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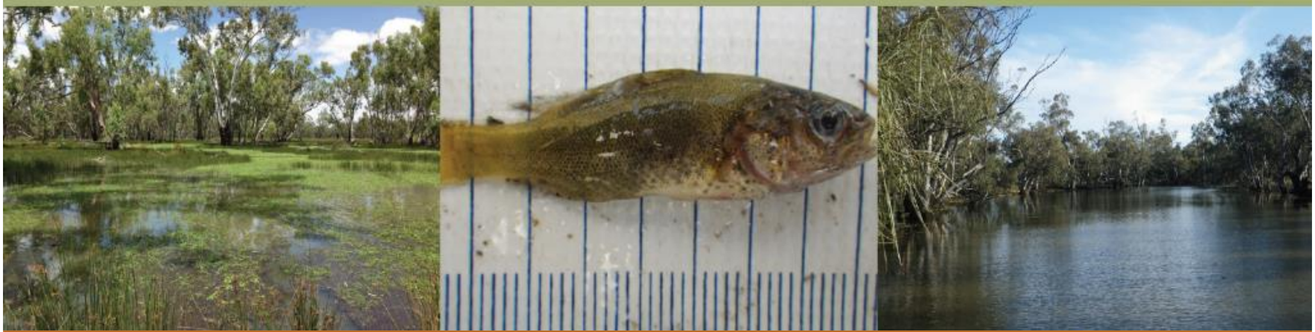

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project Murrumbidgee River System evaluation report 2014-16

Commonwealth Environmental Water Office Long-Term Intervention Monitoring project Murrumbidgee River system Selected Area evaluation report, 2014-16. November 2016

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Executive Summary

The Murrumbidgee River Long-Term Intervention Monitoring (LTIM) project is a collaborative project between Charles Sturt University, NSW Office of Environment and Heritage, NSW Trade and Investment (Narrandera Fisheries Centre) and the University of New South Wales (Centre for Ecosystem Science). Funding from the Commonwealth Environmental Water Office supports monitoring for a five-year period of the hydrological and ecological outcomes of watering actions in the river and wetlands of the Murrumbidgee. This report documents findings from the first two years of the LTIM project, 2014-15 and 2015-16.

The LTIM project focuses monitoring activities through the mid and lower Murrumbidgee River and floodplain, which is referred to in this report as the Murrumbidgee Selected Area. In this report the evaluation of the outcomes of Commonwealth environmental watering actions are presented in two sections: Riverine outcomes and Wetland outcomes. The riverine sections focused on monitoring activities undertaken through a stretch of river extending downstream from Wagga for 187 km (Narrandera Zone), the next 358 km stretch below Tom Bullen storage (Carathool Zone). The wetland section evaluates outcomes of Commonwealth environmental watering actions across three zones: the mid-Murrumbidgee which is a series of lagoons bordering the Murrumbidgee River between Narrandera and Carrathool, the Nimmie-Caira and Redbank zones through the Lower Murrumbidgee floodplain (Lowbidgee).

The Commonwealth Environmental Water Holder in collaboration with NSW Office of Environment and Heritage under took multiple watering actions in 2015-16 with the main focus being floodplains, creek lines and wetland habitats. There were no water actions specifically targeting the main channel of the Murrumbidgee River during 2015-16 or 2014-15, however in-channel delivery of environmental water to floodplain and wetlands systems produced rises in the river. The impact of these water rises on fish spawning, microinvertebrates, nutrients, productivity and water quality was monitored through spring and summer in the Narrandera and Carrathool zones. We predicted that spawning of flow-cued species such as golden perch and silver perch would result from in-channel water level rises (freshes) and bankfull events, and that base flows and above would provide suitable conditions for spawning to occur in opportunistic (e.g. carp gudgeon) and equilibrium (e.g. Murray cod) species (i.e. non

flow-cued species). We expected inundation of dry sediment in the main channel to boost nutrients, metabolism and microinvertebrate productivity, providing additional food for larval fish. Evaluation of the key riverine indicators (for example fish and microinvertebrates) monitored in year 2014-15 and 2015-16 demonstrate that the delivery of environmental flows to wetland assets can still have a positive influence on in-channel habitats. Generating peak flows prior to the timing of peak larval fish spawning may promote boosted nutrients and microinvertebrates to support breeding events, but any flow manipulations must also consider flow requirements for fish recruitment (i.e. post-spawning survival and growth of native fish). Levels of nutrients and metabolism in the Murrumbidgee River are low and wetland reconnections are necessary to augment resources for river food webs. The responses of riverine fish, microinvertebrates, nutrients, productivity and water quality to these water levels changes is summarised over the page.

Riverine monitoring indicator	Key riverine outcomes	Implications for future riverine water actions
Riverine water quality	Nutrient, carbon and chlorophyll-a concentrations were consistent with prior records for the Murrumbidgee River and/or within ANZECC water quality criteria. Nutrient concentrations remain low in the river and it is hypothesised that this trend is due to limited lateral connectivity	Broad-scale wetland reconnections are necessary to promote resources for river food webs. Future planning of watering actions should incorporate actions that allow for wetland reconnections to support habitat and food sources needed for increased recruitment and survival of native fish and other aquatic biota.
Stream metabolism	Rates of metabolism were low compared with other river systems in the MBD during both years. A negative relationship between flow and metabolism was observed at Narrandera.	If rates of metabolism in the Murrumbidgee River are limited by the availability of nutrients and energy, increasing the frequency of environmental flows that reconnect wetlands will promote resources for river food webs.
Riverine microinvertebrates	Microinvertebrate densities exceed levels needed to support larval fish during early November in Carathool Zone. The peak in density matches peak in abundance of larval cod species and Australian smelt from light traps. Macrothricidae, the favoured prey of Murray cod, were present in high numbers. Microinvertebrate densities in the Narrandera zone were low, possibly due to high and more stable water levels.	Further monitoring is needed to confirm that microinvertebrate productivity peaks on the recession of peaks in river flows during spring and early summer. A recommendation for the Narrandera zone is to trial lowering water levels at the time that larval fish abundances peak to assess if this could stimulate an increase in densities of microinvertebrates to enhance larval fish recruitment.
Riverine and larval fish	The probability of silver perch spawning increased with increasing river levels. Golden perch spawning occurred independently of river levels. Environmental conditions were appropriate for spawning to occur in nine native fish species, including a number of equilibrium and opportunistic species.	Predictive relationships are under development for flow-cued spawners and will be strengthened with multiple years of monitoring data. Trialling alternative water delivery volumes (i.e. high or low flow years) will increase our predictive capacity.

In 2015-16 there were four water actions delivering water to the three floodplain monitoring zones (mid-Murrumbidgee, Nimmie-Caira and Redbank), monitored under LTIM, which had objectives for maintaining wetland-dependent vegetation and fauna: The **Nimmie-Caira refuge (North and south channel)** and the **Nap Nap - Waugorah** action which were both undertaken with the primary goal of maintaining refuge habitats through the Nimmie-Caira and northern Redbank zones. The **Yanga National Park waterbird** support action targeted waterbird rookeries in the Yanga National Park and the **Yarradda Lagoon watering** action involved pumping water in to Yarradda lagoon in the mid-Murrumbidgee.

Broadly the delivery of environmental water to wetlands aimed to maintain refuge habitat, improve water quality and to support the habitat and breeding requirements of native vegetation, waterbirds, frogs, turtles and native fish. Evaluation of the key wetland indicators monitored in year 2014-15 and 2015-16 are showing some significant benefits of inundation of wetlands. Without environmental watering events to wetlands in the Murrumbidgee Selected Area over this period, there would have been limited opportunities for the recruitment of native fish, aquatic vegetation, frogs, turtles and waterbirds. Frequent watering to support refuge habitats has also maintained water quality and densities of microinvertebrates and other prey species to support native fish populations. Some recovery of wetland-dependent vegetation has occurred as a result of the delivery of environmental water over successive years. Breeding activity for the six frog species occurring at the monitoring sites were recorded in response to Commonwealth environmental water. There were notable positive outcomes for southern bell frogs and other frog species including inland banjo frogs and Peron's tree frogs following pumping of Yarradda Lagoon in the mid-Murrumbidgee, with southern bell frog tadpoles, recent metamorphs and adults all observed for the first time in 2015-16. Waterbird diversity and total abundance was greater in wetlands that received Commonwealth environmental water in 2015-16 compared to sites that were dry and sites that received water in 2014-15 only. The monitoring indicators are listed in the table below along with a summary of key outcomes and the implications for adaptive management of future watering events.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Wetland hydrology	Overall the total area of the Lowbidgee floodplain inundated by Commonwealth environmental water actions in 2015-16 was about 16,000 ha.	The area of inundation was low relative to the size of the floodplain, larger scale watering actions are required to prevent further degradation of floodplain habitats and to create conditions that would support waterbird breeding.
Wetland water quality	During 2015-16, water was successfully delivered to support water quality in targeted wetlands. Overall, water quality remained within the expected ranges with few exceptions coinciding with the later stages of drying. Water quality was maintained at key refuge sites targeted with environmental water (e.g. Waugorah Lagoon) that were identified as at risk of poor water quality due to mid-season drying.	If environmental watering seeks to maintain a community of native fish within key refuge sites over winter periods, environmental flow managers should consider possible late-summer or autumn top up flows to maintain water quality until temperatures decline.
Wetland microinvertebrates	High densities of microinvertebrates were observed throughout spring and summer 2015-16, with communities dominated by copepods with cladocerans and ostracods present	There remains some knowledge gaps on the response of microinvertebrates during environmental watering of floodplain wetlands. Inundation history, the timing of watering and wetland type can influence outcomes. Multiple years of monitoring will provide information on these aspects that will inform the planning of environmental watering actions that aim to maximise food availability for wetland-dependent species such as filter-feeding duck species. Based on research on other wetlands in the MDB, frequent inundation of wetlands with some draw down over winter will yield the most productive sites. For wetlands that historically flooded annually, this should be the watering target.
Vegetation diversity	Vegetation outcomes included 43 additional aquatic vegetation species that were only recorded at wetlands that received Commonwealth environmental water. Watering supported the establishment of nine aquatic plant communities which included common spike rush, tall spike rush and water primrose. The percentage cover of species belonging to the amphibious functional groups increased following environmental watering across all monitoring zones and wetlands.	Wetlands that have been dry for extended periods can be slow to recover and have low abundance of water dependent species, but the abundance of wetland dependent vegetation species increases with repeated watering. This has been the case at Yarradda Lagoon, in the mid-Murrumbidgee zone, where a steady increase in species diversity and percentage cover has been recorded with repeated environmental watering. Future watering actions should occur in spring which is the ideal time to support aquatic plant communities.

Wetland monitoring indicator	Key wetland outcomes	Implications for future wetland water actions
Wetland fish	Seven native and four exotic fish species were captured in 2015-16. Murray cod juveniles were collected in the Nimmie-Caira zone for the first time, increasing overall number of native species from six in 2014-15 to seven in 2015-16. Evidence of recruitment and survival was identified for three native species, carp gudgeon, Australian smelt and bony herring.	Evidence of a gradual increase in species richness between 2014-15 and 2015-16 indicates that using environmental water to maintain refuges has a positive impact on native fish species richness in some wetland sites. Where possible refuge habitats should be prioritised for watering, particularly in years of low water availability, to maintain fish communities.
Frogs and turtles	Six frog species were recorded in 2015-16 including the vulnerable (EPBC Act) southern bell frog which was recorded at four wetlands and increased in abundance at Eulimbah, in the Nimmie-Caira zone, late in the season. Breeding activity for all six species was recorded in response to Commonwealth environmental water. The percent of wetland inundation was related positively with calling activity of plains froglet, barking marsh frog, inland banjo frog, Peron's tree frog and southern bell frog and abundance of spotted and barking marsh frog tadpoles.	Watering actions aimed at maintaining refuge habitats including pumping into wetlands if needed during periods of low water availability are critical for the long-term persistence of frog and turtle populations in semi-arid landscapes, particularly during dry years. Large-scale inundation of temporary habitats adjacent to refuge sites is also important in spring and summer to support southern bell frog breeding.
Waterbird diversity	Total waterbird diversity and abundance was higher in wetlands that received environmental water over September 2015-March 2016 compared to sites that were not inundated and sites that received water in 2014-15 only. Records of waterbirds in wetlands that received Commonwealth environmental water included; nationally threatened Australasian bittern (Nimmie-Caira) and NSW-listed freckled duck and magpie goose (mid-Murrumbidgee). Colonial waterbird breeding was recorded in five wetlands in the Murrumbidgee Selected Area, which included small-scale breeding in two wetlands of JAMBA listed Eastern great egrets.	Future delivery of Commonwealth environmental water should aim to deliver flows to provide seasonal habitat for migratory shorebirds (unvegetated muddy shorelines and open shallow lagoons and lakes) in spring (August-November) and maximise duration and slow rate of recession to create shorebird foraging habitat. As done successfully in 2014-15 and 2015-16, environmental water should be used to extend duration of inundation and maintain adequate water depths in any active colonial waterbird sites to support breeding events through to completion (minimum of three to four months from egg laying plus post-fledgling care for most species). To increase opportunities for colonial waterbird breeding, Commonwealth environmental water should be used to inundate known colony sites and key foraging grounds for >two months (August-September) before the commencement of the core breeding season.

1 Introduction

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

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

- Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan
- Evaluate the ecological outcomes of Commonwealth environmental watering at each of the seven selected areas
- Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin 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 and 2015-16, the first two years of the five year LTIM Project. More details of results and analyses for each monitoring indicator are presented in technical appendices that follow this evaluation report. This report draws on information presented in the **Murrumbidgee Monitoring and Evaluation Plan (MMEP)** (Wassens, Jenkins et al. 2014).

2 Murrumbidgee River system selected area and zones

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

- The Lower Murrumbidgee River (in-channel flows)(Murray-Darling Basin Authority 2012),
- The mid-Murrumbidgee River wetlands (Murray-Darling Basin Authority 2012), and
- The lower Murrumbidgee floodplain (Murray-Darling Basin Authority 2012).

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

Riverine zones

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

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

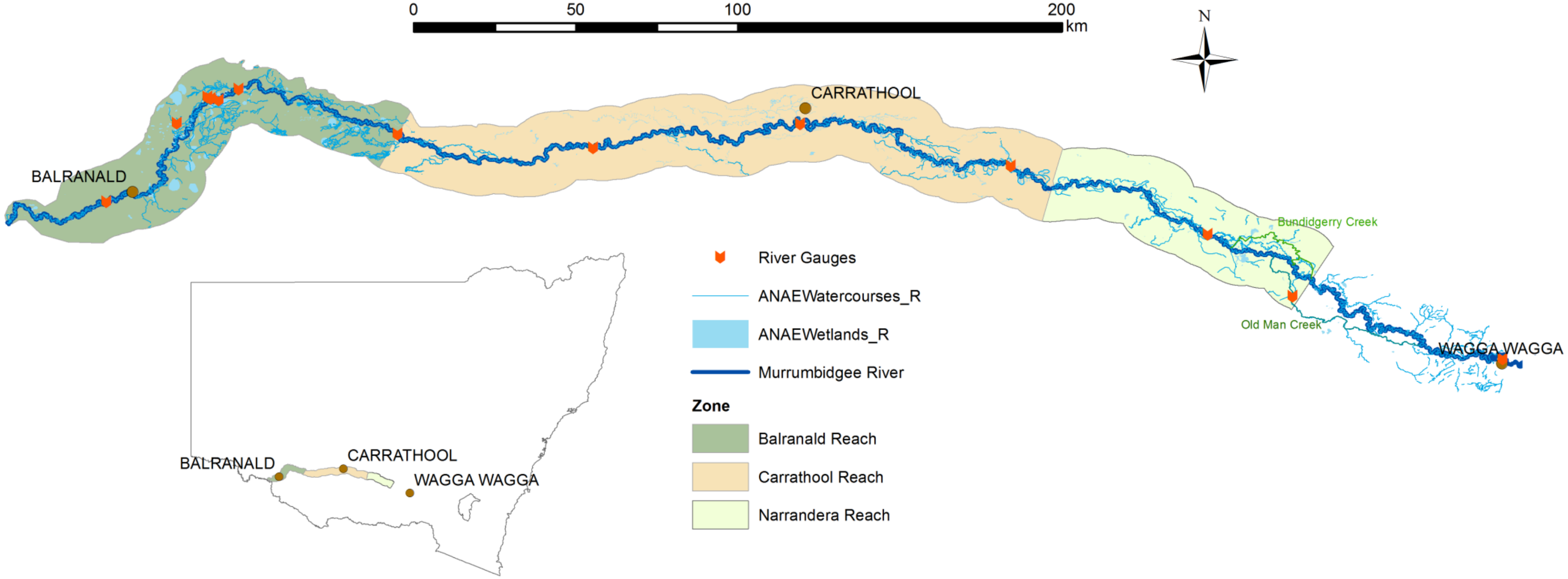


Figure 2-1 Distribution of riverine zones in the Murrumbidgee Selected Area.

