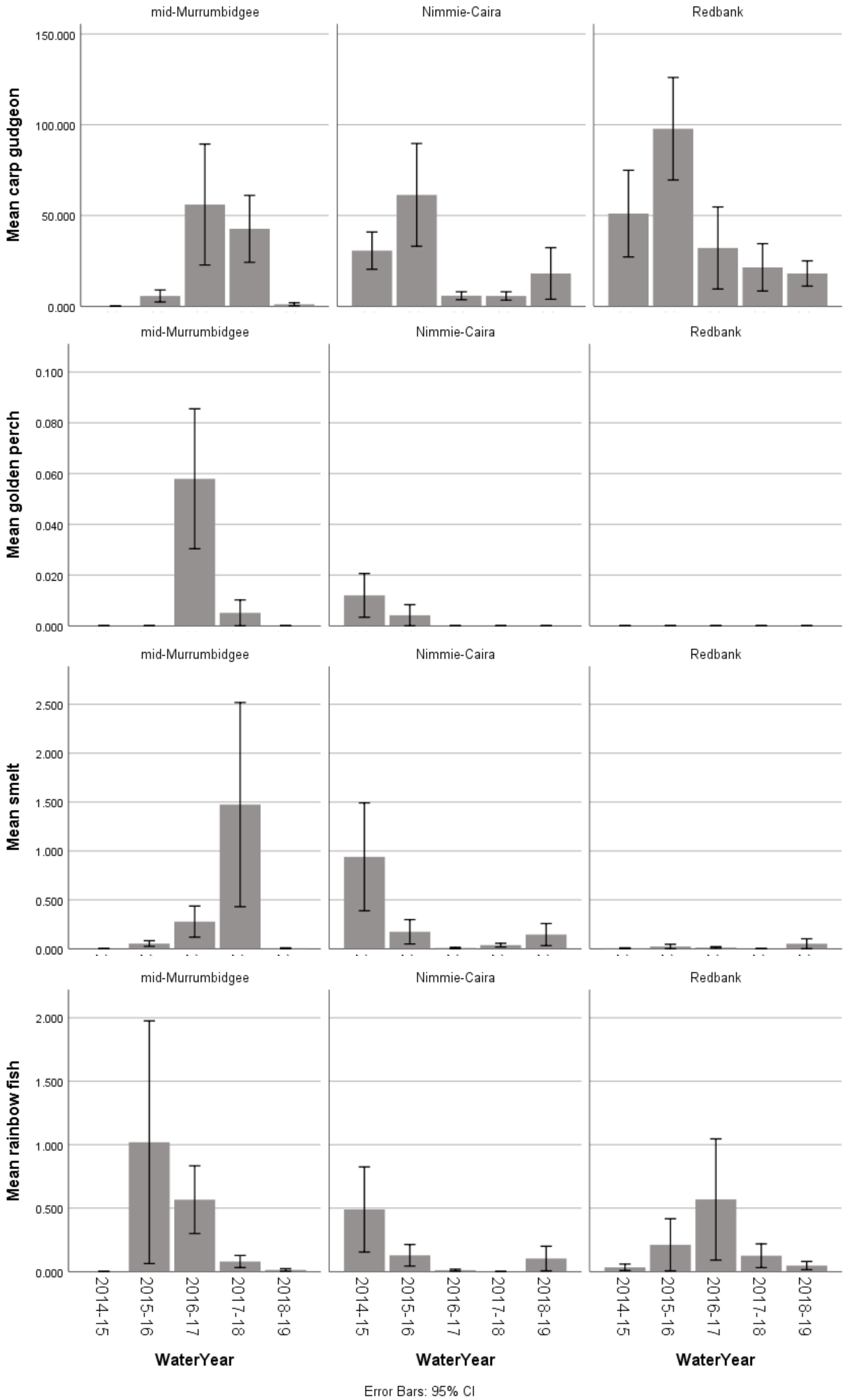


Figure 4-43 Mean catch per unit effort (CPUE) (+ 95% CI) of native species. Note that for clarity the y-axis are on differing scales.

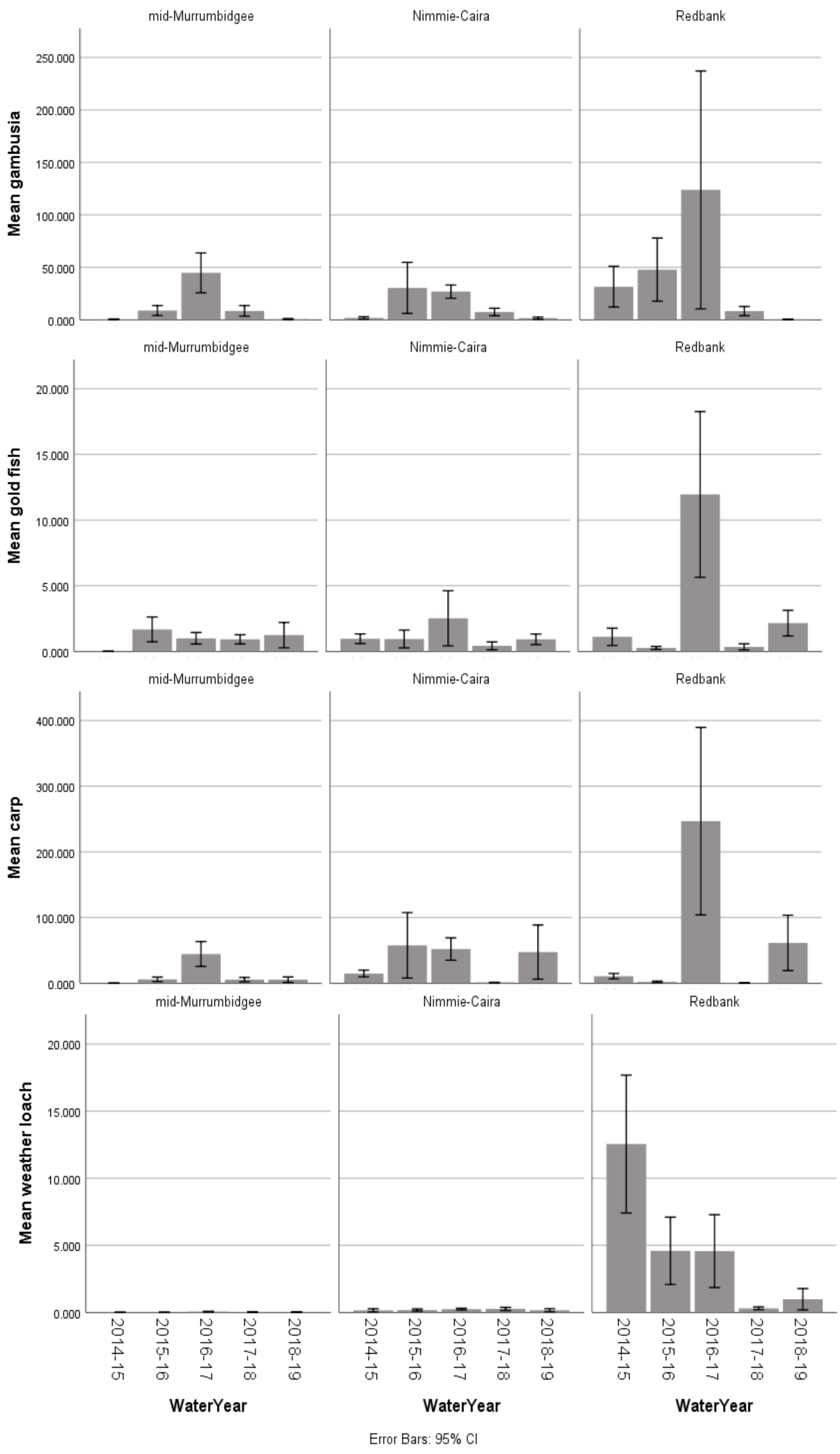


Figure 4-44 Mean catch per unit effort (CPUE) (+ 95% CI) of exotic species. Note that for clarity the y-axis are on differing scales.

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

Over the five years, body size of nine native and five exotic species were measured. Carp gudgeon catch was dominated by juveniles (84%), and of the 103 flat head gudgeon measured, all were juveniles, while 46% of rainbow fish were juveniles (Table 4-9). Australian smelt and bony herring catches were dominated by non-juveniles, while only small numbers of large bodied native fish were recorded, all of the Murray cod captured were juveniles, compared to 10% of the golden perch catch, seven silver perch were recorded over the five years and all were non-juvenile. In terms of exotic species, juveniles dominated the catch for carp and goldfish (92 and 95% respectively), while gambusia and weather loach catches were dominated by non-juveniles (80 and 79% respectively).

The proportion of juveniles remained relatively consistent across water years for carp gudgeon, carp and gambusia (Figure 4-45). While the proportion of juveniles in the annual catch varied considerably between years for other small bodied native species, with Australian smelt having a higher proportion of juveniles in 2015-16 (44%) compared to the five year average of 15%, while bony herring juveniles represented a higher proportion of the catch in 2014-15 (36%) compared to the five year average of 17%. Murray-Darling Rainbow fish also had a higher proportion of juveniles in 2014-15 (84%) compared to the five year average of 37%.

Table 4-9 Total number of native and exotic fish and their proportion by age class.

		Proportion of measured	
Native species	**Total measured**	**Non-Juvenile**	**Juvenile**
Australian smelt	636	0.87	0.13
bony herring	1367	0.81	0.19
carp gudgeon	11233	0.16	0.84
Flat-headed gudgeon	103	0.00	1.00
Murray-Darling rainbowfish	468	0.54	0.46
golden perch	20	0.90	0.10
Murray cod	6	0.00	1.00
silver perch	7	1.00	0.00
un-specked hardyhead	10	0.20	0.80
Exotic species			
common carp	11661	0.08	0.92
gambusia	7258	0.80	0.20
goldfish	2940	0.05	0.95
oriental weatherloach	2386	0.79	0.21
redfin perch	4	0.00	1.00
Grand Total	**38532**		

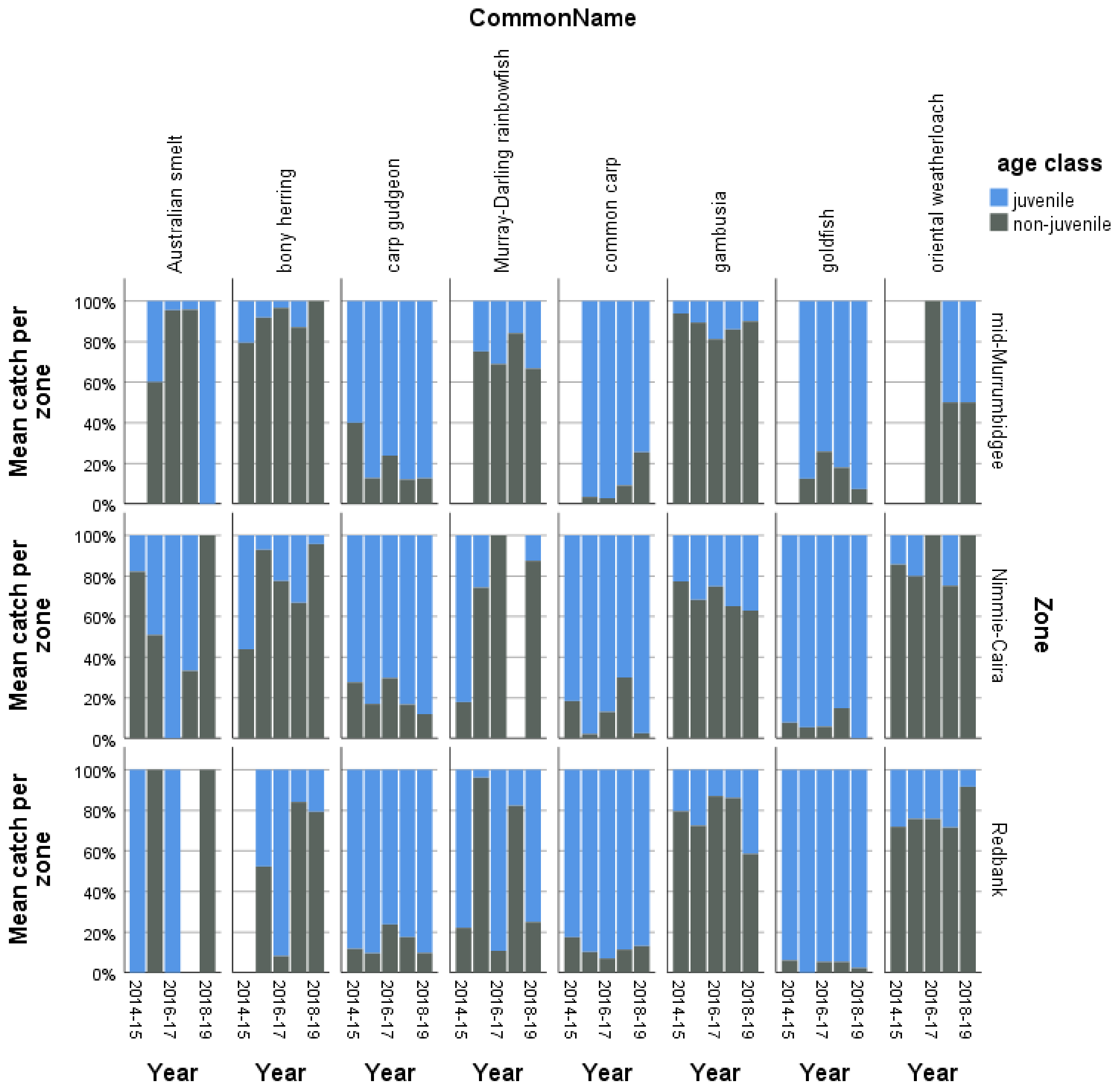
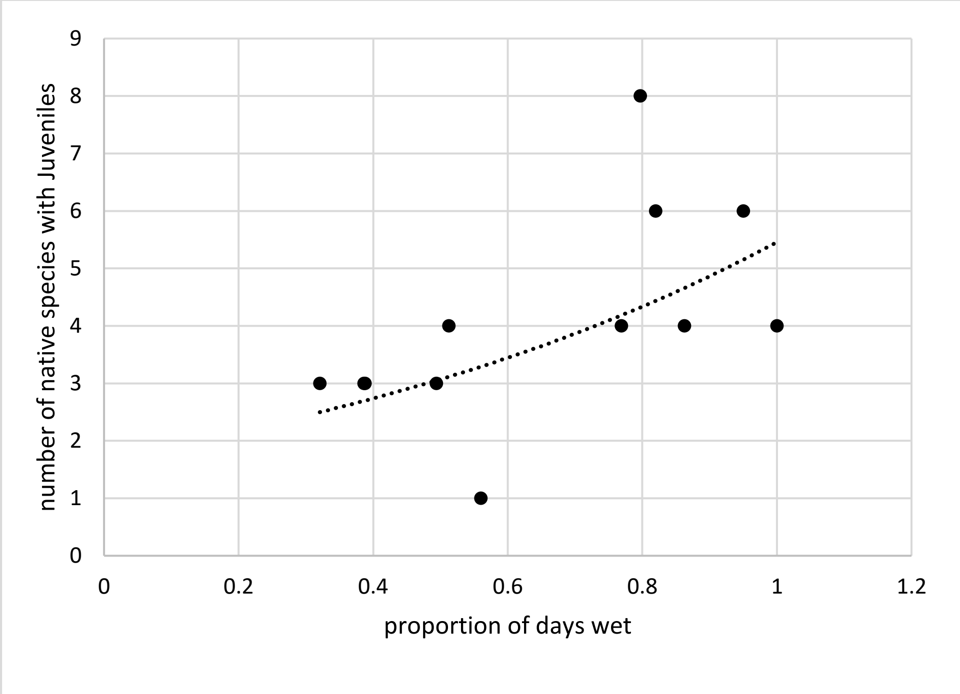


Figure 4-45 Mean percentage of juveniles and non-juveniles within the annual catch for commonly occurring native and exotic wetland fish species.

The number of native species with juveniles increased with increasing duration of inundation (spearman rho r = 0.690, p = 0.013) across the five years, while there were no differences for exotic species (spearman rho r = 0. 112, p = 0.729) (Figure 4-46). The proportion of juveniles within the common carp catch also decreased with increasing duration of inundation (spearman rho r = -0.692, p = 0.013).



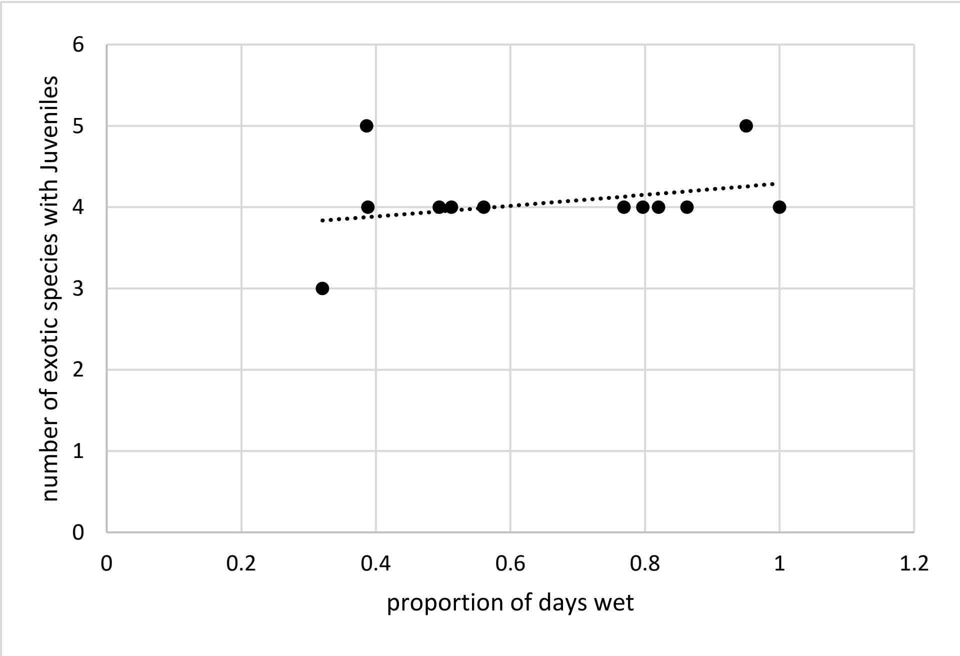


Figure 4-46 Proportion of total native catch represented by juveniles (top) and exotic (bottom) species at the 12 monitored wetlands between 2014 and 2019.

Discussion

Overall, wetland and riverine fish communities across the Murrumbidgee remain in poor condition and are dominated by opportunistic generalist species, while more sensitive floodplain specialist species, such as Murray hardyhead are absent. The loss of persistent off-channel waterbodies has been identified as a key factor contributing to the declining abundance of wetland specialists including the Murray hardy head, purple spotted gudgeon and olive perchlet (Closs *et al.* 2005). Commonwealth environmental water is used to restore aspects of the hydrograph that are missing because of river regulation; this includes actions to increase the duration and frequency of inundation to maintain suitable habitats for native fish (Commonwealth of Australia 2018). When considered over the five-year monitoring period, multiple watering action focused on maintaining persistent waterbodies have contributed to increased native fish diversity in floodplain wetlands. The diversity of native species with juveniles recorded was also higher at the more persistent sites, most likely reflecting the already higher diversity of species occurring at these sites.

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

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. Most of the native species currently occurring in wetlands are flow generalists that either colonise wetlands from the main river during periods of reconnections, including via lateral connection with the river or via irrigation infrastructure, or are resident within persistent pools and lagoons on the floodplain. With this in mind a range of factors, including the number and location of wetlands that are watered, can influence the diversity of native wetland fish in a given year.

The two flow responder species; silver and golden perch were recorded more frequently following the unregulated flows into the mid-Murrumbidgee wetlands in 2016-17 and Commonwealth environmental water in 2017-18 compared to other years when watering actions largely consisted of infrastructure assisted deliveries. However, it is important to note that large numbers of adult and juvenile golden perch were recorded in wetlands lower in the Redbank in Tala Creek and Tala Lake following the Yanga and Tala Lake golden perch watering action (Kopf *et al.* 2019).

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.

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

Young of year small-bodied native and exotic species were recorded in most years. There is some variability in the proportion of the measured catch that fell into the juvenile size classes and some wetlands had consistently higher proportion of juveniles than others. One interesting trend that has emerged in the five-year dataset is the higher proportion of the catch of native species was represented by juveniles in the most frequently watered sites, while there is little difference in the proportion of exotic species catch represented by juveniles.

Almost all of the wetlands monitored under this program are functionally dry between inundation events (except for Avalon Swamp, Telephone Creek and Waugorah Lagoon), Yarradda and Eulimbah lagoons have also been watered relatively frequently, although Yarradda was deliberately dried to reduce the biomass of adult carp in November 2018.

The environmental flow through Yanga National Park reached eight species of native fish and four invasive species across larval, juvenile and adult stages in Yanga and Tala floodplain environments. Successful floodplain spawning and recruitment of golden perch was detected in Tala Creek and the hatch-dates of recruits over-lapped with environmental water delivery. Neither spawning nor recruitment of golden perch was detected in the main channel of the Murrumbidgee River or in Yanga Lake in 2018/19. Larval and juvenile Murray cod were collected drifting from the Murrumbidgee River into the Yanga floodplain system via the environmental flow in November and December 2018 (Kopf *et al.* 2019).

The 2018/19 monitoring results suggest that management decisions to deliver environmental water to inundate and maintain floodplain habits during spring and summer are important to maintain viable native fish populations, and the ecosystem continues to provide food for resident populations of fish and fish-eating waterbirds. Although the golden perch recruitment event in 2018/19 was not widespread, its potential importance to local populations should not be underestimated, especially in a year following fish-kills in the Murrumbidgee River. During the extreme drought conditions and the fish-kills experienced in New South Wales, these inundated floodplain habitats and lakes provide rare refuges of high quality habitat and productivity that attract a diverse waterbird assemblage and contribute to fish spawning, growth and recruitment (Kopf *et al.* 2019).

4.6 Frogs and turtles

Prepared by Dr Damian Michael, Dr Skye Wassens (CSU) and Dr Gilad Bino (UNSW)

Introduction

Environmental watering actions can be used to maintain frog and turtle populations via two key mechanisms. (1) By providing persistent refuge habitat to support frog and turtle populations during periods of low water availability, and (2) 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.

In 2018-19, Commonwealth environmental water was delivered to wetlands in the mid-Murrumbidgee, Nimmie-Caira and Redbank (Table 4-10). The Nimmie-Caria refuge flows, Nap Nap to Wagourah flow (NSW) and Yanga National Park: Yanga Lake top up and system watering all had specific objectives related to outcomes for frogs and turtles. In particular, the watering actions in Nimmie-Caria refuge flows and Nap Nap to Wagourah actions were specifically targeted towards maintaining populations of the vulnerable Southern bell frog (EPBC Act) and are a continuation of a series of watering actions that have been undertaken since 2008 specifically aimed at recovering this threatened population.

Table 4-10 Summary of environmental watering actions that influenced frog diversity during the monitoring period.

Water Action Reference	Event	Objectives
10082-02 &10082-03	Yanga National Park: Yanga Lake top up and system watering (via 1AS)	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
NSW EWA	Nap Nap to Waugorah Lagoon (NSW EWA) 25/09/2018 - 2/11/2018	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
10082-04	Nimmie-Caira refuge flows Avalon Dam, Eulimbah, Telephone Creek	Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frogs (EPBC Act).
10082-08	Yarradda Lagoon Pumping	Maintain important refuge habitat for wetland dependant species, including for the Southern Bell frog; and maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18.
10082-09	Gooragool Lagoon Pumping	Maintain important refuge habitat for native fish, turtles and other water dependent biota.

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?

Methods

Since 2014, frogs and tadpoles have been monitored across the twelve LTIM surveyed wetlands four times per year (September, November, January and March), except when wetlands were dry or water levels were too low to deploy nets. Detailed survey methodology is outlined in Wassens *et al.* (2014a). Adult frogs are surveyed after dark using two 20 minute transects where all frogs observed or heard calling are recorded. Tadpoles are surveyed in conjunction with wetland fish, using a combination of two large and two small fyke nets that are set overnight for an average of 14 hours. When water levels are too low to set large fyke nets, two smaller D-fyke nets are set instead. Tadpole Catch-Per-Unit Effort (CPUE) is calculated for each wetland based on the number of tadpoles collected divided by the average amount of time all four fyke nets remain in the water at each site per sampling period.

Data analysis

The prediction that adult frog abundance, calling activity and tadpole CPUE would vary among water years and wetlands zones was tested using Generalised Linear Models with wetland zone and water year as fixed factors in the analysis. Adult frog observation, tadpoles and calling activity were then combined to examine frog presence and absence relationships with water depth, survey month, wetland zone and water year using Generalised Linear Models. Spearman's rank correlations were used to identify significant relationships between water depth, water temperature and water condition metrics, native and exotic fish and frog calling activity and tadpole (CPUE) abundance between September 2014 and March 2019. Mann-Whitney U test were used to compare size distributions of the three turtle species detected during the five year program.

Results

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

Frog species richness

A total of six frog species were recorded during the 2018-19 water year, 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*). The number of frog species recorded in 2018-19 is consistent with the overall frog diversity recorded in the Murrumbidgee Selected Area over the previous five years (Figure 4-).

Frog diversity varied between zones and across years, largely reflecting both the number of wetlands that contained water (Figure 4-47). As would be expected, the average diversity of frogs in the mid-Murrumbidgee was lowest in the years when only a small number of the monitored sites were watered and was highest in 2016-17 following unregulated flows and 2017-18 following the mid-Murrumbidgee wetland reconnection event (Wassens *et al.* 2019). Likewise, in the Nimmie-Caira, frog diversity was lowest in 2015-16 and 2017-18, most likely reflecting the pattern of wetting and drying at Nap Nap Swamp, which did not receive environmental water in either of those two years (Figure 4-). Broadly similar trends occurred in the Redbank system where diversity was lowest in 2017-18, when wetlands were allowed to dry out in order to improve water quality and tree condition. Interestingly, where this drying action was followed by larger scale watering as part of the Yanga Lake top up and system watering (via 1AS), frog species richness increased in the Redbank zone, largely driven by increases in species richness at Piggery and Two Bridges Swamp where southern bell frogs were recorded.

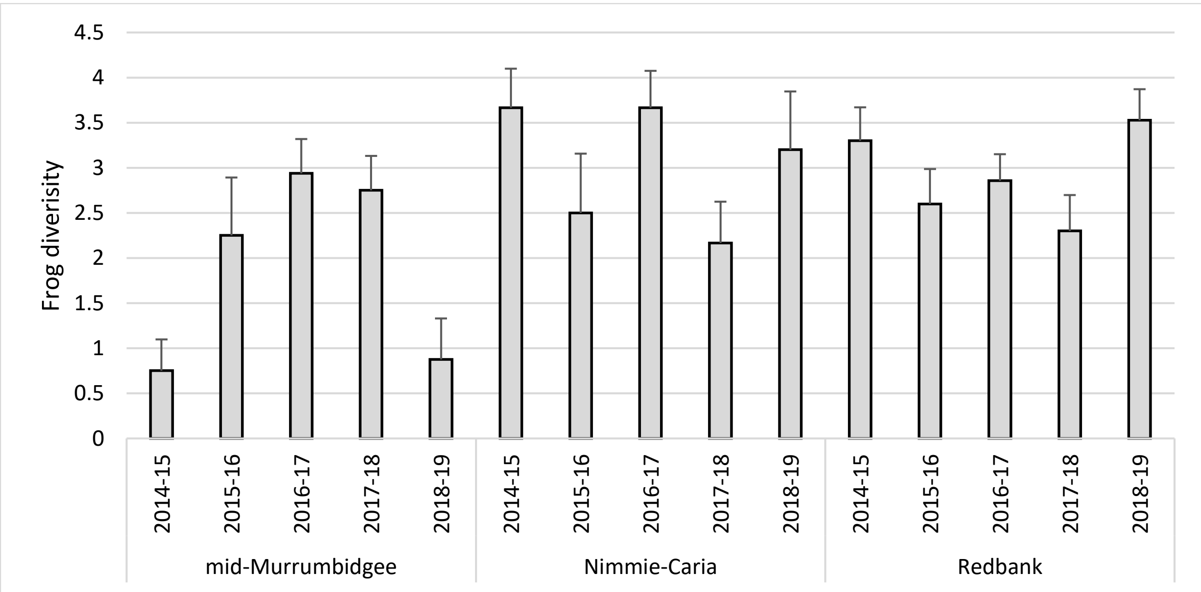


Figure 4-47 Mean frog diversity (+SE) per wetland (n=12) within each zone across the five years.

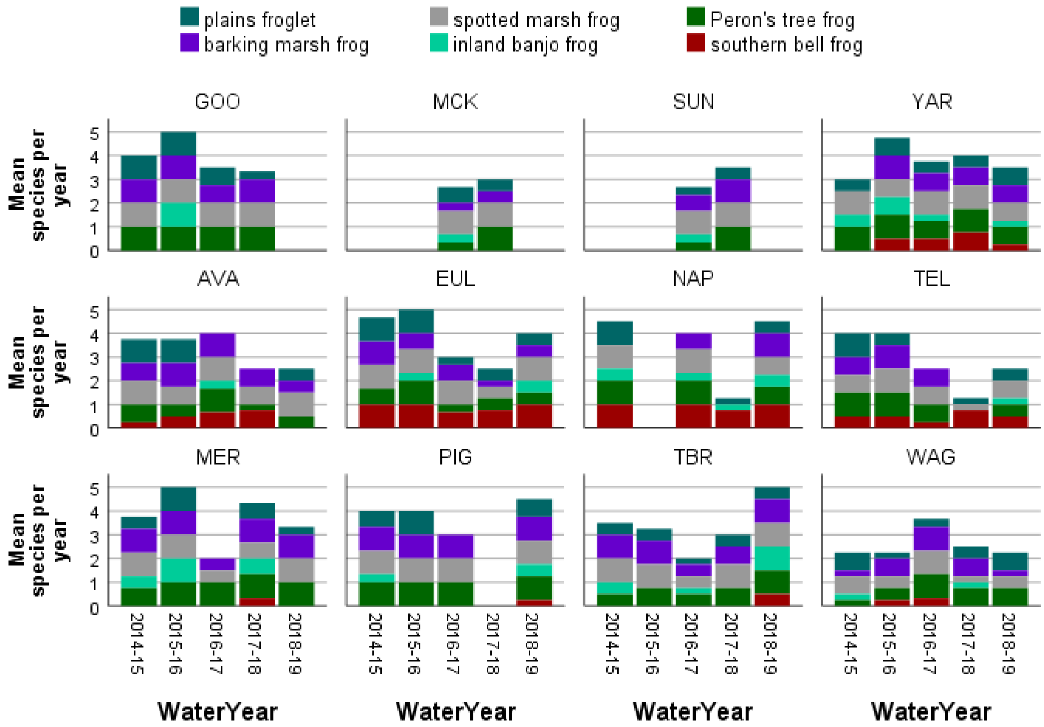


Figure 4-48 Species diversity outcomes at each of the 12 LTIM monitored wetland in the Murrumbidgee Selected Area between 2014-15 and 2018-19. Mid-Murrumbidgee wetlands (top row) (GOO Gooragool, MCK McKennas, SUN Sunshower, YAR Yarradda); Nimmie-Caira (middle row) (AVA Avalon, EUL Eulimbah, NAP Nap Nap, TEL, Telephone Creek); Redbank (bottom row) (MER Mercedes, PIG Piggery, TBR Two Bridges, WAG Waugorah Lagoon).

Frog abundance

Overall, Commonwealth environmental watering actions resulted in 5,925 adult frog observations between September 2014 and March 2019, including 1063 southern bell frog observations (Table 4-11). The mean abundance of adult frog species varied between sites and water years, with the majority of observations being attributed to the two most common and abundant species - the spotted marsh frog and barking marsh frog (Figure 4-49). These two species were detected in high numbers at several key wetlands (e.g. Gooragool Lagoon, Two Bridges Swamp and Piggery Lake), and specifically during the 2016-17 water year.

Table 4-11. Summary statistics for the number of adult frog observations between 2014 and 2019 in the Murrumbidgee Selected Area.