Wetland zones

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

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

- **mid-Murrumbidgee wetlands (82,800 ha)** – River red gum forest interspersed with paleochannels and oxbow lagoons
- **Pimpara–Waugorah (55,451 ha)** – Mosaic of creek lines, paleochannels and wetlands, with River red gum and black box mostly north of the Murrumbidgee River
- **Redbank (92,504 ha)** – Mosaic of river red gum forest and woodland, spike rush wetlands - divided into two management subzones (north and south Redbank)
- **Nimmie-Caira (98,138 ha)** – Mosaic of creek lines, paleochannels, open wetlands and lakes dominated by lignum and lignum-black box communities
- **Fiddlers-Uara (75,285 ha)** – Paleochannels and creek lines bordered by black box
- **The Western Lakes (3459 ha)** – Open quaternary lakes with inactive lunettes west of the Lowbidgee floodplain

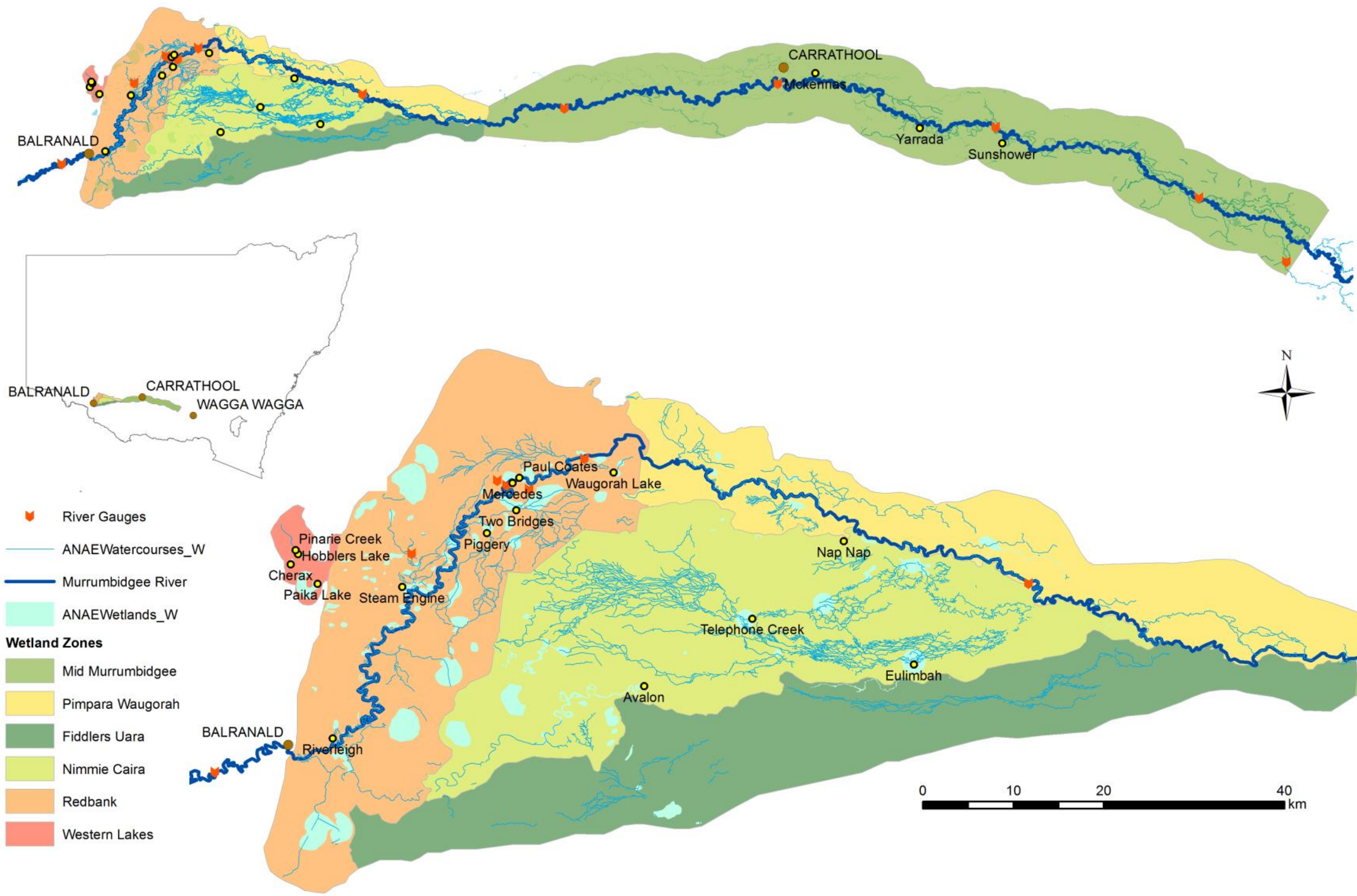


Figure 2-2 Distribution of wetland zones in the Murrumbidgee Selected Area and locations of key wetlands.

2.1 Environmental water delivered in 2015-16, context and expected outcomes

Climate and water context

Environmental watering actions are determined by a combination of catchment and climate conditions, the environmental demand as well as the volume of water holdings. These also provide the context in which the ecosystem responses to watering can be evaluated. The Murrumbidgee River catchment has undergone significant long-term modifications to the dominant hydrological regime, including alterations to the timing of high flow periods and significant reductions in the frequency of moderate and high flow events (Frazier, Page et al. 2005, Frazier and Page 2006). Significant drought between 2000 and 2010 exacerbated the effects of river regulation leading to significant declines in the condition of floodplain vegetation (Wen, Ling et al. 2009). Large scale flooding occurred in 2010 and 2011 which was followed by moderate water availability between 2012 and mid-2016. While river flows remain relatively stable, the extent of inundation across floodplain habitats remains relatively small compared to conditions prior to 2000.

In both water years covered by this report (2014-15 and 2015-16), there were no environmental water deliveries in the main channel of the Murrumbidgee River, however the delivery of water to floodplain wetlands did contribute to water flows in the main river channel. In both years there were a number of actions to inundate wetlands. These are described below for 2015-16 and are found in (Wassens, Thiem et al. 2015) for the 2014-15 water year.

2015-16 Watering Actions

The "integrated planning for the use, carryover and trade of Commonwealth environmental water: Murrumbidgee River Valley 2015–16" sets out watering options for the Murrumbidgee in 2015-16 (Commonwealth of Australia 2015). Eight high level water use options were identified targeting the mid-Murrumbidgee wetlands, Lowbidgee floodplain and the Murrumbidgee River and creek system, under a range of hydrologic conditions. Monitoring activities and recommendations are provided for four of these watering actions. The watering actions primarily targeted outcomes for waterbirds, frogs, fish and aquatic vegetation. Individual actions were identified based on climate conditions, water availability, environmental demands, constraints and risks.

As in 2014-15 the priority watering action was the mid-Murrumbidgee reconnection. This action was dependent on the occurrence of a suitably sized rainfall generated flow event as a trigger, but was constrained by dam operations and potential third party impacts associated with inundation of private lands. Mid-Murrumbidgee reconnection would have delivered a range of outcomes for both floodplain and in channel habitat through the Murrumbidgee systems. In the absence of reconnection flows, alternative uses of Commonwealth environmental water were implemented including pumping to Yarradda Lagoon in the mid-Murrumbidgee, watering of Lowbidgee wetlands and floodplain assets and the Yanco Creek system.

In 2015-16 the Commonwealth environmental water holder delivered 108,328 ML of environmental water as part of 16 watering actions targeting key floodplain and wetland habitats, anabranches and creek lines floodplain through the Murrumbidgee (Table 2-1). Commonwealth environmental watering actions were expected to achieve broad outcomes (Commonwealth of Australia 2015):

- inundation of wetland habitats in the mid-Murrumbidgee and Yanco Creek systems
- protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities
- provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities
- re-instating a more natural wetting-drying cycle for wetland vegetation
- provide reproduction and recruitment opportunities for riparian, floodplain and wetland native fauna
- support the habitat requirements of waterbirds
- support breeding events of colonial nesting waterbirds
- support the habitat requirements of native fish including access to a diversity of in-channel habitats, improving both structural and hydraulic habitat complexity
- support movement opportunities, breeding and recruitment of native fish
- support the habitat requirements of other vertebrates
- support breeding and recruitment of other native aquatic species, including frogs, turtles and invertebrates
- support ecosystem functions, such as dispersal of biota and transfer of nutrients, that relate to longitudinal and lateral connectivity (i.e. connectivity between the river channel, wetlands and floodplain) to maintain populations
- improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

In addition to these overarching objectives, each individual watering action is aligned with a specific set of watering objectives, and target species, for example maintaining habitat for southern bell frogs (*Litoria raniformis*) (listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)) or supporting existing waterbird rookeries. Specific objectives for each watering actions are contained in

Table 2-2 .

Table 2-1 Summary of environmental water usage from Commonwealth and state sources in 2015-16 drawn from Watering Action Acquittal Report Murrumbidgee 2015-16 (Commonwealth of Australia 2016).

Event	CEW Delivered Volume (ML)	NSW Delivered Volume (ML)	Net usage (ML)
Piggyback	0	0	0
Yarradda Lagoon	1394.3	0	1394.3
Yanco Creek trout cod support	8075	0	8075
Nimmie-Caira refuge (north Caira channel)	5000	7400	12 400
Nimmie-Caira sbf refuge (south Caira channel)	5000	42 600 [a]	
Yanco Creek reconnection	0	0	0
North Redbank	20 000	29 000	49 000
Juanbung	10 000	0	10 000
Yanga Waterbirds	10 000	1605	11 605
Waterbird contingency	5000 [b]	0	5000
Junction wetlands pumping (Waldaira)	2000	0	2000
Toogimbie IPA pumping	933	0	933
North Redbank additional	5000	0	5000
Talpee Creek	3000	0	3000
Western Lakes	5000	910	5910
Nap Nap - Waugorah	7000	5717	127170
Nap Nap – Waugorah [c]	2557	0	2557
Sandy Creek	105.7	164.3	270
Yanco Creek Wetland [c]	18 263	4566	22 829

a. (EWA) Uara Creek to Yanga Lake,
b. Eulimbah (waterbird contingency)
c. Murrumbidgee Supplementary Allocation

Table 2-2 Summary of Commonwealth environmental watering actions and expected watering outcomes. Shaded actions were monitored in 2015-16 and outcomes are evaluated in this report. Adapted from (Commonwealth of Australia 2016).

Target asset water reference	Expected outcomes
Yanga National Park waterbird support WUM10035-09	– CEW supplied to support identified waterbird (egret) breeding event – support ecosystem functions – provide habitat for native fish, frogs and other vertebrates – minimise incidental inundation of vegetation that had achieve water requirements and allow target site to support bird breeding event and draw down naturally allowing a drying period
Nimmie-Caira refuge: (north Caira channel) WUM10035-04 (south Caira channel) WUM10035-05	– maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbird (e.g. native fish community in Waugorah Lagoon and Talpee Creek) – support the habitat requirements of southern bell frogs (EPBC Act vulnerable) support potential waterbird breeding in Eulimbah (Australasian bitterns and spoonbills) – Improvement in aquatic habitat, water quality and riparian vegetation. – Support the habitat requirements of native fish and turtles. – Support waterbird habitat
Yarradda Lagoon **WUM10035-02**	– support known native fish and frog community established in 2014-15. – protect and maintain wetland and riparian native vegetation – provide feeding habitat for waterbirds – provide feeding habitat for frogs
Nap Nap - Waugorah **WUM10035-16 WUM10034-05**	– maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbird – support the habitat requirements of southern bell frogs (EPBC Act vulnerable) – support potential waterbird breeding in 2016-17 by improved habitat condition – improve and maintain vegetation condition
North Redbank WUM10035-07	– protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities (e.g. spike rush) – support the habitat and breeding requirements of waterbirds – support the habitat and breeding requirements of native fish and other vertebrates
Juanbung WUM10035-08	– water stressed river gum floodplain and riparian native vegetation – provide habitat for waterbirds – provide habitat for frogs
Hobblers Lake – Penarie Creek WUM10035-15	– stimulate invertebrate response supporting duck species and food web productivity. – Provide winter refuge habitat and drying habitat into spring-summer 2016-17 – Inundate fringing aquatic vegetation communities – Support habitat requirements for waterbird, frog and native fish
Yanco Creek wetland inundation WUM10034-03	– Connect and inundate fringing wetlands to protect and maintain wetland and riparian native vegetation. – provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation – support the habitat requirements of waterbirds – support the habitat requirements of native fish including diversity of in-channel habitats (structural and hydraulic complexity) – support the habitat requirements of other vertebrates – support ecosystem functions, such as dispersal of biota and transfer of nutrients, that relate to longitudinal and lateral connectivity.
Yanco Creek trout cod WUM10035-03	– support the habitat and breeding requirements of native fish particularly trout cod – support movement opportunities, breeding and recruitment of native fish
Waldaira wetlands WUM10035-10	– water drought stressed floodplain and riparian vegetation – provide habitat for waterbirds and frogs
Toogimbie IPA WUM10035-12	– protect and maintain wetland and riparian native vegetation – support the habitat requirements of southern bell frogs (EPBC Act vulnerable) – maintain refuge habitat for a diverse range of frogs and waterbird.

3 Riverine responses to Commonwealth environmental water

3.1 Summary of monitoring activities 2015-16

Riverine monitoring is undertaken at three sites spread across each of the two ecological zones – Narrandera and Carrathool (Figure 4-1). Surveys are conducted fortnightly from October to December each year for water quality, nutrients and carbon, microinvertebrates and larval fish. Stream metabolism is monitored at one site in both the Carrathool (October – April) and Narrandera (October – January) zones concurrent with the larval fish monitoring.

Table 3-1 LTIM monitoring sites in each zone and associated monitoring activities. Selected area (see Figure 2-1)

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

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

3.2 Riverine hydrology

During 2014-15 and 2015-16 there were no Commonwealth environmental watering actions specifically targeting in-channel responses, although environmental flows did pass down the river channel while being delivered elsewhere (Commonwealth of Australia 2016). Long-term watering plans for the Murrumbidgee River (Commonwealth of Australia 2015) forecast in-channel deliveries of Commonwealth environmental water to support primary productivity, nutrient and carbon cycling, biotic dispersal and movement and to provide refuge habitat from adverse water quality events.

River levels over the past two years (between March 2014 and March 2016) have remained low compared to longer-term averages, remaining below the commence-to-fill for the majority of floodplain wetlands. Delivery of Commonwealth environmental water to floodplain assets in the mid and lower Murrumbidgee may have added to minor increases in water levels above baseflow (Figure 3-1).

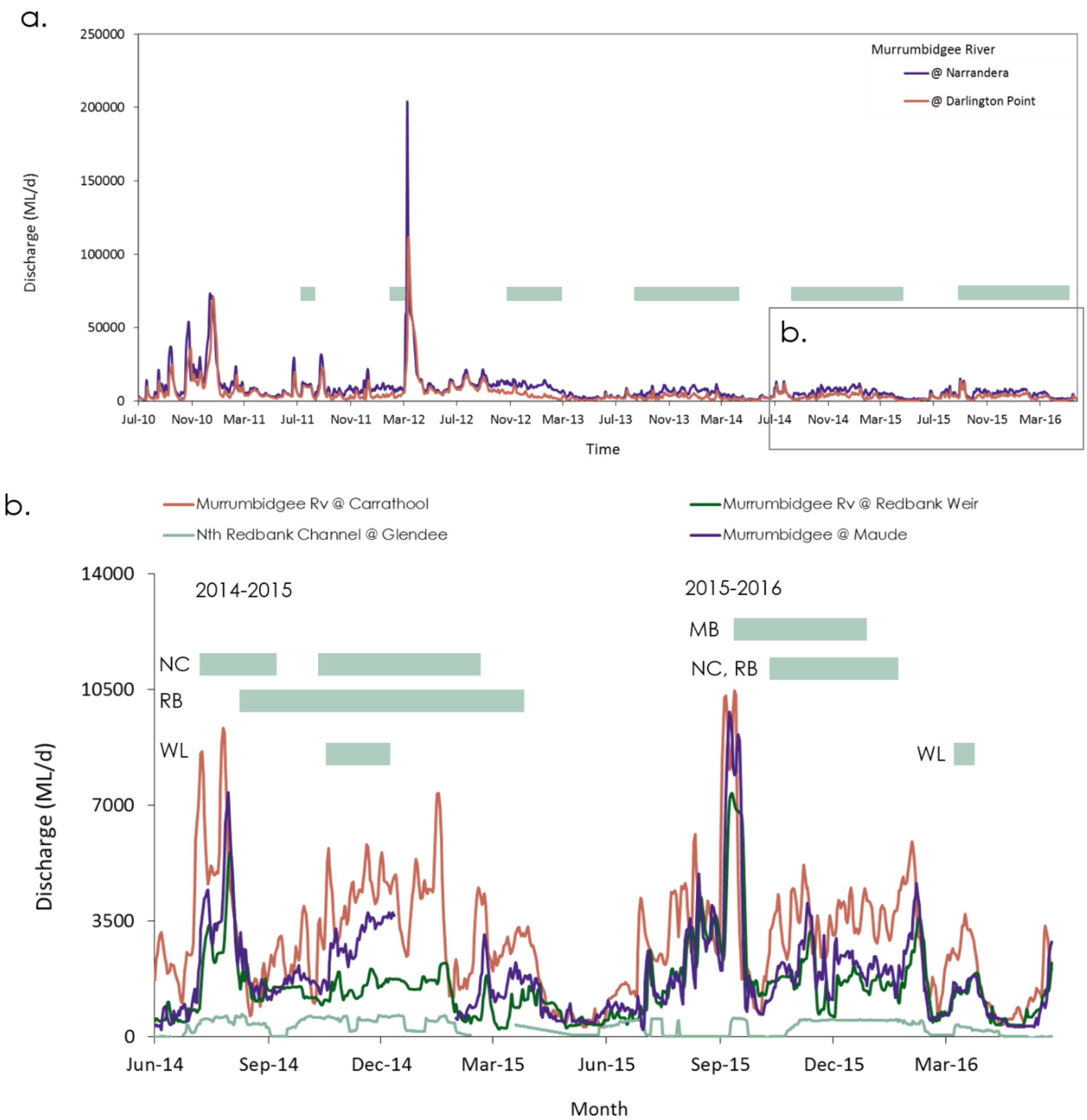


Figure 3-1 a. Mean daily discharge in the Murrumbidgee River at Narrandera and Darlington Point between 1 July 2010 to 30 June 2016. The 2012 flow peaked at 200,000 ML. Horizontal green bars show timing of Commonwealth and NSW environmental water actions in 2011-12, 2012-13, 2013-14, 2014-15 and 2015-16. b. Mean daily discharge in the Murrumbidgee River at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glen Dee in relation to the timing of environmental water delivery (horizontal green bars) to wetland zones Mid-Murrumbidgee (MB), Nimmie-Caira (NC), Redbank (RB) and Western lakes (WL) during survey period (1 July 2014 to 30 June 2016).