Species name	Maximum per year	Total Sum	Mean per site	Standard deviation
plains froglet	13	153	0.63	1.70
barking marsh frog	255	1691	6.99	26.41
spotted marsh frog	295	2452	10.13	28.68
inland banjo frog adult	5	17	0.07	0.38
Peron's tree frog adult	95	549	2.27	7.39
southern bell frog adult	331	1063	4.39	30.95

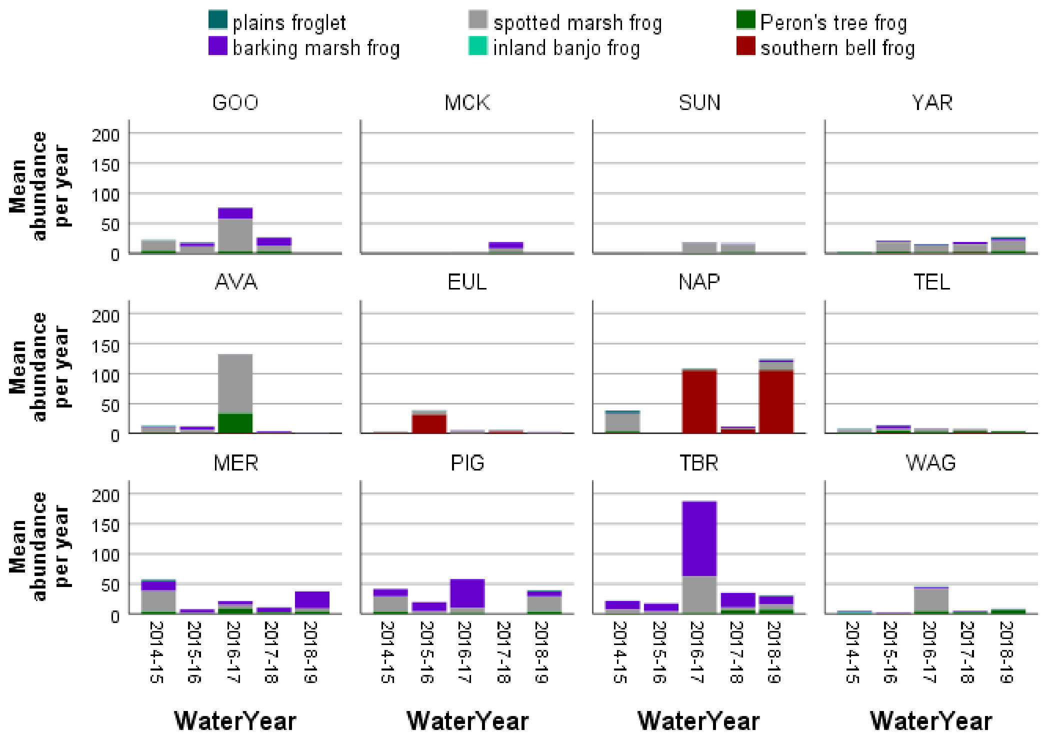


Figure 4-49 Mean frog abundance at each of the 12 LTIM monitored wetlands in the Murrumbidgee Selected Area between 2014-15 and 2018-19. (top row) (GOO Gooragool, MCK McKennas, SUN Sunshower, YAR Yarradda), Nimmie-Caira (middle row) (AVA Avalon, EUL Eulimbah, NAP Nap Nap, TEL, Telephone Creek). Redbank (bottom row) (MER Mercedes, PIG Piggery, TBR Two Bridges, WAG Wagourah Lagoon).

We detected significant differences in adult plains froglet abundance between water years (GLM f = 10.27, p= 0.036). This species was less abundant during the 2016-17 unregulated flood year but had increased to pre-flood numbers during the 2018-19 water year. Similar patterns emerged when we examined plains froglet presence (by combining tadpole, adults and calling data). This species tended to be more common in the Nimmie-Caira wetland zone, less common during the 2016-17 water year and less common during the survey months of January and March (Table 4-11, Figure 4-50). The barking marsh frog was one of the most commonly detected species and like the majority of species, responded positively to water depth. Rates of detection did not differ significantly between wetland zones or among water years, but on average, the barking marsh frog was detected more often early in the watering season during the survey month of November (Table 4-12, Figure 4-51).

Spotted marsh frog abundance differed significantly between water years (GLM f = 10.096, p=0.039), and on average was recorded in higher numbers during the 2016-17 unregulated water year. Overall, the probability of detecting this species increased with water depth. Aside from water depth, detection probabilities did not vary considerably among survey months, wetland zones or water years for this species (Table 4-13, Figure 4-52). Adults of the inland banjo frog were only detected on 17 occasions. However, like other frog species, the probability of detecting the inland banjo frog increased with water depth (Table 4-14, Figure 4-53). The probability of detecting Peron's tree frog increased with water depth and the November survey period (Table 4-15, Figure 4-54). Over 1000 southern bell frogs were observed during the five year monitoring period. The probability of detecting this species increased with water depth, the January survey period, the Nimmie-Caira wetland zone and the latter two watering years. Overall, the probability of detecting the southern bell frog increased over time (Table 4-16, Figure 4-55).

Table 4-11 Generalised linear model for plains froglet showing relationship between water depth, survey month, wetland zone and survey year.

Predictors	Log-Odds	CI	p
(Intercept)	-0.06	-1.37 – 1.25	0.932
Water depth	1.81	1.03 – 2.59	**<0.001**
Survey period			
November	-0.81	-1.77 – 0.15	0.100
January	-2.98	-4.17 – -1.79	**<0.001**
March	-3.12	-4.30 – -1.95	**<0.001**
Wetland zone			
Nimmie-Caira	0.91	-0.37 – 2.19	0.162
Redbank	0.00	-1.29 – 1.29	0.997
Water year			
2015-16	-0.81	-1.89 – 0.26	0.138
2016-17	-2.87	-4.38 – -1.37	**<0.001**
2017-18	-1.42	-2.56 – -0.27	**0.015**
2018-19	-0.70	-1.80 – 0.40	0.210

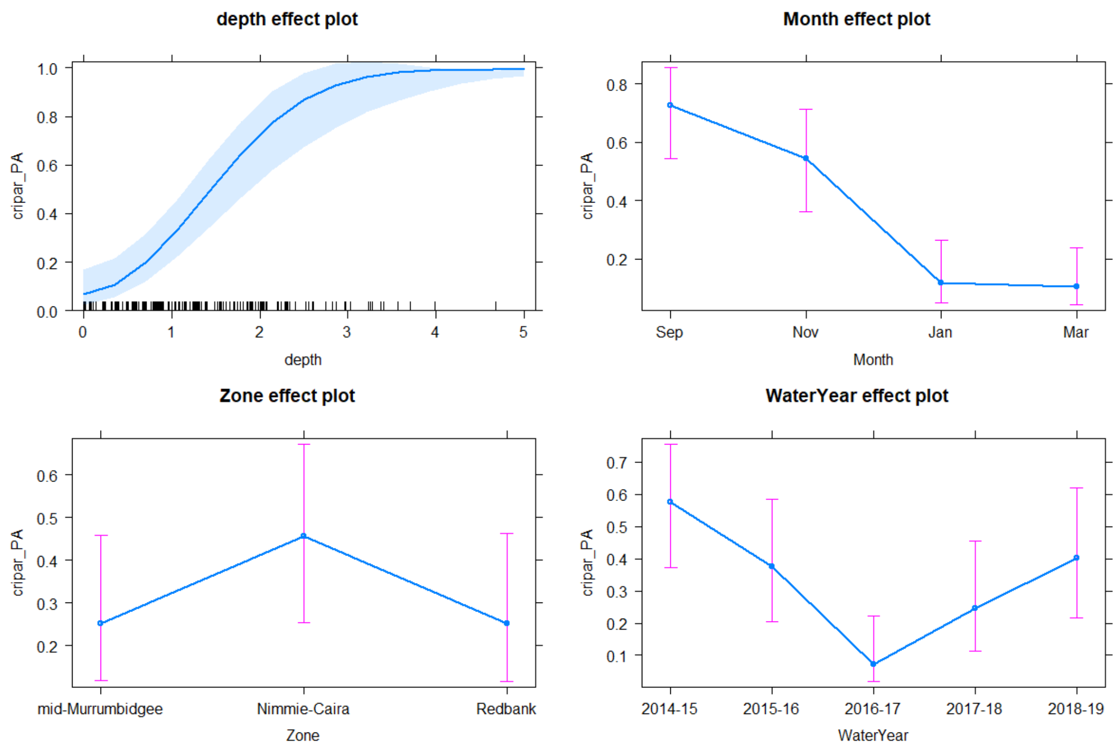


Figure 4-50 Overall trends in plains froglet detection (presence/absence) in relation to water depth, survey month, wetland zone and water year between 2014-15 and 2018-19 in the Murrumbidgee Selected Area.

Table 4-12 Results of the generalised linear model for the barking marsh frog showing relationship between water depth, survey month, wetland zone and survey year.

Predictors	Log-Odds	CI	p
(Intercept)	-2.53	-4.08 – -0.97	**0.001**
depth	1.21	0.70 – 1.72	**<0.001**
Survey period			
Nov	1.07	0.15 – 1.99	**0.023**
Jan	0.75	-0.17 – 1.66	0.110
Mar	0.31	-0.59 – 1.20	0.500
Wetland zone			
Nimmie-Caira	0.86	-0.78 – 2.50	0.304
Redbank	1.30	-0.36 – 2.96	0.125
Water year			
2015-16	0.62	-0.37 – 1.61	0.218
2016-17	0.66	-0.47 – 1.79	0.254
2017-18	0.48	-0.48 – 1.44	0.327
2018-19	0.27	-0.72 – 1.26	0.594

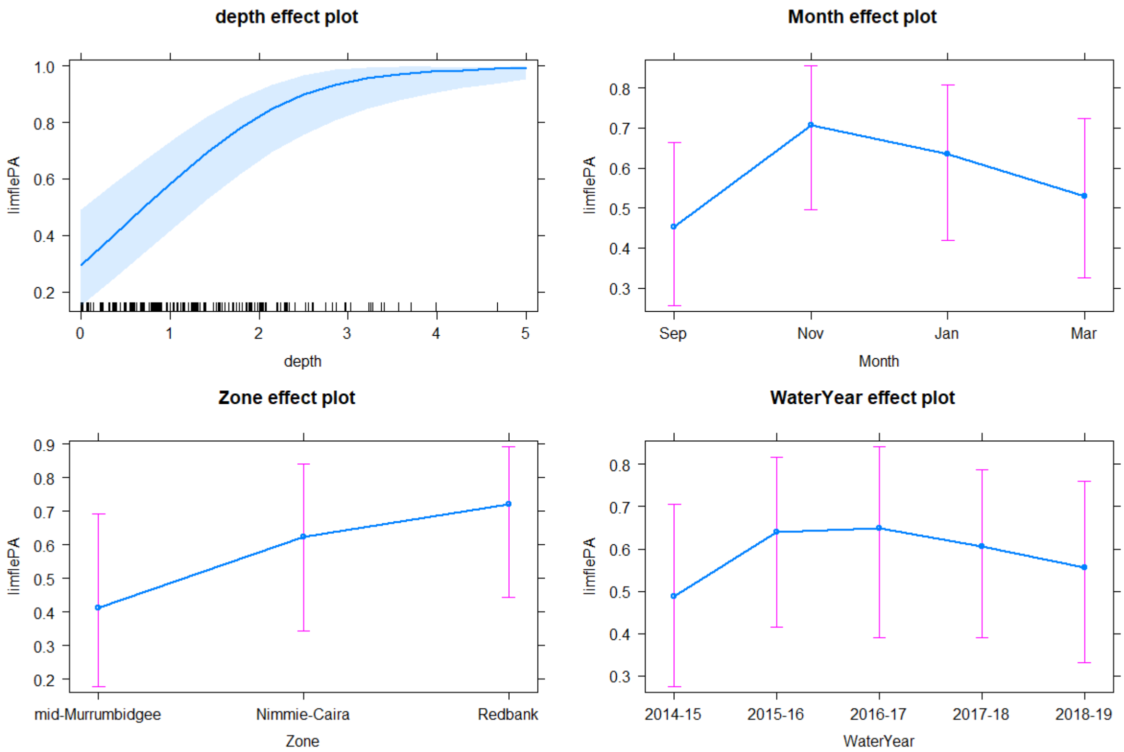


Figure 4-51 Overall trends in barking marsh frog detection (presence/absence) in relation to water depth, survey month, wetland zone and water year between 2014-15 and 2018-19 in the Murrumbidgee Selected Area.

Table 4-13 Generalised linear model for the spotted marsh frog showing relationship between water depth, survey month, wetland zone and survey year.

Predictors	Log-Odds	CI	p
(Intercept)	-0.79	-2.41 – 0.83	0.339
depth	1.59	0.98 – 2.20	**<0.001**
Survey period			
Nov	-0.01	-1.01 – 1.00	0.992
Jan	-0.08	-1.09 – 0.93	0.870
Mar	-0.25	-1.21 – 0.72	0.616
Wetland zone			
Nimmie-Caira	1.30	-0.62 – 3.22	0.183
Redbank	0.31	-1.59 – 2.22	0.747
Water year			
2015-16	-0.70	-1.74 – 0.34	0.185
2016-17	0.98	-0.56 – 2.53	0.212
2017-18	-0.13	-1.14 – 0.89	0.804
2018-19	-0.36	-1.41 – 0.68	0.497

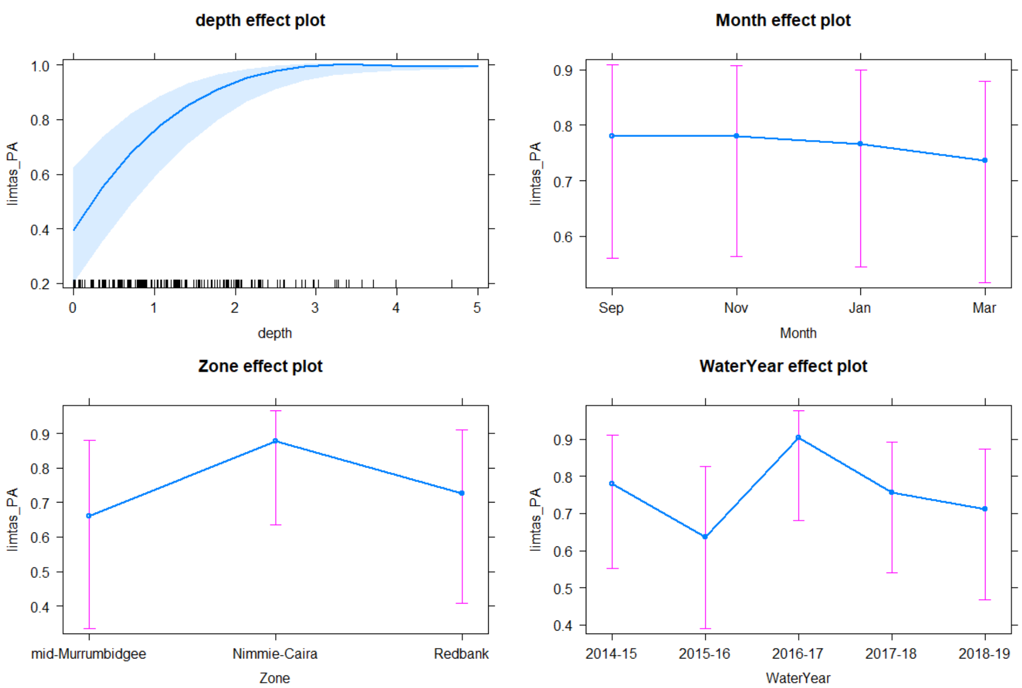


Figure 4-52 Overall trends in spotted marsh frog detection (presence/absence) in relation to water depth, survey month, wetland zone and water year between 2014-15 and 2018-19 in the Murrumbidgee Selected Area.

Table 4-14 Generalised linear model for the inland banjo frog showing relationship between water depth, survey month, wetland zone and survey year.

Predictors	Log-Odds	CI	p
(Intercept)	-2.61	-4.54 – -0.68	**0.008**
Water depth	1.26	0.64 – 1.89	**<0.001**
Survey period			
November	0.15	-0.84 – 1.14	0.766
January	-0.96	-2.10 – 0.18	0.101
March	-1.04	-2.28 – 0.21	0.103
Wetland zone			
Nimmie-Caira	-0.32	-2.48 – 1.84	0.774
Redbank	0.57	-1.53 – 2.67	0.595
Water year			
2015-16	-0.27	-1.42 – 0.88	0.644
2016-17	-1.12	-2.50 – 0.26	0.110
2017-18	-1.18	-2.55 – 0.19	0.092
2018-19	0.38	-0.74 – 1.49	0.509

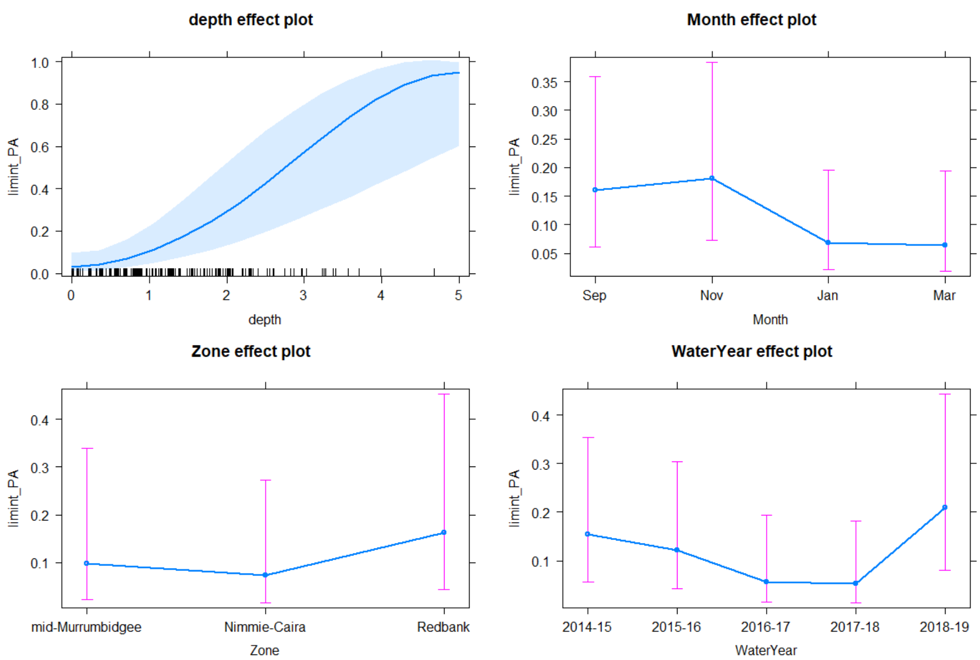


Figure 4-53 Overall trends for the inland banjo frog (presence/absence) in relation to water depth, survey month, wetland zone and water year between 2014-15 and 2018-19 in the Murrumbidgee Selected Area.

Table 4-15 Generalised linear model for Peron's tree frog showing relationship between water depth, survey month, wetland zone and survey year.

Predictors	Log-Odds	CI	p
(Intercept)	-1.86	-3.24 – -0.47	**0.009**
Water depth	1.24	0.73 – 1.74	**<0.001**
Survey period			
November	1.26	0.32 – 2.21	**0.009**
January	0.49	-0.42 – 1.39	0.291
March	-0.38	-1.26 – 0.51	0.403
Wetland zone			
Nimmie-Caira	0.423	0.423	0.423
Redbank	0.423	0.423	0.423
Water year			
2015-16	-0.08	-1.04 – 0.88	0.866
2016-17	0.77	-0.39 – 1.92	0.192
2017-18	0.57	-0.39 – 1.53	0.244
2018-19	0.38	-0.61 – 1.37	0.450

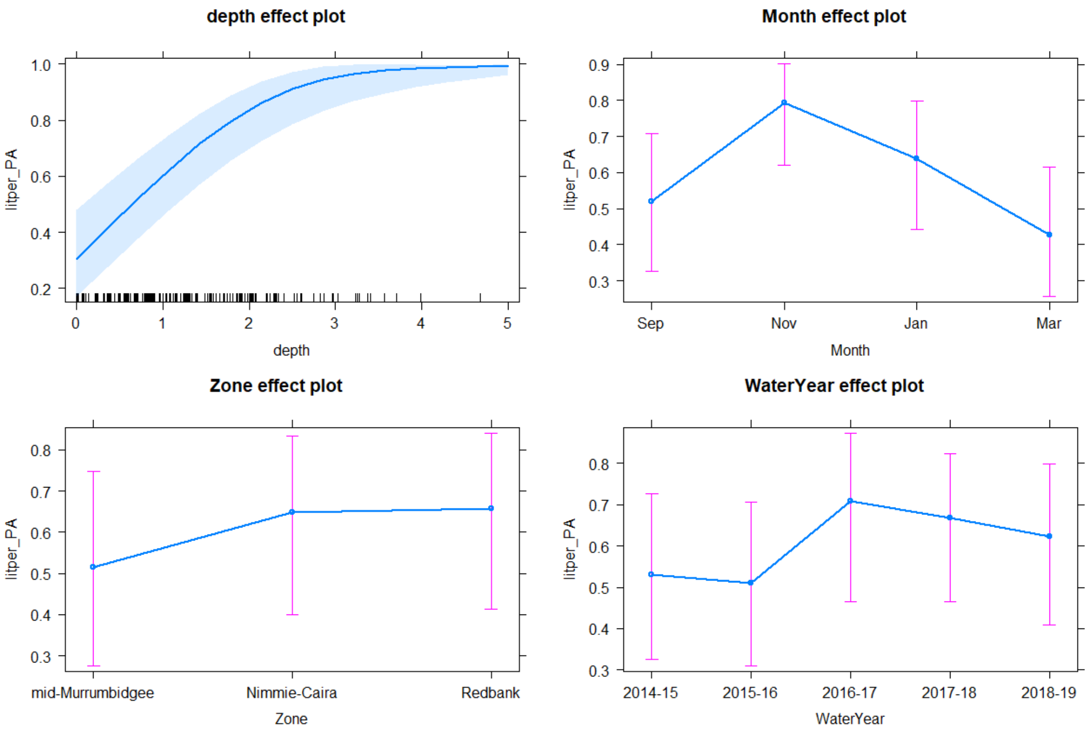


Figure 4-544-33 Overall trends for Peron's tree frog (presence/absence) in relation to water depth, survey month, wetland zone and water year between 2014-15 and 2018-19 in the Murrumbidgee Selected Area.

Table 4-16 Generalised linear model for the southern bell frog showing relationship between survey month, wetland zone and survey year.

Predictors	Log-Odds	CI	p
(Intercept)	-5.49	-7.63 – -3.35	**<0.001**
Water depth	0.95	0.36 – 1.54	**0.002**
Survey period			
November	0.74	-0.44 – 1.92	0.221
January	1.33	0.12 – 2.55	**0.031**
March	0.24	-0.97 – 1.45	0.698
Wetland zone			
Nimmie-Caira	3.70	1.98 – 5.43	**<0.001**
Redbank	-0.09	-1.94 – 1.76	0.922
Water year			
2015-16	0.36	-0.96 – 1.68	0.590
2016-17	0.43	-0.95 – 1.80	0.545
2017-18	1.76	0.46 – 3.07	**0.008**
2018-19	1.61	0.23 – 2.98	**0.022**

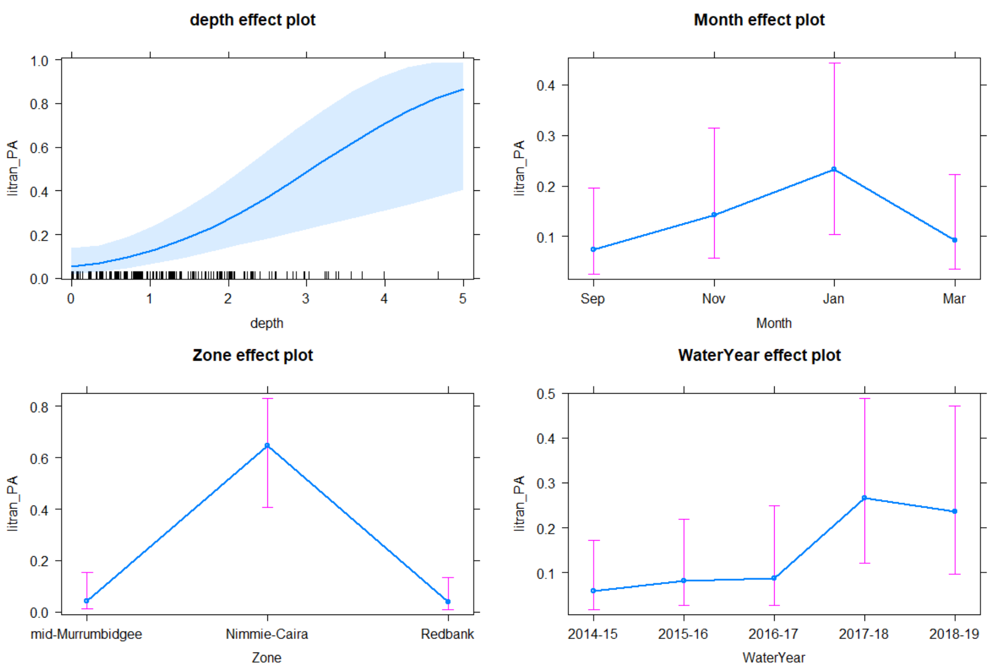


Figure 4-55 Overall trends for the southern bell frog (presence/absence) in relation to water depth, survey month, wetland zone and water year between 2014-15 and 2018-19 in the Murrumbidgee Selected Area.

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

Frog breeding response

Overall, a combination of Commonwealth environmental watering actions and unregulated flows resulted in the detection of 6,695 tadpoles, constituting six species, between September 2014 and March 2019 (Table 4-16). Peron's tree frog tadpoles were the most abundant species detected, with a maximum of 499 individuals recorded at Yarradda in 2018-19 (Figure 4-56). This record number of tadpoles was a direct result of the 2018-19 Yarradda pumping watering action.

Table 4-16 Summary statistics for the number of male frog calls and tadpoles recorded between September 2014 and March 2019 in the Murrumbidgee Selected Area (Note tadpoles of Limnodynastes species are grouped as they cannot be identified in the field).

Species name	Maximum per year	Total Sum	Mean per site	Std. Deviation
Calling activity				
plains froglet	75	1419	5.86	13.10
barking marsh frog	60	806	3.33	8.84
spotted marsh frog	135	1580	6.53	18.62
inland banjo frog	22	95	.39	2.19
Peron's tree frog	50	780	3.22	7.52
southern bell frog	70	336	1.39	6.38
Tadpoles				
plains froglet	3.00	12.00	0.1	0.40
Limnodynastes species	758	3916	23.7	100.04
inland banjo frog	226	926	5.6	26.72
Peron's tree frog	499	1689	10.1	52.46
southern bell frog	42	152	0.9	4.71

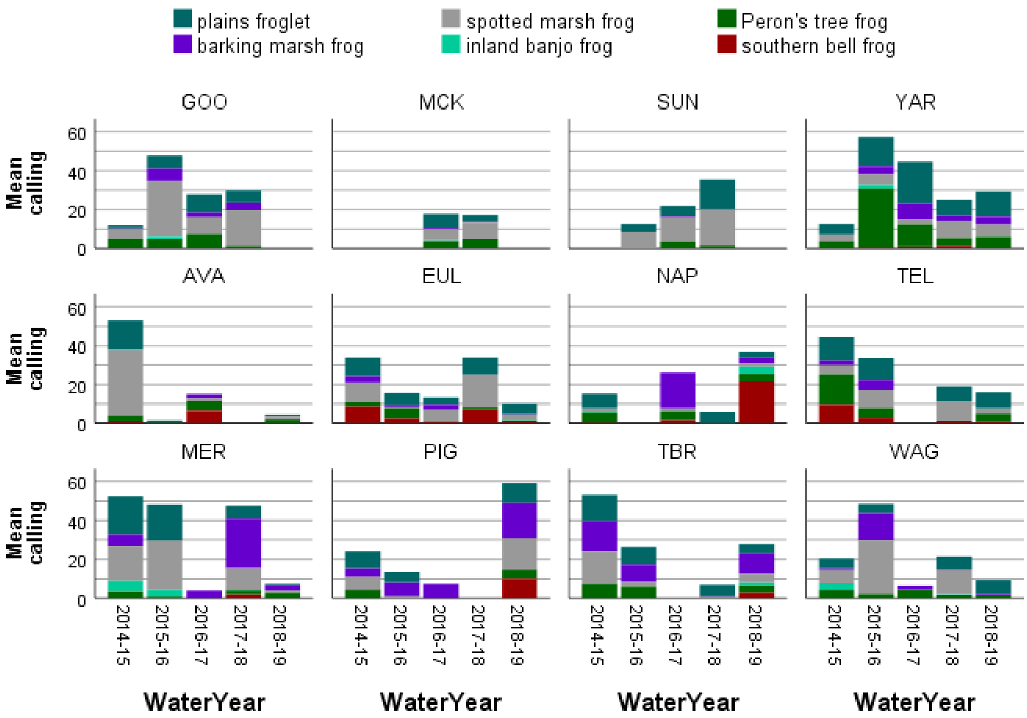


Figure 4-56 Calling activity (mean count) of resident frog species at each of the 12 LTIM wetlands in the Murrumbidgee Selected Area between 2014-15 and 2018-19. (top row) (GOO Gooragool, MCK McKennas, SUN Sunshower, YAR Yarradda), Nimmie-Caira (middle row) (AVA Avalon, EUL Eulimbah, NAP Nap Nap, TEL, Telephone Creek). Redbank (bottom row) (MER Mercedes, PIG Piggery, TBR Two Bridges, WAG Wagourah Lagoon).

Tadpoles were recorded for all resident frog species in 2018-19, and like previous years, there was considerable variability in breeding response at individual wetlands and between wetland zones (Figure 4-57). Very large numbers of Peron's tree frog tadpoles, a single southern bell frog tadpole and low numbers of other species were recorded at Yarradda Lagoon following the 2018-19 environmental water actions. The reduction in exotic carp and improvements in vegetation condition are likely to have influenced frog breeding success at this wetland. At Nap Nap Swamp average tadpole abundance and diversity were slightly higher in 2018-19 compared to previous years, with a reasonably high number of southern bell frog tadpoles also recorded. Small numbers of southern bell frog tadpoles were also recorded early in the season at Eulimbah Swamp in 2018-19. The Inland banjo frog responded to unregulated flow into Mercedes Swamp in 2017-18 but not 2018-19 when the wetland was largely dry over spring and summer. Tadpoles of *Limnodynastes* sp. remained in high numbers at Two Bridges but were lower at Piggery Swamp when compared to 2014-15.

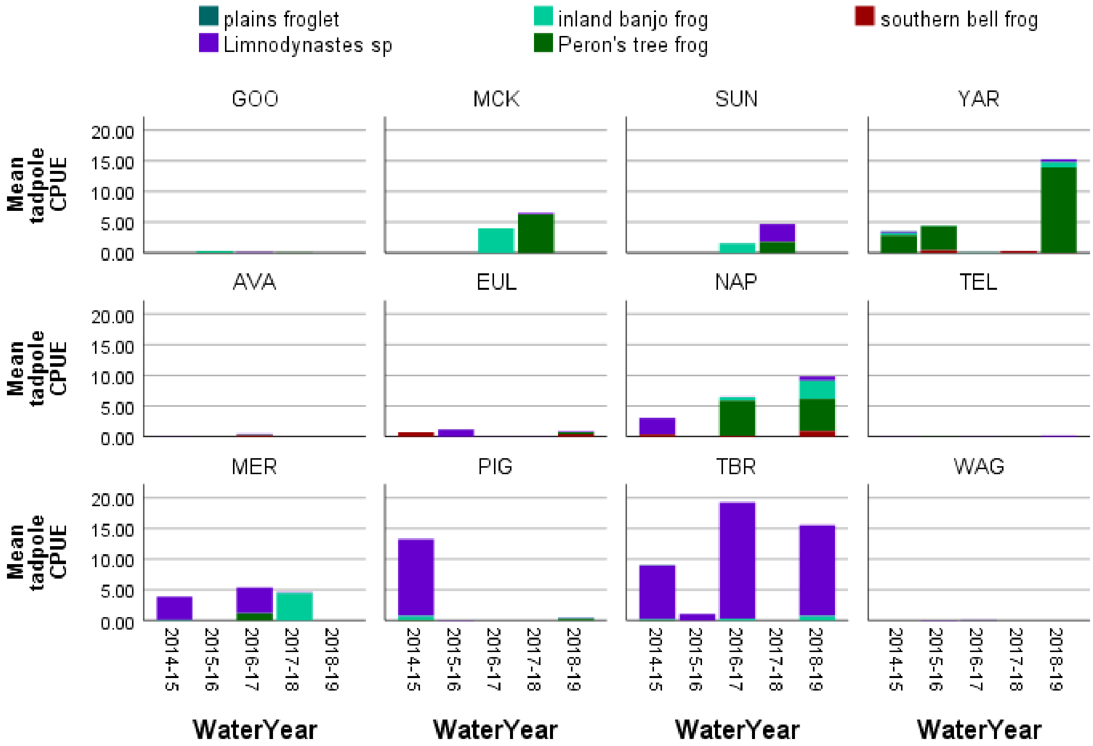


Figure 4-57 Mean tadpole abundance (Catch Per Unit Effort) for each of the 12 LTIM wetlands in the Murrumbidgee Selected Area between 2014-15 and 2018-19. (top row) (GOO Gooragool, MCK McKennas, SUN Sunshower, YAR Yarradda), Nimmie-Caira (middle row) (AVA Avalon, EUL Eulimbah, NAP Nap Nap, TEL, Telephone Creek). Redbank (bottom row) (MER Mercedes, PIG Piggery, TBR Two Bridges, WAG Wagourah Lagoon).

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. During the 2014-19 survey period, a broad range of age cohorts of the long-necked turtle was detected across all three zones. This species exhibited the broadest age range of all turtle species across the five water years. A wide range of age cohorts of the broad-shelled turtle was detected in the mid-Murrumbidgee, whereas predominantly mature individuals of the broad-shelled turtle were detected in the Redbank zone. Both juvenile and adult Macquarie River turtles were detected in the mid-Murrumbidgee and Redbank zones. Juvenile recruitment of all three species were detected during the 2014-19 survey period, and especially during the 2016-17 and 2017-18 water years (Figure 4-).