3.3 River water quality

During 2014-15 and 2015-16 there were no Commonwealth environmental watering actions specifically targeting in-channel responses, although the river channel was used to deliver environmental flows to wetlands downstream (Commonwealth of Australia 2016). Long-term watering plans for the Murrumbidgee River (Commonwealth of Australia 2015) forecast in-channel deliveries of Commonwealth environmental water to support primary productivity, nutrient and carbon cycling, biotic dispersal and movement and to provide refuge habitat from adverse water quality events. In this section we describe the ranges of water quality observed in the Murrumbidgee River during 2014-15 and 2015-16 and compare these findings against prior observations and published water quality guidelines (ANZECC 2000).

Summary of watering actions and outcomes

MMEP and 2015-16 Acquittal Report Expected outcomes	Evaluation questions and predicted outcomes	Watering Action (s) in 2015-16	Measured outcomes	Was the expected outcome achieved
Support primary productivity, nutrient and carbon cycling, biotic dispersal and movement; Provide refuge habitat from adverse water quality events.	Physicochemical variables remain within range tolerated by aquatic species	No in-channel watering actions, Commonwealth water influenced hydrology due to transit of water for floodplain assets resulting in the presence of channel freshes throughout the monitoring period	Physicochemical parameters consistent with prior records and within water quality criteria	Yes
	Nutrient, carbon and chlorophyll-a concentrations within range tolerated by aquatic species		Nutrient, carbon and chlorophyll-a concentrations consistent with prior records and/or within water quality criteria	Yes
	Nutrient concentrations sufficient to support ecosystem functions		Not known if primary production in the Murrumbidgee River is resource-supply limited.	N/A

Main findings from the Murrumbidgee River water quality monitoring program

- Physicochemical parameters were generally within the expected range of water quality for the Murrumbidgee River and do not indicate any adverse conditions under the observed range of flows
- Nutrient concentrations remain low in the Murrumbidgee River

Discussion, recommendations and adaptive management

Commonwealth environmental water was not specifically delivered to support water quality outcomes during 2015-16. Long-term plans for the Murrumbidgee River (Commonwealth of Australia 2015) forecast the need to deliver environmental flows to support habitat and food sources and promote increased movement, recruitment and survival of native fish and other aquatic biota in future water years. Water quality in 2015-16 fell within a small range that was generally consistent with previous findings and below ANZECC (2000) water quality guidelines across all variables, except for chlorophyll-a and pH. Under the observed flows, we found no evidence of ongoing water quality issues at any of the monitored sites requiring additional management or intervention.

Overall, nutrient concentrations remain low in the Murrumbidgee River compared with other inland lowland river systems in Australia (Vink, Bormans et al. 2005) and it is hypothesised that this trend is due to the lack of lateral connectivity. Namely, lateral connections do not appear to have been sufficient to influence river water quality conditions. A broadscale wetland reconnection event is likely to cause significant positive changes in water quality.

Broadscale wetland reconnections are necessary to augment resources for river food webs. Adverse water quality from high carbon concentrations is likely to follow broadscale wetland inundation from unregulated river flows. In-stream carbon concentrations can be managed by dilution and reducing rates of wetland drainage. Both of these objectives can be achieved by in-channel environmental flows that slow rates of flood recession.

3.4 Stream metabolism

Stream metabolism is a measure of the amount of energy produced and consumed by river food webs. It estimates rates of gross primary production (GPP) by algae and aquatic plants as well as rates of heterotrophic respiration (i.e. carbon consumption, ER) by microorganisms. During 2014-15 and 2015-16 there were no Commonwealth environmental watering actions specifically targeting in-channel metabolism responses, although environmental flows did pass down the river channel while being delivered elsewhere. Long-term watering plans for the Murrumbidgee River (Commonwealth of Australia 2015) forecast in-channel deliveries of Commonwealth environmental water to support habitat and food sources and promote increased movement, recruitment and survival of native fish and other aquatic biota. In the absence of targeted environmental water deliveries we investigated the relationship between stream metabolism and river flows during 2014-15 and 2015-16 and discuss these findings with regard to future deliveries of Commonwealth environmental water.

Summary of watering actions and outcomes

MEP and 2015-16 Acquittal Report Expected outcomes	Evaluation questions	Watering Action (s) in 2015/16	Measured outcomes	Was the expected outcome achieved
Provide flows, including restoring natural flow events that are affected by river regulation and/or extraction, to support habitat and food sources and promote increased movement, recruitment and survival of native fish.	What did CEW contribute to patterns and rates of decomposition? What did CEW contribute to patterns and rates of primary productivity?	No in-channel watering actions, Commonwealth water influenced hydrology due to transit of water for floodplain assets resulting in the presence of channel freshes throughout the monitoring period.	Rates of metabolism low compared with other river systems. Negative relationship between flow and metabolism at Narrandera.	Unknown

Main findings from the Stream Metabolism monitoring program

- Rates of metabolism in the Murrumbidgee River are consistently low
- Preliminary findings show weak relationships between metabolism (GPP and ER) with both flow and temperature

Discussion, recommendations and adaptive management

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

Overall rates of metabolism in the Murrumbidgee remain slightly lower than other published data for the Murray-Darling Basin and previous studies from the Murrumbidgee (Vink, Bormans et al. 2005). As noted by Wassens et al. (2015), the discrepancy with the findings by Vink, Bormans et al. (2005) may be explained by differences in methodology (Song, Dodds et al. 2016). This issue will be addressed in the 2016-17 Murrumbidgee LTIM Selected Area evaluation report. If rates of metabolism in the Murrumbidgee River are limited by the availability of nutrients and energy, environmental flows that re-engage lateral and longitudinal connections will help to boost river functions.

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

We found little evidence of a strong predictive relationship between flow and metabolism. The overarching mechanisms by which flow is expected to influence metabolism are 1) wetland and riparian reconnection events that increase the supply of bioavailable nutrients and carbon that support increased rates of production and 2) high flows that scour river biofilms, resuspending nutrients previously tied up in biomass and detritus held in biofilms and by resetting biofilm community succession (Battin, Kaplan et al. 2008). The high-flow events (i.e. overbank flows > 20,000 ML/day at Wagga Wagga) that would achieve this in the Murrumbidgee River are generally absent from the current dataset and this may explain the lack of predictive relationships. If rates of metabolism in the Murrumbidgee River are limited by the availability of nutrients and energy, environmental flows that re-engage lateral and longitudinal connections will help to boost river functions.

3.5 Microinvertebrates

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). During 2014-15 and 2015-16 Commonwealth environmental water was not directly targeting in-channel watering outcomes to support this critical food source for larval fish. However the transfer of Commonwealth environmental water to wetland and floodplain habitats in both years contributed to water level rises in the Murrumbidgee River during our six fortnightly trips to monitor benthic and pelagic microinvertebrates from mid-spring to early summer, coinciding with the sampling of larval fish. We predicted an increase in productivity on sampling trips that follow inundation of previously dry sediment along the channel, in benches and backwaters, coinciding with warm temperatures. Optimally to support larval fish growth and survival, a peak in microinvertebrates would coincide with peaks in larval fish abundance.

Summary of watering actions and outcomes

MEP and 2015-16 Acquittal Report Expected outcomes	Evaluation questions and predicted outcomes	Watering Action (s) in 2015/16	Measured outcomes	Was the expected outcome achieved
Provide flows, including restoring natural flow events that are affected by river regulation and/or extraction, to support habitat, food sources and breeding requirements of waterbirds, native fish and other vertebrates.	What did Commonwealth environmental water contribute to breeding and recruitment of riverine native fish by supporting prey?	No in-channel watering actions, Commonwealth water influenced hydrology due to transit of water for floodplain assets resulting in the presence of channel freshes throughout the monitoring period	Microinvertebrate densities exceed levels needed to support larval fish during early November in Carathool Zone. Microinvertebrate peak in density matches peak in abundance of larval cod species and Australian smelt from light traps. Macrothricidae favoured prey of Murray cod present in high numbers. Microinvertebrate densities in Narrandera zone low, possibly due to high and more stable water level	Yes

Main findings from riverine microinvertebrate monitoring program

- Microinvertebrate densities peaked in early November 2015 in Carathool zone as river levels were falling following a peak due to delivery of environmental water to wetlands in the lower to mid-Murrumbidgee.
- In early November 2015 in Carathool zone, densities of key prey including copepods, macrothricid, chydorid and daphnid cladocerans and ostracods were between the 100-1000 individuals per litre threshold required to support larval fish growth.
- In 2015 the observed peak in microinvertebrates in early November in the Carrathool zone matched a peak in larval cod species and Australian smelt.
- In contrast, in 2014-15 microinvertebrate densities peaked later in December 2014 in Carathool zone also coinciding with a fall in peak river levels, but after the peak in larval fish abundances.
- In the Narrandera zone in both years, microinvertebrate densities were mostly well below 100-1000 individuals per litre. Water levels in the Narrandera zone are higher and more stable than the Carrathool zone.

Discussion, recommendations and adaptive management

A pattern is emerging with microinvertebrate productivity peaking on the recession of peak flows during spring and early summer. There appears to be a threshold river level below which higher densities are observed. A similar pattern was also observed during monitoring of sites in the Carrathool zone and at a site closer to Wagga in 2012-13 (Wassens, Jenkins et al. 2014). These observations based on data from two zones (plus the site near Wagga) over three years will be confirmed with subsequent years of monitoring and statistical analysis. The relationship between larval fish abundance, microinvertebrate densities and recruitment will be examined through multiple years of data collection as part of the Murrumbidgee 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 well before the peak in microinvertebrate densities in early to mid-December.

River levels in the Narrandera zone were at least 1 metre higher than in the Carrathool zone and there was less variability in river level. It appears that the higher river level in the Narrandera zone may impact development of a productive and diverse microinvertebrate community. In contrast in the Carrathool zone with lower more variable river levels, pronounced peaks in microinvertebrate densities were recorded in both 2014-15 and 2015-16. This is likely due to drying and then rewetting of edge sediments stimulating nutrient release that then supports peak densities of microinvertebrates. Before, during and after monitoring as river levels rise, peak and fall would help unravel if these aspects of hydrology are driving the patterns observed in microinvertebrate community dynamics. If this is the case, then environmental water deliveries could aim to produce a peak in river flows at the appropriate time for microinvertebrates to pulse when larval fish are also abundant. The differences in productivity between the Narrandera (high flow) and Carrathool zones (lower more variable flows) could be teased out by replicated monitoring in other locations. Flow manipulations in high flow areas to reduce flow and increase variability with before, during and after monitoring could also shed light on this important process.

3.6 Riverine and larval fish

Introduction

Flow plays a critical role in the early life-cycle of native fish, with the duration, magnitude and timing of flows strongly influencing adult spawning and the subsequent survival and growth of larvae. During 2015-16, Commonwealth environmental water was not directly targeted at in-channel watering outcomes, however the transfer of Commonwealth environmental water to wetland and floodplain habitats contributed to water level rises that coincided with in-channel monitoring activities. We evaluated native fish in-channel spawning during periods of Commonwealth environmental water delivery. Specifically, we predicted that spawning of flow-cued species such as golden perch and silver perch would result from in-channel water level rises (freshes) and bankfull events, and that base flows and above would provide suitable conditions for spawning to occur in opportunistic (flow-cued) (e.g. carp gudgeon) and equilibrium (e.g. Murray cod) species (i.e. non flow-cued species). Larval fish and eggs were sampled fortnightly at three sites in each of two hydrological zones in the Murrumbidgee River from October to December 2015. During the 2015-16 watering year the hydrology of the Murrumbidgee River was characterised by high but generally variable water levels. Predictive relationships were developed for flow-cued spawning responses to abiotic drivers (hydrology and water temperature), with a view towards providing watering targets to maximise reproductive opportunities in future years.

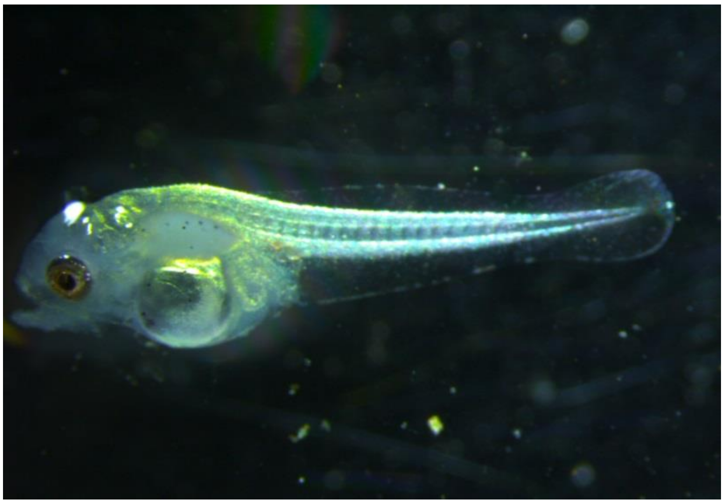


Plate 3-1 Golden perch (*Macquaria ambigua*) larva captured as an egg in the Murrumbidgee River in 2015-16 and subsequently hatched in the laboratory.

Summary of watering actions and outcomes

Expected outcomes	Evaluation questions and predicted outcomes	Watering Action (s) in 2015/16	Measured outcomes	Was the expected outcome achieved
Provide flows, including restoring natural flow events that are affected by river regulation and/or extraction, to support habitat and food sources and promote increased movement, recruitment and survival of native fish.	*What did Commonwealth environmental water contribute to native fish reproduction?* In-channel freshes and bankfull events delivered in late spring and summer stimulate spawning in periodic species (golden perch and silver perch). Base flows and above provide reproductive opportunities for equilibrium and opportunistic species.	No in-channel watering actions, although Commonwealth water influenced hydrology due to transit of water for floodplain assets resulting in the presence of in-channel freshes throughout the monitoring period.	The probability of silver perch spawning increased with increasing river levels. Golden perch spawning occurred independent of river levels. Environmental conditions were appropriate for spawning to occur in nine native fish species, including a number of equilibrium and opportunistic species.	Yes

Main findings from fish reproduction monitoring program

- At least nine native fish species (Australian smelt (*Retropinna semoni)*, bony herring (*Nematalosa erebi)*, carp gudgeon (*Hypseleotris* spp.), flat-headed gudgeon (*Philypnodon grandiceps)*, golden perch (*Macquaria ambigua)*, Murray cod (*Maccullochella peelii)*, Murray-Darling rainbowfish (*Melanotaenia fluviatilis)*, silver perch (*Bidyanus bidyanus)* and trout cod (*Maccullochella macquariensis)*) and one alien species (common carp (*Cyprinus carpio)*) spawned in the Murrumbidgee River in 2015-16.
- Larval fish catches were dominated by cod (*Maccullochella* spp.; October-November peak) and Australian smelt (October - November peak).

- Based on egg captures, multiple spawning events occurred for both golden perch and silver perch, with peak spawning occurring earlier than in 2014-15. A single golden perch larva was also captured.
- Predictive relationships are under development for flow-cued spawners and will be strengthened in future years of monitoring. These indicate little association between golden perch spawning and hydrology metrics, although a positive association between silver perch spawning and water level was found.

Discussion, recommendations and adaptive management

Delivery of Commonwealth environmental water to wetlands contributed to the overall volume, timing and magnitude of flows within the Murrumbidgee Selected Area. These flows coincided with spawning in at least nine native species of fish across the two monitored hydrological zones. Predictive relationships were developed for flow-cued spawning species - golden perch and silver perch. In the case of golden perch, we hypothesise that the in-channel hydraulic conditions in the monitored zones within the Murrumbidgee River are suitable to trigger a spawning response and these types of conditions are available throughout much of the watering season.

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

Similarly to 2014-15, the outcomes of 2015-16 indicate that spawning of small and large bodied native fish species can occur during years of normal river operations, in zones where discharge levels are already relatively high due to irrigation and water in transit (environmental water, Inter Valley Transfers or consumptive purposes) to other parts of the system. It is important to note that this monitoring project is restricted to the Narrandera and Carrathool zones of the Murrumbidgee River and does not include assessment of spawning further downstream, in areas which may be affected by reduced discharge levels.