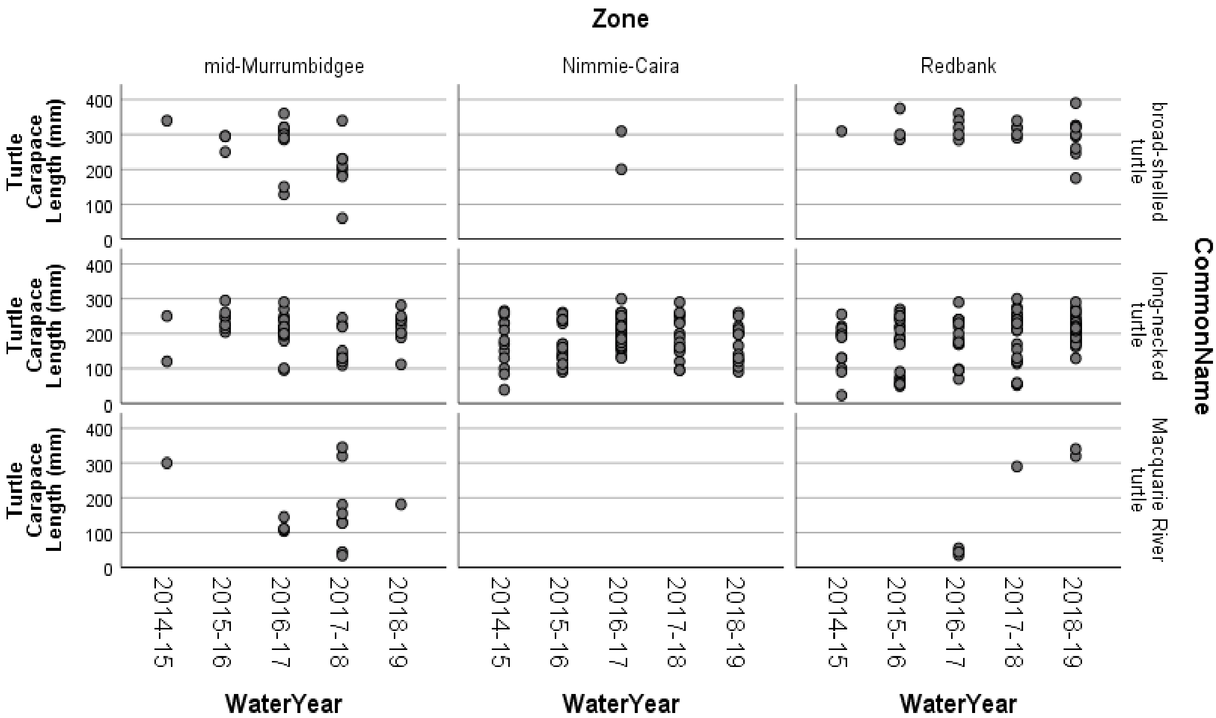


Figure 4-58 Size distribution of individual turtles caught between 2014 and 2019 in each wetland zone.

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 refuge habitats, these are Yarradda Lagoon in the mid-Murrumbidgee, Telephone Creek in the Nimmie-Caira and Waugorah Lagoon in the Redbank system.

During the 2014 – 2019 survey period, a total of 350 turtles from three species were recorded (i.e. broad-shelled turtle = 47, long-necked turtle = 283, Macquarie River turtle = 20). Turtles were detected at all 12 wetlands, although numbers were consistently high at Yarradda Lagoon, Nap Nap Swamp and Two Bridges Swamp. Yarradda Lagoon, Gooragool Lagoon and Waugorah Lagoon were the only wetlands to support all three species (Figure 4-).

In 2018-19, environmental watering actions included pumping at Yarradda Lagoon in the mid-Murrumbidgee which built on previous water actions and the natural flood event in 2016-17. The cumulative effects of these watering actions resulted in an increasing number of turtles being recorded, especially eastern long-necked turtles.

Environmental watering actions at Two Bridges also resulted in above average number of turtles being recorded. Water levels in Telephone Creek and Waugorah 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 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 Waugorah lagoons support all three species, while Telephone Creek is an important refuge for broad-shelled turtles in the Nimmie-Caira (Figure 4-59).

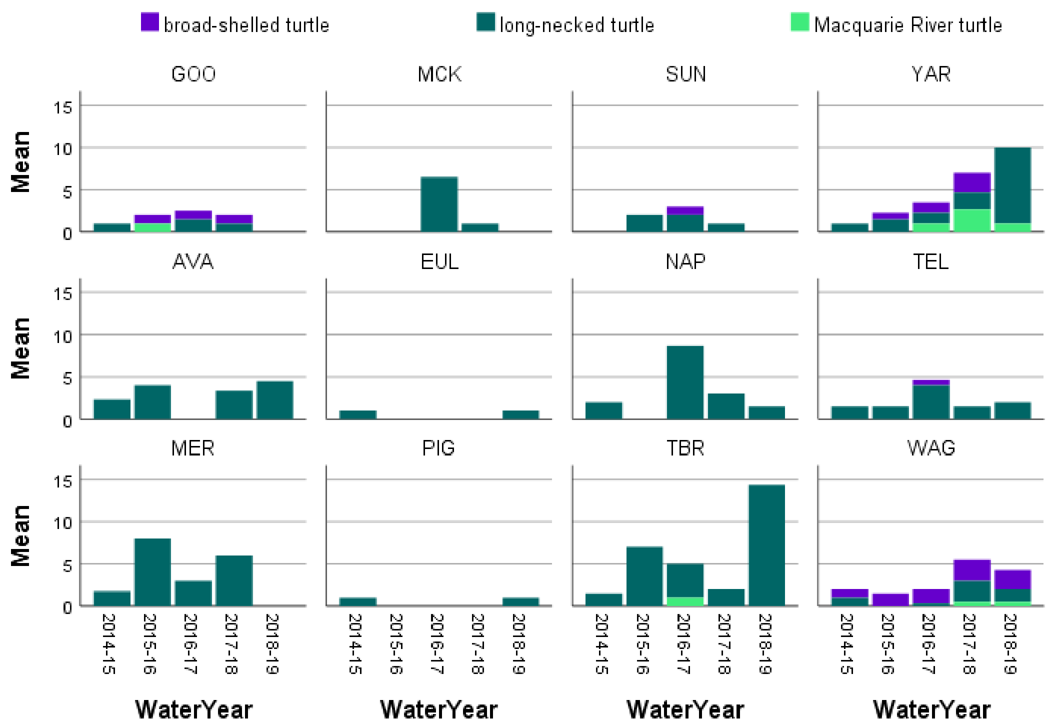


Figure 4-59 Turtle abundance across the five water years at each monitoring location (mid-Murrumbidgee wetlands (upper), Nimmie-Caira (mid) and Redbank (lower) zones).

Discussion

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

The focus of Commonwealth environmental watering actions in 2018-19 was the inundation of wetlands in the Nimmie-Caira (Nap Nap to Waugorah NSW EWA and Nimmie-Caira refuge flows (CEWO)) and Redbank system (Yanga National Park: Yanga Lake top up and system watering (via 1AS) CEWO) and to undertake a managed draw down in Yarradda Lagoon followed by pumping into Yarradda Lagoon (CEWO). These actions had clear benefits for frogs and turtles in targeted wetlands and were successful in achieving the objective of supporting breeding and habitat requirements (Table 4-17).

During the five year monitoring period, the overall numbers of adult frogs peaked in 2016-17, coinciding with extensive floodplain inundation due to a combination of unregulated flows complimented by managed environmental water. This outcome highlights 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 contributed to low tadpole abundance across the Nimmie-Caira and Redbank, despite the large mid-Bidgee reconnection event that occured. However, large numbers of tadpoles from a variety of species were recorded in Nap Nap Swamp in 2018-19 as a result of the Nimmie-Caira refuge flow, and in Two Bridges Swamp following the Yanga Lake top up and system watering, demonstrating that over the five years CEWO water management has contributed to the overall resilience of the system.

Since 2014, southern bell frogs have been recorded at seven wetlands out of the 12 long-term monitoring sites, while breeding (tadpoles and juveniles) was detected at three sites, Nap Nap Swamp and Eulimbah Swamp in the Nimmie-Caria, and Yarradda Lagoon in the mid-Murrumbidgee. These three wetland systems are core habitats for southern bell frogs providing both breeding and refuge habitat, Commonwealth environmental water has been used successfully over the five year period to maintain and grow these key populations.

In the mid-Murrumbidgee, outcomes for frogs varied considerably among survey sites. In 2017-18, following a managed Commonwealth environmental water reconnection, McKennas and Sunshower Lagoons supported high abundances of tadpoles, but had low diversity of frogs and smaller adult populations overall, both of these wetlands along with Gooragool Lagoon were dry throughout 2018-19 and no frogs were recorded, which lowered the overall average frog diversity in the mid-Murrumbidgee.

At Yarradda Lagoon, frog and tadpole abundance has been variable over time, frog and tadpole numbers were highest in 2014-15 after the wetland was filled via pumping, which limited the biomass of large carp. However frog and tadpole numbers declined once the wetland reconnected with the main river channel in 2016-17 through unregulated flows and 2017-18 and through the managed reconnection. In 2018, we predicted that the very high biomass of adult carp that entered the wetlands during the unregulated flows might have contributed to the reduced breeding by resident frogs. In 2018, Yarradda Lagoon was dried briefly to remove large carp and then refilled. This action was successful in increasing tadpole abundance, and particularly the summer breeding Peron's tree frog. Very small numbers of southern bell frog tadpoles were also recorded. This reinforces our belief that management actions to remove carp prior to pumping will have a positive impact on frogs. However, while the draw down did not impact turtle abundance, broad-shelled turtles were not recorded in 2018-19, and it is possible that these individuals may have abandoned the wetland as it began to dry.

Evidence for successful maintenance of refuge habitats was also noted for turtles at Telephone Creek and Waugorah Lagoon, with Waugorah Lagoon being particularly important for the broad-shelled turtle, which is generally rare within wetlands of the Murrumbidgee.

Table 4-17 Summary of watering actions with outcomes targeting frog and turtle habitat and responses

Events	Expected outcomes	Measured outcomes	Was the objective achieved
Yanga National Park: Yanga Lake top up and system watering (via 1AS Nap Nap to Waugorah Lagoon (NSW EWA) Nimmie-Caira refuge flows Avalon Dam, Eulimbah, Telephone Creek Yarradda and Gooragool Lagoon Pumping	Support reproduction and improved condition vegetation, waterbirds, native fish and other biota 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.	Six frog and three turtle species were recorded in 2018-19, 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

4.7 Waterbird Diversity

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

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. Inundated areas of lignum and red gums provide key nesting areas for colonial waterbirds. These sites regularly support tens of thousands of birds breeding in mixed species colonies, including ibis, spoonbills, egrets and herons.

Water for the environment can directly impact or provide flows that waterbirds require to persist. Environmental water is often delivered to support or initiate colonial waterbird breeding events, and actively provide foraging and refuge habitat for a wide range of species.

Relevant watering actions and objectives

There were four LTIM monitored watering actions in the Murrumbidgee Selected Area, which provided outcomes for waterbirds in the 2018-19 water year (Table 4-18). Three of these watering actions were focused on the Redbank and Nimmie-Caria zones over the September 2018 – May 2019 period. The aim of these watering events was to benefit large bodied native fish species and to support the habitat requirements of other water-dependent species including waterbirds, frogs and turtles. The fourth watering action focused on Yarradda Lagoon, in the Mid-Murrumbidgee zone from November 2018 to January 2019 which was inundated to support wetland vegetation outcomes.

Table 4-18 Summary of environmental watering actions that influenced waterbird diversity during the monitoring period.

Water Action Reference	Event	Objectives
10082-02 &10082-03	Yanga National Park: Yanga Lake top up and system watering (via 1AS)	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
NSW EWA	Nap Nap to Waugorah Lagoon (NSW EWA) 25/09/2018 - 2/11/2018	Maintain and increase the extent and quality of habitat available to golden perch in Yanga Lake, to avoid fish mortality from drying or habitat degradation.
10082-04	Nimmie-Caira refuge flows Avalon Dam, Eulimbah, Telephone Creek	Maintain critical refuge habitat requirements for waterbirds, native fish, turtles and frogs, including for the vulnerable southern bell frogs (EPBC Act).
10082-08	Yarradda Lagoon Pumping	Maintain important refuge habitat for wetland dependant species, including for the Southern Bell frog; and maintain vegetation resilience and condition gained through Commonwealth environmental water delivery in 2014-15, 2015-16, natural flooding during winter-spring 2016 and delivery of environmental water again in 2017-18.
10082-09	Gooragool Lagoon Pumping	Maintain important refuge habitat for native fish, turtles and other water dependent biota.

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). Methods followed those employed previously to survey waterbirds in the Murrumbidgee Catchment and are documented in Wassens *et al.* (2014). Waterbird ground surveys were carried out on four occasions bimonthly between September and March in the five water years from 2014-19. Due to adverse weather conditions it was not possible to complete surveys in three sites in the Nimmie-Caria zone during the January 2019 surveys.

Complementary waterbird monitoring was also undertaken by DPIE and UNSW. DPIE completed ground-based surveys in October 2018 at the same time as annual aerial surveys of the Lowbidgee floodplain completed by UNSW 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). DPIE also completed event-based surveys over the September to April 2019 period which included surveys of active colony sites. Ground surveys were conducted at seven colony sites which were active in the Murrumbidgee Selected Area over the October 2018 – April 2019 period. The colony ground surveys were conducted on foot, or using small kayaks, 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 four 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 and number of active colonies). Repeat visits were not undertaken to evaluate fledgling success.

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 the 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 2014-19 monitoring period. The inundation status of each site during each survey period was determined using a combination of on-ground observations and inundated 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, 66 wetland-dependent bird species (included raptors and reed-inhabiting passerines) were recorded in the 2014-19 period in the Murrumbidgee Selected Area (see Appendix 1). Over the five 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. In comparison, the number of waterbird species observed in the other water years was lower (2014-15 and 2015-16 (36 species), 2017-18 (34 species) and 2018-19 (40 species)) in response to much less total inundated habitat being available (Figure 4-60). In 2018-19, the total number of waterbird species in the Mid-Murrumbidgee and Redbank zones increased over the survey period in response to the delivery of environmental water to key sites within each zone over the spring-summer period (Figure 4-61).

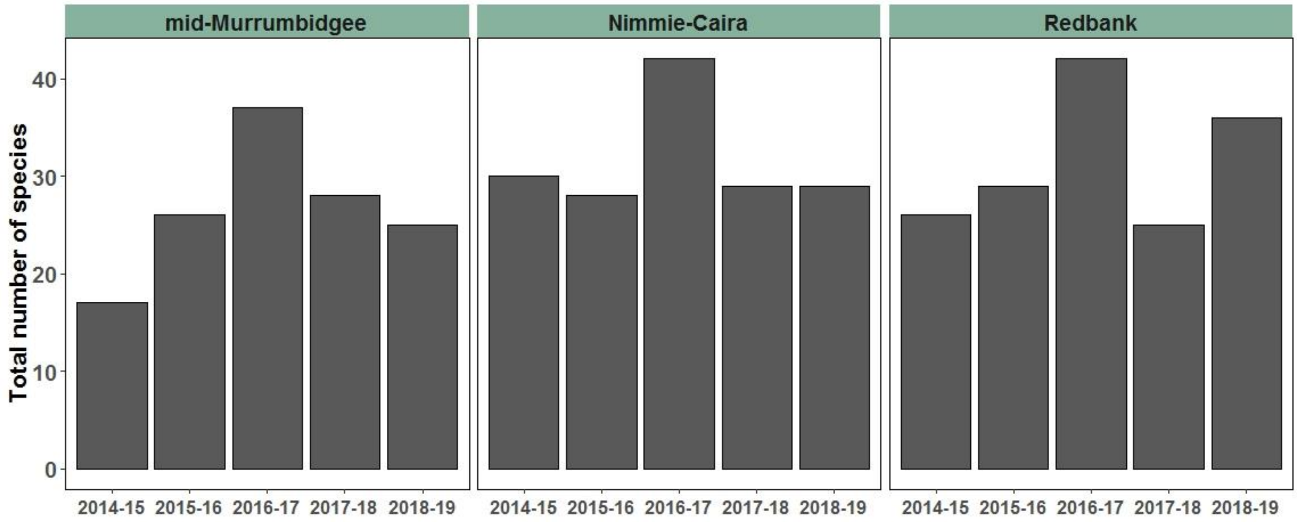


Figure 4-60 Total number of waterbird species recorded in each wetland zone in the five years of the LTIM program between 2014-15 and 2018-19. (Note that reed-inhabiting passerines and raptors are not displayed here).

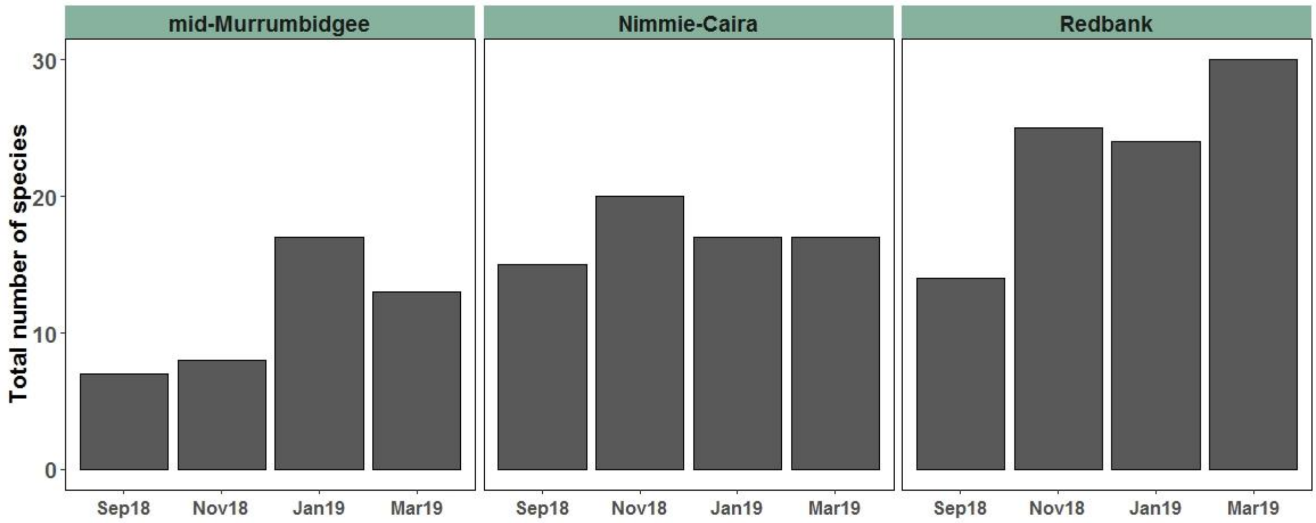


Figure 4-61 Total number of waterbird species recorded in each wetland zone in the four LTIM survey periods in the 2018-19 water year. (Note that reed-inhabiting passerines and raptors are not displayed here).

Sites that received environmental water in 2018-19 supported diverse waterbird assemblages despite the dry conditions across much of the Murrumbidgee Selected Area. Seven species of conservation significance were detected during the 2018-19 LTIM and complementary DPIE surveys. This included the endangered Australasian bittern (*Botaurus poiciloptilus)* (EPBC Act), vulnerable magpie goose (*Anseranas semipalmata*), freckled duck (*Stictonetta naevosa*) and white-bellied sea-eagle (*Haliaeetus leucogaster*)(BC Act). Four species listed under international migratory bird agreements Australia has signed with Japan (JAMBA), China (CAMBA) and the Republic of Korea (RoKAMBA) were also detected: Caspian tern (*Hydroprogne caspia*) (JAMBA only), marsh sandpiper (*Tringa stagnatilis*), red-necked stint (*Calidris ruficollis*) and sharp-tailed sandpiper (*Calidris acuminata*) (JAMBA, CAMBA and RoKAMBA).

Australasian bitterns have been detected in the Murrumbidgee Selected Area in every year since the LTIM program commenced. The Australasian bittern was heard and seen during LTIM surveys of Two Bridges Swamp during November 2018, January and March 2019 (Plate 4-3), and was heard during frog surveys of Nap Nap Swamp during the November 2018 survey. Follow-up DPIE funded surveys confirmed Australasian bittern and Australian little bittern (*Ixobrychus dubius*) were nesting in spike rush in Yanga National Park (Herring 2019) from inundated parts of Breer Swamp and south of Piggery Swamp, wetlands which received environmental water in the spring-summer of 2018-19.

A pair of white-bellied sea-eagles were observed nesting in Nap Nap Swamp (Nimmie-Caria) in September 2018 and September 2017. There were further records of white-bellied sea-eagles at Nap Nap Swamp (November 2018) and Telephone Creek (November 2018 and March 2019) in the Nimmie-Caira zone, Piggery Lake and Two Bridges Swamp, in the Redbank zone (September 2018, November 2018), and Yarradda Lagoon, in the mid-Murrumbidgee zone (November 2018, March 2019) over the 2018-19 LTIM surveys.

Plate 4-3: Inundated sites such as Two Bridges Swamp (Yanga National Park) provided habitat for a diverse range of waterbirds including the nationally endangered Australasian bittern (January 2019).

In the 2018-19 LTIM surveys, the most common waterbird species recorded were fish-eating waterbirds and dabbling ducks across all wetland zones (Figure 4-). Overall the most common species (>10% of total abundance) recorded in the mid-Murrumbidgee zone were the Australian pelican (*Pelecanus conspicillatus*), grey teal (*Anas gracilis*), red-necked avocet (*Recurvirostra novaehollandiae*) and Pacific black duck (*Anas superciliosa*), while the most common species recorded in the Nimmie-Caira zone were grey teal, Pacific black duck and Australian pelican. The Australian pelican, grey teal and hoary-headed grebe (*Poliocephalus poliocephalus*) were the most abundant species recorded in the Redbank zone during the 2018-19 water year.

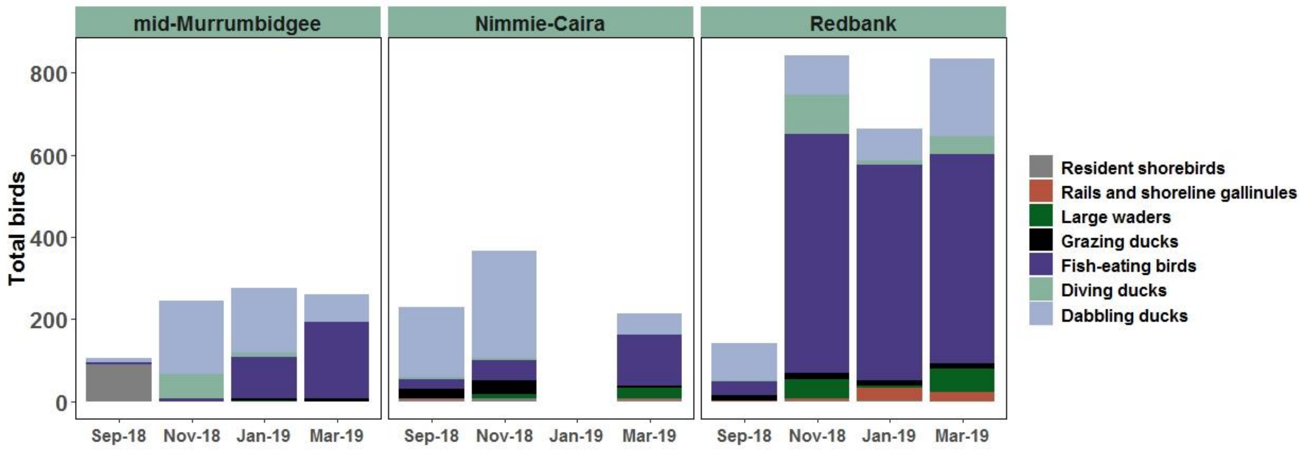


Figure 4-62 Overall waterbird community composition (max count per waterbird functional group) in each wetland zone over the 2018-19 water year. Note that surveys were incomplete in the Nimmie-Caria zone in January 2019 and so are not displayed here.

Waterbird community composition varied over the five years of LTIM surveys. Overall, dabbling ducks (e.g. grey teal and pink-eared duck (*Malacorhynchus membranaceus)* and fish-eating waterbirds (e.g. pelicans and cormorants) have dominated waterbird communities in each wetland zone across all survey years, including the 2018-19 water year (Figure 4-63). Fish-eating waterbirds made up a larger proportion of total waterbirds observed in the Redbank zone in the 2018-19 surveys compared to the previous water year but the abundance of all waterbird groups was much lower in the Redbank zone in the 2017-18 surveys, despite the large mid-Bidgee reconnection watering action that year (see Figure 4-63).

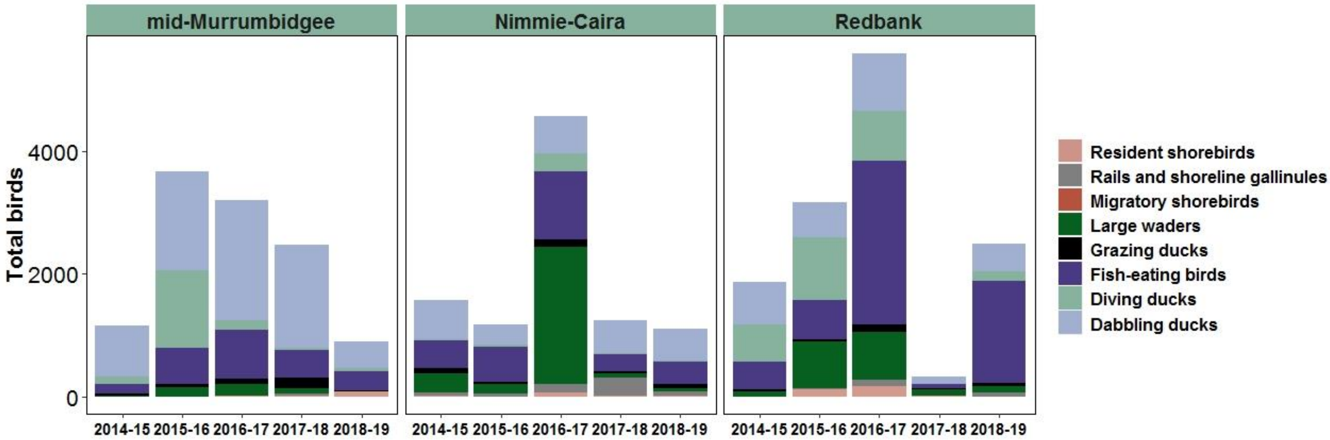


Figure 4-63 Overall waterbird community composition (max count per waterbird functional group) in each wetland zone over the five years of the LTIM Program (2014-15 to 2018-19).

There were significant differences in waterbird assemblages across the surveyed LTIM wetlands among the five water years (ANOSIM *Global R* 0.1, p = 0.001) and among the three wetland zones (ANOSIM *Global R* 0.04, p = 0.001). The 2014-15 and 2015-16 water years differed from the wetter 2016-17 water year, and the relatively drier 2017-18 and 2018-19 water years, but not from each other (Pair-wise tests 2014-15: 2015-16 *Global R -0.006*, *p* = 0.627). 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* -0.006, *p* = 0.795).

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 the 2014-2019 surveys. The total number of waterbird species and abundance of waterbirds was greater across inundated sites compared to sites which were predominately dry (<10% inundated) over the 2014-2019 survey period (GLM total species Z value = 19.66, p <0.001; abundance Z value = 13.01, p <0.001) (Figure 4-64).

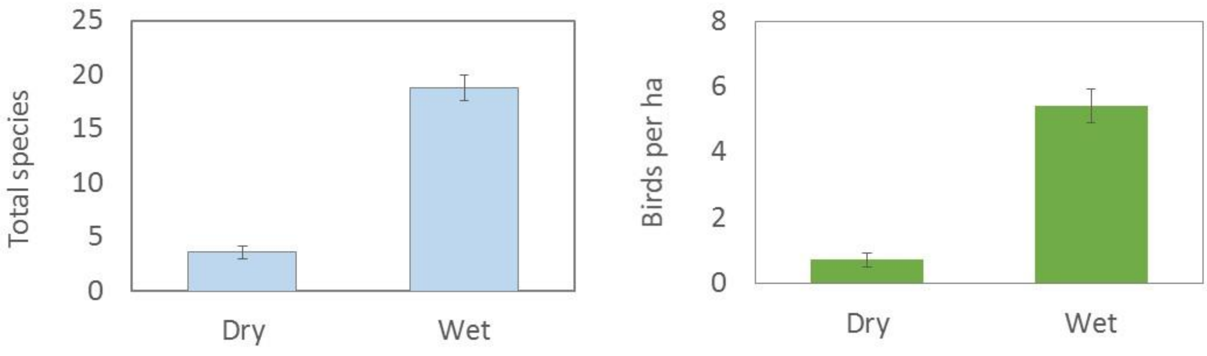


Figure 4-64 Comparison of average (+/- standard error) number of waterbird species (left) and abundance (max. count/ha) (right) recorded in inundated (>10% wet) and dry (<10% wet) wetlands surveyed from 2014-19.

What did Commonwealth environmental water contribute to waterbird breeding?

Waterbird breeding activity was limited in the Murrumbidgee Selected Area in 2018-19. Thirteen waterbird species were confirmed breeding during the LTIM quarterly wetland surveys and complementary DPIE surveys. This was compared to 32 species detected in 2016-17, during a large flood year, and 16, 17 and 8 species recorded in 2014-15, 2015-16 and 2017-18 water years, respectively (see Appendix 1).

There were seven colony sites that supported active nests (6 to 555 nests in total per site) in the Murrumbidgee Selected Area between October 2018 and April 2019 (see Table 4-1919). All seven colony sites received environmental water in 2018-19. Complementary monthly colony surveys were done at Tarwillie Swamp in Yanga National Park by DPIE staff from October 2018 to April 2019. More than 200 Eastern great egret nests were detected in total with active nests of an additional eight colonial species recorded breeding at the site during the 2018-19 surveys (Table 4-1919). Juvenile birds of each species were recorded over the January to April 2019 period and surveys completed in mid-April 2019 confirmed that nesting had been completed with some fledglings still remaining in the colony area.

Breeding activity was also observed in four non-colonial waterbird species in 2018-19. This included the Australasian bittern, Australian little bittern (North Yanga), Pacific black duck (*Anas superciliosa*) (Nap Nap Swamp, Yarradda Lagoon) and Australian shelduck (*Tadorna tadornoides*) (Nap Nap Swamp).

Table 4-19 Summary of colonial waterbird breeding activity recorded in the Murrumbidgee Selected Area in 2018-19. Data was collected through DPIE event-based surveys and LTIM quarterly wetland surveys.

			Breeding species*									
Colony locations^		Active nesting observed	DAR	GC	GE	LBC	LPC	NNH	RSB	WFH	WI	Est. total nests
MM	Yarradda Lagoon	Jan-Mar 2019	8	4	0	0	29	0	0	0	0	41
NC	Telephone Creek	Jan 2019	6	0	0	0	0	0	0	0	0	6
	Nap Nap Swamp	Nov-Dec 2018	2	0	0	0	9	0	0	0	0	11
RB	Breer Swamp	Jan 2019	1	0	0	0	17	0	0	0	0	18
	Piggery Lake	Nov 2018 - Apr 2019	7	1	0	7	17	0	0	0	0	32
	Tala Lake	Dec 2018 - Feb 2019	15	0	0	0	0	0	0	0	0	15
	Tarwillie Swamp	Oct 2018- Apr 2019	52	9	253	76	137	1	8	3	17	555

^Region codes MM = Mid-Murrumbidgee, NC = Nimmie-Caira, RB = Redbank.

*Species codes: DAR = Australasian darter, GC = great cormorant, GE = Eastern great egret, LBC = little black cormorant, LPC = little pied cormorant, NNH = nankeen night-heron, RSB = royal spoonbill, WFH = white-faced heron, WI = Australian white ibis.

Plate 2-4 Mature and recruiting river red gums can provide breeding habitat for egrets, herons, cormorants and darters in Tarwillie Swamp (Yanga National Park) in the Redbank zone during managed and natural overbank events. (Credit: Carmen Amos, DPIE, November 2018).

Response to 2018-19 watering actions

Compared to the 2016-17 water year, which coincided with a large flood event, the total numbers of waterbirds observed in each wetland zone in 2018-19 was comparatively low (Figure 4-60). However, there was evidence of some response of waterbirds in sites that received environmental water in 2018-19, including Yarradda Lagoon (YAR) in the Mid-Murrumbidgee zone, Piggery Lake (PIG) and Two Bridges Swamp (TBR) in the Redbank zone, and Nap Nap Swamp (NAP) in the Nimmie-Caira. These sites supported the most diverse waterbird communities in the Murrumbidgee Selected Area in 2018-19. With the exception of Tarwillie, the remaining survey sites supported fewer waterbird species overall in 2018-19 (Figure 4-5).

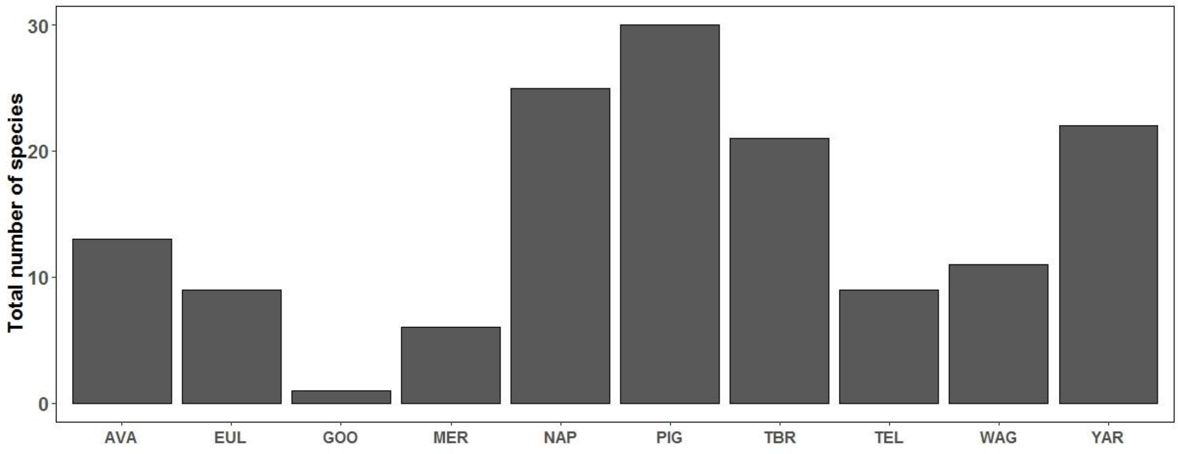
Redbank watering actions

Two Bridges Swamp and Piggery Lake in north Yanga National Park were inundated from September 2018 as part of the fish-flow that connected to Tala and Yanga Lakes. Both sites supported a diverse range of waterbird species in the 2018-19 water year (21 species and 30 species, respectively), and Piggery Lake supported large numbers of fish-eating waterbirds (e.g. Australian pelican, hoary-headed grebe and cormorants) (Figure 4-65).

Complementary DPIE monitoring also indicated that the Australasian bittern and Australian little bittern were breeding with nine colonial waterbird species also recorded breeding in inundated parts of north Yanga (see 4-3 and

Plate 2-4). This included Tarwillie Swamp, Breer Swamp and Piggery Lake over summer 2018-19 (see above). These areas received additional top-up flows over summer months to maintain water levels into March 2019.

Additional waterbird monitoring was also completed at Yanga Lake and Tala Lake as part of a short-term intervention monitoring project examining the responses of fish and waterbirds to a targeted Commonwealth environmental action aimed at supporting native fish populations in persistent floodplain. Full lake surveys were completed at both lakes between June 2018 and March 2019. Across all surveys, including incidental sightings, 38 waterbird species were observed across both lakes including 16 fish eating species (see Appendix 2).



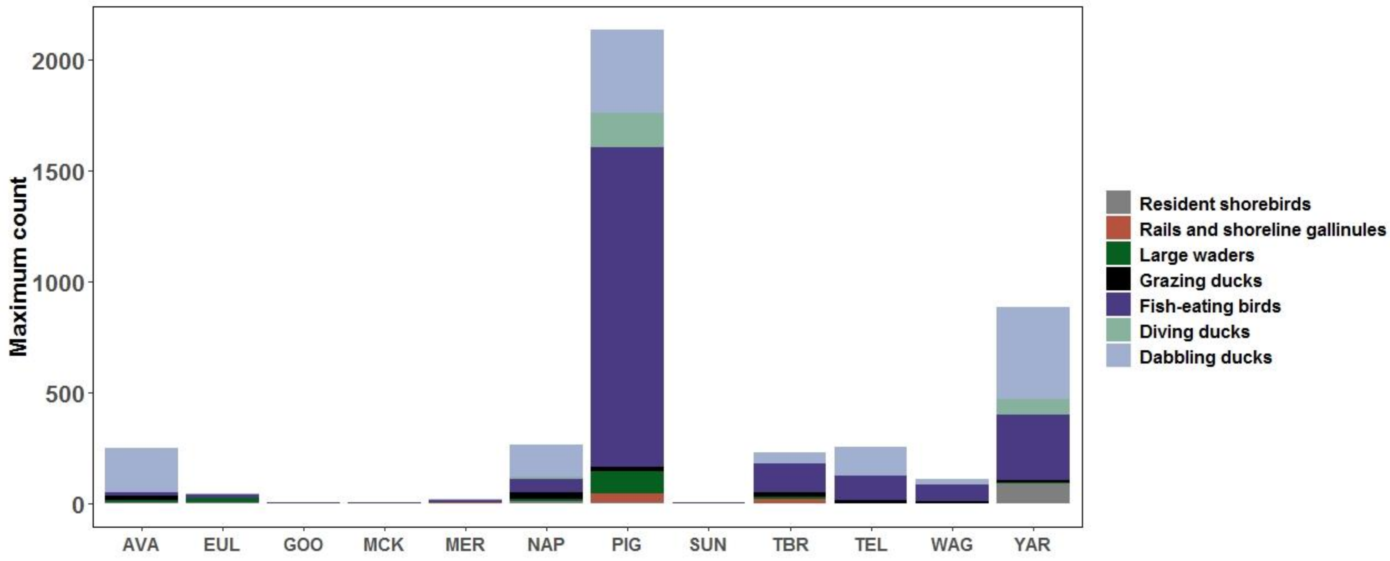


Figure 4-65 Overall waterbird community composition (upper) total number of species and (lower) maximum count per waterbird functional group) in each wetland site recorded over the 2018-19 water year. Site codes: AVA = Avalon Swamp, EUL = Eulimbah Swamp, NAP = Nap Nap Swamp, TEL = Telephone Creek (Nimmie-Caira), GOO = Gooragool Lagoon, MCK = Mckennas Lagoon, SUN = Sunshower Lagoon, YAR = Yarradda Lagoon (Mid-Murrumbidgee), MER = Mercedes Swamp, PIG = Piggery Lake, TBR = Two Bridges Swamp, WAG = Waugorah Lagoon (Redbank).

Nimmie-Caira watering actions

The Nimmie-Caira zone received environmental water in September 2018 as part of targeted flows delivered to Nap Nap Swamp (Nimmie-Caira) and the Waugorah system. Inundated habitat was maintained in Nap Nap Swamp through spring into autumn 2019. The site supported 26 waterbird species in total (Figure 4-65) including the endangered Australasian bittern and small number of cormorant and darter nests (see below). Over the summer months this site provided feeding habitat for water hens, rails and crakes which were observed feeding on shallow mudflat habitats during the January 2019 surveys. The other Nimmie-Caira surveys sites were much drier in comparison and supported fewer waterbirds overall (

65).

Further flows were delivered to Eulimbah and Avalon in September 2018 to provide refuge and maintain habitat for waterbirds and other wetland-dependent species. This coincided with a period of extreme heat when there was limited wetland habitat available across the Nimmie-Caira zone. A large waterbird response was observed at Avalon swamp in the November 2018 survey with an increase in abundance of dabbling ducks, fish-eating birds, grazing ducks, large waders and resident shorebirds. This was compared to the September 2018 survey which had no waterbirds. Eulimbah also saw an increase in abundance and functional groups. Avalon Swamp, Eulimbah Swamp and Telephone Swamp also received refuge flows from December 2018-May 2019 to continue to maintain habitat for these waterbirds and other wetland-dependent species throughout the season.

Yarradda (midbidgee) watering action

Yarradda Lagoon was the only site in the mid-Murrumbidgee zone which supported waterbirds with the three other mid-Murrumbidgee sites being dry during the 2018-19 surveys (

65). Surveys completed in January and March 2019 at Yarradda Lagoon showed an increase in total species richness (14 species in January and 13 species in March 2019) compared to November 2018 (5 species) when water levels were very low. Yarradda Lagoon also supported small numbers of nesting Australasian darters (*Anhinga novaehollandiae*), great cormorants (*Phalacrocorax carbo*) and little pied cormorants (*Microcarbo melanoleucos*) (estimated 40 nests in total) over the January-March 2019 period (see Table 4-1919).

Discussion

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

Over the five years of the LTIM program around 70-80% of Commonwealth environmental watering actions in the Murrumbidgee Catchment have targeted waterbird outcomes each year. Commonwealth environmental watering actions inundated waterbird feeding habitat in all five water years. In the drier years (e.g. in 2015-16, 2017-18 and 2018-19) there were additional watering actions later in summer months targeting refuge habitats for waterbirds, turtles, wetland fish and frogs. Commonwealth watering actions also successfully supported colonial waterbird breeding in the Murrumbidgee Selected Area over the 2014-19 period. This included delivery of environmental water to initiate and maintain small egret and cormorant colonies in 2014-15, 2015-16 and 2018-19 and augmentation of natural widespread flooding in 2016-17 to ensure water levels were maintained in large ibis, egret, heron and pelican colonies over summer months.

Monitoring results from the past five 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 five years of surveys had a higher overall species richness and abundance when compared to wetlands that were dry for extended periods during 2014-19.

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, waterbird habitat was most limiting in 2017-18, compared to the 2014-15, 2015-16 and 2018-19 periods, which coincided with greater environmental watering.

The largest colonial nesting events in the Murrumbidgee, since 2010-2011, were monitored in 2016-17. These were initiated by natural flooding and where possible supported with Commonwealth environmental water to ensure the completion of chick rearing. The most significant of these events were three large straw-necked ibis rookeries (totalling more than 50,000 nests) within the Nimmie-Caira and Redbank zones. The delivery of Commonwealth environmental water to maintain water levels at these, and other, colonial nesting events was crucial to the completion of these events as the sites would have otherwise dried out.

The 2018-19 water year had the most evidence of waterbird responses to environmental watering in the Redbank zone (in the northern part of Yanga National Park) where Australasian bitterns were detected breeding and colonial waterbird species nested at Tarwillie Swamp, Piggery Lake, Breer Swamp and Tala Lake. There was also a breeding event at Yarradda Lagoon in the mid-Murrumbidgee. Excluding the 2017-18 water year, Tarwillie Swamp has supported colonial waterbird breeding in each year of the survey program. In 2018-19, environmental water delivered to Tarwillie supported at least nine breeding species including an estimated 253 pairs of eastern great egrets. Tarwillie Swamp was one of only 11 known small colonies detected across the NSW Murray-Darling Basin during DPIE ground surveys and UNSW aerial surveys in spring 2018. Tarwillie was also the only egret site active this water year with the remaining sites spread across the Murrumbidgee, Macquarie and NSW Murray catchments supporting small numbers of cormorants, herons and white ibis only.

Management implications

Where possible, environmental water should be prioritised to provide some annually seasonally-flooded habitat (spring-summer) for waterbirds in the Lowbidgee floodplain and mid-Murrumbidgee wetlands. In dry years this can help provide refuge habitat for waterbirds and other species. Most waterbirds commence breeding in spring. However, the stimuli for breeding is usually a combination of season, rainfall and flooding. Inundating some breeding sites in spring can also provide breeding opportunities for small numbers of colonial waterbirds in the Murrumbidgee catchment. When breeding occurs, water levels in active sites need to be maintained into summer months to ensure the successful fledging of young birds. 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 will benefit waterbird populations in the Murray-Darling Basin by promoting the survival of juvenile and adult waterbirds in years where there is limited natural overbank flooding.

4.8 Riverine water quality

Prepared by Dr Ben Wolfenden (DPIE) and Dr Damian Michael (CSU)

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

During the 2018-19 water year, a total of 195,419 ML of environmental water (61,795 ML of Commonwealth environmental water) was delivered in channel to inundate low-lying wetlands in Murrumbidgee Selected Area as part of the mid-Murrumbidgee Lagoon pumping actions (e.g. Darlington Point, Yarradda and Gooragool), Yanga and Nimmie-Caira refuge flows. River flows peaked at Narrandera at approximately 7,130 ML/d and Carrathool at 4,973 ML/day on 30 September 2018. Water levels calculated as percentage bankfull during the water quality sampling period are presented in Figure 4-66. With the exception of the Lowbidgee low DO action (10082-16), there were no other specific 2018-19 objectives related to riverine water quality. Therefore, we examined potential flow-on effects from environmental water actions 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 2018-19?

Methods

River water quality was monitored six times between October and December in each monitoring year (2014-15, 2015-16, 2016-17, 2017-18 and 2018-19). Sampling coincided with microinvertebrate and larval fish monitoring programs. 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 4.9). 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, water quality and physiochemical data were analysed using a general linear model. Zone (n=2) and water year (n=5) were treated as fixed factors in the analysis. The error for the test included a random intercept. Results were considered significant at P<0.05. 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 20).

*Table 4-20 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 (7.64-10.86)
No. of samples (*n*)	39	39	43	43	48	48	47	48

Results

During 2018-19, physicochemical conditions (Figure 4-67) and water quality parameters (Figure 4-68) remained broadly within the expected range and were similar to the two years before the 2016-17 flood year (2014-15 and 2015-16). Overall, there was a significant degree of variation among monitoring years for all measured parameters, and significant differences in several parameters among zones (Table 4-20). For example, conductivity during the 2018-19 water year was relatively low in comparison to previous years, although remained above expected values during all sampling occasions except for early November. Levels of pH in the Narrandera reach were low compared to previous years but spiked above the 95% upper threshold during late December. Other parameters such as dissolved organic carbon, total nitrogen, total phosphorous and Chlorophyll-a levels were among the lowest readings recorded across the five year monitoring program. Concentrations of bioavailable nutrients such as NOx were also significantly low compared to previous years (Table 4-20) and remained below the 5th percentile (Figure 4-69). The large variation in water parameters across years is likely due to differences in river discharge. Overall, large inter-annual differences in water quality and nutrients were influenced by flood waters and river discharge during the 2016-17 water year. Several parameters were strongly correlated with rates of discharge and river water levels during the 2016-17 water year (Table 4-21), where high river water levels during October were reflected in high concentrations of NH3, FRP, DOC, TN and TP.

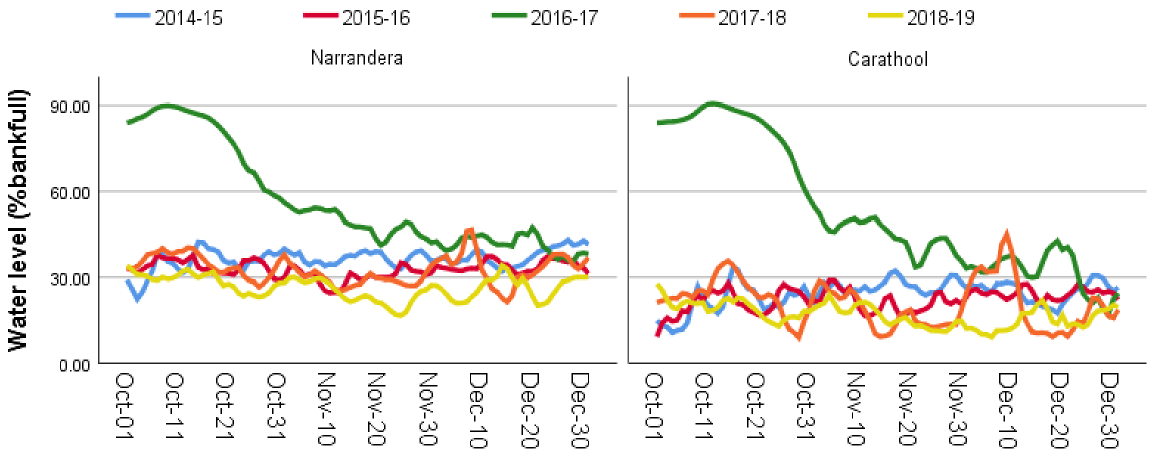


Figure 4-66 Mean daily water level from the Narrandera and Carrathool gauges (data sourced from http://waterinfo.nsw.gov.au/) and calculated as a proportion of estimated bankfull height.

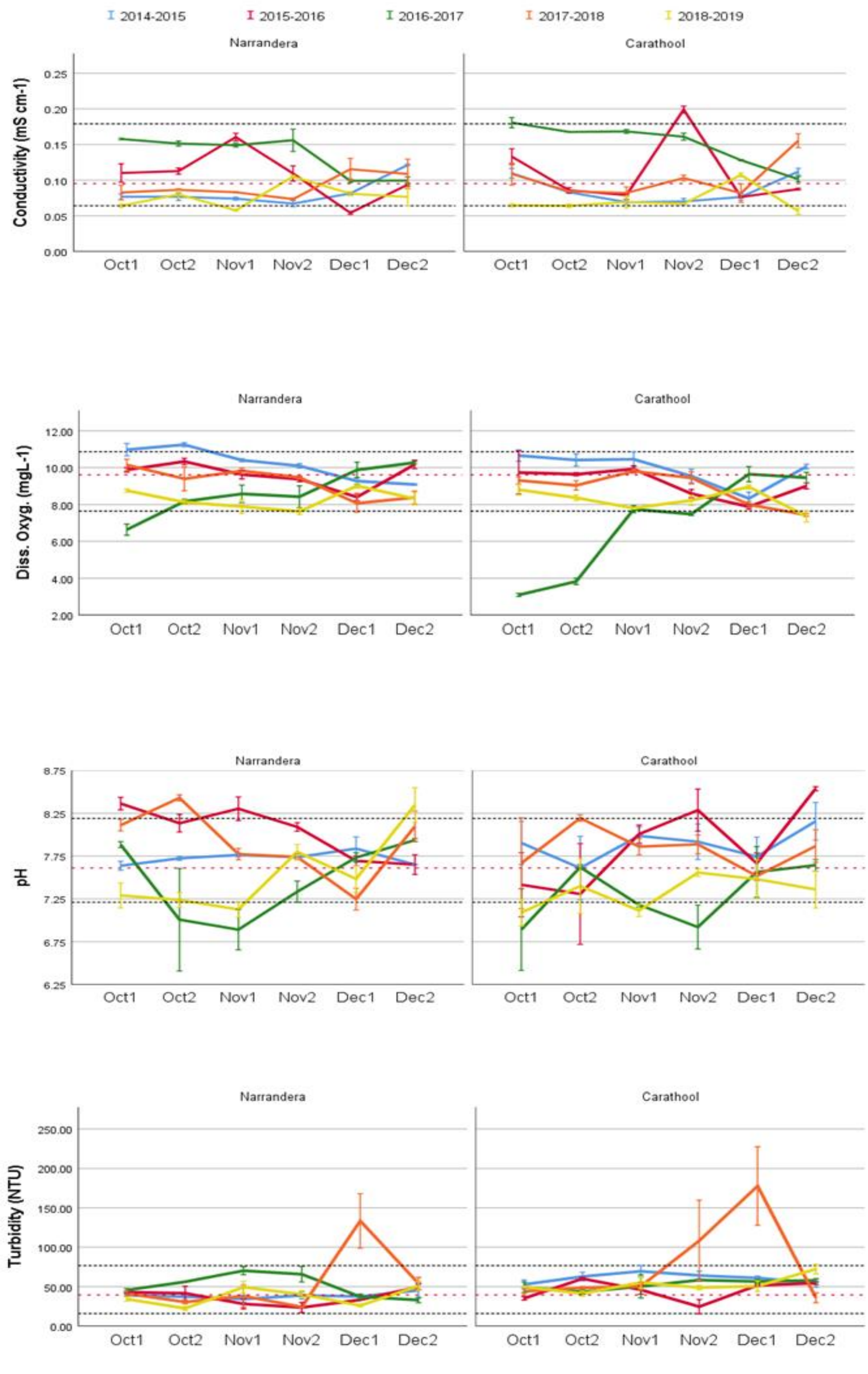


Figure 4-67 Mean ± standard error for physicochemical parameters (turbidity, pH, dissolved oxygen and conductivity) measured on six occasions between October and December during 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

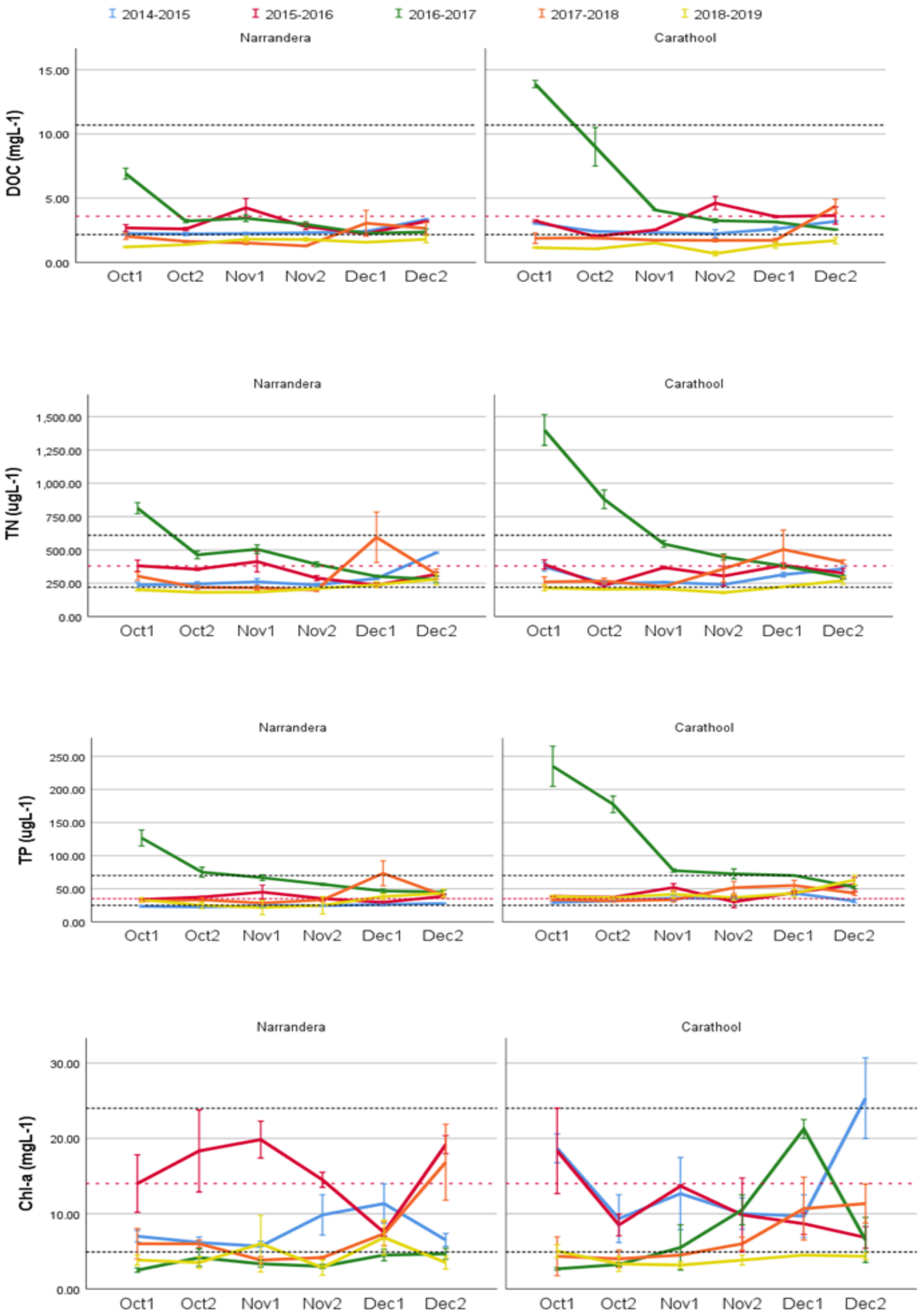


Figure 4-68 Concentrations of dissolved organic carbon (DOC), total nitrogen (TN), total phosphorous (TP), and chlorophyll-a (Chl-a) in water samples collected on six occasions between October and December during each of 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

*Table 4-21 General linear model results for water quality data collected for the Narrandera and Carrathool Zones for the 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19 water years. Significance levels are *p<0.05, **p<0.01, ***p<0.001*

Term	**WaterYear(WY)**			**Zone(Zo)**			**WY*Zo**		
	df	*F value*	*Sig.*	*df*	*F value*	*Sig.*	*df*	*F value*	*Sig.*
Total N	4	21.111***	.000	1	5.307*	.023	4	3.375*	.011
Total P	4	31.034***	.000	1	17.065***	.000	4	4.848**	.001
NH3	4	13.864***	.000	1	4.212*	.042	4	3.946**	.004
NOx	4	18.704***	.000	1	5.212*	.024	4	1.597	.178
FRP	4	31.191***	.000	1	3.086	.081	4	6.125***	.000
Chl-a	4	19.057***	.000	1	2.141	.145	4	7.083***	.000
DOC	4	24.256***	.000	1	7.612**	.006	4	5.314***	.000
Cond.	4	26.230***	.000	1	2.150	.145	4	1.046	.386
pH	4	11.389***	.000	1	1.941	.166	4	1.435	.225
DO	4	23.158***	.000	1	13.371***	.000	4	4.140**	.003
Turb.	4	3.728**	.006	1	10.918**	.001	4	.791	.533

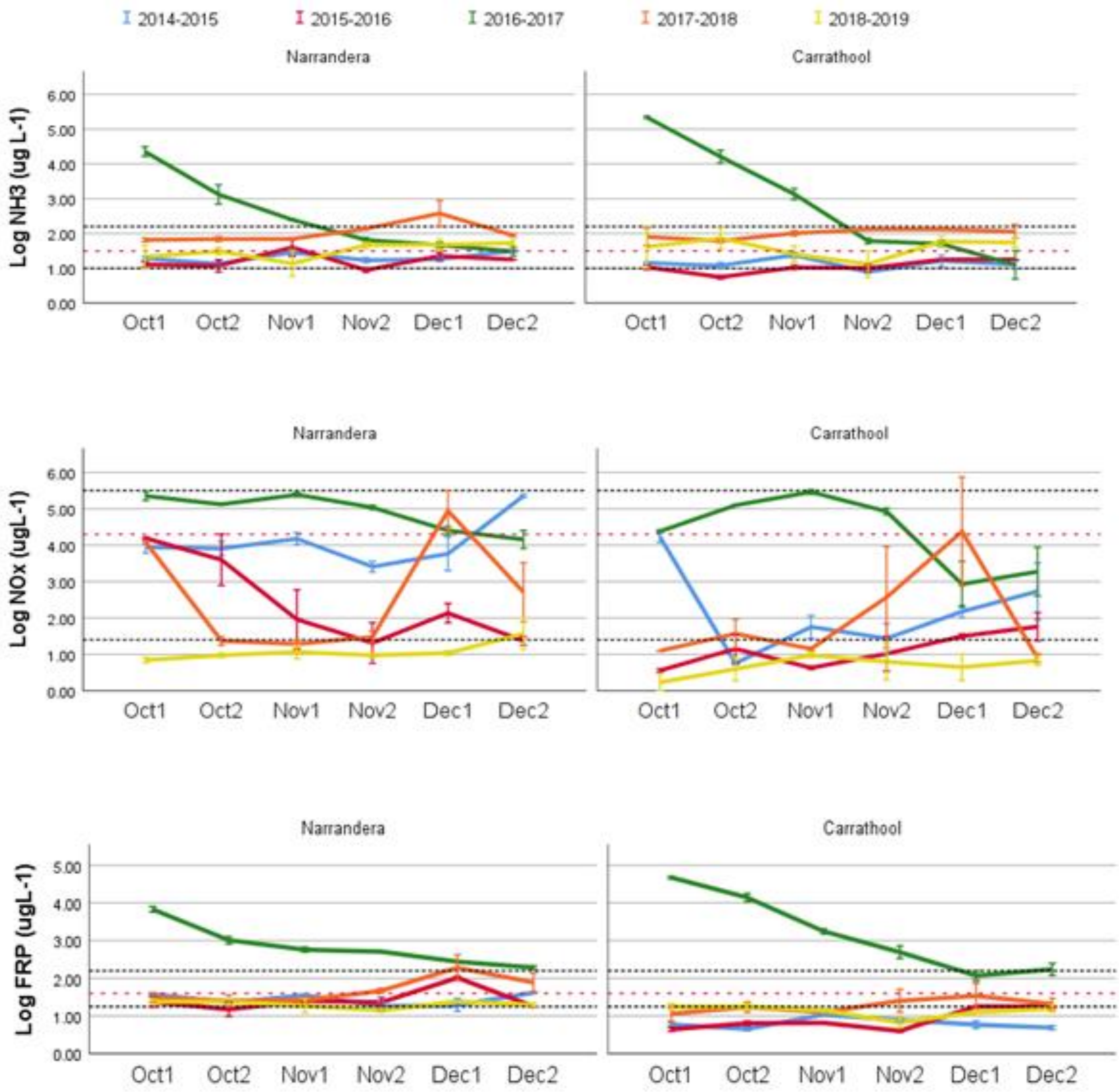


Figure 4-69. Concentrations of bioavailable nutrients (filterable reactive phosphorus – FRP; oxidised nitrate/nitrite – NO_x; and ammonia – NH_3) in water samples collected on six occasions between October and December during each of 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19. Data are the mean of three sites ± 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.

Discussion

How did Commonwealth environmental water affect the cycling of nutrients and carbon in the Murrumbidgee River during 2018-19?

During 2018-19, water quality in the river in the Narrandera and Carrathool reaches remained within acceptable bounds throughout the monitoring period. Interestingly, riverine nutrient concentrations were lower during 2018-19 compared to previous watering years. As is expected, flows that connect large areas of the floodplain, as was the case during unregulated flows in 2016-17, contribute to increased nutrient and carbon loads in the river. The smaller wetland to river reconnection in 2017-18 may also have contributed to small peak in nitrates.

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 2018-19. 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).

4.9 Stream metabolism

Prepared by and Dr Yoshi Kobayashi (NSW DPIE), Gayleen Bourke (CSU) and Dr Ben Wolfenden (NSW DPIE)

Introduction

Stream metabolism is a measure of the amount of energy produced and consumed by river food webs. It includes rates of gross primary production (GPP: autotrophic carbon production) by algae and aquatic macrophytes as well as rates of ecosystem respiration (ER: heterotrophic carbon consumption) by all stream aquatic organisms. Metabolism is calculated using the diurnal change in dissolved oxygen due to these two processes, accounting for the effects of 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 likely flow-on effects to food web dynamics and water quality (Marcarelli *et al.* 2011). Thus, 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 September 2018 and April 2019, a total of 195,419 ML of environmental water (including 61,795 ML of Commonwealth environmental water) was delivered along the Murrumbidgee River channel. During the same period, river flows peaked at Narrandera at approximately 7,130 ML/d and Carrathool at 4,973 ML/day on 30 September 2018. 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, 2017-18 and 2018-19, 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 and Narrandera (primarily October – April) 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 Pearson product-moment correlation analysis to examine if there was a significant association between the annual median daily flow rate and the annual median GPP/ER ratio at the both Narrandera and Carrathool sites over the entire watering period (the years 2014 to 2019). Statistical analyses were performed using the statistical-computing environment 'R' (R Development Core Team 2014).

Results

Overall 158 and 198 observations were available for the assessment of stream metabolism from the Narrandera and Carrathool Zone loggers between September 2018 and April 2019 (Table 4-2222) respectively. The rates of GPP and ER varied temporarily at both sites, with median values ranging from 1.20-1.34 and 0.77-1.32 mgO_2 L^{-1} d^{-1}, respectively (Table 4-22). At the Narrandera site, the relatively high metabolic rates for 2018 were observed in mid November, coinciding with relatively low flow periods, while the relatively high metabolic rates for 2019 were observed in mid February and again in mid-March (Figures 4-70 and 4-71). At the Carrathool site, the relatively high metabolic rates for 2018 were observed in mid to late December, and again in mid to late January for 2019 (Figures 4-70 and 4-71).

Table 4-22 Summary statistics for stream metabolism at Narrandera and Carrathool in the Murrumbidgee River from October 2014 to April 2019 (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	**2018-19**	2014-15	2015-16	2016-17	2017-18	**2018-19**
	24/10/14 – 8/1/15	1/10/15 – 31/1/16	2/11/16 – 31/1/17	1/10/17 – 23/4/18	**26/9/18 – 16/4/19**	1/10/14 – 18/3/15	1/10/15 – 30/4/16	23/11/16 – 1/5/17	25/10/17 – 23/4/18	**25/9/18 – 16/4/19**
Number of available observations (number of missing observations)	82 (3)	112 (7)	79 (10)	220 (15)	**168 (10)**	151 (14)	195 (12)	117 (33)	178 (14)	**198 (0)**
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]	1.40 [0.14-6.75]	**1.34 [0.03-13.58]**	1.14 [0.42-2.85]	1.28 [0.41-13.45]	1.24 [0.71-2.88]	1.33 [0.26-5.25]	**1.20 [0.20-8.56]**
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]	0.96 [0.14-3.23]	**0.80 [0.06-7.94]**	1.31 [0.09-6.12]	1.58 [0.59-26.82]	1.49 [0.26-3.47]	1.53 [0.11-3.96]	**1.30 [0.13-14.81]**
Flow rate (ML d^{-1}) median [range]	7,845 [2,205-11,865]	6,331 [2,89-8,588]	11,259 [4,180-81,862]	5,650 [1,703-13,108]	**2,773 [440-7,129]**	3,126 [383-7,361]	3,069 [373-5,892]	4,399 [551-60,737]	1,056 [223-8,148]	**1,871 [373-4,533]**

A bivariate plot of the annual median flow rates and annual mean metabolism rates for the years 2014 to 2019 is shown Figure 4-72. The GPP/ER ratio at the Narrandera site was less than 1 for the water years 2014-15 and 2016-17 but well above 1 for the water years 2015-16, 2017-18 and 2018-19. At the Carrathool site, the GPP/ER ratio remained slightly less than 1 for all the water years at Carrathool (range: 0.81-0.92).