The key recommendation that can be drawn from 2015-16 when planning in-channel flows to target native fish responses is the importance of assessing the dominant hydrological regime and identifying the critical components of the hydrograph that have changed due to river regulation.

In other river systems, and in absence of irrigation flows that appear to provide suitable in-channel flow conditions in the Murrumbidgee, targeted environmental flows have been linked to spawning in flow-cued species such as golden and silver perch. Understanding the critical in-channel hydraulic thresholds for spawning in golden perch and silver perch within the Murrumbidgee Selected Area, and then examining whether these thresholds are met in other parts of the Murrumbidgee River (particularly downstream) would be useful for extrapolating the results of the current monitoring program to other locations.

4 Wetland evaluation

Plate 4-1 Yarradda Lagoon January 2016

4.7 Summary of monitoring activities

Wetland monitoring is undertaken at 12 wetlands spread across three ecological zones – the mid-Murrumbidgee, Nimmie-Caira and Redbank (Table 4-1, Figure 4-1). Surveys are conducted four times per year in September, November, January and March and target water quality, nutrients and carbon, microinvertebrates, wetland vegetation, wetland fish, tadpoles, frogs, turtles, and waterbirds.

Table 4-1 Summary of monitoring activities and locations across three wetland zones in the Murrumbidgee floodplain (see Figure 4-1). D indicates that the site was dry throughout entire year and no samples for that indicator could be collected.

Site Name		Zone	ANAE classification	Nutrients , carbon, chl a	Microinvertebrate	Vegetation Diversity	Wetland Fish community	Frogs and turtles	Waterbird Diversity
Gooragool Lagoon	GOO	mid-Murrumbidgee	Permanent floodplain wetland	X	X	X	X	X	X
McKennas Lagoon	MCK		Intermittent river red gum floodplain swamp	D	D	X	D	D	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	D	D	X	D	D	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	X	X	X	X	X	X
Two Bridges Swamp	TBR		Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Waugorah Lagoon	WAU		Permanent floodplain wetland	X	X	X	X	X	X

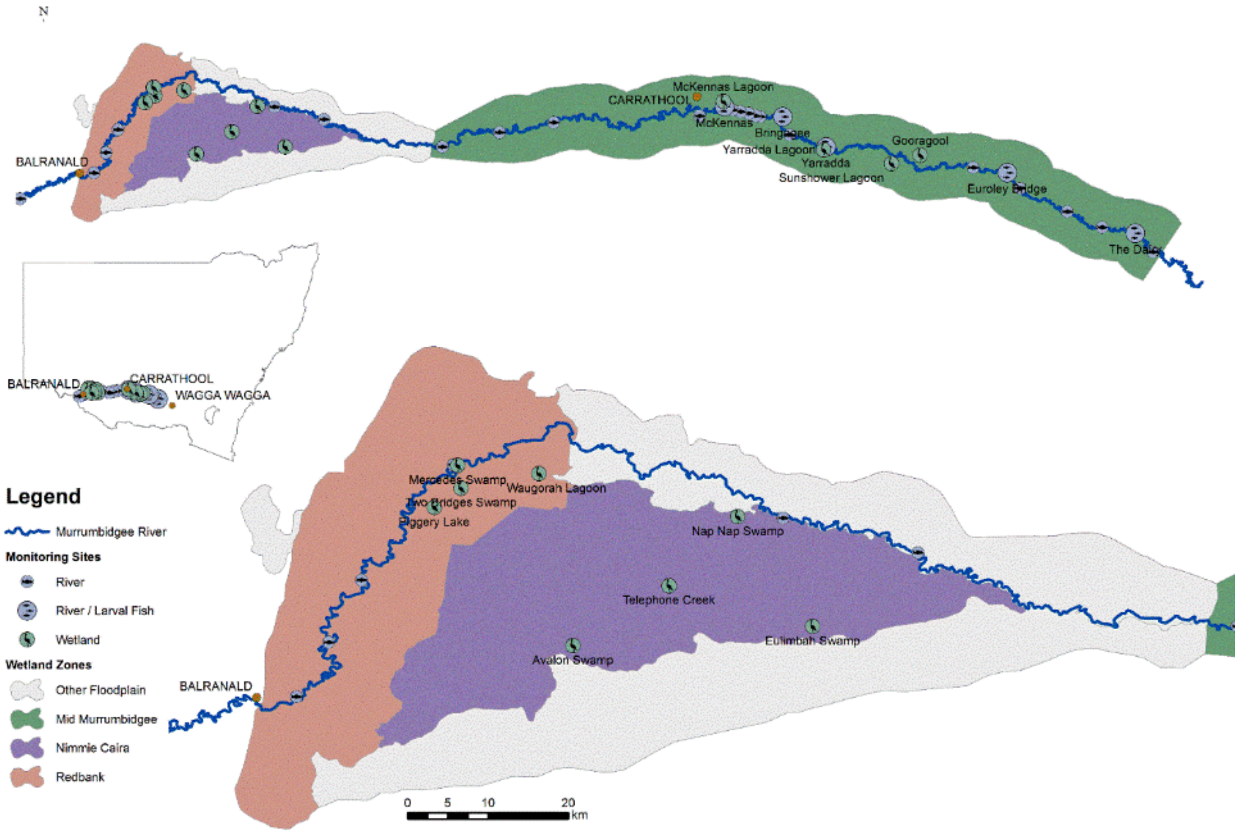


Figure 4-1 Distribution of wetland zones and key monitoring locations in the Murrumbidgee Selected Area

4.8 Wetland hydrology

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee in order to "inundate wetland and refuge habitat" in the Murrumbidgee Catchment. Overall the total area of the Lowbidgee floodplain inundated from Commonwealth environmental water actions was about 16,000 ha (75% of the area of floodplain inundated in 2015-16). Total area of the Lowbidgee floodplain inundated in 2015-2016 (21,137 ha) was about half the area of floodplain inundated in 2014-2015 (41,999 ha) (Figure 4-2). This difference is due to comparatively large inundated areas in the Redbank, Nimmie-Caira and Fiddlers zones in 2014-2015. In 2015-2016, almost half of the inundated area in the Redbank zone can be attributed to Commonwealth environmental water actions (Redbank action). Most (~85%) of the 2015-2016 inundated area in the Nimmie-Caira zone can be attributed to the combined Commonwealth and NSW environmental water actions as there were some locations of the floodplain already inundated prior to water actions within the water year.

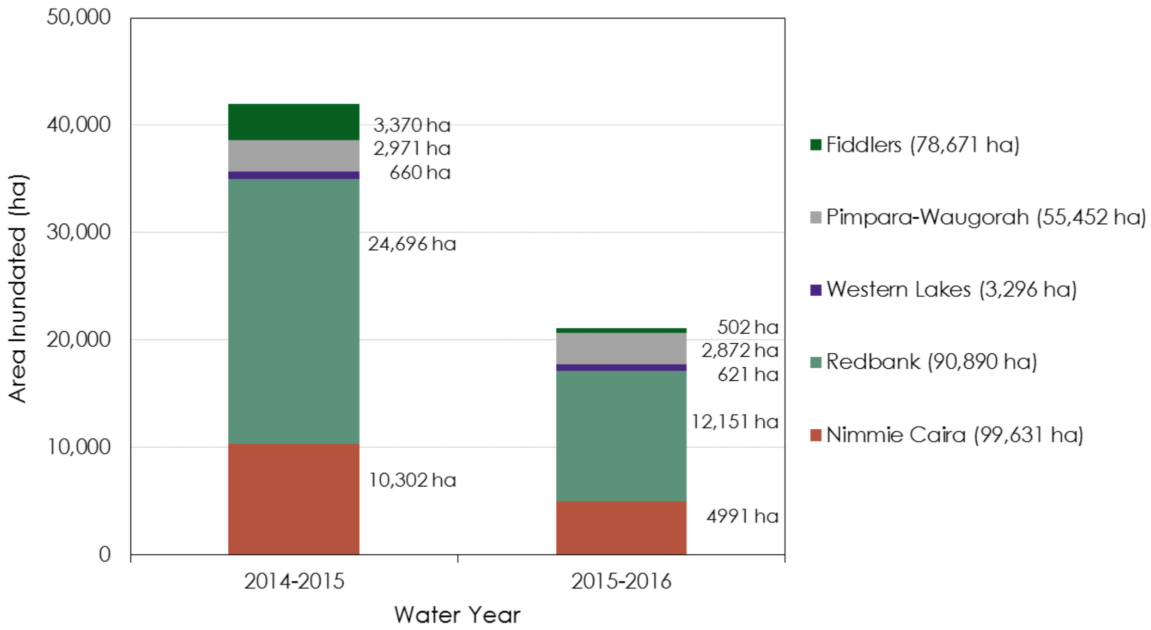


Figure 4-2 Cumulative total area (ha) of the floodplain inundated for the Lowbidgee floodplain and wetland zones for the 2014-2015 and 2015-2016 water years.

Nimmie-Caira zone

Commonwealth environmental water contributed just over a quarter (18,000 ML) of the total environmental water volume (68,000 ML) for this water action. Inundation outcomes were evident in the targeted wetland assets of the Nimmie-Caira zone (Eulimbah Swamp and Telephone Creek), and Waugorah Lagoon in Yanga National Park (

Figure 4-3). Prior to the Nimmie-Caira water action Eulimbah Swamp and Waugorah Lagoon were mostly dry while Telephone Creek was about 60% inundated. Waugorah Lagoon was inundated to 60% of its wetland extent in December 2015 and then contracted to less than 20% by January 2016. Eulimbah Swamp was fully inundated by late November-early December 2015 also inundating the adjacent floodway downstream at this time. Eulimbah Swamp remained mostly full until late March 2016 and so inundation duration was about four months. Telephone Creek remained mostly (>85%) full from November 2015 to late April 2016 and so inundation duration of this area was for about five and a half months.

Yanga National Park (Redbank zone)

Commonwealth environmental water was delivered using the most direct flow path to Tarwillie Swamp and so from the pre-watering extents (~2000 ha) there was only a small 300 ha expansion of inundated area to about 2,300 ha on 1 December 2015 (Figure 4-4). This expansion was confined to the flow path region in North Yanga around the east of Two Bridges and in Two Bridges Swamp, which then started receding by mid-January and was dry by March 2016 (Figure 4-3 and Figure 4-4). Adjacent wetlands (e.g. Piggery Lake) were not inundated by this watering action and were able to dry out over summer (Figure 4-3 and Figure 4-4) having been inundated for over 12 months (since late November 2014). Inundation extent in Tarwillie Swamp remained about the same as the pre-watering extents (~150 ha) through November to January and then started to recede in February 2016 until it was dry by April 2016 (Figure 4-4). By mid-January 2016 about 80% of the 150 ha of Tarwillie Swamp had been inundated for just over 12 months (since late November 2014). Overall the total area of floodplain wetland inundated by the Yanga National Park action was 2,555 ha.

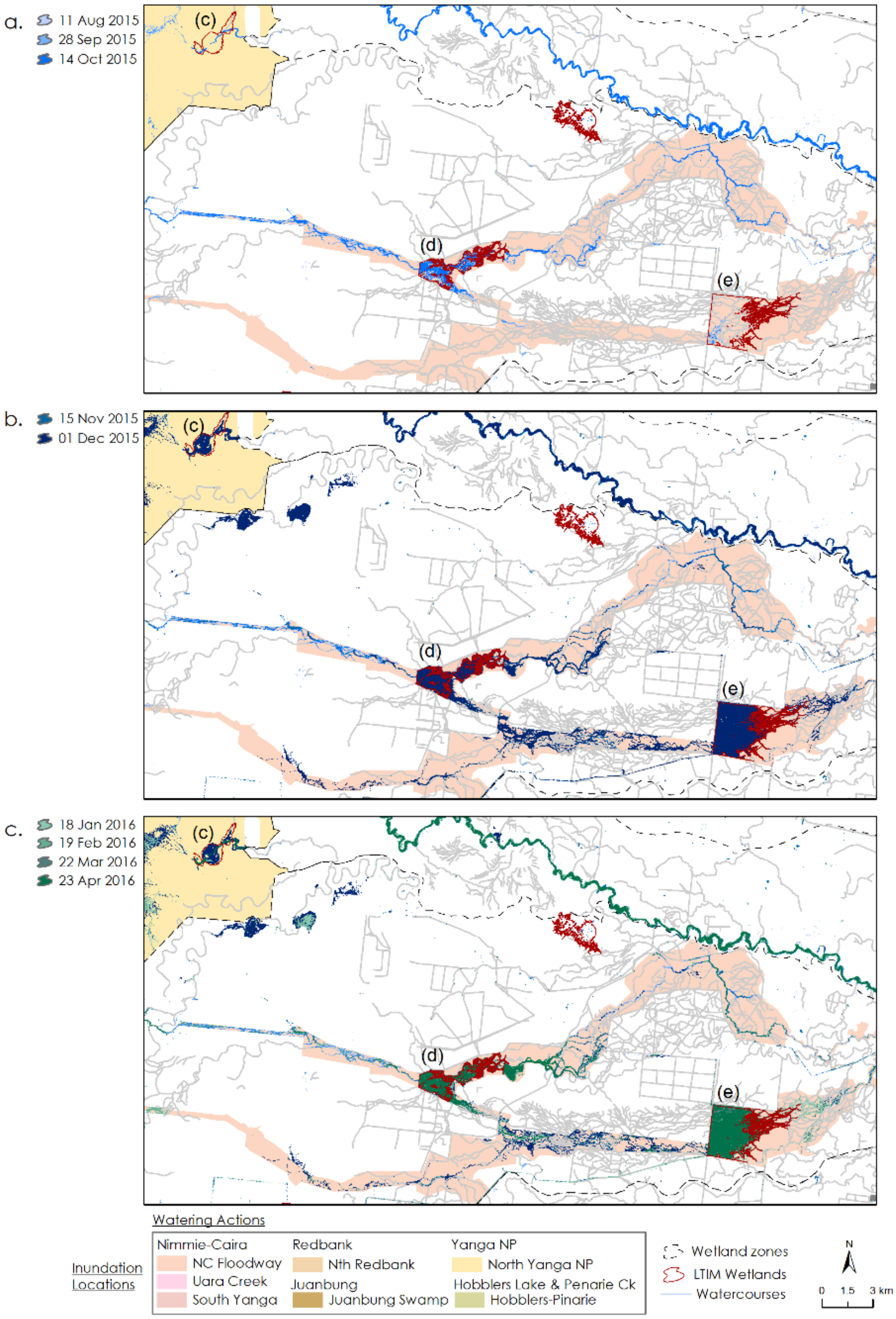


Figure 4-3 Inundation outcomes located around the Nimmie-Caira zone from the Nimmie-Caira watering actions (17/10/15-09/02/16) showing a. pre-watering inundation conditions, and cumulative outcomes during b. Nov-Dec 2015 and then c. Jan-Apr 2016 in the LTIM surveyed wetlands (c) Waugorah Lagoon, (d) Telephone Creek and (e) Eulimbah Swamp. NB Waugorah Lagoon inundation is located in North Yanga NP but is inundated during this time by the Nimmie-Caira watering action.

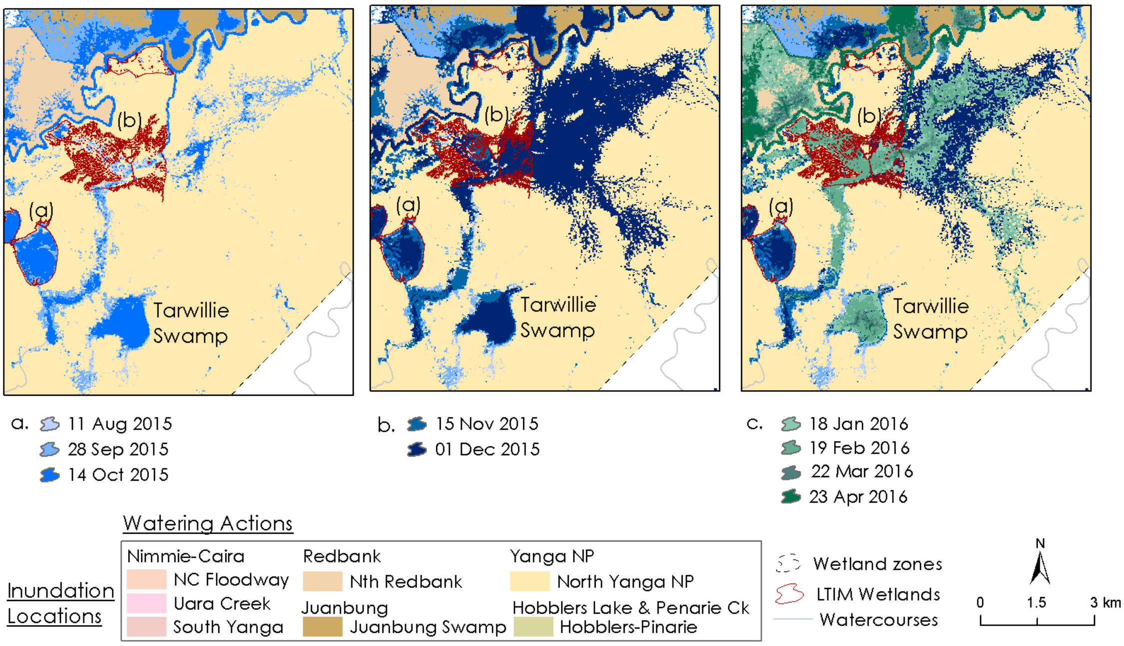


Figure 4-4 Inset of inundation outcomes located in the North Yanga National Park from the Yanga NP waterbird support watering action showing a. pre-watering inundation conditions, and cumulative outcomes during b. Nov-Dec 2015 and then c. Jan-Apr 2016 in the LTIM surveyed wetlands (a) Piggery Lake and (b) Two Bridges, and in Tarwillie Swamp

Yarradda Lagoon (mid-Murrumbidgee zone)

Commonwealth environmental water filled Yarradda Lagoon to about 50% (87 ha) of its delineated boundary (177 ha) (Figure 4-5). The peak of inundation was in December 2015 and then this contracted to just over 20% during the early months of 2016. Based on an overlay assessment with high resolution Satellite Pour l'Observation de la Terre (SPOT) 5 imagery the inundation extents aligned with the mature tree line.