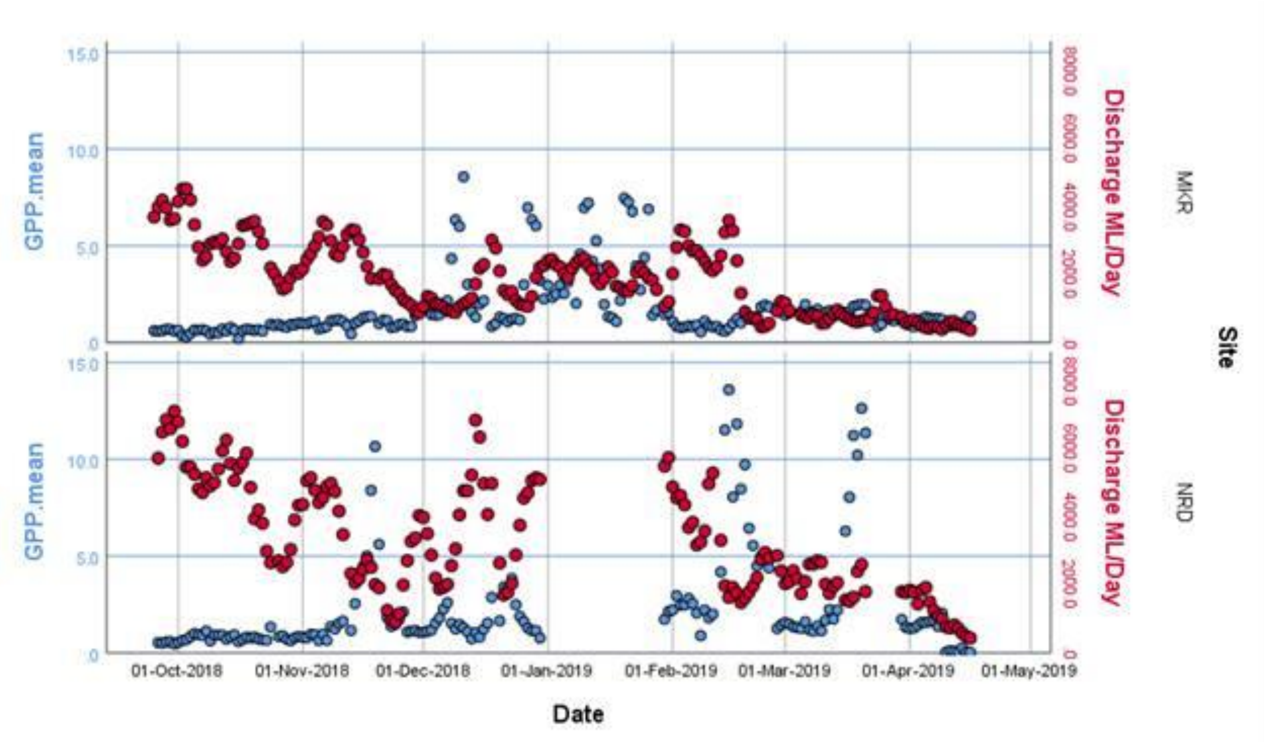


Figure 4-70 Daily flow rate (ML d-1) and metabolism rates (GPP: gross primary productivity) measured at the Narrandera and Carrathool site from 26 September to 30 December 2018 and from 30 January to 16 April 2019).

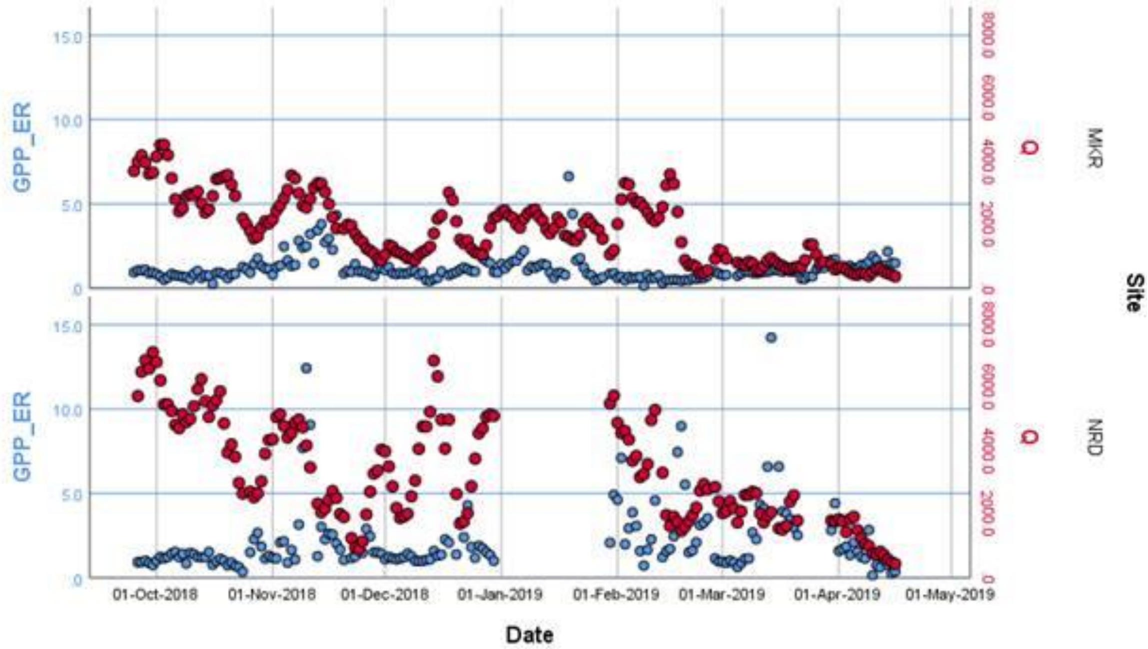


Figure 4-71 Daily flow rate (ML d-1) and the ratio of GPP to EP (GPP/ER) measured at the Narrandera and Carrathool site from 25 September to 31 December 2018 and from 1 January to 16 April 2019.

There was a negative correlation between the annual median daily flow rate and the annual median GPP/ER ratio at the both Narrandera and Carrathool sites (Pearson product-moment correlation coefficient or r = -0.80 and -0.58, p = 0.10 and 0.30, respectively; n =5 for each).

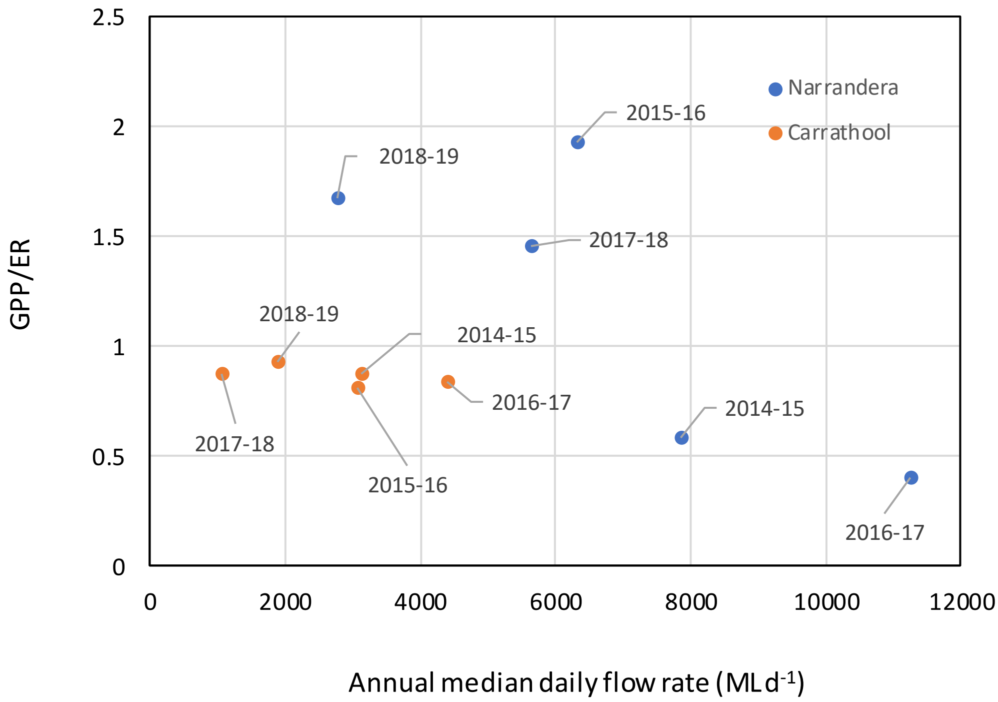


Figure 4-72 Annual median daily flow rate (ML d^{-1}), annual median ratio of gross primary productivity and ecosystem respiration (GPP/ER) for the years 2014 to 2019. The period for each water year corresponds to those shown in Table 4-22.

Discussion

During 2018-19, we found that median rates of stream metabolism were within the range observed for the previous water years (2014-15 to 2017-18). As noted previously (Wassens *et al.* 2018), rates of stream metabolism in the Murrumbidgee River are relatively low, corresponding with apparently low nutrient availability. This pattern was seen again in 2018-19. In fact, the riverine nutrient concentrations were lower during 2018-19 compared to previous watering years (see "4.8 River water quality" in this report). 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. 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.

The comparison of the annual median GPP/ER ratios against the annual median flow rate for the five water years (2014-15 to 2018-19) showed the site-specific patterns at the Narrandera and Carrathool sites (Figures 4-70 & 4-71). Namely, the GPP/EP ratio tended to decrease with increasing flow rate at the Narrandera, shifting from highly autotrophic state (GPP/ER >1) to higher heterotrophic state (GPP/ER <1). At the Carrathool site, the GPP/EP ratio changed within a narrow range, remaining slightly heterotrophic state (GPP/ER <1), independent of flow rate.

What are the ecological implications when ER exceeds GPP? Does the heterotrophic condition (GPP/EP ratio <1) of the river water imply the likelihood of hypoxic conditions, leading to fish and crustacean mortality? In our view, the low GPP/EP ratio alone is unlikely to indicate the likelihood of hypoxic conditions. We would need to consider other environmental factors concurrently. For example, hypoxic conditions in lowland river systems are often associated with high levels of dissolved organic carbon (DOC) in the water column, the metabolism of which by microorganisms depletes dissolved oxygen (Whitworth *et al*. 2012). In the studied area of the Murrumbidgee River system, the DOC concentration remained relatively low throughout the monitoring period (mostly <5 mg/L DOC, Figure 4-68). Note that the GPP/ER ratio differed markedly between the two sites even within the similar range of flow rate (approximately 1,000 to 6,000 ML d^{-1}) (Figure 4-72). This indicates that the stream metabolism response, hence GPP/ER ratio, to river flow may be largely regulated by site-specific factors in the Murrumbidgee River. In this regard, studies of the amount of additional bank area inundated with increasing river flow may be useful when understanding how GPP and ER rates (and loads) respond to flow, specifically if we assume that site-specific response of the metabolism is significantly driven by site-specific benthic and epiphytic algal communities. Although there was a relatively high negative correlation between the GPP/ER ratio and flow rate at the Narrandera site, the correlation was significant only at p=0.10 level.

With further continuing the monitoring of stream metabolism (that is, adding more annual data), we are likely to obtain significant ecological insights on the patterns and processes of in stream metabolism in relation to river flows that carry environmental water. In relation to the low metabolic rates in the Murrumbidgee relative to other river systems in the Murray-Darling basin, our results may indicate a system-scaling effect: the Murrumbidgee is a large system, which may have inherently lower rates of metabolism, but this is mere conjecture. Basin-scale analysis may help provide further insights.

4.10 Riverine microinvertebrates

Prepared by Dr Kim Jenkins (CSU), Dr Ben Wolfenden (DPIE), Claire Sives (UNSW), Sylvia Hay (UNSW), Dr Gilad Bino (UNSW), Kendal Krause (CSU) 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 fish 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 2018-19 are considered in the context of 2014-15, 2015-16, 2016-17 and 2017-18 outcomes. Commonwealth environmental water was not directly targeted at in-channel watering outcomes during 2014-15, 2015-16, 2016-17, 2017-18 or 2018-19. However, the delivery of environmental and irrigation water, along with inter valley transfers influences the hydrology of the Murrumbidgee River and can be linked to microinvertebrate activity. 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 the 2018-19 water year, a total of 195,419 ML of environmental water (61,795 ML of Commonwealth environmental water) was delivered in channel to inundate low-lying wetlands in Murrumbidgee Selected Area as part of the mid-Murrumbidgee Lagoon pumping actions (e.g. Darlington Point, Yarradda and Gooragool), Yanga and Nimmie-Caira refuge flows. River flows peaked at Narrandera at approximately 7,130 ML/d and Carrathool at 4,973 ML/day on 30 September 2018. Water levels calculated as discharge during the microinvertebrate sampling period are presented in Figure 4-73. While there were no specific objectives related to riverine microinvertebrates we examined potential flow-on effects from environmental watering actions by investigating differences in microinvertebrate activity among LTIM monitoring years and between zones.

Evaluation Questions

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

Methods

Microinvertebrate samples were collected fortnightly from the six larval fish sampling sites along the Murrumbidgee River (three sites in each of the Carrathool and Narrandera zones) from mid spring to early summer in 2014, 2015, 2016, 2017 and 2018. In year one of the LTIM project (2014-15), sampling occurred fortnightly between 20 October 2014 and 1 January 2015. In year two (2015-16), sampling was undertaken fortnightly from 13 October until 24 December 2015. In year three, sampling occurred fortnightly from 10 October until 22 December 2016. In year four, sampling occurred fortnightly from 9 October until 21 December 2017 and in year five, sampling occurred fortnightly from 8 October until 20 December 2018. 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 1983, Shiel 1995, Shiel, 1995). A maximum of 30 individuals of each taxa per sample were measured for length and width.

Data analysis

To determine differences in microinvertebrate density between zones (Mid-Murrumbidgee, Nimmie-Caira and Redbank) and years (2014-15, 2015-16, 2016-17, 2017-18 and 2018-19), 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) using the vegan package (Oksanen *et al.* 2011) in R version 3.6.1 (R Development Core Team 2019). Raw data were initially log transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$.

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. Microinvertebrate density data are represented graphically to explore trends between zones, year and time of sampling.

Results

In all five years of the LTIM project, densities of microinvertebrates were two orders of magnitude higher in benthic (<3000/L) than pelagic (<10/L) habitats within the Murrumbidgee River (Figure 4-73). Pelagic densities were consistently an order of magnitude below the lowest prey density threshold suggested for successful feeding by larval fish (Figure 4-73). Therefore we have focussed this results section on trends in benthic microinvertebrates.

Densities of benthic microinvertebrates showed a peak in late October in the Carrathool zone, contrasting to later peaks observed in 2014-15 (mid-December 2014) and 2015-16 (mid-November 2015) (Figure 4-7373). In the Narrandera zone, a peak occurred in December 2018, similar to peaks observed in 2014 and 2015 (Figure 4-73). In the two years during and after the 2016-17 flood event, no peaks were observed in microinvertebrate densities in either zone (Figure 4-73). 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. The lack of consistent trends across time were reflected in the non-significant test of the sampling trip factor. However, the occurrence of peaks in some years resulted in year being a significant factor, with higher benthic densities observed in 2014-15, 2015-16 and 2018-19 than the other two years ($p<0.008$). During the 2018-19 peaks in benthic microinvertebrate densities in the Carrathool and Narrandera zones, cladocerans dominated communities with ostracods also contributing (Figure 4-74). Densities of copepods were low in 2018-19 (and also 2017-18) compared to earlier years (Figure 4-74).

Overall, densities of microinvertebrates were significantly higher in the Carrathool than Narrandera zone ($p<0.02$, Figure 4-73). Water levels in the Carathool zone were consistently lower and less variable than in the Narrandera zone throughout the five year project (Figure 4-73). Water temperatures were consistently higher in the Carrathool than the Narrandera zone throughout the project (Figure 4-73).

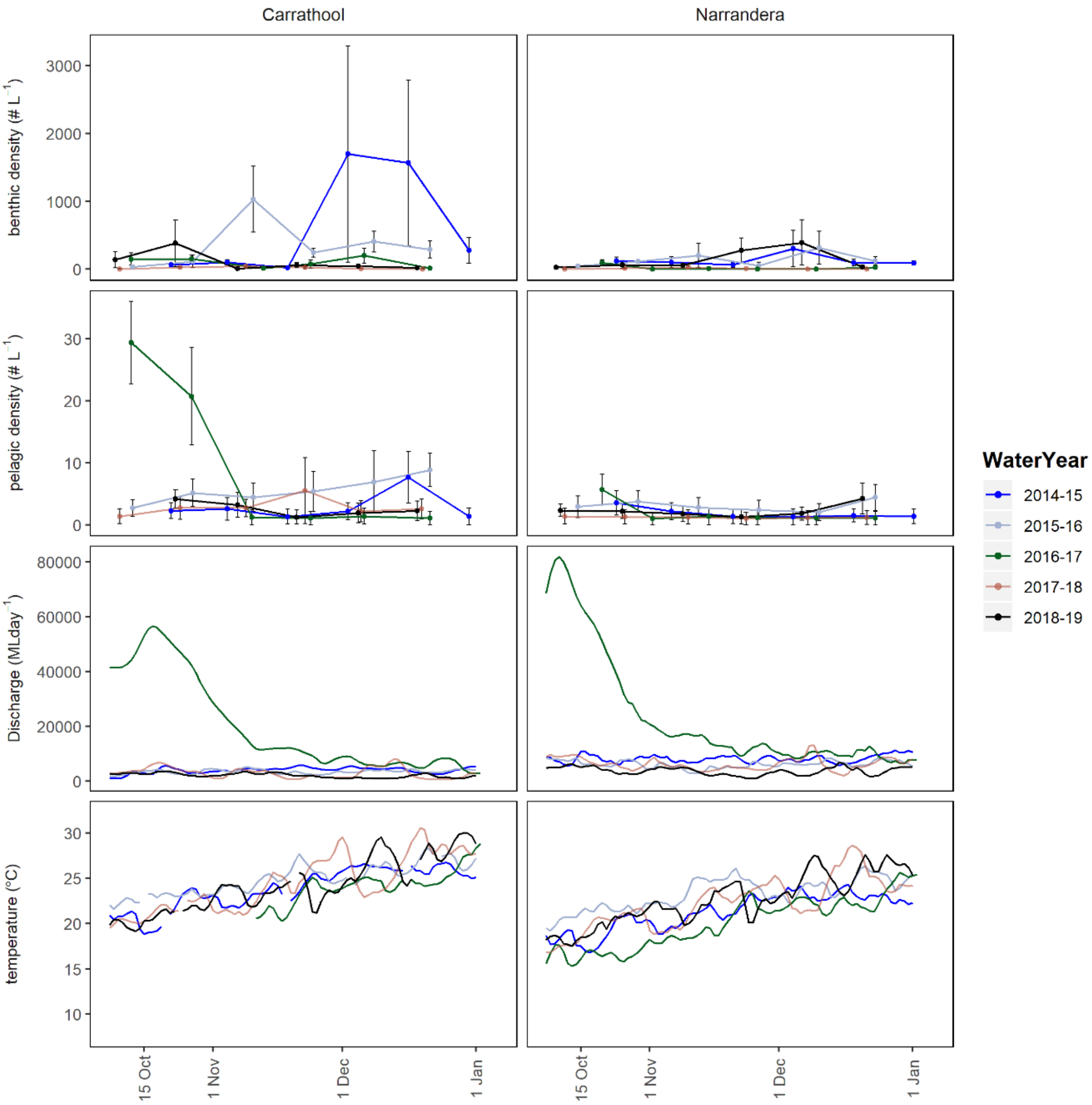


Figure 4-73 Benthic (upper row) and pelagic (second row) microinvertebrate densities (L-1) for 3 sites in the Carrathool zone (left graphs) and 3 sites in the Narrandera zone (right graphs) of the Murrumbidgee River sampled for five years from October 2014 to December 2018. Data are plotted as scatter 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 discharge (third row) is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature (lower row) was taken from the gauge data for Narrandera. The Carrathool temperature data is collected by the LTIM metabolism monitoring program which was disrupted in 2016-17 due to flooding.

The lower densities observed in 2018-19, 2017-18 and 2016-17 (Figure 4-73), were reflected in a different taxa composition compared to 2014-15 and 2015-16 (Figure 4-). In the earlier years, there were high densities of copepods and of key microinvertebrate taxa including cladocerans (macrothricids and a number of chydorids) and ostracods. In 2017-18, compared to other years, two cladocerans (*Macrothrix spinosa* and a chydorid *Alona* sp.) dominated communities with very low numbers of copepods observed (Figure 4-74). In 2018-19, some higher densities of macrothricid and chydorod cladocerans along with ostracods were observed, while copepods remained in low densities (Figure 4-74).

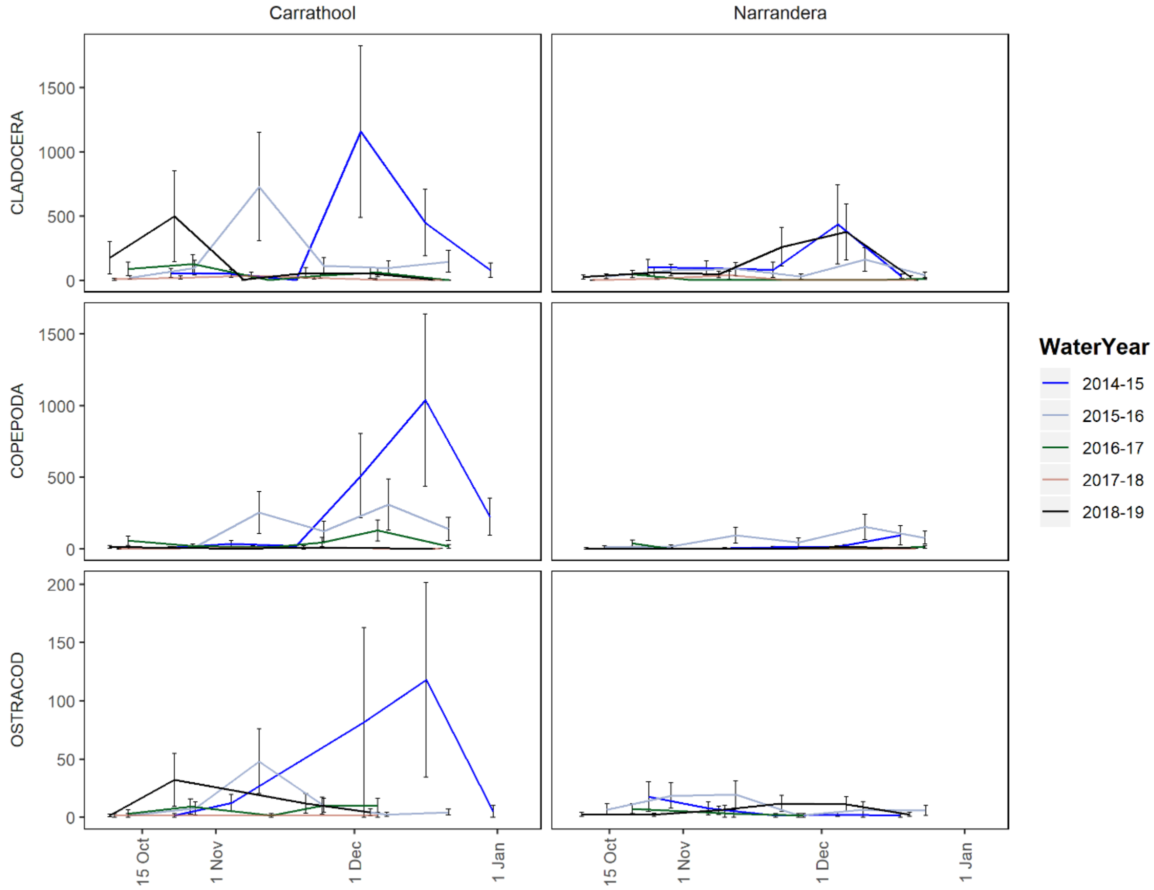


Figure 4-74 Benthic densities (L-1) of cladocera (upper graph), copepoda (middle graph) and ostracods (lower graph) for 3 sites in the Carrathool zone (left graphs) and 3 sites in the Narrandera zone (right graphs) of the Murrumbidgee River sampled for five years from October 2014 to December 2018. Data are plotted as scatter plots with the mean and standard errors for the three sites in each zone on each trip.

Discussion

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

The delivery of Commonwealth environmental water to creeks and wetlands in the mid to lower Murrumbidgee, along with water deliveries for irrigation and consumptive purposes influenced hydrology within the Murrumbidgee River in the Carrathool Zone and to a lesser extent in the Narrandera Zone (See Figure 4-7373).

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 (Figure 4-7373). In 2014-15 peaks occurred in mid-December for chydorids, ostracods and copepods, while in 2015-16 peaks occurred in mid-November. This same response was not observed in 2016-17 when higher flows and lower temperatures were observed during flood flows in the Murrumbidgee River (Figure 4-7373 and **Error! Reference source not found.**). 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. However, in 2018-19 cladoceran and ostracod densities peaked in the Carrathool zone in October 2018 and in the Narrandera zone in December 2018.

Although not significantly different, densities of microinvertebrates were higher in the Carrathool than Narrandera zone across the five years of this study (see Figure 4-7373). River levels in the Narrandera zone were at least one metre higher in the Narrandera than in the Carrathool zone and there was less variability in river level, except for 2017-18 where variability was greater in both zones. In addition, water temperatures were slightly higher in the Carrathool zone. It appears that the higher river level and cooler temperatures in the Narrandera zone may impact development of a productive and diverse microinvertebrate community.

In contrast, in the Carrathool zone with lower, more variable river levels, pronounced peaks in microinvertebrate densities were recorded in both 2014-15 and 2015-16 and again in 2018-19. 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 or maybe the flooding disrupted microinvertebrate communities and these are now recovering with peaks observed again in 2018-19. 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.

As well as supporting more productive densities of microinvertebrates, the Carrathool zone consistently supported higher CPUE of larval native fish species across the five years of the LTIM project.

The peak in benthic microinvertebrate densities in 2015-16 coincided with peaks in Australian smelt and cod species captured in light traps. However peak numbers of cod species and perch captured in drift nets occurred two weeks earlier in late October, suggesting peak densities of larval fish and microinvertebrates were offset. This mismatch in timing between peaks was more apparent in 2014-15 when larval fish numbers peaked in early to mid-November **Error! Reference source not found.**well before the peak in microinvertebrate densities in early to mid-December. In 2016-17, microinvertebrate densities did not peak in November when most larval fish were captured. In 2017-18 no peaks were observed in microinvertebrate densities, while in 2018-19 the peaks in late October 2018 timed with the peak breeding season in Murray cod.

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

The relationships between flow (at the time of sampling) and microinvertebrate densities indicates a complex relationship that interacts with water quality. It was striking that during 2017-18 the low microinvertebrate densities coincided with low levels of productivity in riverine nutrients. Although riverine nutrients remained low in 2018-19, we detected modest peaks in microinvertebrate densities akin to those observed in the first two years of the project.

4.11 River Fish communities

Prepared by Dr Jason Thiem and Daniel Wright (NSW DPI)

Introduction

Native fish communities in the Murrumbidgee Catchment are severely degraded and have exhibited declines in abundance, distribution and species richness (Gilligan 2005). Furthermore, alien species (specifically common carp *Cyprinus carpio*), occupy up to 90% of the total biomass in some areas (Gilligan 2005). In addition, 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 from Murrumbidgee River wetland habitats (Anderson 1915, Cadwallader 1977), but have since been considered locally extinct from this region (Gilligan 2005).

River regulation has significantly contributed to native fish declines in the Murrumbidgee catchment. Reductions in the frequency and duration of small-medium natural flow events prevent regular connections between the river and off-channel habitats (Arthington and Pusey 2003), also resulting in a loss of natural flow cues for in-channel species. The use of Commonwealth environmental water to restore more natural flow characteristics can benefit native fish by providing cues that stimulate reproductive behaviour, or by providing access to suitable breeding habitats and nursery areas (e.g. King *et al.* 2009, Beesley *et al.* 2014). Appropriate delivery of environmental water can also result in increased riverine productivity, food resources (i.e. microinvertebrates) and water quality, as well as facilitate longitudinal and lateral connectivity and dispersal (Koehn *et al.* 2014a). Resulting positive changes in native fish species richness, abundance and biomass are predicted to occur.

Numerous Commonwealth environmental watering actions were undertaken from 2015 to 2019, a number of which directly sought positive outcomes for native fish in wetlands and the main channel of the Murrumbidgee River. Other regulated and unregulated flow events occurred throughout the study, including a large overbank natural flood in late 2016. The purpose of this report is not to attribute changes to the fish community assemblage in response to Commonwealth environmental water over five years. Rather, we document the broad-scale patterns and change in species-specific abundance, biomass and size structure in different parts of the lowland

Murrumbidgee River to provide an indication of overall river health using the fish community as an indicator.

Methods

Riverine fish

Fish community sampling was undertaken in February – April in both 2015 and 2019. Data was collected from 17 Murrumbidgee River sites spanning three hydrological zones (Narrandera, Carrathool and Balranald; Figure 4-75). Sampling sites and methods followed those in the Murrumbidgee Monitoring and Evaluation Plan for Category 3 (Wassens *et al.* 2014). Additionally, data collected from four sites (Mckennas, Bringagee, Birdcage and Yarradda) as part of the Basin-Scale evaluation (Hale *et al.* 2014) was subsampled for the first 12 electrofishing operations (comparable effort to Category 3 methods), and bait trap captures were also included. Thus, 7 sites were sampled for each of the 3 hydrological zones (21 sites in total).

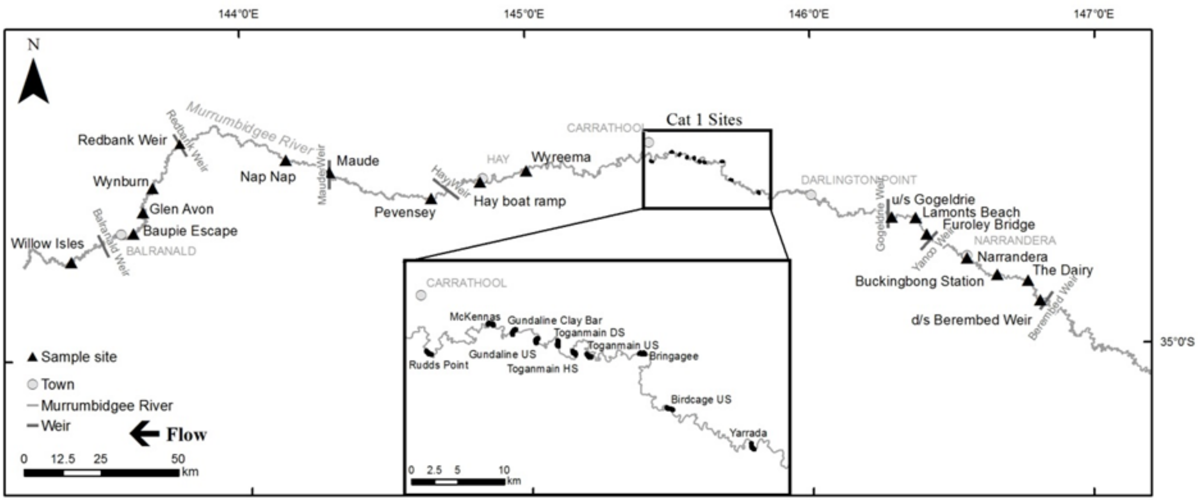


Figure 4-75 Location of fish community sites sampled in 2015 and 2019 on the Murrumbidgee River. Data from four Cat 1 sites (McKennas, Bringagee, Birdcage and Yarradda) were used for this Selected area Evaluation.

To determine differences in fish communities among years (2015 vs. 2019) and hydrological zones (Narrandera, Carrathool, and Balranald), abundance and biomass data were analysed separately using two-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson *et al*. 2008) using the vegan package (Oksanen *et al.* 2019) in R (R version 3.6.1, (R Development Core Team

2019)). 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 $P < 0.05$. An intermediate level of transformation (four root) was selected as this is recommended to lower the contribution of abundant species compared to rare species in Bray-Curtis measure calculations (Clark & Green 1988). Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which zones and years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between zones.

Additionally, four Sustainable Rivers Audit (SRA) fish community indices (Nativeness, Expectedness, Recruitment and Overall Fish Condition) were calculated for each year and hydrological zone to quantify overall condition of the fish community assemblage (Appendix 4). Data were first portioned into recruits and non-recruits. Large-bodied and generally longer-lived species (max. age >3 years) were considered recruits when length was less than that of a one-year-old. Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature, or by expert opinion when literature was not available (Table 323).

To determine differences in the length-frequency distributions (size-structure) among years for each hydrological zone, species-specific length distributions were analysed using two-sample Kolmogorov-Smirnoff tests. These tests were only performed on the four most abundant large-bodied species and the three most abundant small-bodied species.

Table 3 Size limits used to distinguish new recruits for each species. Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year and the respective information source (F = measured to the tail fork and T = total length)

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)
Native species	
Australian smelt	40 mm (F) (Pusey *et al.* 2004)
bony herring	67 mm (F) (Cadwallader 1977)
carp gudgeon	35 mm (T) (Pusey *et al.* 2004)
river blackfish	80 mm (T)
golden perch	75 mm (F) (Mallen-Cooper 1996)
Murray cod	222 mm (T) (Gavin Butler, *unpublished data*)
Murray-Darling rainbowfish	45 mm (F) (Pusey *et al.* 2004: for M. *duboulayi*)
silver perch	75 mm (F) (Mallen-Cooper 1996)
trout cod	150 mm (T)
un-specked hardyhead	38 mm (F) (Pusey et al. 2004)
Alien species	
common carp	155 mm (F) (Vilizzi and Walker 1999)
Eastern gambusia	20 mm (T) (McDowall 1996)
goldfish	127 mm (F) (Lorenzoni *et al.* 2007)
oriental weatherloach	76 mm (T) (Wang *et al.* 2009)

Results

Riverine fish

A total of 1,044 fish comprising ten native and three exotic species were captured across 21 river sites in 2015. In 2019, 907 fish were caught consisting of nine native and three exotic species at the 21 river sites (Table 24). Three native species listed as threatened (trout cod – endangered, Fisheries Management Act and EPBC Act; silver perch – vulnerable, Fisheries Management Act and critically endangered, EPBC Act; Murray cod - vulnerable, EPBC Act) were caught in both 2015 and 2019.

The overall condition of the fish community tended to decrease from 2015 to 2019. Carrathool fell two bands from "poor" to "extremely poor", Narrandera fell one band from "poor" to "very poor", while Balranald remained in the same band of "very poor" (Figure 4-7676,

Table5). Recruitment and Expectedness were consistently lower in 2019 across all hydrological zones. However, Nativeness increased in Carrathool and Narrandera, but decreased in Balranald in 2019 (Figure 4-76,

Table26).