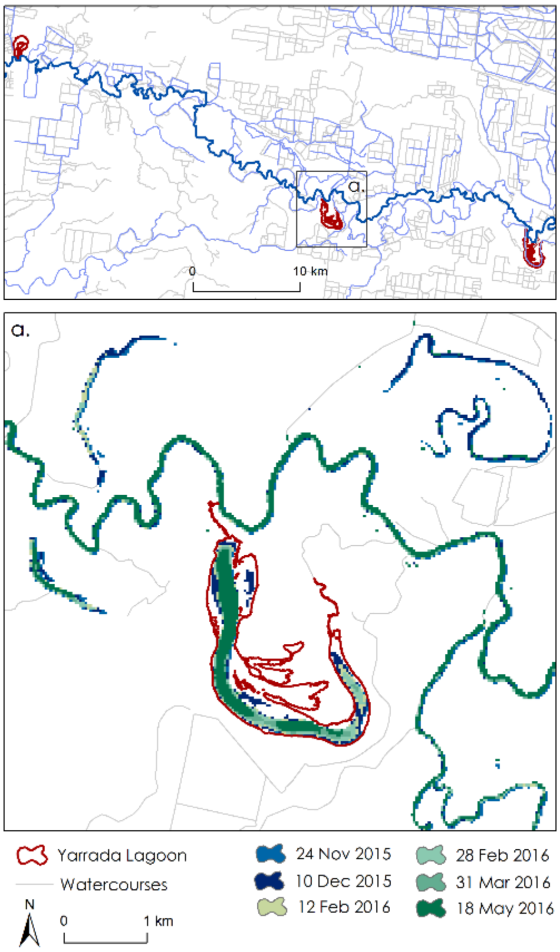


Figure 4-5 Inundation outcomes for Mid-Murrumbidgee Yarradda Lagoon watering action (02/09/15-20/12/15) showing maximum inundation conditions in December 2015 (dark blue) and recession over the following months to May 2016.

Water depth

Water depth gauges placed in monitored wetlands continuously recorded water depths across the entire reporting period. The data derived from the gauges enables accurate analysis of site conditions at a fine temporal scale: analysis of inundation effects on ecological data collected at the sites proceeds based on these point data (Figure 4-6). In 2015-16 seven of the monitored wetlands received water (Figure 4-6), Piggery Lake still contained water from watering actions undertaken in 2014-15, while Sunshower Lagoon and Mercedes Swamp received very small inflows from natural overbank flows. McKenna's Lagoon has now been dry since 2012.

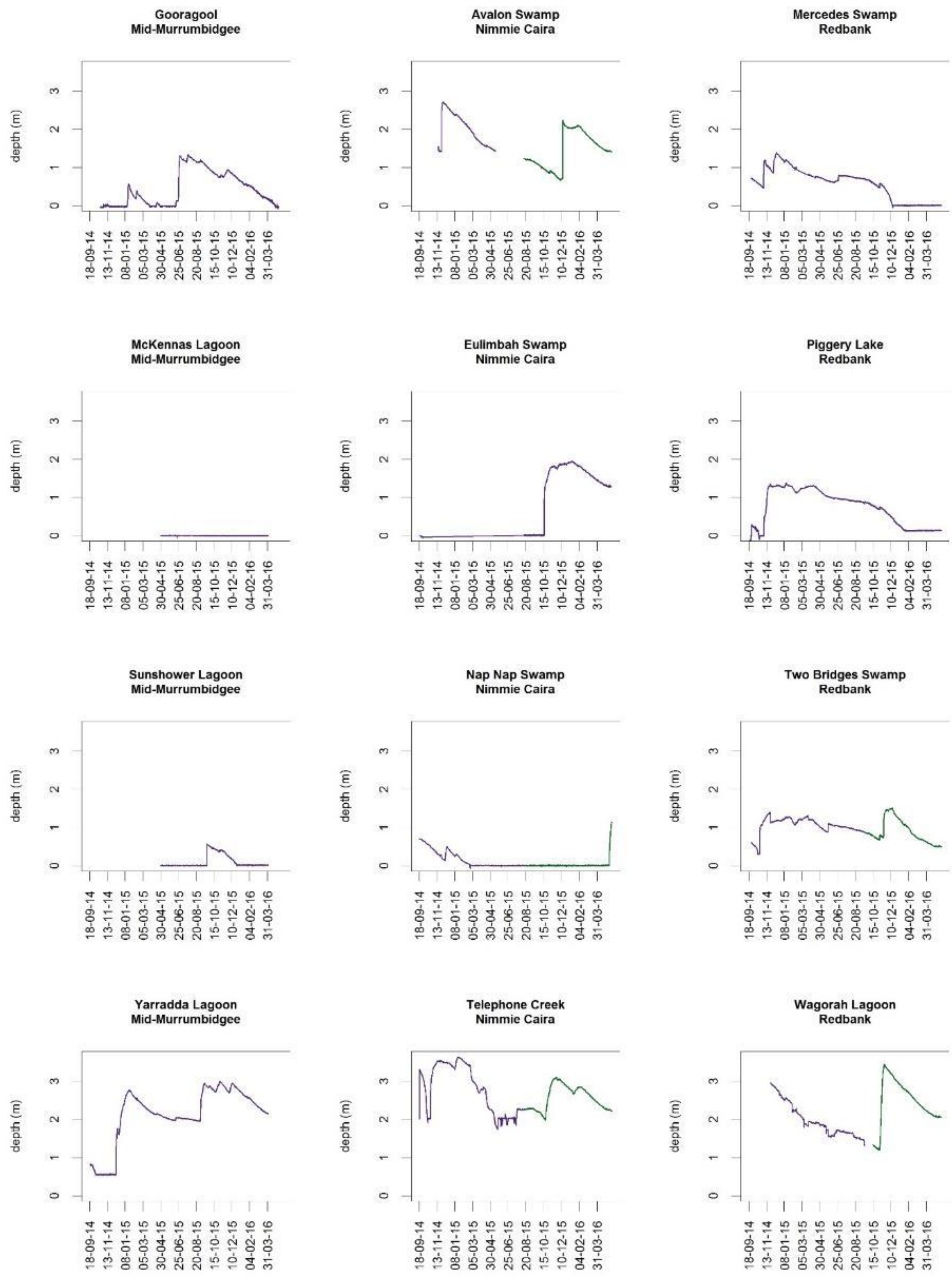


Figure 4-6 Water depth at wetlands' deepest points of the twelve wetland monitoring sites. Watering actions at sites correspond with rapid increases in depth. A change in colour of the plotted line indicates a repositioning of the depth gauge to more optimal location; corrective actions resulted in negligible impact on the continuity of the data series.

Discussion, recommendations and adaptive management

All Commonwealth water actions achieved the expected inundation objectives for targeted wetland assets. These inundation outcomes included increasing inundation extents in core wetland and refuge habitats, maintaining inundation extents to increase periods of inundation duration, minimising inundation of wetlands on flow paths and allowing wetlands to dry out.

Increased inundation extents were achieved in the core wetlands of the North Redbank region, for refuge habitats in the Nimme-Caira zone (e.g. Telephone Creek and Eulimbah Swamp) and in Juanbung Swamp as expected.

Maintaining inundation duration is critical for the completion of the life history stages of flora and fauna, especially during dry periods. Commonwealth environmental water was successfully used to maintain the water levels, or inundation extent, in Tarwillie Swamp to support a waterbird breeding event. This water action effectively extended inundation duration of the core wetland area (~120 ha) to just over 12 months. Inundation duration outcomes were evident in refuge habitats across the Nimmie-Caira with most of Eulimbah Swamp inundated for 4 months and most of Telephone Creek inundated for 5.5 months.

Maintaining the spatial variability of inundation patterns is important for the persistence of the wet-dry mosaic of diverse habitats across wetland landscapes. Commonwealth environmental water actions facilitated the drying of wetland vegetation that had their water regime requirements met in previous years. Understanding the variability in vegetation and fauna inundation requirements will help to inform environmental water actions to maintain a diverse wetland mosaic across the landscape.

4.9 Wetland water quality

Commonwealth environmental water was delivered to wetlands in order to improve water quality and to support the habitat and breeding requirements of native vegetation, waterbirds and fish. In wetlands, the quality of physical habitat for aquatic species can be affected by water quality (here defined as the physicochemical environment and concentrations of dissolved nutrients and carbon). Water quality is naturally variable over time, reflecting changes in air temperature, discharge, patterns of wetting and drying, salinisation and rates of aquatic photosynthesis. During times of extreme weather and/or hydrology (e.g. recent inundation or the latter stages of drying), water quality may exceed the tolerance limits for biota, impacting on reproductive success or habitat occupation, or survival of sensitive species. In most cases, appropriately timed environmental water deliveries can be used to off-set the negative impacts of drying or extreme climate, allowing affected biota to complete their lifecycles.

In 2015-16 Commonwealth environmental water was used to **improve aquatic habitat, water quality and riparian vegetation** at sites in the Nimmie-Caira system. Water quality was also indirectly targeted in the Redbank and mid-Murrumbidgee wetlands where environmental flows were used to support the habitat and breeding requirements of native vegetation, waterbirds and fish. To evaluate these objectives we compared 2015-16 wetland 1) physicochemical parameters and 2) concentrations of carbon, nutrients and chlorophyll-a against previously collected data and against other wetlands in the Murrumbidgee catchment.

Summary of watering actions and outcomes

Expected outcomes	Related watering actions	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Improve aquatic habitat, water quality and riparian vegetation Support the habitat and breeding requirements of native vegetation, waterbirds and fish	Yanga National Park Nap Nap - Waugorah	What did Commonwealth environmental water contribute to suitable physicochemical conditions for wetland fauna? What did Commonwealth environmental water contribute to wetland nutrient and carbon concentrations?	Water quality within expected ranges tolerated by resident species in targeted wetlands	Yes
	Nimmie-Caira SBF refuge (south Caira channel) Nimmie-Caira refuge (north Caira channel)		Water quality remained within expected ranges.	Yes
	Yarradda Lagoon		Water quality remained within expected ranges until late in the water season.	Yes

Main findings from the wetland water quality monitoring program

- Overall, water quality remained within the expected ranges with some exceptions caused by the latter stages of drying.
- Water quality was maintained at key refuge sites (i.e. Waugorah Lagoon) that were identified as at risk of poor water quality due to mid-season drying
- Water quality at Yarradda Lagoon had declined by March 2016, with high concentrations of total nutrients and chlorophyll-a as well as increased turbidity. This decline may have been caused by high solar exposure or the senescence of large amounts of red milfoil.

Discussion, recommendations and adaptive management

Commonwealth environmental water was delivered to **improve, maintain or provide aquatic habitat** at wetlands in the Redbank, Nimmie-Caira and mid-Murrumbidgee systems. Water quality measurements were within the expected range of values, as defined by sampling across the Murrumbidgee catchment prior to 2014. Where water quality did appear to decline, sites were typically in the later stages of drying. Overall, water quality at sites receiving Commonwealth environmental water was successfully maintained within the ranges tolerated by aquatic species.

During 2015-16 Commonwealth environmental water was successfully delivered to support water quality in targeted wetlands. Maintaining permanent refuges is an important mechanism allowing the persistence of sensitive species in these systems, and ensuring adequate water quality for these populations to survive. Ongoing monitoring provides a means to identify water quality problems before they arise.

Repeat watering of Yarradda Lagoon has yielded multiple positive ecological outcomes, although there is some evidence for potential water quality issues. It is not known whether this cycling of nutrients is part of the natural pattern within this wetland. Late-summer or autumn top-up flows to Yarradda Lagoon would help offset declining water quality, increasing the survival of fish and other biota through to the winter period.

4.10 Wetland microinvertebrates

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. In both 2014-15 and 2015-16, Commonwealth environmental water was delivered to wetlands in order to improve water quality and to support the feeding habitat and breeding requirements of native vegetation, waterbirds, fish and other vertebrates (turtles, frogs). Inundation of wetlands stimulates emergence and reproduction of microinvertebrates, often resulting in an abundant food supply. In 2015-16 environmental watering occurred in the Nimmie-Caira system, the Redbank and mid-Murrumbidgee wetlands. We monitored benthic and pelagic microinvertebrate communities in wetlands and three river comparison sites coinciding with the wetland fish and tadpole monitoring from September 2015 to March 2016.

Summary of watering actions and outcomes

Expected outcomes	Related Watering actions	Evaluation questions and predictions	Measured outcomes	Was the expected outcome achieved
Improve aquatic habitat, water quality and riparian vegetation Support the habitat and breeding requirements of native vegetation, waterbirds and fish	Yanga National Park Nap Nap - Waugorah Nimmie-Caira SBF refuge (south Caira channel) Nimmie-Caira refuge (north Caira channel) Yarradda Lagoon	What did Commonwealth environmental water contribute to wetland productivity nutrients and carbon fluxes, primary productivity (CHL a) and secondary productivity (Microinvertebrates)?	High densities of microinvertebrates observed throughout spring and summer, dominated by copepods with cladocerans and ostracods present	Yes

Main findings from microinvertebrate monitoring program

- High densities of microinvertebrates (500-1000 /L) were recorded following inundation of monitored wetlands with Commonwealth environmental water in both 2014-15 and 2015-16.
- Densities were higher in the mid-Murrumbidgee (Yarradda Lagoon) and Nimmie-Caira wetlands than in the Redbank wetlands in both years.

- In both watering years, densities of microinvertebrates fell by March in all zones.
- In both watering years, copepods dominated wetland assemblages, with cladocerans and lower densities of ostracods also present.
- Responses of microinvertebrates to inundation were consistent across years suggesting the current regime of wetting and drying is maintaining the egg bank and high levels of productivity.

Discussion, recommendations and adaptive management

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

The fall in microinvertebrate densities in March is likely due to falling temperatures, depletion of nutrients as inundation extends, possibly increased predation pressure as water levels fall and declining water quality as wetlands dry. It is not known why densities are higher in Yarradda and Nimmmie-Caira than Redbank. Wetlands receiving Commonwealth environmental water via infrastructure in 2014-15 in the mid-Murrumbidgee (Yarradda Lagoon) had similar densities of microinvertebrates as those in the Lowbidgee floodplain (Nimmie-Caira refuge watering) and were higher than wetlands in the Redbank zone (Yanga Waterbird and Nap Nap Waugorah), indicating that the mode of water delivery had little impact on microinvertebrate density or diversity.

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

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

4.11 Vegetation diversity

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee with the primary objective to "*Protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities*". The types of aquatic species present in a wetland is strongly influenced by the flow regime, in particular, inundation frequency, water depth and duration of inundation. Variability in the flow regime across the Murrumbidgee floodplain helps to support a wide array of different plant communities, which are often classified by their dominant tree and shrub species. Key communities monitored as part of this program include Lignum and Lignum-Black Box through the Nimmie-Caira and fringing river red gum wetlands in the mid-Murrumbidgee and river red gum-spike rush communities through the Redbank zones.

Aquatic plant species need water to grow and reproduce. In seasonally inundated wetlands there are distinct wet and dry phases contributing to regular transitions between short lived terrestrial plant species and water dependent species which grow while the wetland contains water. Drying periods that extend the normal wet and dry cycle can lead to the establishment of longer lived terrestrial species and subsequent declines and disappearances of aquatic species from the population and from the seedbank.

With these factors in mind, the responses of aquatic plant communities following environmental watering will be influenced by the length of time the wetland had been dry, the length of time the wetland contains water and water depth, with most wetlands undergoing a rapid increase in water depth following inundation with a gradual decline in water depth occurring over time. The general pattern expected in wetlands is an initial decline of species diversity immediately upon watering due to the drowning out of terrestrial species, followed by an establishment and maturation of the aquatic community and then gradual senescence of aquatic species and colonisation of drying wetlands by mud-flat specialists and opportunistic terrestrial species. Following the delivery of environmental water larger wetland complexes can hold water for between 12 and 18 months which means that the full benefit of environmental watering sometimes need to be considered across multiple years. An example of this process is shown for Piggery Lake in the Lowbidgee floodplain (Plate

4-2). This large wetland takes over 12 months to dry and we can see the gradual change in the community over a 16 month period.

Plate 4-2 Piggery lake cycle of vegetation communities between the wet and dry phase over a 16 month period between September 2014 and January 2016. September 2014 Dry phase community, November 2014 initial inundation with limited vegetation growth, November 2015 well developed aquatic community, January 2016 dry phase community. The wetland received environmental water in late October 2014.

In order to determine the extent to which the Commonwealth environmental watering actions achieved their objectives with respect to riparian, floodplain and native vegetation, we considered three key aspects of the plant community response 1) species diversity (number of species), in particular the diversity of water depend species, 2) the community diversity which is a measure of the number of unique plant communities (groups of species) that formed following environmental water, 3) the relative abundance of water dependant plant species following environmental water when compared to dry sites, and 4) the percentage cover of plant functional groups change in response to environmental watering.

Summary of watering actions and outcomes

Expected outcomes	Related watering actions	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities	Yanga National Park Nimmie-Caira SBF refuge (south Caira channel) Nimmie-Caira refuge (north Caira channel) Yarradda lagoon Nap Nap - Waugorah	Did Commonwealth environmental water contribute to vegetation species diversity?	Contributed 43 additional aquatic species that were only recorded at wetlands following Commonwealth environmental watering.	Yes
		Did Commonwealth environmental water contribute to vegetation community diversity?	Established 9 unique aquatic vegetation communities.	Yes
		Did environmental watering influence the types of species present in wetlands?	Watering supported the establishment of aquatic plant species, including common spike rush, tall spike rush and water primrose.	Yes
		Did the percentage cover of plant functional groups change in response to environmental watering?	The percentage cover of species belonging to the amphibious (aquatic) functional groups increased following environmental watering across all monitoring zones and wetlands.	Yes

Main findings from vegetation diversity monitoring program

Commonwealth and State environmental water is the primary driver of aquatic plant communities through the Murrumbidgee and is critical for the persistence of 43 water dependant plant species. Key water dependent species included common spike rush, tall spike rush, water primrose and common water milfoil (Table 4-2).

Table 4-2 Examples of species that were comparably more abundant at sites in their wet and dry phases

Examples of Aquatic species Most abundant during wet phase	**Examples of Transition species Similar abundances during wet and dry phases**	**Examples of dry site species Most abundant at sites not receiving environmental water**
Common spike rush (*Eleocharis acuta*)	Common sneeze weed (*Centipeda cunninghamii*)	Spear Thistle (*Cirsium vulgare*) *
Common water milfoil (*Myriophyllum verrucosum*)	Crumbweed (*Dysphania pumilio*)	Wire weed (*Polygonum aviculare*) *
Water primrose (*Ludwigia peploides ssp. Montevidensis*)	Yellow Twin-heads (*Eclipta platyglossa*)	Annual exotic grasses *
Azolla (*Azolla filiculoides*)	Pale knotweed (*Persicaria lapathifolia*)	Berry saltbush (*Atriplex semibaccata*)
Tall spike rush (*Eleocharis sphacelata*)	Nardoo (*Marsilea drummondii*)	

* Indicates introduced species

Commonwealth environmental water supported species diversity in floodplain wetlands. Overall 208 species (147 native and 61 exotic) have been recorded since September 2014, and 43 wetland dependant species were recorded at sites that had received environmental water. Overall species richness has remained stable across the monitoring locations, the exception being Yarradda Lagoon where species richness has increased following environmental watering.

Wetlands in the mid-Murrumbidgee that did not receive environmental water in either 2014-15 or 2015-16 (Sunshower and McKennas Lagoons) remain in poor condition and are dominated by a mix of native and exotic terrestrial species.

Repeat environmental watering of Yarradda Lagoon in 2014-15 and 2015-16 has supported the reestablishment of key water dependant species including spiny mudgrass, tall spike rush (Plate 4-3) and fringe lily.

Plate 4-3 tall spike rush at Yarradda Lagoon January 2016

Environmental water supported culturally significant species including Budhaay (Wiradjuri) (*Centipeda cunninghamii*) and Ngarru (Wiradjuri) (*Marsilea drummondii*). These species were widespread through the Nimmie-Caira and parts of the Redbank system.

Discussion, recommendations and adaptive management

The Commonwealth environmental watering actions evaluated here achieved their watering objectives with respect to water dependant species. There are a range of long and short term hydrological drivers that can influence the response of water dependant species during environmental watering. In particular wetlands that have been dry for extended periods can be slow to recover and have low abundance of water dependent species, but abundance increases with repeated watering. This has been the case at Yarradda Lagoon where a steading increase in species diversity and percentage cover has been recorded with repeated environmental watering. In the Lowbidgee floodplain, the wetlands monitored as part of this program have received regular inundation over a number of years. The aquatic vegetation communities are in good condition and changes in species richness and composition are more likely to reflect annual variability in wet-dry transitions rather than long-term changes in community composition and structure.

Environmental watering actions in the Murrumbidgee were carried out with the objective of “Protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities”.

Watering actions undertaken in 2015-16 were largely undertaken in spring which is the ideal time to support aquatic plant communities.

Repeat watering of Yarradda Lagoon through 2014-5 and 2015-16 has supported the reestablishment of spiny mudgrass, tall spike rush and fringe lily. These species require frequent inundation and with short (preferably less than one year) dry period. In order to protect and maintain these communities watering of Yarradda Lagoon and where practical of similar wetlands in the mid-Murrumbidgee system such as Gooragool, McKennas and Sunshower lagoons should be maintained as a high priority under all water availability scenarios.

4.12 Wetland fish

Four watering actions were monitored as part of the LTIM project that had objectives related to native fish communities in wetlands. In the Redbank system the Yanga National Park action inundated Two Bridges swamp with the objective to "provide habitat for native fish, frogs and other vertebrates" while the Nap Nap – Waugorah action targeted flood ways through the Redbank zone including Waugorah Lagoon, as well as the northern section of the Nimmie-Caira. The Nimmie-Caira SBF refuge (south Caira channel) and Nimmie-Caira refuge (north Caira channel) inundated Eulimbah swamp and Telephone Creek and maintained small areas of water in a dam associated with Avalon Swamp in the Nimmie-Caira zone with the objectives "maintain refuge habitat for a diverse range of native fish, frogs, turtles and waterbirds" and "support the habitat requirements of native fish and turtles". In the mid-Murrumbidgee wetland pumping was undertaken at Yarradda Lagoon with the objective of "support known native fish and frog community established in 2014-15" while NSW environmental water was used to maintain Gooragool Lagoon. In 2015-16 two sites (McKennas in the mid-Murrumbidgee and Nap Nap in the Nimmie-Caria) were dry throughout the monitoring period.

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, Thiem et al. (2015).

Ecological outcomes of Commonwealth environmental watering actions targeting native fish communities were evaluated against two criteria:

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

Summary of watering actions and outcomes

Expected outcomes	Related watering actions	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Support the habitat and breeding requirements of native vegetation, waterbirds and fish	Yanga National Park Nap Nap - Waugorah Nimmie-Caira SBF refuge (south Caira channel) Nimmie-Caira refuge (north Caira channel) Yarradda Lagoon	*What did Commonwealth environmental water contribute to native fish populations and native fish diversity?*	Seven native and four exotic species were captured in 2015-16. Murray cod juveniles were collected in the Nimmie-Caira for the first time, increasing overall number of native species from six in 2014-15 to seven in 2015-16.	Yes
		What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?	Evidence of recruitment and survival was identified in three native species, carp gudgeon, Australian smelt and bony herring.	Yes for generalist native species

Main findings from wetland fish monitoring program

- Seven native and four exotic species were captured across 10 LTIM surveyed wetland sites that contained water between September 2015 and March 2016. Murray cod juveniles were collected at Eulimbah swamp in the Nimmie-Caira for the first time, increasing overall number of native species from six in 2014-15 to seven in 2015-16.
- As in previous years (Wassens, Thiem et al. 2015). exotic fish species were widespread through the monitoring locations, with gambusia, common carp, goldfish and oriental weatherloach the most commonly recorded exotic species.
- The native species richness differed significantly between individual wetlands, zones and water years.
- At Yarradda Lagoon which received water via pumping in 2014-15 and 2015-16 with the objective of "support known native fish and frog community established in 2014-15", had an increase in the number of native fish species

from two (carp gudgeon and bony herring) in 2014-15 to four in 2015-16 with Murray-Darling rainbowfish and Australian smelt also detected.

- In the Nimmie-Caira the number of native species increased from three in 2014-15 to seven in 2015-16 with Murray cod, unspecked hardyhead, golden perch and Murray-Darling rainbow fish also recorded.
- Increases in the size of individuals within the catch over time can indicate breeding and growth within the wetland, in the mid-Murrumbidgee (Yarradda Lagoon) and Nimmie-Caira (Nimmie-Caira refuge north and south watering actions) the size structure of the Australian smelt and carp gudgeon was skewed towards smaller individuals in spring with a shift towards larger individuals in late summer. Bony herring populations were dominated by larger individuals in spring with smaller individuals dominating the catch in late summer.

Discussion, recommendations and adaptive management

Four watering actions that have objectives targeting native fish communities were undertaken in 2015-16. Overall these actions were successful in achieving their stated objectives for the native fish species. Nevertheless wetland fish communities remain in poor condition and are dominated by opportunistic generalist species with floodplain specialist species such as Murray hardyhead absent from the mid-Murrumbidgee and Lowbidgee floodplains. While the stabilisation of populations of some native species is positive, native species richness has declined since 2008 (Spencer, Thomas et al. 2011).

In wetlands, community composition and species richness is influenced by a number of factors, for permanent waterbodies breeding and recruitment of resident populations is important while colonisation of both permanent and temporary wetlands during filling can also influence species richness due to the arrival of new species. The Murrumbidgee River is an important source of colonising individuals and it is expected that the Murray cod and golden perch juveniles collected at Eulimbah Swamp in the Nimmie-Caira originated form the Murrumbidgee River at Maude. However, gradual increases in species richness observed between 2014-15 and 2015-16 may indicate that the strategy of maintaining refuges is having a positive impact on species richness at some sites. Environmental watering actions at Yarradda Lagoon which are undertaken with the objective of supporting known native fish and frog communities established in 2014-15 have successfully achieved this goal, with no native species lost from the wetland and the detection of additional species - Murray-darling rainbow fish in 2015-16.

Native fish communities were dominated by one larger bodied (bony herring) and two small bodied (Australian smelt and carp gudgeon) native fish. There was evidence of juveniles being present for all three species suggesting that breeding occurred in the mid-Murrumbidgee and Nimmie-Caira zones. Australian smelt and carp gudgeon are a short-lived species and respond rapidly to wetland watering events, but due to their short lifespan, turnover of individuals between water years may be limited. This means that gradual increases in abundance between water years are not necessarily expected for these small-bodied native species. However for longer-lived species the maintenance of well connected refuge habitats should be prioritised for watering, particularly in years of low water availability, to maintain fish communities.

4.13 Frogs and turtles

The availability of standing water is critical to the survival of frog populations through floodplain wetland systems. Environmental watering actions can be used to maintain frog populations via two key mechanisms: providing refuge habitat that support frog populations during periods of low water availability and through the provision of breeding habitat that allows frog populations to reproduce. Many of the frog species that occupy floodplain habitats have limited capacity to survive extended dry periods, so the maintenance of refuge habitat is critical for the long-term persistence of populations, especially for the vulnerable southern bell frog (*Litoria raniformis*) (EPBC Act). While persistent water is import for keeping frogs alive during dry periods, breeding success is typically greater in areas of shallow, temporary habitat. Therefore environmental watering actions that have objectives for frog breeding outcomes need to increase the area of inundation within and around wetland sites.

The overriding objective of Commonwealth environmental water as it relates to frogs is to "support the habitat and breeding requirements of native fish and other vertebrates". In 2015-16, Commonwealth environmental watering actions carried out in the Nimmie-Caira southern bell frog refuge (north Caira channel), Nimmie-Caira southern bell frog refuge (south Caira channel) and Nap Nap – Waugorah had the specific objective of "maintaining refuge habitat for a diverse range of native fish, frogs and turtles and waterbirds" and "supporting the habitat requirements of southern bell frogs". The Redbank watering action inundated one LTIM monitoring site (Two Bridges Swamp). Water was pumped into Yarradda Lagoon in the mid-Murrumbidgee to "support known native fish and frog community established in 2015-16". Detailed evaluation outcomes of each watering action are in the appendices of this report, and this section summarises key outcomes for frogs and tadpoles with respect to three key evaluation criteria:

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

Summary of watering actions and outcomes

Expected outcomes	Related watering actions	Evaluation questions and predictions	Measured outcomes	Was the objective achieved
Support the habitat and breeding requirements of native fish and other vertebrates.	Yanga National Park Nimmie-Caira SBF refuge (south Caira channel) Nimmie-Caira refuge (north Caira channel) Yarradda Lagoon Nap Nap - Waugorah	What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?	Six frog species were recorded in 2015-16 including the vulnerable (EPBC Act) southern bell frog.	Yes
		What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?	Breeding activity for all six species known to occur across the monitoring sites was recorded in response to Commonwealth environmental water.	Yes
		What did Commonwealth environmental water contribute to the maintenance of refuge habitats?	Watering actions in the Nimmie-Caira were undertaken to create refuge habitat for the southern bell frog, there were large increases in abundance of southern bell frogs at Eulimbah late in the season	Yes

Main findings from frog monitoring program

In 2015-16 southern bell frogs were recorded at four wetlands that received environmental water in the mid-Murrumbidgee (Yarradda Lagoon), Nimmie-Caira (Eulimbah Swamp and Telephone Creek) and Redbank (Waugorah Lagoon). Other known southern bell frog sites Avalon Swamp and Nap Nap Swamp in the Nimmie-Caira were largely dry through 2015-16 and subsequently no southern bell frogs were recorded.

When considered across all monitoring locations, increasing the percent of wetland inundation contributed to an increase in the abundance and calling activity of southern bell frog, spotted marsh frog, barking marsh frog, inland bango frog, Peron's tree frog and plains froglet) and also contributed to increased abundance of spotted and barking marsh frog tadpoles

When considered across all monitoring locations there was a positive relationship between the percentage of the wetland inundated and calling activity for the plains froglet, barking marsh frog, inland banjo frog, Peron's tree frog and southern bell frog.

Plate 4-4 Recently metamorphosed southern bell frog from Yarradda Lagoon in the mid-Murrumbidgee

Discussion, recommendations and adaptive management

Commonwealth environmental watering actions targeting frogs were largely successful in achieving their objectives in the Murrumbidgee Selected Area. There were notable positive outcomes for southern bell frogs, inland banjo frog and Peron's tree frogs following pumping of Yarradda Lagoon in the mid-Murrumbidgee, with southern bell frog tadpoles, recent metamorphs and adults all observed in 2015-16. This was the first record of southern bell frogs breeding in Yarradda Lagoon. Positive aquatic vegetation responses and low densities of exotic fish in Yarradda Lagoon may have contributed to the positive outcomes for southern bell frogs and Peron's tree frog. These results demonstrate that wetland pumping can be a useful tool for maintaining wetlands during years where lower river flows and other constraints prevent natural reconnections between rivers and wetlands.

Refuge habitat is critical for the long-term persistence of frog populations in semi-arid landscapes, particularly during dry years. Watering actions aimed at maintaining refuge habitats were undertaken at wetlands known to support southern bell frog populations in the Nimmie-Caira. These watering actions were designed to create and maintain areas of persistent habitats between water years. The abundance of southern bell frog adults increased in areas where refuge habitat was maintained compared to wetlands that were allowed to dry which suggests that the watering actions were successful in creating refuge. While the availability of refuge habitat is important, large-scale inundation of temporary habitats adjacent to refuge sites is also important in spring and summer to support southern bell frog breeding.

4.14 Waterbirds

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee zones as part of four key watering actions: Redbank (Yanga National Park) waterbird contingency, Redbank (north), Nimmie-Caira refuge and Yarradda Lagoon. The broad objective across the Murrumbidgee Selected Area is to "support the habitat requirements of waterbirds", with individual watering actions focused on either maintaining habitat for waterbirds or supporting breeding outcomes - for full evaluation of the outcomes of individual watering actions please see Appendices. Across the Murrumbidgee Selected Area the responses of waterbirds to environmental watering actions were assessed against four key evaluation questions shown in the table below.

Summary of watering actions and outcomes

Expected Selected Area outcomes	Relevant Watering Action (s) in 2015/16	Evaluation questions and predictions	Measured outcomes	Was the expected outcome achieved
Support the habitat requirements of waterbirds	Redbank (Yanga National Park) waterbird contingency Redbank (North) Nimmie-Caira SBF refuge (south Caira channel) Nimmie-Caira refuge (north Caira channel) Yarradda Lagoon Nap Nap - Waugorah	What did Commonwealth environmental water contribute to waterbird species diversity?	Total waterbird diversity was higher in wetlands that received environmental water over September 2015-March 2016 compared to sites that were not inundated.	Yes
		What did Commonwealth environmental water contribute to waterbird abundance?	Total waterbird abundance was higher in wetlands that received environmental water over September 2015-March 2016 compared to sites that were not inundated.	Yes
		What did Commonwealth environmental water contribute to waterbird species of conservation significance?	Nationally threatened Australasian bittern (Nimmie-Caira) and NSW-listed freckled duck* and magpie goose (Mid-Murrumbidgee) were recorded in wetlands that received Commonwealth environmental water. Two wetlands that received Commonwealth environmental water supported small-scale breeding in JAMBA listed Eastern great egrets.	Yes
		What did Commonwealth environmental water contribute to waterbird breeding*?	Colonial waterbird breeding was recorded in five wetlands across the Murrumbidgee Selected Area which received Commonwealth environmental water in 2015-16. This included delivery of Commonwealth environmental water to maintain stable water levels in the Tarwillie (Redbank) and Telephone (Nimmie-Caira) Swamps where small numbers (approx. 250 pairs in total) of JAMBA listed Eastern great egrets nested successfully.	Yes

* Assessed through complementary NSW OEH waterbird diversity and colonial waterbird breeding monitoring (see Spencer *et al.* 2016a).