The fish community assemblage differed significantly in abundance among years (Pseudo-$F_{1,38}$ = 2.813, P = 0.026) and hydrological zones (Pseudo-$F_{2,38}$ = 8.920, P < 0.001; Figure 4-). SIMPER analysis indicated that the observed differences among years was caused by less bony herring, carp gudgeon, Murray-Darling rainbowfish and Murray cod in 2019 compared to other years. Zone differences were primarily driven by variability in the abundance of bony herring, carp gudgeon, Murray cod, Murray-Darling rainbowfish and golden perch, and contributions to differences were zone-specific (Appendix 3). Pair-wise tests indicated that the abundance of the community assemblage was significantly different between all zone combinations (Narrandera-Carrathool: F = 8.665, P = 0.001; Narrandera-Balranald: F = 12.255, P < 0.001; Carrathool-Balranald: F = 3.950, P = 0.021).

Table 4-24 Summary of catch data from fish sampled in three hydrological zones of the Murrumbidgee River in 2015 and 2019.

Species	Narrandera		Carrathool		Balranald	
	2015	2019	2015	2019	2015	2019
Native fish species						
Australian smelt	65	61	30	39	47	14
bony herring			126	76	151	198
carp gudgeon	27	5	45	4	69	24
river blackfish	1					
golden perch	10	8	9	15	13	17
Murray cod	49	30	34	55	9	18
Murray-Darling rainbowfish	38	28	35	22	43	35
silver perch	1		1	3	2	2
trout cod	6	8				
un-specked hardyhead	1	36	2		4	
Alien fish species						
common carp	81	35	46	33	72	136
Eastern gambusia	3	1		1	10	1

goldfish	1	3	10	2

Biomass did not differ between years (Pseudo-$F_{1,38}$ = 1.533, P = 0.202), but varied among hydrological zones (Pseudo-$F_{2,38}$ = 9.668, P < 0.001). SIMPER analysis indicated that the observed differences among zones were primarily driven by variability in the biomass of Murray cod, bony herring, golden perch, common carp and trout cod, and contributions to differences were zone-specific (Appendix 3). Pair-wise comparisons indicated that the biomass at sites was significantly different between all zone combinations (Narrandera-Carrathool: F=6.741, P=0.003; Narrandera-Balranald: F=13.547, P=0.003; Carrathool-Balranald: F=7.253, P=0.003). In 2015, common carp, Murray cod, golden perch and bony herring contributed the greatest to overall biomass, with an average biomass per site (and average percentage contribution) of 10933 ± 1644 g (64 ± 4%), 4518 ± 1645 g (16 ± 4%), 1465 ± 276 g (11 ± 2%) and 595 ± 267 g (7 ± 3%), respectively (Figure 4-78). In 2019, these same species comparably contributed an average biomass per site (and average percentage contribution) of 11078 ± 2098 g (61 ± 12%), 4885 ± 1423 g (27 ± 8%), 1657 ± 517 g (9 ± 3%) and 356 ± 111 g (2 ± 1%), respectively (Figure 4-7878).

Differences in species-specific size-structure between 2015 and 2019 were identified for five of the seven species examined, although not for all hydrological zones (Figure 4-79, Figure 4-,

Table 426). Bony herring were larger in 2019 at Balranald, smaller in 2019 at Carrathool and were not captured at Narrandera (Figure 4-7979, Table 4). Murray cod were larger in 2019 at Carrathool, and were similarly sized at Narrandera and Balranald between years (Figure 4-7979,

Table 4). Common carp were larger in 2019 at Narrandera, smaller at Balranald in 2019, and were similarly sized at Carrathool in both years (Figure 4-7979, Table 4). Murray-Darling rainbowfish were smaller in 2019 at Balranald, but unchanged between years at other zones (Figure 4-80,

Table 4). Australian smelt were larger in 2019 at Balranald, smaller in 2019 at Narrandera, and of similar size between years at Carrathool (Figure 4-,

Table 4).

Recruits of five longer-lived (silver perch, river blackfish, trout cod, Murray cod and bony herring) and four short-lived native fish species (un-speckled hardyhead, carp gudgeon, Murray-Darling rainbowfish and Australian smelt) were present in 2015 (Figure 4-77, Figure 4-7979, Figure 4-80). In 2019, only four longer-lived native species were observed with silver perch recruits absent, golden perch recruits present, and no river blackfish adults or recruits detected. Alien common carp and goldfish recruits were present in both 2015 and 2019.

Table 4-25 Average Sustainable Rivers Audit (SRA) fish indices (+SE) for each of the three hydrological zones monitored in the Murrumbidgee River in 2015 and 2019. (G = good, M = moderate, P = poor, V = very poor, E = extremely poor)

Year	**Hydrological zone**	**Metric** Recruitment	Nativeness	Expectedness	Overall condition
2015	Narrandera	46.8 ± 0.0 (P)	70.2 ± 2.5 (M)	49.2 ± 1.2 (P)	43.5 ± 0.7 (P)
	Carrathool	61.3 ± 0.0 (M)	75.8 ± 4.2 (M)	46.4 ± 2.4 (P)	49.8 ± 2.5 (P)
	Balranald	46.9 ± 0.0 (V)	68.8 ± 3.8 (M)	39.4 ± 3.3 (V)	36.9 ± 2.5 (V)
2019	Narrandera	44.1 ± 0.0 (V)	75.2 ± 5.2 (M)	34.8 ± 2.0 (V)	33.8 ± 2.1 (V)
	Carrathool	18.1 ± 0.0 (E)	84.5 ± 3.5 (G)	33.7 ± 2.6 (V)	18.9 ± 1.4 (E)
	Balranald	30.5 ± 0.0 (P)	62.0 ± 4.3 (M)	33.0 ± 5.0 (V)	24.7 ± 3.0 (V)

Table 4 Results of length-frequency distribution pair-wise comparisons between 2015 and 2019 for the most abundant fish species captured in the Murrumbidgee River for each hydrological zone. Significant differences are indicated by the P values below < 0.05 in bold. Note that no bony herring were caught in the Narrandera hydrological zone.

Species	**Year comparison** Balranald 2015 – Balranald 2019 *P*	Carrathool 2015 – Carrathool 2019 *P*	Narrandera 2015 – Narrandera 2019 *P*
Australian smelt	**0.004**	0.506	**0.001**
bony herring	**<0.001**	**<0.001**	**-**
carp gudgeon	0.116	0.463	0.092
common carp	**0.022**	0.445	**<0.001**
golden perch	0.415	0.398	0.648
Murray cod	0.366	**0.007**	0.366
Murray-Darling rainbowfish	**<0.001**	0.234	0.138

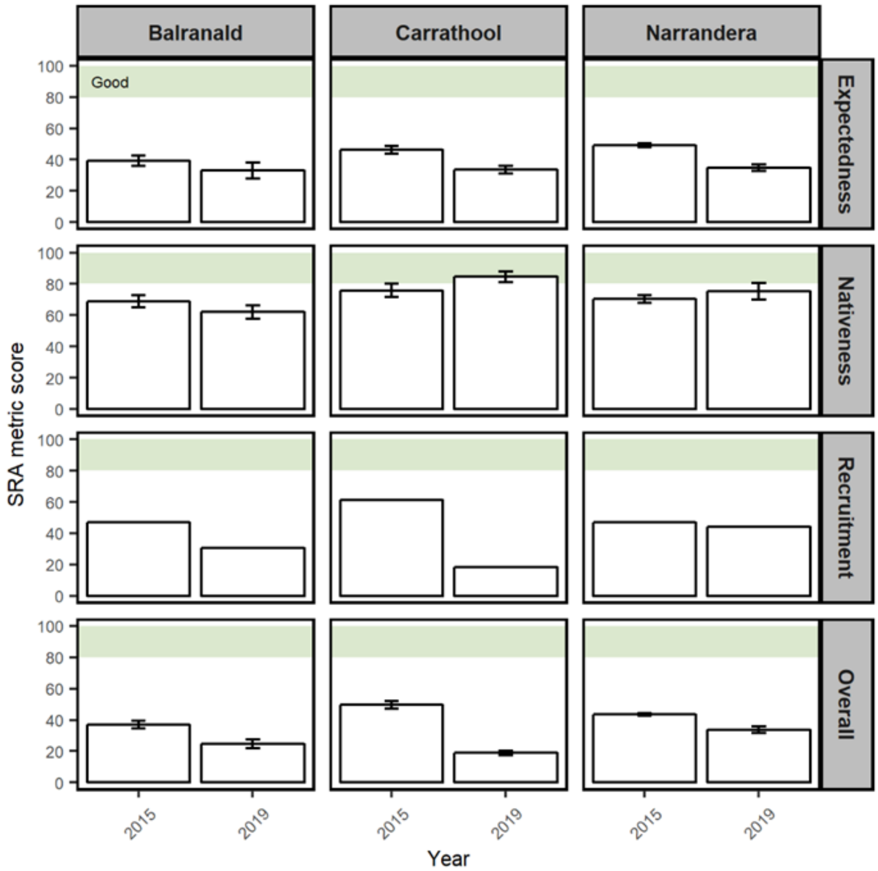


Figure 4-76 Average SRA metric scores (+SE) in 2015 and 2019 for each of three zones of the Murrumbidgee River. Note that only a single zone-level score is provided for recruitment score, so standard error cannot be calculated. Green shading represents the "good" band for metric scores.

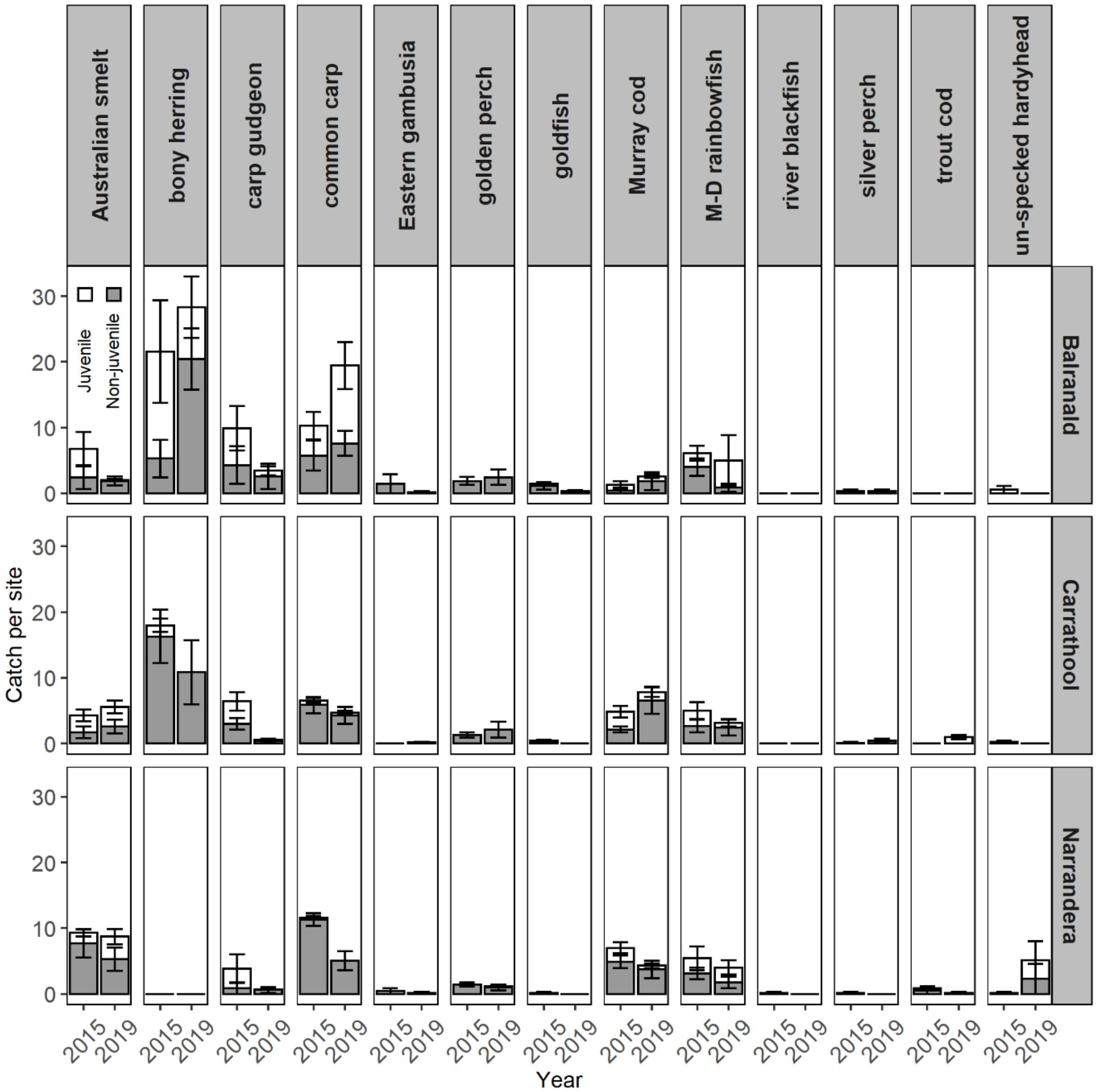


Figure 4-77 Total average catch per unit effort (CPUE) per site (+SE) of each fish species within three zones of the Murrumbidgee River sampled in 2015 and 2019. This is represented by stacked bars, splitting juveniles and non-juveniles. The white stacked bar for each species represent CPUE of young-of-year recruits or non-mature individuals for short-lived species that reach sexual maturity within their first year of life (juveniles) (Table 4-23). The grey stacked bar represents CPUE of all other individuals for each species (non-juveniles).

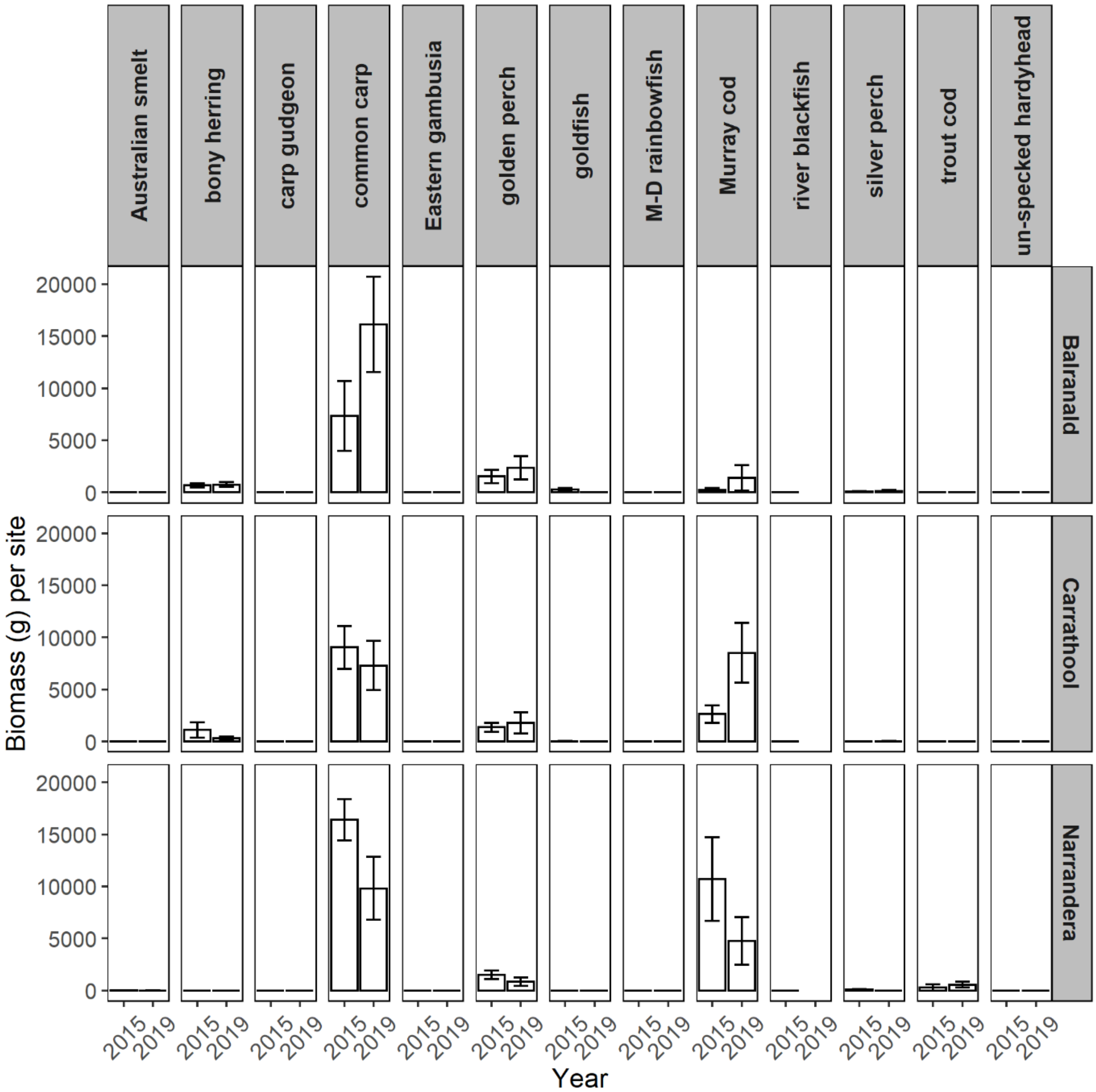


Figure 4-78 Average biomass per site (+SE) of each fish species within three zones of the Murrumbidgee River sampled in 2015 and 2019.

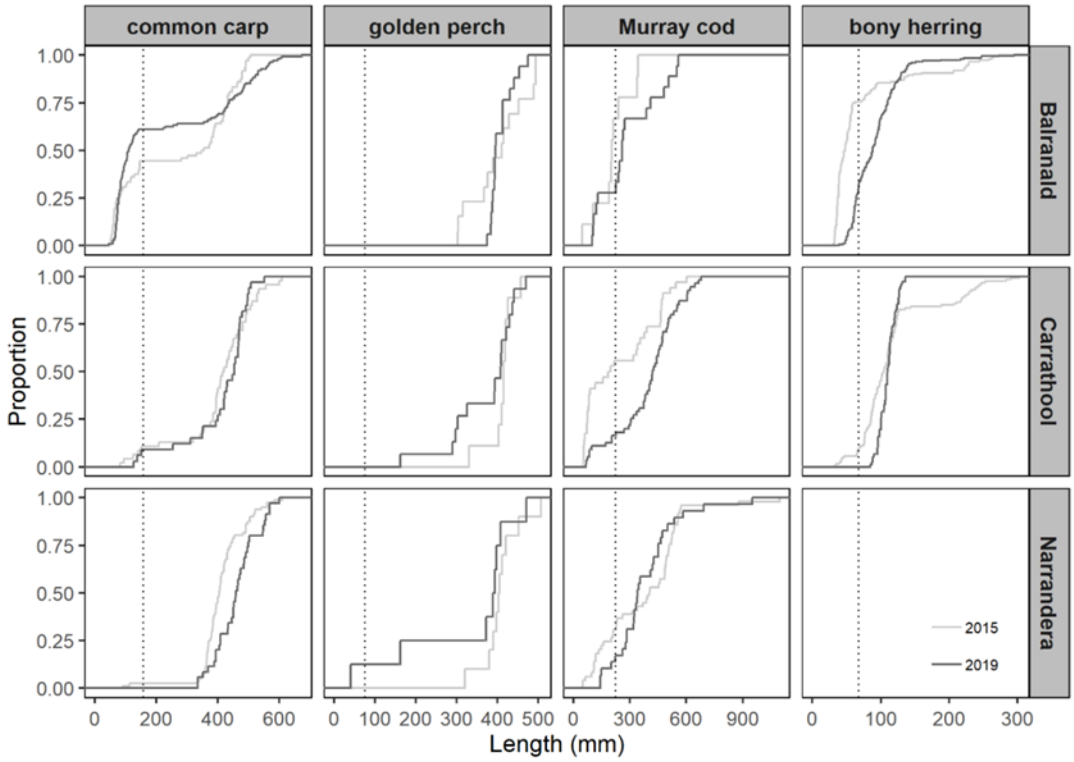


Figure 4-79 Length-frequency distributions of the most commonly encountered large-bodied species captured in the Murrumbidgee River between 2015 (light grey) and 2019 (dark grey). Dotted line represents length at sexual maturity.

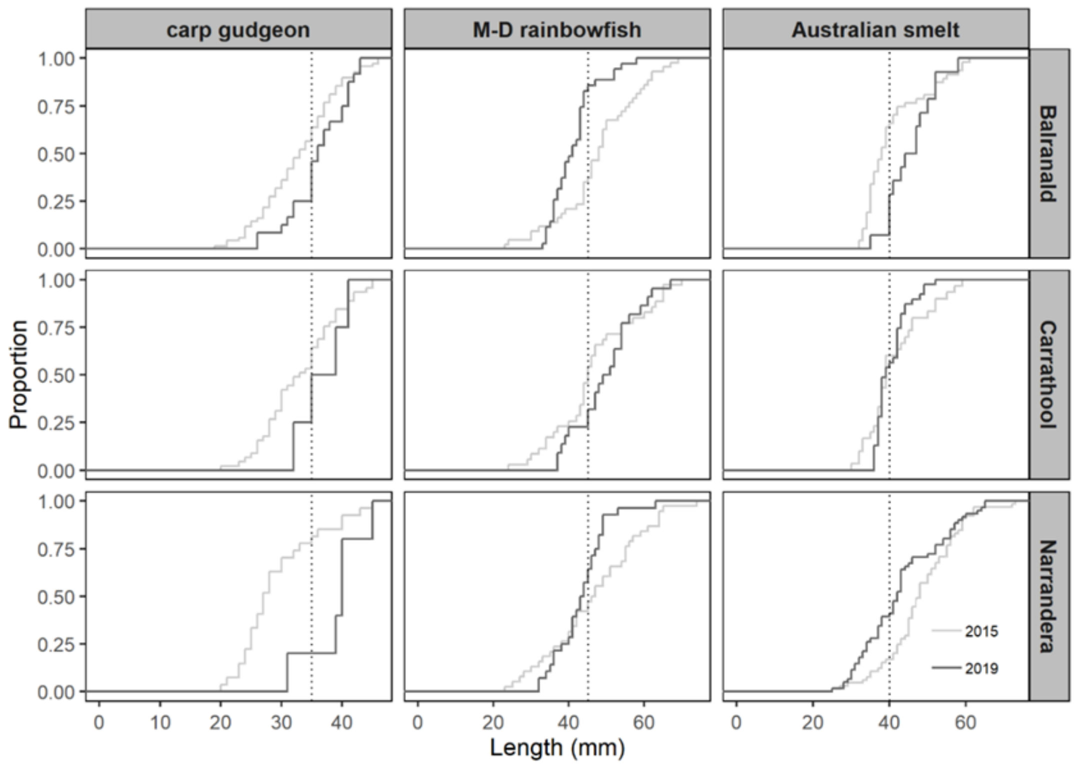


Figure 4-80 Length-frequency distributions of the most commonly encountered small-bodied species captured in the Murrumbidgee River between 2015 (light grey) and 2019 (dark grey). Dotted line represents length at sexual maturity.

Discussion

The current study provides a benchmark with which to compare changes in the fish community assemblage composition across the Murrumbidgee system over a five year period under the LTIM program. Of a total of 19 native species predicted to have occurred in lowland reaches of the Murrumbidgee River, 10 were captured in 2015 and 9 were recorded in 2019. Three threatened species were captured during sampling in both years, although no captures of any species resulted in range expansions from previous studies. Of the remaining nine species predicted to occur in the lowland Murrumbidgee catchment, only recent catch records of flathead gudgeon (*Philypnodon grandiceps*) and freshwater catfish (*Tandanus tandanus*) exist, and these species are generally not captured within the main river channel (Wassens *et al.* 2014, DPI Fisheries, unpublished data). Of the remaining seven species, six are considered locally extinct from the study area (flathead galaxias *Galaxias rostratus*, Macquarie perch *Macquaria australasica*, Murray hardyhead, olive perchlet, southern purple spotted gudgeon, southern pygmy perch) and one (shortheaded lamprey *Mordacia mordax*) was a historical record likely from a vagrant (Gilligan 2005). A number of these locally extinct species are off-channel specialists, and their absence is likely due to long-term disconnection of these habitats. Subsequently, it is important to recognise that any future watering of these off-channel habitats is undertaken with realistic expectations that floodplain species may not return. Future off-channel watering strategies should support long-term watering plans that will enable conservation stocking or translocation, and the subsequent re-establishment of resident populations of off-channel specialists.

The fish community composition of the lowland Murrumbidgee River differed among years and hydrological zone in the current study. Differences between years were evident in species richness, and species-specific abundance and size structure, although not for all zone-specific comparisons. Similarly, differences between hydrological zones were confirmed for species richness, and species-specific abundance, biomass and size structure, although not for all pairwise zone comparisons. It is likely that the extent of river regulation and water delivery influence some of these differences, and indeed this was the premise for the current study. However, other factors including physical habitat availability, barriers to passage, thermal pollution, stocking, harvest, antecedent conditions and alien species have all contributed to the past (Gilligan 2005) and current state of fish populations in the Murrumbidgee River and across the entire Murray-Darling Basin (Koehn *et al.* 2014b, Lintermans *et al.* 2014). As such, while the effects of environmental flow delivery have been the focus of the LTIM program, numerous complementary actions are required to improve and restore native fish populations (Baumgartner *et al.* 2019).

A number of longer-lived native species appear to be recruiting within the lowland Murrumbidgee catchment. For example, bony herring recruits were captured at Carrathool and Balranald zones in both years, although proportionately more recruits were present in 2015 than 2019 within these zones. This species was absent from the Narrandera zone. Bony herring spawn independently of flooding, generally at water temperatures of 21–23 °C (Puckridge and Walker 1990) and are often abundant in both river and wetland habitats (Wassens *et al.* 2013, 2014, this study). Both the abundance and proportion of bony herring recruits appear to be higher in slower flowing, and less regulated locations (Gehrke 1997, Pusey *et al.* 2004), a result consistent with patterns in their presence among zones. Reductions in bony herring recruits in 2019 was unexpected given zone-specific adult population sizes were either higher or at similar levels in 2019 compared to 2015, and the underlying mechanisms are unknown.

Murray cod recruits were also detected in 2019, but abundances were lower than in 2015 at the Carrathool zone, while similar numbers were observed among years in Narrandera and Balranald zones. Spawning of Murray cod was evident at Narrandera and Carrathool zones, where larval sampling took place, in all years from 2014–2019 (larval chapter). The apparent decrease in Murray cod recruitment at Carrathool in 2019 did not appear to relate to adult population size, as more adults were present in this zone. Interestingly, the density of key prey items for Murray cod larvae at first feed, such as cladocerans and copepods (Rowland 1992, Kaminskas and Humphries 2009), were high at Carrathool in 2015 when numbers of recruits were elevated. Given that the species spawns in response to day length and temperature cues, rather than flow, understanding the mechanisms driving prey availability for larvae and juveniles and their links to flow represent an important component of the current LTIM program.

While spawning of silver perch was detected at Carrathool and Narrandera in most years from 2014–2019 (larval chapter), only a single silver perch recruit was captured in the Carrathool zone in 2014–2015. Recent evidence from the Murray River indicates that the strongest year classes were associated with a combination of low to average river discharge (i.e. within channel) and high water temperatures over the peak spawning period, followed in the next year by extended high flows and widespread flooding that promoted survival of age-1+ juvenile fish (Tonkin *et al.* 2019). Similarly, there was evidence of golden perch spawning at Carrathool and Narrandera in most years from 2014–2019 (larval chapter), but only a single recruit was found at Narrandera in 2019. Previous studies have reported golden perch spawning in multiple river systems within a single season, although limited recruitment in these same systems (Zampatti *et al.* 2015). As both species are known to actively disperse over large spatial scales during early life stages, it is possible that the spawning outcomes being observed in the current LTIM reaches of the Murrumbidgee River may be contributing to successful (unmonitored) recruitment outcomes elsewhere (e.g. Zampatti *et al.* 2018). However, given the lack of upstream fish passage on the Murrumbidgee River, active or passive dispersal would likely be in a downstream direction from the study reaches.

4.12 Larval fish

Prepared by Dr Jason Thiem and Daniel Wright (NSW DPI Fisheries) and Dr 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 and Schiller 2003) and microinvertebrate abundance for first feed (King 2004). Commonwealth environmental water deliveries that target native fish responses, have 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 2018-2019 (LTIM Years 1-5; Wassens *et al.* 2018) are included to provide 5 year trends.

Relevant watering actions and objectives

With the exception of the Lower Murrumbidgee dissolved oxygen management flow in 2018-19, the Murrumbidgee River focal zones experienced no flows specifically targeting native fish in-channel spawning. However, the hydrology in the sampling zone was impacted by Commonwealth environmental water actions targeting outcomes further downstream from August 2018 until June 2019, as well as irrigation releases and downstream delivery targets. In this section we describe the range of fish responses observed during 2018-19, 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 4-81). 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 (required to adequately sample commonly encountered larvae such as Murray cod (*Maccullochella peelii*). Sampling was undertaken fortnightly from 8 October until 20 December 2018, 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 2017-18 (Wassens *et al.* 2015, Wassens *et al.* 2016, Wassens *et al.* 2018). 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 and Humphries 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).

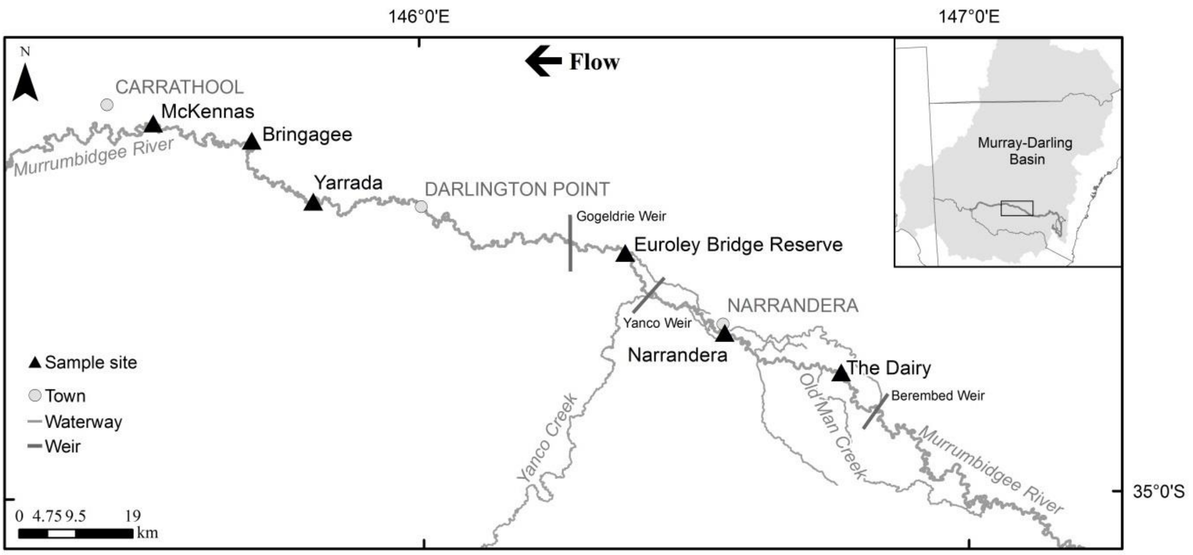


Figure 4-81 Locations of larval fish in-channel sampling sites on the Murrumbidgee River, encompassing Narrandera (The Dairy (DAI), Narrandera (NRD) and Euroley Bridge (EUB)) and Carrathool (Yarradda (YRR), Bringagee (BRI) and McKennas (MKR)) hydrological zones.

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. To determine differences in larval fish CPUE between zones (Narrandera and Carrathool) and years (2014-15, 2015-16, 2016-17, 2017-18 and 2018-19), 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) using the vegan package (Oksanen *et al.* 2011) in R version 3.6.1 (R Development Core Team 2019). 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 generalised 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) over the duration of the 5 year study. Daily water temperature data was obtained from the NSW Office of Water gauge 410005 for sites in the Narrandera zone (The Dairy, Narrandera and Euroley Bridge) and from the data logger stationed at McKennas site to measure stream metabolism for sites in the Carrathool zone (Yarradda, Bringagee, McKennas). Modelled daily river flows (ML day^{-1}) were obtained for representative zones (Narrandera and Carrathool) (Enzo Guarino, *unpublished data*). A dataset was generated that paired presence/absence of golden perch and silver perch eggs and larvae with corresponding water temperature and river flows for each respective sampling event at a site on a given day. In addition, change in weekly river flow and water temperature were included as predictors as per King *et al.* (2016).

Model-selection was undertaken by examining a suite of standardised hydrological variables (daily river flow (ML day^{-1}), change in weekly river flow) and climatic variables (water temperature (°C), change in weekly water temperature), for each site nested within a hydrological zone, during each of the sampling events within watering years. Silver and golden perch spawning was analysed in relation to abiotic 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).