Main findings from waterbird monitoring program

- Waterbird diversity and total waterbird abundance was greater in monitored wetlands that received Commonwealth environmental water in 2015-16 compared to sites that were dry, and sites that received water in 2014-15 only.

- Wetlands that received Commonwealth environmental water supported species of conservation significance including the threatened Australian bittern (*Botaurus poiciloptilus)* (EPBC Act endangered), freckled duck (*Stictonetta naevosa)* and magpie goose (*Anseranas semipalmata)* (vulnerable NSW Threatened Species Conservation (TSC) Act 1995).
- Commonwealth environmental watering contributed to colonial waterbird breeding in five wetlands across the Murrumbidgee Selected Area, including breeding in JAMBA listed Eastern great egret (*Ardea modesta)*.

Discussion, recommendations and adaptive management

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee in order to "support the habitat requirements of waterbirds" in the Murrumbidgee Selected Area. The results of the quarterly LTIM wetland surveys and complementary NSW OEH monitoring indicated that delivery of Commonwealth environmental water contributed to waterbird outcomes across the Murrumbidgee Selected Area including increased waterbird diversity, abundance and small-scale waterbird breeding in 2015-16. The delivery of environmental water created wetland habitat for at least 44 species of waterbirds, including threatened species and species listed under international migratory bird agreements.

Ten species of colonial waterbird species successfully bred in small numbers (in total around 1250 nests) across six wetlands in the Murrumbidgee Selected Area including river red gum habitats in the Redbank, Nimmie-Caira and mid-Murrumbidgee, and lignum shrubland in the Nimmie-Caira. Commonwealth environmental water was delivered to support the successful completion of breeding in JAMBA-listed Eastern great egrets in Tarwillie Swamp (Redbank), and Telephone Creek (Nimmie-Caira), and also completion of cormorant breeding in Yarradda Lagoon (mid-Murrumbidgee).

Several approaches to environmental water management can be taken to maximise outcomes for waterbirds depending on the water availability scenario for a given water year. The timing of flows, total wetland area flooded and types of habitat inundated are important factors influencing the total number and type of waterbird species, and extent of breeding activity (number of breeding species, number of active colony sites and total number of nests) in a given water year.

We recommend future management of Commonwealth environmental water in the Murrumbidgee Selected Area consider the following:

The late spring timing of the four key watering actions across the Murrumbidgee Selected Area in 2015-16 was outside of the ideal timing for many waterbirds, including migratory shorebirds. Future delivery of Commonwealth environmental water, should aim to deliver flows to provide seasonal habitat for migratory shorebirds (unvegetated muddy shorelines and open shallow lagoons and lakes) in late winter/early spring and maximise duration and slow rate of recession to create shorebird foraging habitat into late spring and summer.

As done successfully in 2014-15 and 2015-16, extend duration of inundation and maintain adequate water depths in any active colonial waterbird sites using environmental water to support breeding events through to completion (minimum of three to four months from egg laying plus post-fledgling care for most species).

To increase opportunities for colonial waterbird breeding, Commonwealth environmental water should be used to inundate known colony sites and key foraging grounds for more than two months (August-September) before the commencement of the breeding season. Although some small-scale colonial waterbird breeding was recorded in response to the Nimmie-Caira watering action in late spring 2015, this response may have been greater if there had been an opportunity to deliver flows to foraging habitats adjoining Eulimbah and Telephone Swamps earlier in spring.

If colonial waterbird breeding is detected in the Murrumbidgee Selected Area and/or neighbouring catchments, Commonwealth environmental water should be used to maintain inundation of foraging habitat over summer and autumn months to promote the survival of young birds. This approach will also maximise opportunities for breeding in non-colonial waterbird species.

Following colonial waterbird breeding events in the Lowbidgee floodplain and neighbouring wetlands (i.e. the Lower Lachlan and mid-Murray) Commonwealth environmental water should be prioritised for delivery to key foraging areas in the Nimmie-Caira and Redbank systems in the months and the water year following breeding to promote the survival of first year birds.

5 Technical Appendices

5.15 River water quality

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

Introduction

During 2014-15 and 2015-16 there were no Commonwealth environmental watering actions specifically targeting in-channel responses, although Commonwealth environmental flows did pass down the Murrumbidgee River channel while being delivered to floodplain and wetland habitats. Long-term watering plans for the Murrumbidgee River (Commonwealth of Australia 2015) forecast in-channel deliveries of Commonwealth environmental water to support primary productivity, nutrient and carbon cycling, biotic dispersal and movement and to provide refuge habitat from adverse water quality events. 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, Allan et al. 1997). High flows, low flows, and variability in flows can contribute to changes in physicochemical parameters and nutrient concentrations (Watts, Allan et al. 2009). Large perturbations that have widespread negative impacts for riverine biota, such as hypoxic blackwater events (McCarthy, Zukowski et al. 2014) or in-stream algal blooms, are infrequent and can sometimes be offset with timed deliveries of environmental water.

In the absence of environmental water deliveries targeting water quality we sought to describe the range of river water quality observed during 2014-15 and 2015-16. We compared observed ranges of 1) physicochemical parameters and 2) concentrations of carbon, nutrients and chlorophyll-a between the two zones monitored under the Murrumbidgee LTIM project and with data collected in the Murrumbidgee River before 2014. Where applicable we also discuss these findings with respect published water quality guidelines (ANZECC 2000).

Methods

River water quality was monitored six times per year between October and December. Sampling coincided with larval fish and microinvertebrate monitoring (sections 5.4 and 5.3 respectively). Measurements of physicochemical parameters (electrical conductivity (EC, mS cm^{-1}), turbidity (NTU) and pH and dissolved oxygen (mg L^{-1})) were taken at three randomly-chosen locations at each site using a calibrated water quality meter (Horiba U-52G). Note that dissolved oxygen was monitored continuously at Narrandera and Carrathool (see Section 5.2). Duplicate water samples were also collected and later analysed for dissolved organic carbon (DOC, mg L^{-1}), chlorophyll-a (CHLA, mg L^{-1}), filterable reactive phosphorus (FRP, µg L^{-1}) and oxidised nitrogen (NOX, µg L^{-1})(Wassens, Thiem et al. 2015).

Data analysis

To test for differences between zones and sample occasions, data were analysed using a three-way permutational analysis of variance (PERMANOVA; Anderson et al. 2008) with zone, water year and sample occasion as fixed factors. Sample occasion was nested within water year. Data were not transformed prior to analysis. Resemblance matrices were calculated using a Euclidian distance measure. Post-hoc tests were used to further isolate significant terms, using Monte-Carlo tests where numbers of unique permutations were low. Results were considered significant at $P<0.05$. All data were analysed using Primer 6 with PERMANOVA (Primer-E Ltd.).

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 5-1).

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

Indicator	NOx µg L^{-1}	FRP µg L^{-1}	Chl-a µg L^{-1}	DOC mg L^{-1}	Cond. mS cm^{-1}	pH	Turbidity NTU	DO mg L^{-1}
ANZECC (2000) trigger*	500	50	5	NA	2.2	6.5-8	6-50	(90-110%)
Median (5th-95th)	79.9 (3.80-217.49)	4.40 (2.51-8.58)	9.6 (3.9-19.9)	3.59 (2.16-10.69)	0.095 (0.064-0.179)	7.61 (7.21-8.19)	39.4 (15.79-76.65)	9.61 (7.64-0.86)
Number of samples (*n*)	39	39	43	43	48	48	47	48

*ANZECC trigger guidelines for lowland rivers in south-east Australia

Results

Riverine physicochemical parameters varied significantly between zones, years and sample occasions as indicated by significant high-order interaction terms (Figure 5-1; Table 5-2). Results were broadly consistent between the two water years and fell within the range of previously reported values and within ANZECC water quality guidelines except for peaks in electrical conductivity and pH (Figure 5-1). Overall dissolved oxygen was slightly lower in 2015-16 than 2014-15 (Table 5-2); however, values were approximately at saturation and no adverse dissolved oxygen conditions (i.e. falling below 4 mg L^{-1}) were observed.

During late November, there was a significant increase in electrical conductivity (Table 5-2, pairwise: trip 3 *vs*. trip 4, t=23.24, p(mc)=0.001) that coincided with a decline in both turbidity and water level. A similar pattern was observed in the Narrandera zone, but during the prior sample occasion in early November. Despite conductivity increasing above previous records for the Murrumbidgee River, values remained below the ANZECC (2000) trigger guideline of 2.2 mS cm^{-1}. During 2015-16, pH periodically increased to above previously recorded values and above ANZECC water quality guidelines. The highest pH values reached 8.75 at the river site near Yarradda Lagoon (Carrathool zone) during late November, coinciding with reduced water levels.

Like physicochemical parameters, nutrient, carbon and chlorophyll-a concentrations also varied significantly between zones, years and among sample occasions (Figure 5-2; Table 5.2). In the Narrandera zone chlorophyll-a concentrations were significantly greater in 2015-16 than 2014-15 (Figure 5-2, Table 5-2 pairwise t=5.77, p(perm)=0.001), with results approximately coinciding with increased water temperature and decreased water level. Chlorophyll-a concentrations in the Carrathool zone were more variable, particularly during 2014-15, with values typically higher at the Yarradda river site than the other two sites in this zone (Wassens, Thiem et al. 2015). Overall, chlorophyll-a concentrations were above the ANZECC (2000) trigger guideline of 5 mg L^{-1}, but were similar to previous data. During 2015-16, there was a small increase in DOC in the Narrandera (early November; pairwise t=2.24, p(mc)=0.087) and Carrathool (late November; pairwise t=4.03, p(mc)=0.025) zones.

Table 5-2 PERMANOVA results for water quality data collected during 2014-15 and 2015-16. The highest-order significant term is shaded for each measured variable. Significance levels are *p<0.05, **p<0.01, ***p=0.001

Term		df	NOx	FRP	Chl-a	DOC	Cond.	pH	Turb.	DOC
1	Zone (Zo)	1	96.86***	200.03***	0.003	6.01*	2.84	0.01	55.01***	13.63***
2	Water Year (WY)	1	74.58***	42.93***	12.56**	21.01***	128.22***	3.29	18.16***	39.56***
3	Trip (WY)	10	16.89***	41.88***	1.25	4.94**	48.29***	1.52	4.68***	16.43***
4	Zo x WY	1	20.47***	4.86*	6.54*	0.05	0.003	4.55*	10.14**	1.33
5	Zo x Tr(WY)	10	10.91***	3.57**	1.41	6.06***	33.90***	3.53***	2.07*	2.78*

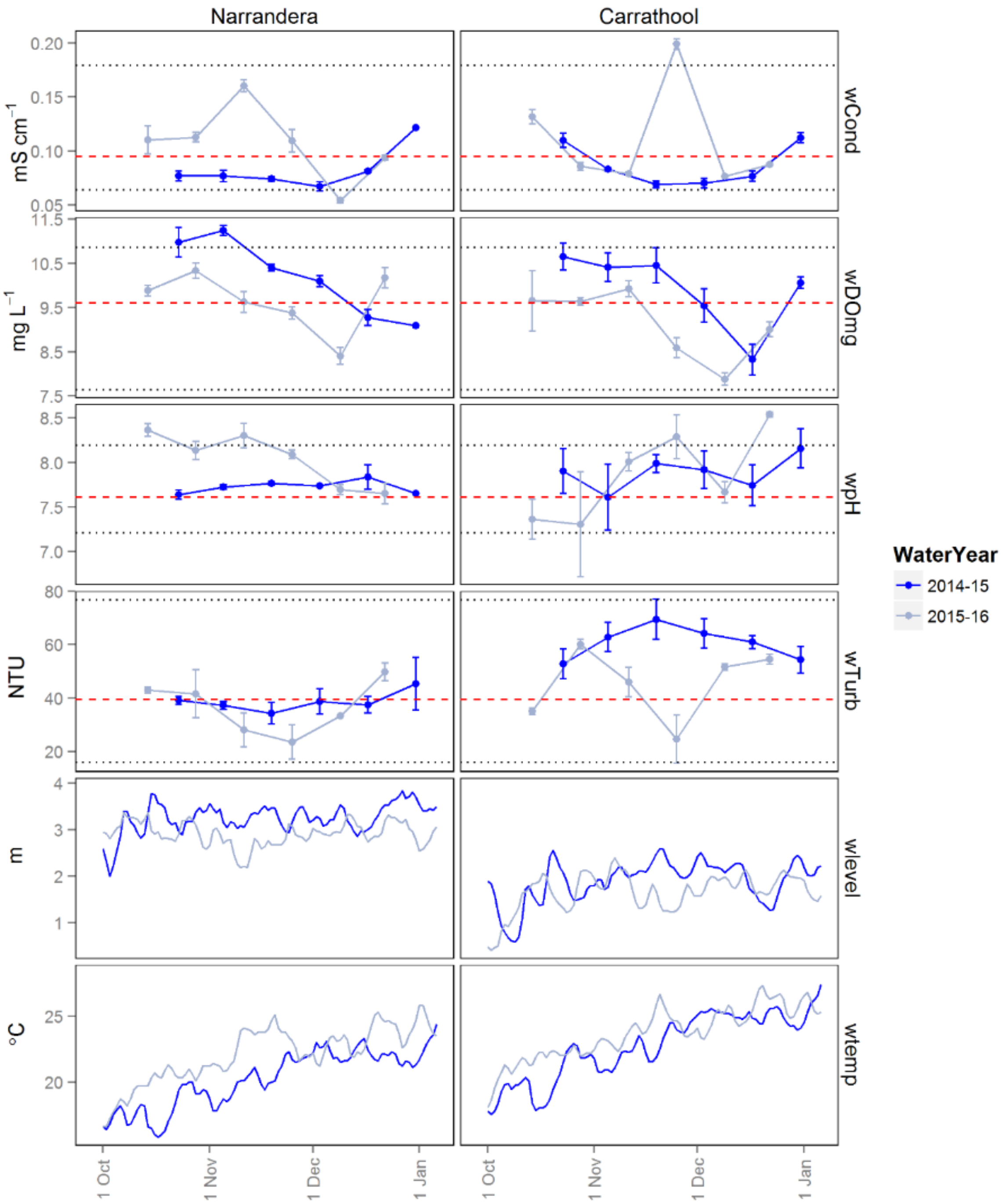


Figure 5-1 Mean ± standard error for physicochemical parameters (dissolved oxygen - wDO; turbidity – wTurb; pH –wpH; and conductivity – wCond) measured on six occasions between October and December during 2014-15 and 2015-16. Data are the mean of three sites ± standard error of the mean. Mean daily water level (wlevel) is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature (wtemp) was monitored continuously. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

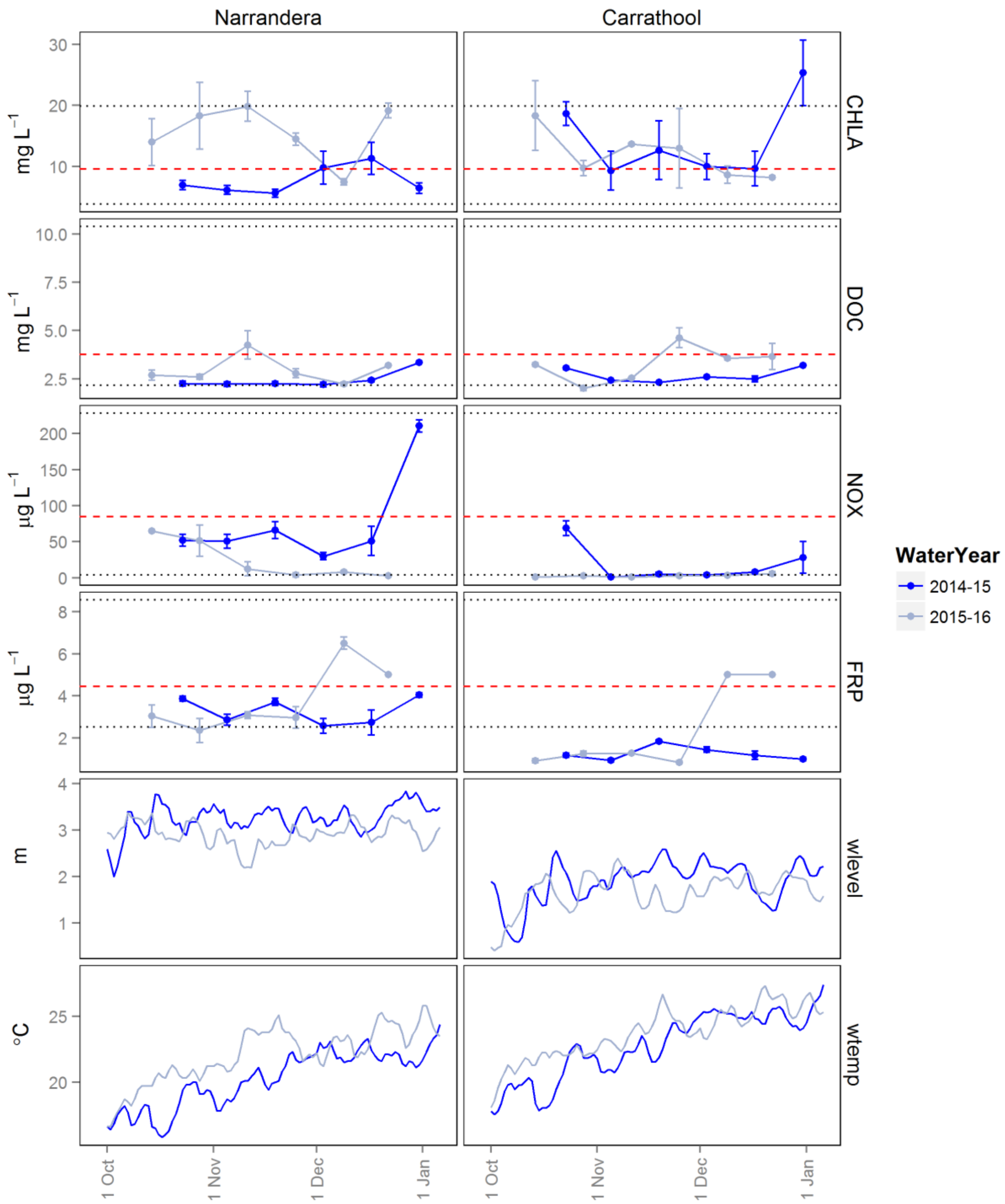


Figure 5-2 Mean ± standard error for filterable reactive phosphorus (FRP), total oxidised nitrogen (NOx), dissolved organic carbon (DOC) and chlorophyll-a (CHLA) measured on six occasions between October and December during 2014-15 and 2015-16. Data are the mean of three sites ± standard error of the mean. Mean daily water level (wlevel) is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature (wtemp) was monitored continuously. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for river sites in Murrumbidgee.