Results

A combined total of 4,129 eggs and larvae were collected during the 2018-19 sampling. Nine native fish species (Australian smelt, bony herring, carp gudgeon, flat-headed gudgeon, golden perch, Murray cod, Murray-Darling rainbowfish, river blackfish, silver perch) and two alien species (common carp, Eastern gambusia) were detected spawning in the Murrumbidgee River in 2018-19 (

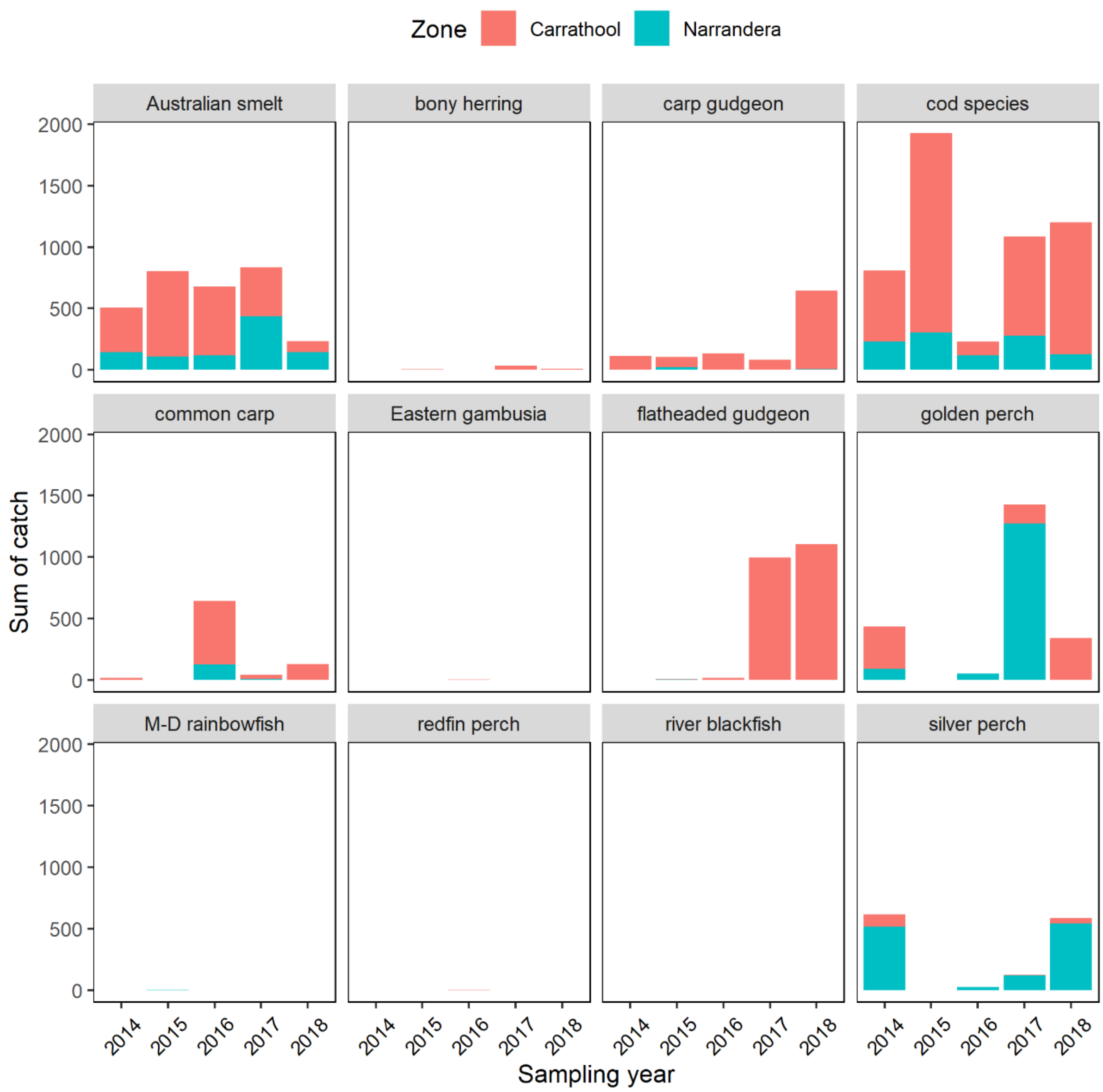


Figure 4-8282). This represents the highest number of native species (9) detected spawning over five years of monitoring (

Table 27). Cod larvae (n=1201), flat-headed gudgeon larvae (n=1105) and carp gudgeon larvae (n=646) were captured in the highest abundances (Table 4-28).

Catch of larvae and eggs differed significantly among years ($Pseudo\text{-}F_{4,24}$ = 3.2936, $P < 0.001$) and between hydrological zones ($Pseudo\text{-}F_{1,24}$ = 11.7283, $P < 0.001$) (Figure 4-84). Pair-wise comparisons indicated that there were no significant differences in catch between 2018-19 and any other sampling years ($F \leq 4.3$, $p \geq 0.07$), except for 2014-15 ($F = 4.3$, $P = 0.04$) (Table 29). Significant differences between zones ($F = 8.8$, $P = 0.001$) were primarily driven by higher catches of carp gudgeon, flatheaded gudgeon, common carp and Australian smelt larvae in the Carrathool zone (Table 30).

Captures of eggs and larvae peaked at distinct water temperatures over the 5 year study. For example, bony herring, carp gudgeon, flatheaded gudgeon, Eastern gambusia, Murray-Darling rainbowfish and silver perch were predominantly caught at water temperatures above the median of 21.4 °C (Figure 4-83). In contrast, Australian smelt, cod, common carp, golden perch, redfin perch and river blackfish were predominantly captured at or below median water temperatures (Figure 4-83). Australian smelt and flatheaded gudgeon exhibited the widest breadth of capture temperatures (Figure 4-83).

Table 4-27 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 and captured in 2018-19.

		Hydrological zone					
		Narrandera			**Carrathool**		
		The Dairy	Narrandera	Euroley Bridge	Yarradda	Bringagee	McKennas
Native fish species							
Australian smelt	eggs	0	0	0	0	1	1
	larvae	72	54	17	65	9	16
bony herring	larvae	0	0	0	0	9	0
carp gudgeon	larvae	0	1	7	387	221	30
cod species	larvae	29	77	20	266	493	316
flat-headed gudgeon	larvae	0	0	0	252	693	160
golden perch	eggs	0	0	0	1	257	11
	larvae	0	0	0	0	75	0
Murray-Darling rainbowfish	larvae	0	0	0	1	0	0
river blackfish	larvae	1	0	0	0	0	0
silver perch	eggs	193	353	0	17	24	0
Alien fish species							
common carp	larvae	0	2	0	127	3	0
Eastern gambusia	larvae	0	0	1	0	0	0

Table 4-28 Presence/absence of eggs and larvae captured using larval drift nets and light traps in the Murrumbidgee River under LTIM

	Sampling year				
Fish species	2014-15	2015-16	2016-17	2017-18	2018-19
Native fish species					
Australian smelt	✓	✓	✓	✓	✓
bony herring		✓		✓	✓
carp gudgeon	✓	✓	✓	✓	✓
cod species	✓	✓	✓	✓	✓
flatheaded gudgeon		✓	✓	✓	✓
golden perch	✓	✓	✓	✓	✓
M-D rainbowfish		✓	✓		✓
river blackfish					✓
silver perch	✓		✓	✓	✓
Alien fish species					
common carp	✓	✓	✓	✓	✓
Eastern gambusia			✓		✓
redfin perch	✓		✓		
Total number of species					
native	5	7	7	7	9
introduced	2	1	3	1	2
total	7	8	10	8	11

Table 4-29 Pair-wise comparisons of larval fish CPUE among sampling years.

Comparison	**F.Model**	**p.adjusted**
2014 vs 2015	4.322477	**0.04**
2014 vs 2016	2.92562	0.31
2014 vs 2017	1.393253	1
2014 vs 2018	1.10481	1
2015 vs 2016	3.177583	0.14
2015 vs 2017	4.348352	0.07
2015 vs 2018	1.41053	1
2016 vs 2017	2.653595	0.38
2016 vs 2018	1.728073	1
2017 vs 2018	1.394564	1

Table 4-30 Contributions by species to the difference in larval fish CPUE (Catch per unit effort) between hydrological zones (Narrandera and Carrathool) in the Murrumbidgee River from pairwise comparison (F = 8.84, P = 0.001), determined through SIMPER analysis.

	Average CPUE per zone		
Fish species	Carrathool	Narrandera	Ordered cumulative contribution
carp gudgeon	0.65	0.14	0.23
flat-headed gudgeon	0.34	0.02	0.36
common carp	0.26	0.21	0.48
Australia smelt	0.85	0.72	0.59
Murray cod	0.79	0.63	0.69
golden perch	0.14	0.20	0.79
silver perch	0.11	0.23	0.88
bony herring	0.12	0.00	0.92
M-D rainbowfish	0.02	0.06	0.96
redfin perch	0.04	0.00	0.98
Eastern gambusia	0.02	0.02	1.00
river blackfish	0.00	0.01	1.00

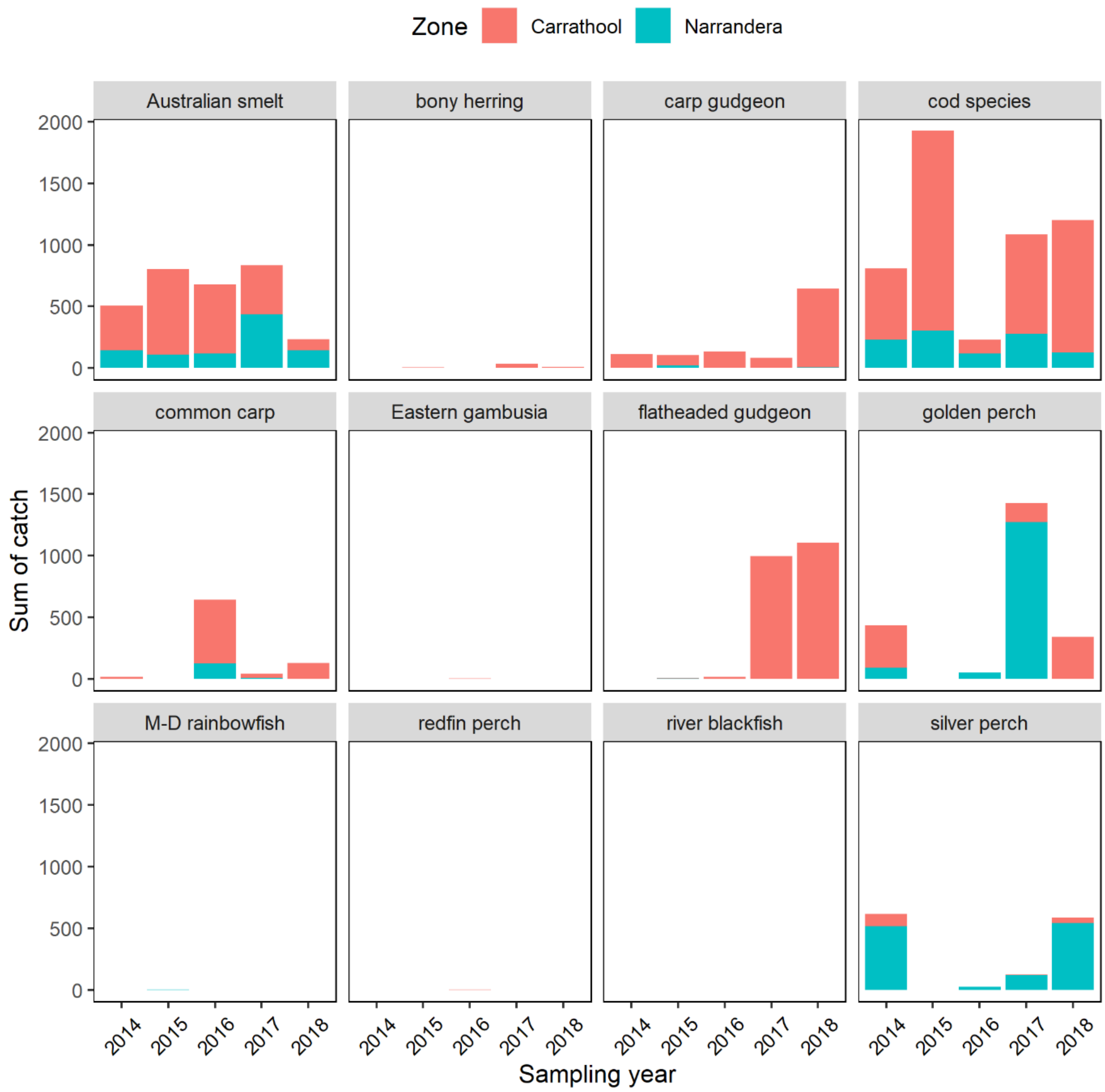


Figure 4-82 Unstandardised catch of larval fish and eggs from Narrandera and Carrathool zones over 5 years of LTIM in the Murrumbidgee River (2014 = 2014-15 water year through to 2018 = 2018-19 water year). Data are pooled for sites (n=3), sampling events (n=6 per season) and gear types (drift net, light trap).

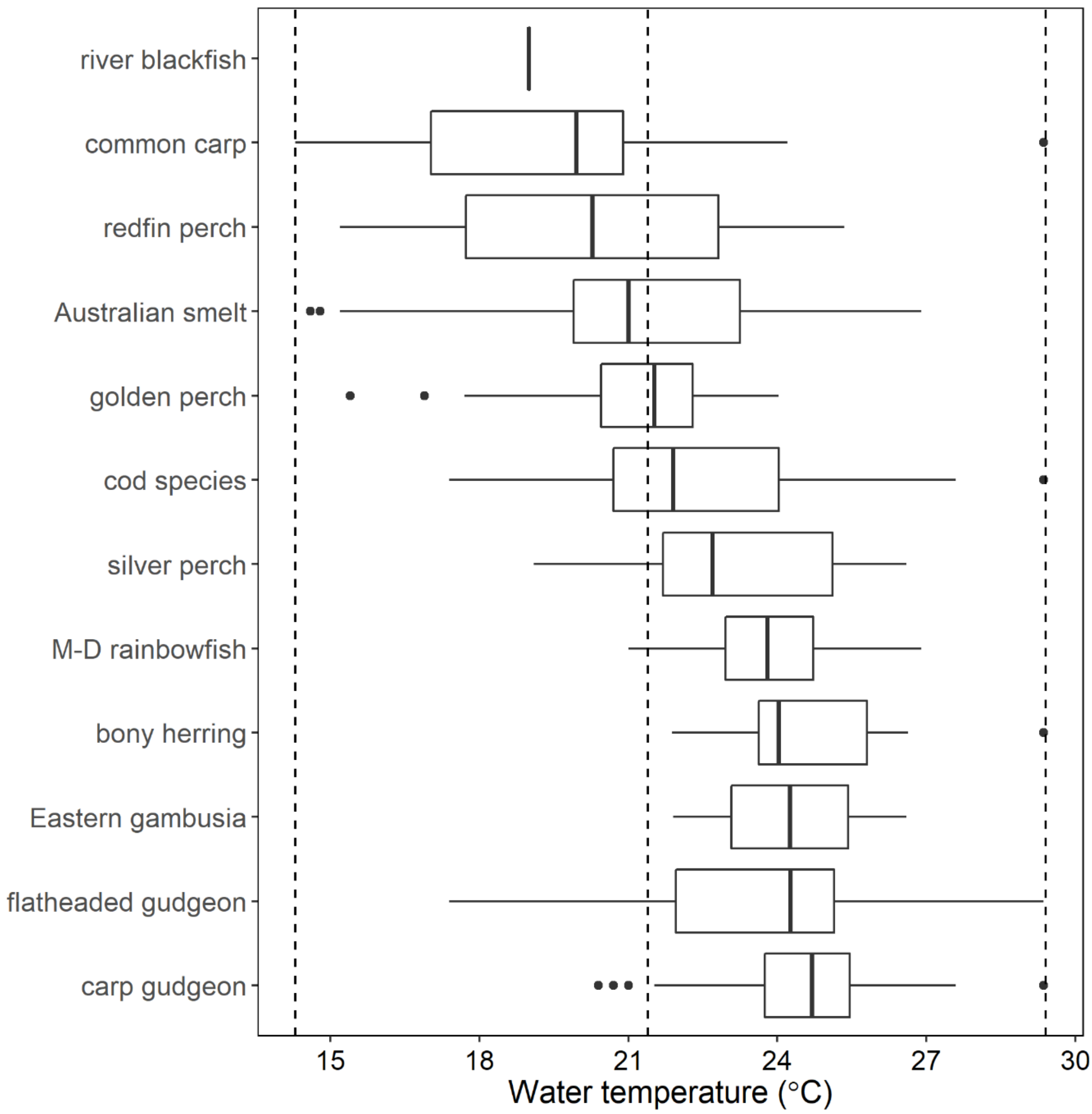
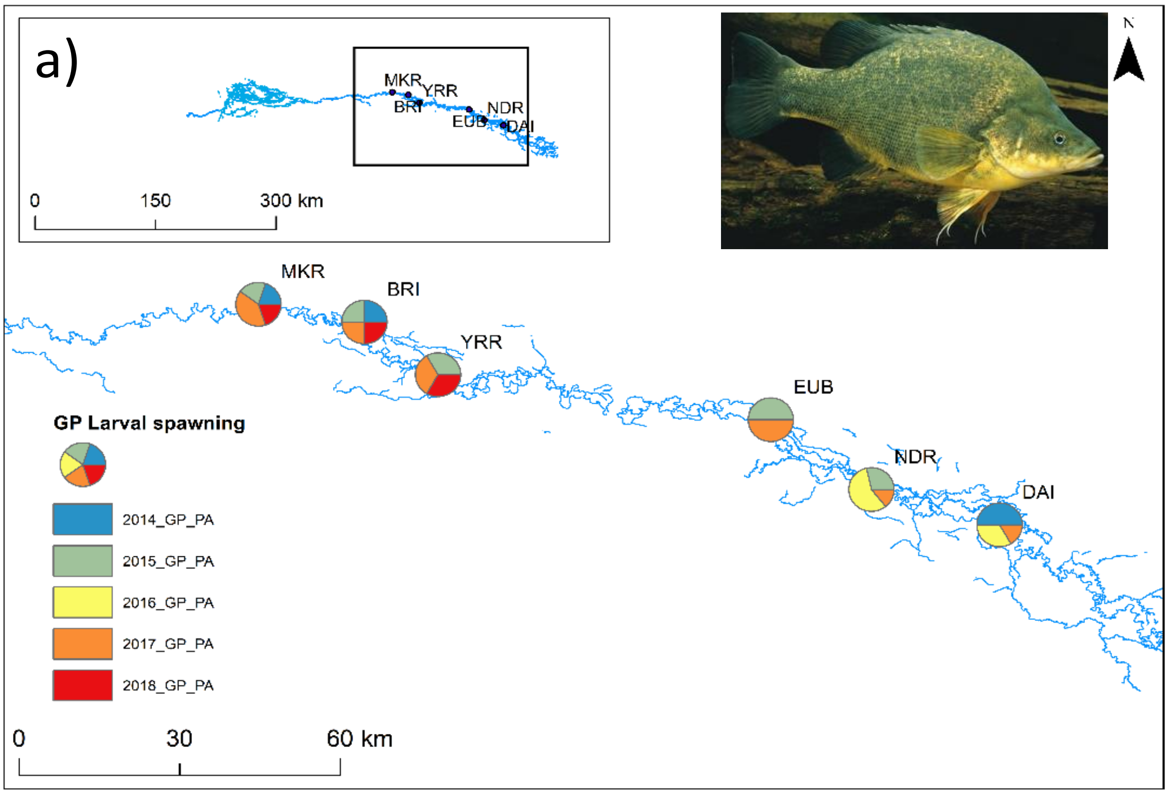


Figure 4-83 Indicative water temperature at the time of capture of eggs and larval fish in the Murrumbidgee River from 2014-2019 inclusive. Minimum, median and maximum water temperatures observed for the study period are represented by dashed vertical lines. Data are represented as median, 25th and 75th percentiles (box) and 5th and 95th percentiles (whisker).

The number of sampling events that the presence/absence of golden perch and silver perch eggs and larvae were captured was variable among sites, zones and years (Figure 4-84). Subsequently, predictive relationships were established separately for each zone and site was included as a random effect.

Golden perch exhibited a spawning association with weekly change in water temperature (Figure 4-85 and Table 31). Decreasing water temperature was linked to increased spawning probability. However there was no evidence for a spawning association with discharge for golden perch (Figure 4- and Table 32). In contrast, silver perch spawning was best explained by a model that included discharge, water temperature, and an interaction between discharge and water temperature (Figure 4-86 and Table). At lower water temperatures (15–18°C), silver perch spawning probability was negatively associated with flow, while at higher water temperatures (26–30°C), spawning probability was positively associated with flow (Figure 4-86).



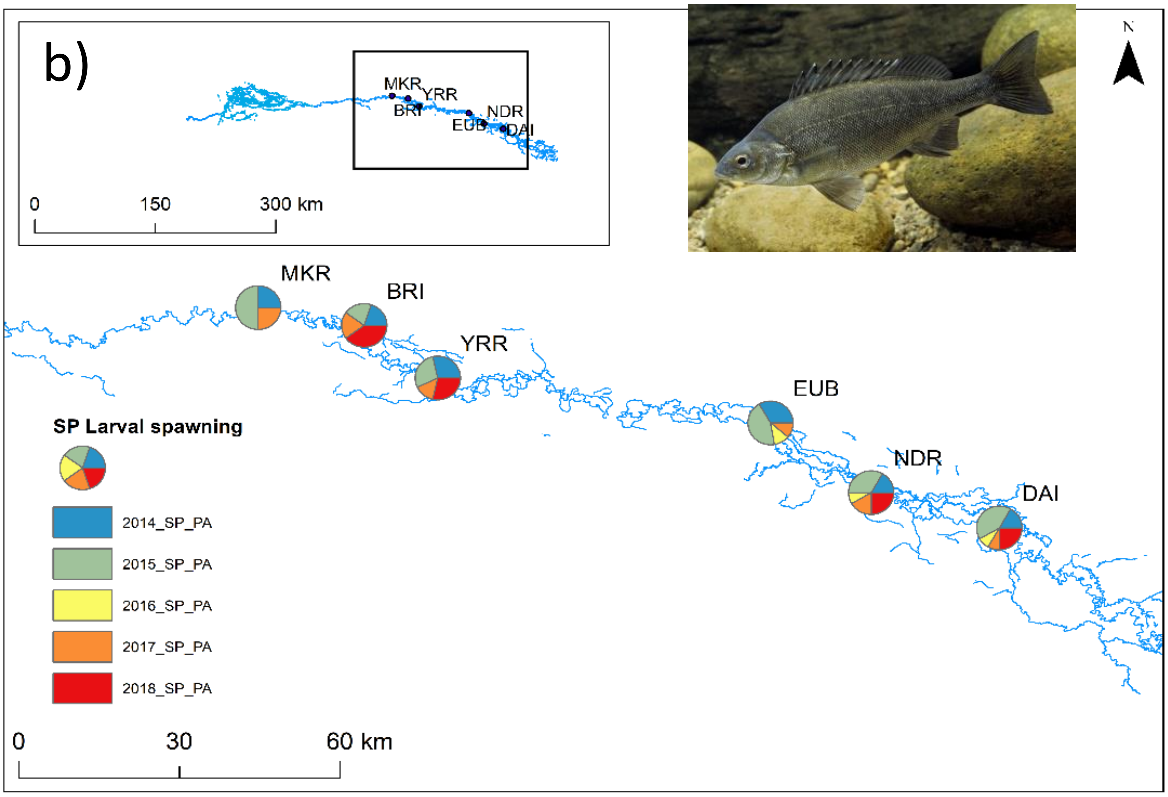


Figure 4-84 Variation in the presence/absence of eggs and larvae captured in the Murrumbidgee River for both a) golden perch, and b) silver perch among sampling years n=5) and between hydrological zones (n=2; Carrathool (MKR, BRI, YRR) and Narrandera (EUB, NDR, DAI)) each of which had n=3 sites.

Table 4-31 Model parameter estimates explaining the probability of golden perch spawning in relation to weekly changes in water temperature (Chwtemp). Confidence interval is abbreviated to CI.

Parameter	Estimate	Lower CI	Upper CI	*P*
(Intercept)	-1.67	-2.11	-1.24	0.00
Chwtemp	-0.44	-0.70	-0.19	0.00

Table 4-32 Model parameter estimates explaining the probability of golden perch spawning in relation to daily river discharge (L_flow; values on a log-axis). Confidence interval is abbreviated to CI.

Parameter	Estimate	Lower CI	Upper CI	*P*
(Intercept)	-3.17	-7.22	0.88	0.13
L_flow	0.17	-0.30	0.63	0.48

Table 4-33 Model parameter estimates explaining the probability of silver perch spawning in relation to daily river discharge (L_flow; values on a log-axis), water temperature (Wtemp), zone and the interaction between discharge and water temperature (L_flow:Wtemp). Confidence interval is abbreviated to CI.

Parameter	Estimate	Lower CI	Upper CI	*P*
(Intercept)	64.82	15.74	113.90	0.01
L_flow	-9.17	-15.15	-3.18	0.00
Wtemp	-2.93	-5.09	-0.77	0.01
Zone	1.94	1.02	2.85	0.00
L_flow:Wtemp	0.40	0.14	0.67	0.00

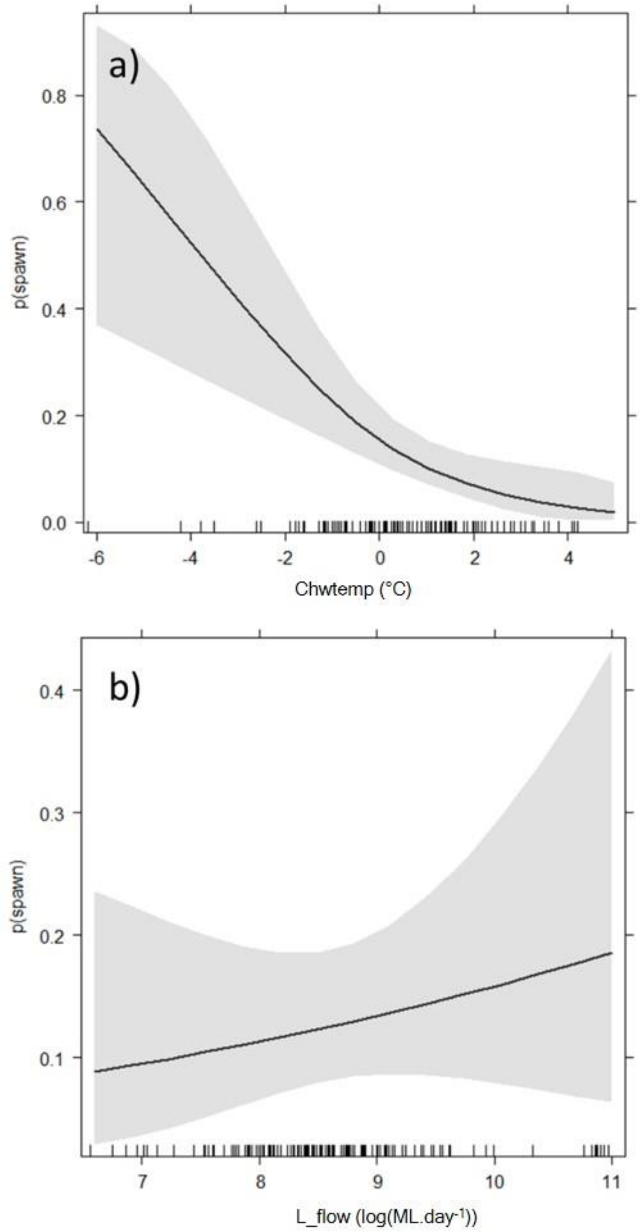


Figure 4-85 Predictive relationship describing the spawning probability (pa; y-axis) for golden perch in relation to a) changes in weekly water temperature (Chwtemp), and b) daily river discharge flow (value logged; L flow). Data were collected over four watering years (2014-15 to 2018-19) using larval drift nets in the Murrumbidgee River and probabilities are based on the presence/absence of drifting egg captures.

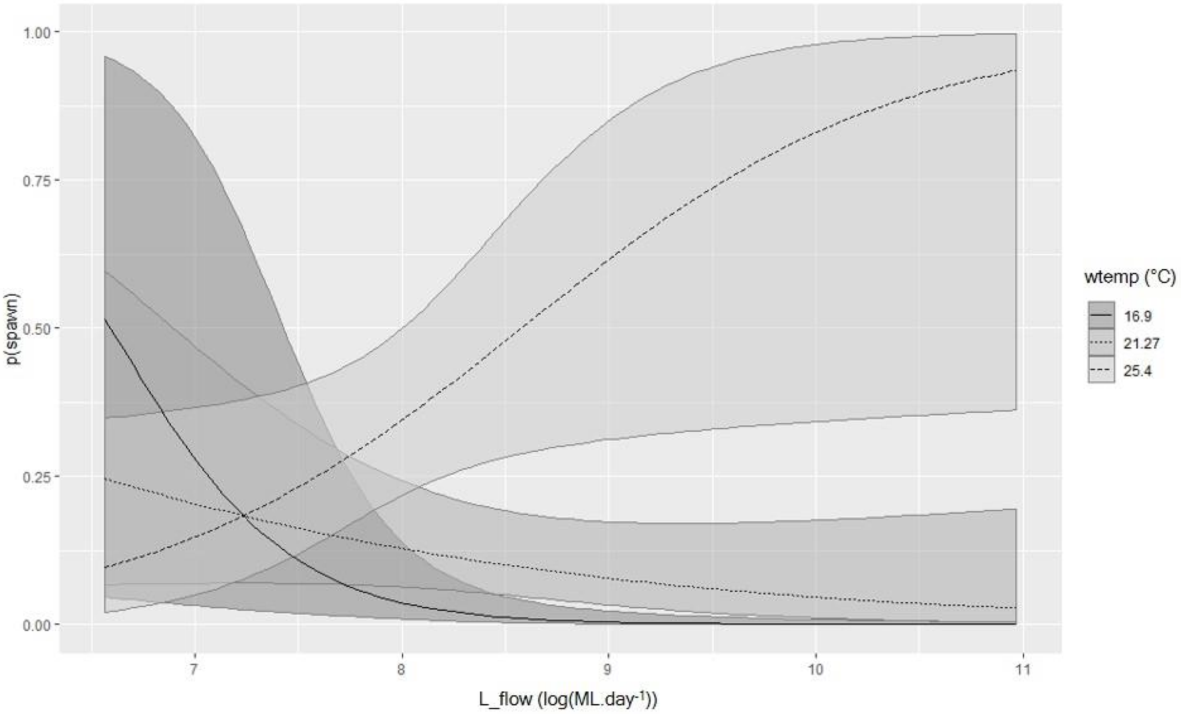


Figure 4-86 Predictive relationship describing the spawning probability (pa; y-axis) for silver perch in relation to the interaction between daily river discharge (values logged; L flow) and water temperature (Wtemp). Data were collected over four watering years (2014-15 to 2018-19) using larval drift nets in the Murrumbidgee River and probabilities are based on the presence/absence of drifting egg captures.

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 2018-19, however Commonwealth environmental watering actions influenced the hydrology of the Murrumbidgee River through deliveries from August 2018 to June 2019 targeting outcomes further downstream. Under the 2018-19 flow conditions, we detected the spawning of nine native and two alien fish species at the two monitored hydrological zones. Predictive relationships were further developed for golden perch and silver perch. Spawning of both golden perch and silver perch was detected, at both the Narrandera and Carrathool zone in 2018-19. However, in 2019 we only detected golden perch recruitment (a single recruit) at Narrandera but not Carrathool, and no silver perch recruitment at Narrandera or Carrathool, following these spawning events (riverine fish communities chapter). Further, Murray cod young-of-year (YOY) proportional abundance was reduced in 2019 compared to 2015 (see riverine fish section 4.11).

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 2018-19, and in previous years, does not appear to be translating to recruitment for either of these species within the river. Furthermore, while one juvenile silver perch was captured in 2014-15, none were captured from 2015-16 to 2018-19. 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 recent 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 five years of monitoring in the Murrumbidgee Selected Area, indicate that spawning for golden 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 consistent with recent findings by King *et al.* (2016) who also identified that spawning of golden 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 silver perch, spawning was best explained by an interaction between flow and water temperature. Appropriate in-channel hydraulic conditions for triggering silver perch spawning responses appear to be available within the mid-Murrumbidgee river channel throughout much of the spawning season, due to the frequent fluctuations in flow that occur in the river as a result of irrigation releases. However, flows were only positively linked to silver perch spawning during warmer water temperatures of 26–30 °C. This result was consistent with recent findings by King *et al.* (2016) in the Murray river, where silver perch spawning was positively associated with both flow and water temperature.

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 and Schiller 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 and Stuart 2003, Balcombe *et al.* 2006, Balcombe and Arthington 2009). The evidence presented to date, therefore, does not refute a spawning response of golden perch 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.

5. Evaluation of the 2018-19 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, 2017-18 and 2018-19 water years (Figure 5-1). However, the watering objectives each year have varied and in 2018-19 the majority of environmental water was used in the Redbank system, with the Yanga National Park –Yanga Lake top up delivered via the Yanga 1AS regulator and via Gayini Nimmie-Caira between August 2018 and January 2019. This action aimed to maintain water levels in Yanga and Tala Lake and increase inundation extents throughout the Yanga system of the Redbank zone. Further environmental water actions began in September 2018 and aimed to increase inundation extents in core wetlands to maintain aquatic refuge habitats in North Redbank, and to maintain refuge habitat from Nap Nap to Waugorah in the Gayini Nimmie-Caria.

From December 2018 to the end of the water year, a series of flow deliveries targeted key refuge sites within the Nimmie-Caira zone. In response to hot climatic conditions and poor water quality during the summer months, a low dissolved oxygen management flow was delivered through the lower Murrumbidgee River and provided water quality outcomes. These watering actions raised the water levels of all four LTIM monitored wetlands in the Redbank and Nimmie-Caira wetland systems. However, three LTIM monitored wetlands remained dry in the mid-Murrumbidgee wetland system. In the mid-Murrumbidgee, Yarradda Lagoon was pumped with environmental water from mid-November 2018 to mid-January 2019 following a brief drying period to remove a large number of adult carp.

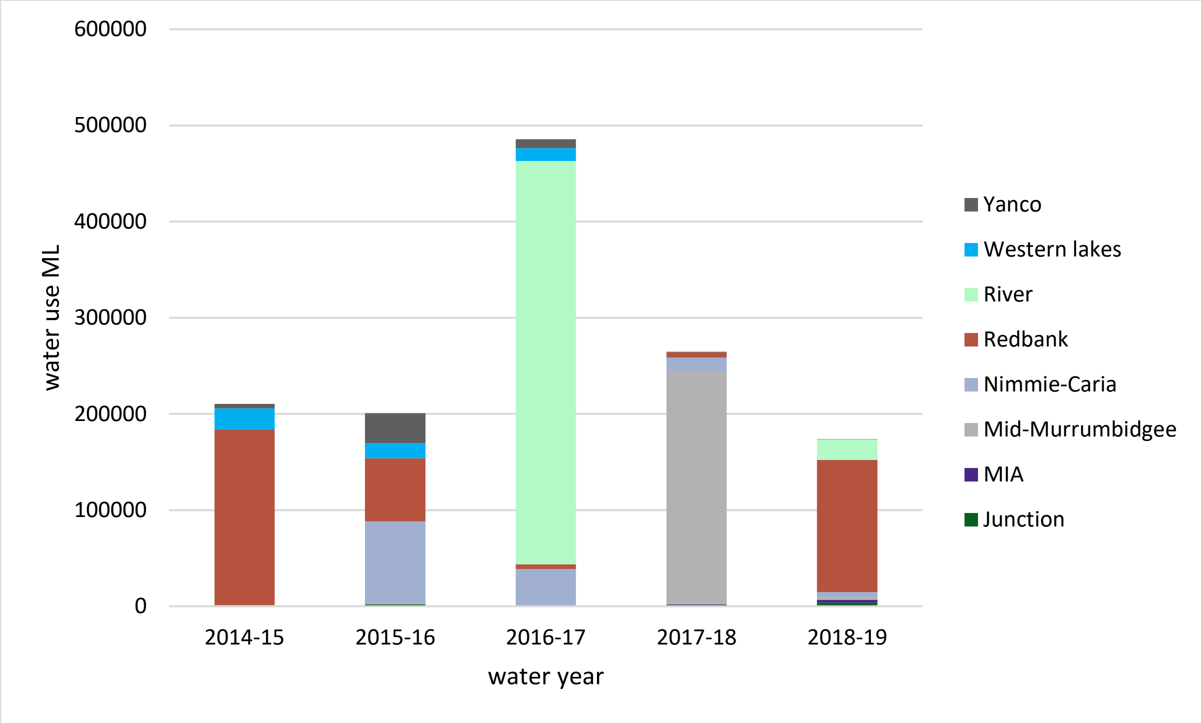


Figure 5-1 Summary of NSW and Commonwealth environmental watering actions by volume in key management zones in the Murrumbidgee between 2014 and 2019. Total environmental water delivered to the Murrumbidgee Catchment is a combination of Commonwealth licensed environmental Water (CEW), NSW licensed environmental water (NSW) and Environmental Water Allowance (EWA) accrued under the Water Sharing Plan for the Murrumbidgee Regulated River Water Source 2016. 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 previous years. Although end of systems flows at Balranald were lower in 2018-19 compared to previous years due to limited delivery of inter valley transfers (IVTs). As in previous years with similar flows, there was little evidence of in channel water deliveries altering the concentration of dissolved organic carbon, nitrogen or phosphorus or the rates of primary or secondary productivity in the main river channel (Table 5-1). 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 continued to spawn in the Murrumbidgee River during the 2018-19 water year (Table 5-1), with spawning closely linked to water temperature. A combined total of 4,129 fish eggs and larvae were collected in 2018-19, slightly lower than the previous year. 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 2018-19 spawning by golden perch and silver perch was similar to previous years, although spawning by Murray cod were the highest since monitoring commenced. However, we did not detect any evidence of recruitment by golden or silver perch in the Carrathool zone following these spawning events.

Table 5-1 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 and fell within expected ranges. Conductivity, pH levels, dissolved organic carbon, total nitrogen and total phosphorous levels were among the lowest readings recorded across the five year monitoring program. Concentrations of bioavailable nutrients such as NOx were also significantly low compared to previous years.	Broad-scale wetland reconnections and periods of low flow may promote increased primary and secondary productivity and support river food webs. Implimenting 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	In 2018-19, the median rates of stream metabolism were within the range observed for the previous water years, although overall 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 five 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 altered through reduced flow variability and changed patterns of nutrient availability due to the loss of natural wetland reconnections and periods of low flow in the main river channel.
Microinvertebrates	In all five years of the LTIM project, densities of microinvertebrates were two orders of magnitude higher in benthic than pelagic habitats within the Murrumbidgee River. In 2018-19, peaks in benthic microinvertebrate densities in the Carrathool and Narrandera zones were dominated by cladocerans and ostracods. Densities of copepods were low in 2018-19 compared to earlier years.	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 and cooler temperatures 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. Environmental flows that inundate dried sediments without creating stable high flows or cooler water temperature maybe important for maintaining high levels of riverine microinvertebrate density.

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 2018-19, 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 both 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. Continued monitoring of flow-cued spawning responses will strengthen the predictive relationships presented in this report and will, in turn, facilitate the development of transferable information for management of spawning of native freshwater species in the future.
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) in the main Murrumbidgee River channel. However, small numbers of young-of-year golden perch were recorded in floodplain wetlands, creeks and lakes. A number of locally extinct species are off-channel specialists, and their absence is likely due to long-term disconnection of these habitats. Future off-channel watering strategies should support long-term watering plans that will enable conservation stocking or translocation, and the subsequent re-establishment of resident populations of off-channel specialists.

Wetland outcomes

A number of environmental watering actions targeting floodplain and wetland habitats were undertaken in 2018-19 (Table 5-2). Monitoring as part of this program was focused on evaluating outcomes in the Redbank and Nimmie-Caira zones, and

Yarradda Lagoon in the mid-Murrumbidgee. A total of 23,613 ha of the Lowbidgee floodplain were inundated during 2018-2019, 26% more extensive than the previous water year. Most of the Lowbidgee inundation extent was distributed in the zones of Redbank and Nimmie-Caira covering 14,833 ha and 5,230 ha respectively. The Yanga National Park watering action targeted wetlands monitored in this program including Two Bridges Swamp and Piggery Lake, additional inundation occurred during the low dissolved oxygen native fish flow water action during February 2019. In the Gayini Nimmie-Caria zone, Nap Nap Swamp was pre-watered in July 2018 to about 60% after having dried out the previous water year. Environmental water from the NSW EWA Nap Nap to Waugorah Lagoon water action increased inundation extent to almost 100% of its boundary in early October 2018 and was full by mid-November 2018.

Table 5-2 Summary of key wetland outcomes in 2018-19 and implications for management of environmental water in the Murrumbidgee Selected Area

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 26% greater than the previous year and was confined to core wetlands in the Redbank (82% more extensive) and Gayini Nimmie-Caira (20% more extensive) zones.	Environmental water is the primary driver of ecological responses for water dependent species in the mid and lower Murrumbidgee floodplains. Maintaining core permanent refuge habitats and providing foraging opportunities for resident species should be a priority in all water years, the creation of larger continuous areas of inundated floodplain habitats that support breeding opportunities should continue to be a priority action in years in years of moderate and high water availability. With the persistence of hotter and drier than average conditions into 2019-2020, the importance of environmental flows cannot be overstated. Environmental flows may provide the only habitats and foraging for resident species and environmental flows will be critical for maintaining core refuge habitats and to avoid local extinctions and ecological degradation during dry periods.
Water quality	Carbon, nutrient and chlorophyll-a concentrations seen in 2018-19 typically fell within the expected range and were broadly consistent with readings in previous years, with the exception of Avalon Swamp which recorded above average chlorophyll-a readings in the 2018-19 water year.	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.

	Water quality in wetland sites that received Commonwealth environmental water improved due to increased water depth.	
Microinvertebrates	As in previous years, microinvertebrate densities were above 1000 individuals/litre across all monitoring sites and contained a 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. Watering actions that allow key wetlands to drawn down and temporarily dry out will contribute to maintaining microinvertebrate densities.
Vegetation diversity	Overall, environmental water contributed to a significant increase in the number of water dependent and native flora species, while contributing to a decrease in the species richness of exotic and terrestrial species. Wetlands that received environmental water multiple times between 2014 and 2019 (e.g. Yarradda and Gooragool Lagoons) had higher overall diversity of native water dependent species and native water dependant species established at a higher rate when compared to wetlands that received environmental water on just one occasion.	The majority of monitored wetlands have received environmental water at least once over the past 5 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. Given the current level of River Red Gum at this wetland, mechanical removal coupled with repeat inundation over a number of years maybe required if this wetland were to be considered a priority for restoration.
Fish	The diversity of native fish in floodplain wetlands was similar to previous years. The 2018-19 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. Overall native fish diversity and the proportion of the native fish catch represented by juveniles was highest at the most persistent wetlands, while the proportion of juveniles in the exotic fish catch was largely insensitive to wetland permanence. Invasive fish densities in remaining permanent creek systems (e.g. Telephone Creek and Waugorah 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 2018-19, including the vulnerable (EPBC Act) southern bell frog which is the same as previous years. Overall frog diversity was high in the Nimmie-Caira and Redbank zones, and 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 Yarradda Lagoon supporting the inland banjo frog, spotted/barking marsh frog and Peron's tree frog tadpoles. Frog species richness increased in the Redbank and Nimmie-Caira zones, largely driven by increases in species richness at Piggery Lake, Two Bridges Swamp, Nap Nap and Eulimbah where southern bell frogs were recorded. Large numbers of southern bell frog juveniles and tadpoles were recorded at Nap Nap Swamp. Overall, southern bell frog numbers have increased steadily in response to environmental watering actions over the Selected Area since monitoring commenced.	Limited availability of suitable habitats in some zones during spring and summer (e.g. Eulimbah) contributed to lower overall frog abundances than in previous years. However there were significant positive outcomes in terms of frog breeding and recruitment at key wetlands targeted with Commonwealth and NSW Environmental water. At Yarradda Lagoon there were large increases in tadpole abundance (Peron's tree frogs) which may have been linked to the reduction in carp biomass following managed drying and pumping. Practical pumping may be an import management tool to reduce carp numbers and allow for the establishment of aquatic vegetation and for breeding by frogs and native fish. The combination of watering actions targeted at maintaining refuge habitat, complemented to larger deliveries during spring and summer has been successful in maintaining, and at some locations, increasing southern bell frog populations and should be continued. 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 Waugorah 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	In total, 66 wetland-dependent bird species were recorded during 2014-19. In 2018-19, 7 waterbird species were confirmed breeding during the surveys. This was similar to 2017-18 but considerably lower than the previous three survey years. 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 five years of surveys had a higher overall species richness and abundance when compared to wetlands that were dry for extended periods during 2014-19. Breeding activity is linked to the area of floodplain inundation during spring and summer, in 2018-19 there was limited breeding habitat availably at key rookery sites in the Lowbidgee. It is recommended that watering actions that inundate large areas of continuous floodplain habitat through spring and summer will be beneficial for triggering bird breeding activity.

Management implications

Southern bell frogs at Nap Nap

Since 2014, Commonwealth and NSW watering has contributed to the recovery of the southern bell frog population at Nap Nap Swamp and a general increase in the presence and abundance of the southern bell frog across wetlands in the lower Murrumbidgee. Environmental water is used to support breeding by southern bell frogs at two key locations within the Gayini Nimmie-Caira - Nap Nap Swamp and Eulimbah Swamp and Yarradda Lagoon in the mid-Murrumbidgee. To date environmental water has also been used to maintain refuge habitat for southern bell frogs at additional sites in the Gayini Nimmie-Caria including Nimmie Creek, Telephone Creek and Avalon Swamp. Breeding by southern bell frogs was previously recorded at Avalon and Telephone Creeks, and with larger deliveries of water in spring and summer these sites could also be re-established as breeding populations. Positive outcomes for southern bell frogs highlight the critical importance of the use of NSW and Commonwealth environmental water to maintain suitable watering regimes at key southern bell frog breeding sites. Maintaining these sites as southern bell frog refuge habitat into the future will be of considerable importance in the long-term management of this species in the Murrumbidgee Selected Area.

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, prioritisation 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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7. Appendices

Appendix 1 summary of watering actions 2014-19.

water year	Zone	Target asset	Dates	Flow component type	CEW volume used (ML)	Other volumes (ML)	Total volume – all contributors (ML)
2014-15	Western lakes	Juanbung	4/5/15 to 29/6/15	Wetland inundation	5688.2	4667	10355.2
	Redbank	Mid North Redbank and Return Flows	12/08/14 to 20/01/15	Wetland inundation	40000	16340	56340
	Western lakes	Paika Lake	25/5/15 to 27/6/15	Wetland inundation	8498	2994	11492
	Yanco	Sandy Creek	22/03/15 to 1/4/15	Flow fresh	250	130	380
	Yanco	Sandy Creek	22/03/15 to1/4/15	Flow fresh	250	130	380
	Redbank	Upper North Redbank	1/10/14 to 25/03/15	Wetland inundation	20000	6648.0 0	26648
	Yanco	Yanco Creek	23/6/15 to 30/6/15	Flow fresh	2462	1617	4079
	Yanco	Yanco Creek	23/6/15 to 30/6/15	Flow fresh	2462	1617	4079
	Redbank*	Yanga National Park	23/10/14 to10/04/15	Wetland inundation	74512	25350	99862
	Mid-Murrumbidgee	Yarradda Lagoon	4/12/14 to 22/1/15	Wetland pumping	1150		1150
	Mid-Murrumbidgee*	Yarradda Lagoon	4/12/14 to 22/1/15	Wetland pumping	1150		1150
2015-16	Western lakes	Hobblers Lake – Penarie Creek	15/03/16 to 13/04/16	Wetland inundation	5000	910	5910
	Western lakes	Juanbung	04/11/15 to 17/02/16	Wetland inundation	10,000	0	10000
	Junction	Junction Wetlands (Lowbidgee SAL no take)	08/09/15 to 30/10/15	Fresh, Wetland Inundation	0	0	0
	Nimmie-Caria*	Nap Nap - Waugorah	06/05/16 to 30/06/16	Wetland inundation	9557	5717	15274
	Nimmie-Caria*	Nimmie-Caira	17/10/15 to 09/02/16	Wetland inundation	18,000	50,528	68528
	Redbank	North Redbank	21/10/15 to 10/2/16	Wetland inundation	25,000	29,000	54000
	Yanco	Sandy Creek	01/04/16 to 12/05/16	Flow fresh	105.7	164.3	270
	Nimmie-Caria	Toogimbie IPA	15/03/16 to 15/06/16	Wetland pumping	933	0	933
	Nimmie-Caria	Toogimbie IPA	15/03/16 to 15/06/16	Wetland pumping	933	0	933
	Nimmie-Caria	Toogimbie IPA	15/03/16 to 15/06/16	Wetland pumping	933	0	933
	Nimmie-Caria	Toogimbie IPA	15/03/16 to 15/06/16	Wetland pumping	933	0	933
	Junction	Waldaira wetlands (Junction Wetlands)	09/02/16 to 15/06/16	Wetland pumping	2000	0	2000
	Yanco	Yanco Creek trout cod support flow	15/10/15 to 11/11/15	Flow fresh	8075	0	8075
	Yanco	Yanco Creek trout cod support flow	15/10/15 to 11/11/15	Flow fresh	8075	0	8075
	Yanco	Yanco Creek wetland inundation	01/07/15 to 13/08/15 (Two delivery periods: 01/07/15 to 04/07/15 and 23/07/15 to 13/08/15)	Flow fresh	18,263	4566	22829
	Redbank*	Yanga National Park waterbird support	17/11/15 to 7/12/15	Wetland inundation	10,000	1605	11605
2015-16	Mid-Murrumbidgee*	Yarradda Lagoon	01/09/15 to 07/12/15	Wetland pumping	1394	0	1394.3

2016-17	Junction	Junction Wetlands: no take LBG SAL	7/07/2016 to 31/08/2016	Wetland inundation			0
2016-17	Nimmie-Caria	Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake)	04/08/2016 to 03/09/2016	Wetland inundation	15,507	0	15507
2016-17	River	Lower Murrumbidgee River: Autumn fish pulse	01/04/2017 to 20/04/2017	Flow fresh	47,548	1039	48587
2016-17	River*	Murrumbidgee River Fresh: Flood recession and dissolved oxygen management	28/10/2016 to 05/01/2017	Fresh, Wetland Inundation	150,978	219861	370839
2016-17	Nimmie-Caria*	Nimmie-Caira: Nap Nap waterbird breeding support	3/01/2017 to 07/01/2017	Wetland inundation	630	0	630
2016-17	Nimmie-Caria*	Nimmie-Caira: Telephone Bank waterbird breeding support	24/11/2016 to 20/03/2017	Wetland inundation	5425	0	5425
2016-17	Nimmie-Caria*	Nimmie-Caira: Eulimbah waterbird breeding support	28/11/2016 to 03/03/2017	Wetland inundation	2320	3923	6243
2016-17	Nimmie-Caria*	Nimmie-Caira: Eulimbah waterbird breeding support	28/11/2016 to 03/03/2017	Wetland inundation	2320	3923	6243
2016-17	Nimmie-Caria	Nimmie-Caira: Is-y-Coed (Kieeta and Kia Lakes) pelican breeding support	10/02/2017 to 20/03/2017	Wetland inundation	5000	4903	9903
2016-17	Redbank	North Redbank: Tori Lignum Swamp waterbird support	27/01/2017 to 13/02/2017	Wetland inundation	844	1946	2790
2016-17	Nimmie-Caria	Toogimbie IPA Wetlands	18/03/2017 to 04/04/2017	Wetland inundation	998	0	998
2016-17	Western lakes	Western Lakes	01/05/2017 to 7/06/2017	Wetland inundation		13,300	13300
2016-17	Yanco	Yanco-Billabong Creek System: Water Quality	16/11/2016 to 04/01/2017	Flow fresh	0	3500	3500
2016-17	Yanco	Yanco-Billabong-Forest Creek system: Wanganella Swamp waterbird breeding support	19/11/2016 to 04/01/2017	Wetland inundation	5000	800	5800
2016-17	Redbank*	Yanga National Park: waterbird support	29/01/2017 to 13/02/2017	Wetland inundation	2155	0	2155
2017-18	Mid-Murrumbidgee*	Gooragool Lagoon – Forego Kooba Ag. water transfer	1/06/2018 to 1/06/2018	Wetland inundation	750	750	1500
2017-18	Mid-Murrumbidgee*	Gooragool Pumping	18/07/2017 to 11/08/2017	Wetland Inundation	1426	0	1426
2017-18	Mid-Murrumbidgee	Mid-Murrumbidgee wetlands reconnection	24/07/2017 to 01/09/2017	Fresh, Wetland Inundation	159,283	76,922	236205
2017-18	Mid-Murrumbidgee	Coonancoocabil Lagoon	11/12/2017 to 02/01/2018	Wetland inundation	900	0	900
2017-18	Mid-Murrumbidgee	Oak Creek	28/12/2017 to 02/01/2018	Wetland inundation	620	0	620
2017-18	Nimmie-Caria*	Nimmie-Caira Refuge	15/04/2018 to 28/05/2018	Wetland inundation	5000	8850	13850
2017-18	Redbank	North Redbank	9/10/2017 to 19/10/2017	Wetland inundation	5528	0	5528
2017-18	Yanco	Sandy Creek	17/02/2018 to 23/04/2018	Flow fresh	400	0	400
2017-18	Nimmie-Caria	Toogimbie IPA Wetlands	7/11/2017 to 01/06/2018	Wetland inundation	1000	0	1000
2017-18	MIA	Tuckerbil Swamp	16/04/2018 to 9/04/2018	Wetland inundation	600	0	600

2017-18	Junction	Waldaira Lagoon	09/02/2018 to 07/05/2018	Wetland inundation	1500	0	1500
2017-18	Mid-Murrumbidgee*	Yarradda Lagoon	20/11/2017 to 25/11/2017	Wetland inundation	177	0	177.64
2017-18	Mid-Murrumbidgee	Yarradda Lagoon Pumping	4/07/2017 to 24/07/2017	Wetland Inundation	326	500	826
2018-19	MIA	Campbells Swamp and McCaugheys Lagoon and Turkey Flats Swamp	08/11/2018 to 18/02/2019	Wetland inundation	1594	0	1594
2018-19	Mid-Murrumbidgee*	Darlington Lagoon	19/12/2018 to 31/05/2019	Wetland Inundation			0
2018-19	MIA	Fivebough Swamp (Ramsar site)	25/10/2018 to 22/03/2019	Wetland Inundation	794	0	794
2018-19	Mid-Murrumbidgee*	Gooragool Lagoon	07/02/2019 to 03/05/2019	Wetland inundation	82.7	0	82.7
2018-19	River*	Lower Murrumbidgee River: Low Dissolved Oxygen management flow	30/01/2019 to 09/04/2019	Fresh, Wetland Inundation	5,000	16,100	21100
2018-19	Junction	Mainie Swamp (Junction Wetlands)	10/10/2018 to 04/03/2019	Wetland inundation	2,000	0	2000
2018-19	Nimmie-Caria	Nimmie-Caira refuge flows	01/12/2018 to	Wetland inundation	2300	2000	4300
2018-19	Redbank	North Redbank	18/09/2018 to 28/02/2019	Wetland inundation	6,000	21,000	27000
2018-19	Yanco	Sandy Creek	29/09/2018 to 07/02/2019	Wetland Inundation	400	0	400
2018-19	Nimmie-Caria	Toogimbie IPA	15/10/2018 to 18/03/2019	Wetland inundation	900	600	1500
2018-19	MIA	Tuckerbil Swamp (Ramsar site) (Murrumbidgee Irrigation Area)	24/10/2018 to 09/05/2019	Wetland Inundation	609	0	609.6
2018-19	Junction	Waldaira (Junction Wetlands)	31/10/2018 to 30/06/2019	Wetland inundation	1,700	0	1700
2018-19	Junction	Waldaira (Junction Wetlands)	15/03/2019	Wetland inundation			0
2018-19	Redbank*	Yanga National Park: Yanga Lake top up (via Gayini Nimmie-Caira)		Wetland inundation	30,000	0	30000
2018-19	Redbank*	Yanga National Park: Yanga Lake top up and system watering (via 1AS)	20/08/2018 to 26/01/2019	Wetland inundation	12,500	68,187	80687
2018-19	Mid-Murrumbidgee*	Yarradda Lagoon	16/11/2018 to 18/01/2019	Wetland inundation	2013	0	2013
2018-19	Nimmie-Caria*	MBG1819-08 Nap Nap to Waugorah Lagoon	01/11/2018 to 01/01/2019	Wetland inundation		16,000	16000

Appendix 2 Wetland-dependent bird species recorded from 2014-19.

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 (piscivores)	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
Raptors	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 and Boles (2008).

Appendix 3. Wetland-dependent bird species recorded in 2018-19 STIM project at Yanga and Tala Lakes.

Functional Group	Common Name	Scientific Name	CAVS Code
Dabbling ducks	Australasian Shoveler	Anas rhynchotis	212
	Freckled Duck	Stictonetta naevosa	214
	Grey Teal	Anas gracilis	211
	Pacific Black Duck	Anas superciliosa	208
	Pink-eared Duck	Malacorhynchus membranaceus	213
Diving ducks	Black Swan	Cygnus atratus	203
	Eurasian Coot	Fulica atra	59
	Hardhead	Aythya australis	215
Fish-eating birds (piscivores)	Australasian Darter	Anhinga novaehollandiae	8731
	Australasian Grebe	Tachybaptus novaehollandiae	61
	Australian Gull-billed Tern	Gelochelidon macrotarsa	8794
	Australian Pelican	Pelecanus conspicillatus	106
	Caspian Tern	Hydroprogne caspia	112
	Eastern Great Egret	Ardea alba modesta	8712
	Great Cormorant	Phalacrocorax carbo	96
	Great Crested Grebe	Podiceps cristatus	60
	Intermediate Egret	Ardea intermedia	186
	Little Black Cormorant	Phalacrocorax sulcirostris	97
	Little Pied Cormorant	Microcarbo melanoleucos	100
	Pied Cormorant	Phalacrocorax varius	99
	Sacred Kingfisher	Todiramphus sanctus	326
	Silver Gull	Chroicocephalus novaehollandiae	125
	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
Large waders	Australian White Ibis	Threskiornis molucca	179
	Royal Spoonbill	Platalea regia	181
	Yellow-billed Spoonbill	Platalea flavipes	182
Migratory shorebirds	Marsh Sandpiper	Tringa stagnatilis	159
	Red-necked Stint	Calidris ruficollis	162
	Sharp-tailed Sandpiper	Calidris acuminata	163
Rails and shoreline gallinules	Black-tailed Native-hen	Tribonyx ventralis	55
Raptor	Black Kite	Milvus migrans	229
	Brown Falcon	Falco berigora	239
	Whistling Kite	Haliastur sphenurus	228
	White-bellied Sea-Eagle	Haliaeetus leucogaster	226
Resident shorebirds	Black-fronted Dotterel	Elseyornis melanops	144
	Black-winged Stilt	Himantopus leucocephalus	146
	Masked Lapwing	Vanellus miles	133
	Red-capped Plover	Charadrius ruficapillus	143
	Red-necked Avocet	Recurvirostra novaehollandiae	148

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

Maximum count of each wetland-dependent bird species recorded in each of the Murrumbidgee wetland zones during LTIM 2014-19 surveys (*indicates breeding detected). Wetland zone: MM-Mid-Murrumbidgee, NC- Nimmie-Caria, RB Redbank.

	2014-15			2015-16			2016-17			2017-18			2018-19		
Common Name^	***MM***	***NC***	***RB***	***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	0	0#	2*
Australasian darter	0	8	2	31*	14	2	23*	26*	11*	21*	1	1	21*	6*	52*
Australasian grebe	45	0	4	20	11	73	25	8	2	10	3	2	11	4	12
Australasian shoveler	6	0	0	0	0	8	4	5	2	0	0	0	0	0	6
Australian gull-billed tern	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
Australian hobby	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
Australian pelican	0	75	64	80	20	131	0	16	60	48	49	4	112	157	292
Australian reed-warbler	0	1	0	1	1	6	6	9	17	2	22	9	2	7	3
Australian shelduck	0	3	2	2	0	6	2	6	20	2	2	2	0	13*	2
Australian spotted crake	0	0	0	0	0	0	0	6*	0	0	0	0	0	8	0
Australian white ibis	9	39	10	8	24	135	9	27	76	7	19	84	1	25	42*
Australian wood duck	38	16	17	23	15	12	20	31	34	70	30	8	6	17	11
Baillon's crake	0	0	0	0	0	0	0	5	0	0	0	0	0	2	0
Black-fronted dotterel	0	7	0	0	0	0	3	2	2	4	2	0	3	4	1
Black-shouldered kite	0	0	0	0	0	0	0	0	0	0	22	0	0	1	0
Black-tailed native-hen	0	23	0	0	36	0	0	67	2	20	173	2	0	49	23
Black-winged stilt	0	4	0	0	2	101	7	42	119	0	0	0	0	0	3
Black kite	0	0	0	0	0	0	2	2	0	7	1	0	0	3	1
Black swan	0	8	57	31	6	245*	5*	13*	80*	0	4	1	0	0	17
Brown falcon	0	0	0	0	0	0	1	0	0	0	3	0	0	1	0
Buff-banded rail	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Cattle egret	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Chestnut teal	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Dusky moorhen	0	0	0	0	0	3	2	1	5	7	4	0	0	0	1
Eastern great egret	2	17	4	2	32	38	45	18	80	3	5	3	1	4	19*

	2014-15			2015-16			2016-17			2017-18			2018-19		
Common Name^	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***
Eurasian coot	65	4	204	575	8	710	26*	88*	353*	7	0	1	0	2	95
Glossy ibis	0	0	0	0	0	270	0	6	120	0	0	0	0	0	0
Golden-headed cisticola	0	0	0	0	0	1	2	0	0	1	2	0	0	0	0
Great cormorant	38	2	12	65	58	20	15*	36	85*	17*	17	5	25*	6	31*
Great crested grebe	0	0	0	0	0	0	4	0	155*	0	0	0	0	0	41
Grey teal	215	202*	312	383*	99	422	497*	112*	474*	445	255	58	110	100	128
Hardhead	32	0	15	110	0	10	3	12	7	0	12	0	59	5	8
Hoary-headed grebe	58	0	110	24	2	0	1	11	22	0	0	0	18	2	142
Intermediate egret	0	1	7	6	12	61	19	12	252	1	0	1	3	0	14
Latham's snipe J,R	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Little black cormorant	5	100	21	7	75	12	88*	66	65*	93	28	1	29	16	57*
Little egret	0	5	0	0	4	7	4	1	14	0	1	0	0	0	2
Little grassbird	0	0	0	0	1	1	2	4	5	1	5	2	0	3	6
Little pied cormorant	4	7	17	56*	50	24	21*	52*	127*	60	18	7	3*	5*	61*
Masked lapwing	0	2	2	2	2	5	0	13	6	2	0	2	1	2	0
Musk duck	0	1	0	0	0	0	1	4*	0	0	2	0	0	0	1
Nankeen kestrel	0	0	0	1	0	2	0	0	1	1	4	1	1	2	1
Nankeen night-heron	0	0	5	0	0	0	16	94*	137*	22	0	1	0	1	0*
Pacific black duck	48*	55	52	100*	50*	18*	170*	16*	65*	184*	96	10	69*	80*	36
Pied cormorant	0	0	0	6	1	0	2*	1	2	1	1	4	3	0	20
Pied heron	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Pink-eared duck	259	18	125	16	0	0	75*	29*	2	3	0	0	39	6	22
Plumed whistling-duck	0	35	0	0	0	0	10	5	0	0	0	0	0	0	0
Purple swamphen	0	0	0	0	0	8	4	4	34	1	1	0	0	2	6
Red-capped plover	0	2	0	0	0	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	11	4	0
Red-necked avocet	0	0	0	0	0	0	0	0	20	0	0	0	74	0	0
Royal spoonbill	0	7	0	22*	6	12	4	14	94	17	22	2	1	8	27*

	2014-15			2015-16			2016-17			2017-18			2018-19		
Common Name^	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***	***MM***	***NC***	***RB***
Sacred kingfisher	0	1	1	2	1	0	3	2	6	4	4	3	3	3	4
Sharp-tailed sandpiper J,C,R	0	2	0	0	0	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	0	0	1
Swamp harrier	0	0	0	1	3	0	0	2	1	0	2	0	0	2	0
Unidentified cormorant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Unidentified duck	0	0	0	0	0	0	10	7	157	25	0	0	0	4	0
Unidentified egret	0	0	0	0	2	0	1	0	188	3	2	0	0	0	18
Unidentified small grebe	0	0	0	0	0	0	0	0	0	2	0	0	0	0	122
Unidentified small migratory wader	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Unidentified spoonbill	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Unidentified tern	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Wedge-tailed eagle	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1
Whiskered tern	0	0	0	0	120	0	4	68	20	0	0	0	0	0	0
Whistling kite	2	0	4	1	4	3	4	4	2	5	4	2	1	5	5
White-bellied sea-eagle v	0	2	2	1	1	2	1	1	1	2	1	1	1	2	1
White-faced heron	3	19	2	7	4	4	6	6	42	16	6	4	6	4	3*
White-necked heron	0	3	9	5	1	9	33	16	48	4	2	1	1	4	6
Yellow-billed spoonbill	2	25	4	51	16	210	420*	18	26*	25	5	4	0	10	9

^ 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 *Biodiversity Conservation Act 2016* (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 DPIE monitoring. # Incidental observations of bitterns were recorded during frog surveys.

Appendix 4. Calculation of Sustainable Rivers Audit (SRA) fish indices.

Eight fish metrics were calculated using the methods described by Robinson (2012). These metrics were subsequently aggregated to produce three indices (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition score. Metric and indicator aggregation used Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) using the rules sets developed by Davies *et al.* (2010). Expectedness represents the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition. This value is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). Nativeness represents the proportion of native compared to alien fishes, and is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robinson 2012). Recruitment represents the recent reproductive activity of the native fish community within each hydrological zone, and is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). Aggregation of individual metrics into relevant indices was undertaken using the expert rule set (Carter 2012). The three indices were subsequently aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition can be partitioned into five equal categorical bands to rate the condition of the fish community as; “Good” (81–100), “Moderate” (61–80), “Poor” (41–60), “Very poor” (21–40), or “Extremely poor” (0–20).

Contributions of fish species abundance and biomass to variability among years and zones in the Murrumbidgee River, determined through SIMPER analysis. Note that only results for significant pairwise comparisons are presented, and only species contributing ≥10% to changes in community composition are included.

Indicator	Zone comparison	Species	Year or zone with greater value	Contribution to difference (%)
Abundance	2015-2019	bony herring	2015	19
		carp gudgeon	2015	15
		Murray-Darling rainbowfish	2015	14
		Murray cod	2015	12
	Narrandera-Carrathool	bony herring	Carrathool	26
		carp gudgeon	Carrathool	13
		Murray-Darling rainbowfish	Narrandera	12
	Narrandera-Balranald	bony herring	Balranald	26
		Murray cod	Narrandera	13
		Murray-Darling rainbowfish	Narrandera	11
	Carrathool-Balranald	Murray cod	Carrathool	17
		carp gudgeon	Balranald	15
		bony herring	Balranald	15
		Murray-Darling rainbowfish	Carrathool	15
		golden perch	Balranald	11
Biomass	2015-2019	*No significant difference identified*		
Biomass	Narrandera-Carrathool	bony herring	Carrathool	21
		golden perch	Carrathool	18
		Murray cod	Carrathool	18
		common carp	Narrandera	13
		trout cod	Narrandera	13
	Narrandera-Balranald	Murray cod	Narrandera	26
		bony herring	Balranald	20
		golden perch	Balranald	14
		common carp	Narrandera	12
		trout cod	Narrandera	10
	Carrathool-Balranald	Murray cod	Carrathool	33
		golden perch	Balranald	19
		common carp	Balranald	12
		bony herring	Balranald	12