Discussion

What are the baseline physicochemical conditions in the Murrumbidgee River?

Water quality across both 2014-15 and 2015-16 fell within a narrow range. This is consistent with previous findings and below ANZECC (2000) water quality guidelines across all variables, except for high chlorophyll-a and pH. High-order interaction terms were significant across all variables reflecting both a high degree of similarity among replicate sites and moderate differences within and between water years. There was no evidence of adverse water quality events in either of the studied years.

During November 2015, falling water levels, coinciding with increasing water temperature and reduced turbidity, may have contributed to increased electrical conductivity, DOC and chlorophyll-a. The combined increases in hydrological retention, solar exposure and temperature can affect water quality during low flows (Kobayashi, Ryder et al. 2011), creating positive outcomes for fish when low flows increase availability of food and slow-flow habitat (Humphries, King et al. 1999). Higher pH also appeared to coincide with falling water levels, exceeding ANZECC water quality guidelines.

What are the baseline nutrient, carbon and chlorophyll-a concentrations in the Murrumbidgee River?

Overall, relatively low nutrient concentrations in the Murrumbidgee River are also consistent with previous findings and are within the ANZECC (2000) water quality guidelines. Current findings indicate that nutrient and carbon concentrations are similar to those reported for other regulated lowland river systems in the Murray - Darling Basin. There is speculation that production in the Murrumbidgee River is limited by the supply of carbon and nutrients from lateral reconnection events (Vink, Bormans et al. 2005). The mid-Murrumbidgee contains many fringing wetlands, riparian zones and flood-runners that can be connected to the river by natural events, triggering aquatic processes at the water-sediment interface and within the water-column (Baldwin and Mitchell 2000, Knowles, Iles et al. 2012) and transporting nutrients into the river channel with water returning to the river. The nutrient results suggest these processes were not activated during the monitoring period in either 2014-15 or 2015-16. However, higher nutrient and carbon concentrations were observed during 2011 and 2012 (Wassens, Jenkins et al. 2013, Wassens, Jenkins et al. 2014) following large overbank flows. Therefore, a broad-scale wetland reconnection event is likely to create positive changes in water quality, increasing the availability of resources for aquatic consumers.

5.16 Stream metabolism

Introduction

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

During 2014-15 and 2015-16 there were no Commonwealth environmental watering actions specifically targeting in-channel responses, although environmental flows did pass down the river channel while being delivered elsewhere. Long-term watering plans for the Murrumbidgee River (Commonwealth of Australia 2015) forecast in-channel deliveries of Commonwealth environmental water to support habitat and food sources and promote increased movement, recruitment and survival of native fish and other aquatic biota. In the absence of targeted environmental water deliveries we investigated the relationship between stream metabolism and river flows during 2014-15 and 2015-16 and discuss these findings with regard to future deliveries of Commonwealth environmental water.

Methods

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

Data analysis

Daily rates of ecosystem metabolism were calculated using the BASE modelling package in the statistical-computing environment R (Grace, Giling et al. 2015). There has been a recent update to the BASE package that has not been applied to the results here.

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

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

with errors

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

where y_t is the value of GPP (mg O_2 L^{-1} d^{-1}) or ER (mg O_2 L^{-1} d^{-1}) at day t, β_0 and β_1 are regression coefficients (i.e. intercept and slope estimates), x_t is the value of mean daily water level (m d^{-1}) at day t, ε_t and $\varepsilon_{t-1}$are the errors at days t and $t-1$, ρ is the first-order autocorrelation coefficient, and ω_t ~ iid $N\,(0, \sigma^2)$. A Cochrane-Orcutt procedure was used to model and predict GPP and EP using AR(1) errors for each site and each water year with the significance level of 0.05 (Cochrane and Orcutt 1949, Chatterjee and Simonoff 2013). Prior to analysis, missing values were fitted with spline interpolation. All statistical analyses were performed using the statistical-computing environment 'R' (R Development Core Team 2014).

Results

Summary statistics for GPP, ER and water level at the Narrandera and Carrathool sites are presented in Table 5-3. GPP and ER varied through time at both sites, but median values broadly fell within the same range of 0.79-1.55 and 0.81-1.36 mgO_2 L^{-1} d^{-1}, respectively (Figure 5-3). At the Narrandera site, GPP was slightly increased and ER slightly decreased in 2015-16. The resulting GPP/ER ratio (PR_ratio, Figure 5-3) was < 1 at both Narrandera and Carrathool during the 2014-15 water year, but was > 1 at Narrandera but remained ~1 at Carrathool for both water years.

The overall mean water level at Narrandera and Carrathool was similar between the two water years (Figure 5-3) but was consistently higher in the Narrandera zone during 2014-15 than 2015-16. All flows were typically within-channel, not engaging floodplain or riparian areas.

Table 5-3 Summary statistics for stream metabolism at Narrandera and Carrathool in the Murrumbidgee River (GPP: Gross Primary Productivity; ER: Ecosystem Respiration).

	Narrandera		Carrathool	
Monitoring period	2014-15	2015-16	2014-15	2015-16
	23/10/2014 – 18/01/2015 (88 days)	01/10/2015 – 01/02/2016 (124 days)	21/10/2014 – 30/4/2015 (192 days)	01/10/2015 – 01/04/2016 (184 days)
Number of available observations (number of missing observations)	86 (2)	120 (4)	188 (4)	172 (12)
GPP (mg O_2 L^{-1} d^{-1}) mean (median) [range]	0.87 (0.79) [0.24-2.15]	1.67 (1.55) [0.45-4.65]	1.19 (1.03) [0.45-2.84]	1.40 (1.27) [0.37-6.06]
ER (mg O_2 L^{-1} d^{-1}) mean (median) [range]	1.26 (1.21) [0.57-4.28]	0.90 (0.81) [0.32-3.72]	1.55 (1.29) [0.55-4.40]	1.50 (1.36) [0.27-7.00]
GPP/ER ratio mean (median) [range]	0.72 (0.63) [0.17-2.22]	2.04 (1.74) [0.72-7.74]	0.84 (0.74) [0.24-3.17]	1.08 (0.93) [0.30-3.40]
Water level (m) mean (median) [range]	3.33 (3.36) [2.70-3.93]	2.95 (2.95) [2.19-3.37]	1.60 (1.61) [0.20-3.07]	1.56 (1.64) [0.40-2.62]

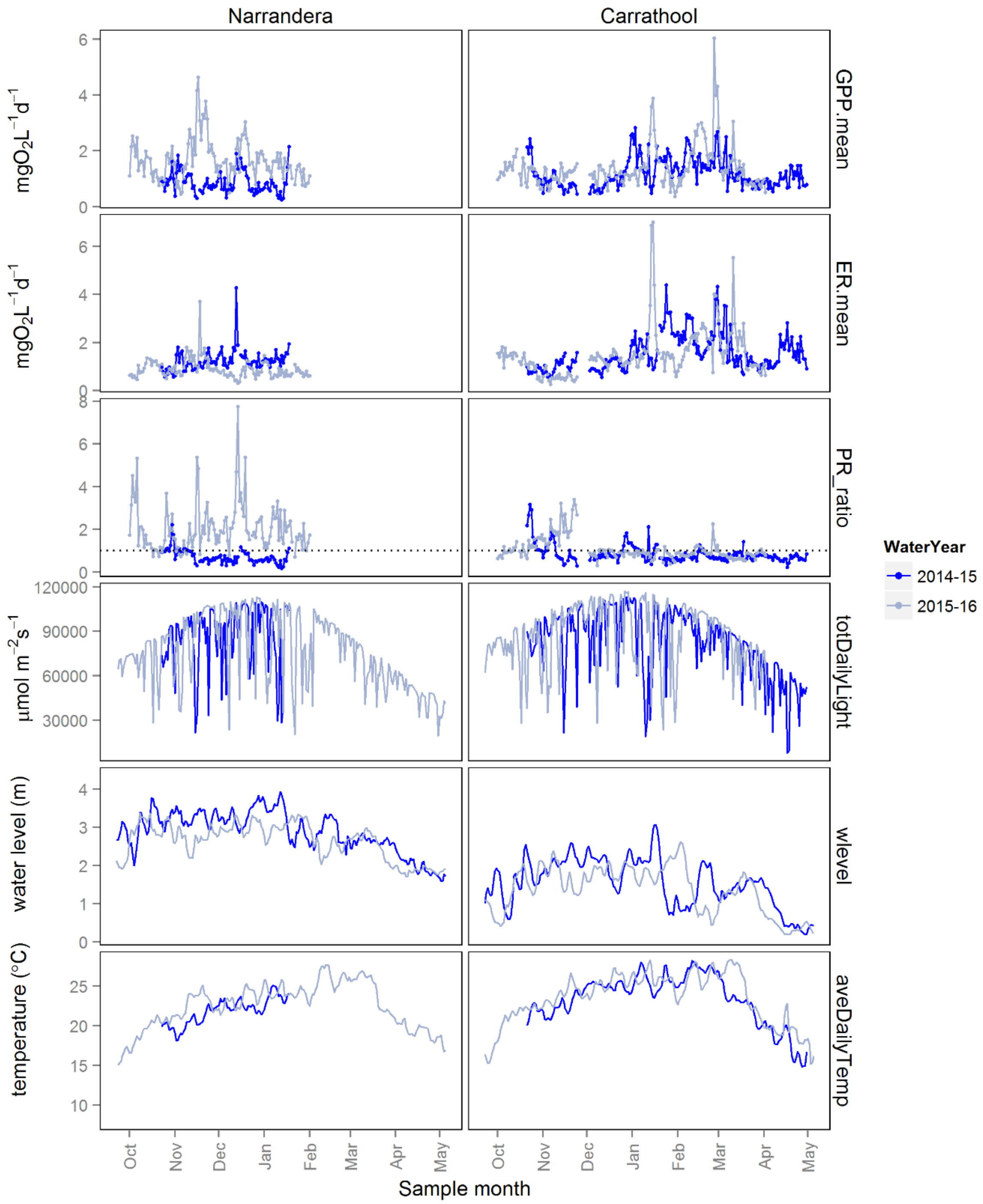


Figure 5-3 Metabolism results (GPP.mean – gross primary production; ER.mean – ecosystem respiration; PR_ratio – the ratio of GPP:ER) measured continuously at the Narrandera Cat3 (October to December) and Carrathool Cat 1 (October to April) sites. The P:R ratio of 1 is indicated by the dotted line. Data are shown for 2014-15 and 2015-16 using ordinal date on the x-axis. Total daily light (totDailyLight) is calculated as the sum of all 10-minute measures collected in a single 24 hour period. Mean daily water level (wlevel) is taken from the Narrandera and Carrathool gauges (see http://waterinfo.nsw.gov.au/). Mean daily water temperature (wtemp) was monitored continuously.

Linear regression analysis showed significant negative relationships between water level and GPP at Narrandera for the 2014-15 water year (Adjusted R^2 = 0.70, $F_{2,85}$ = 101.2, P <0.0001) and ER at Narrandera for the 2015-16 water year (Adjusted R^2 = 0.75, $F_{2,121}$ = 188.2, P <0.0001; Figure 5-4). No significant relationship was found between stream metabolism (either GPP or ER) and water level at Carrathool for either water year.

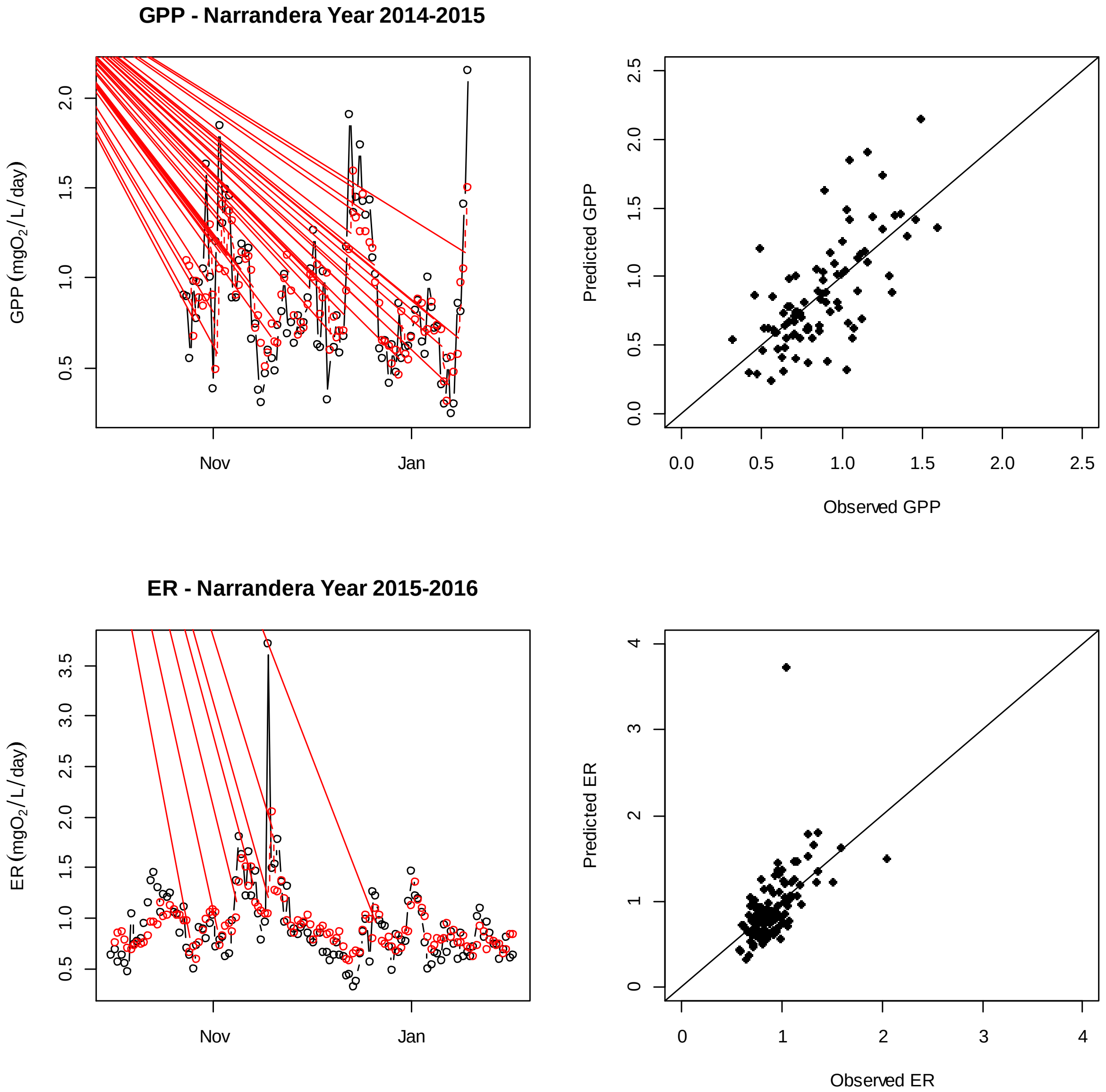


Figure 5-4 Predicted and observed values of gross primary productivity (GPP) at Narrandera for the 2014-15 water year (upper panel) and ecosystem respiration (ER) at Narrandera for the 2015-16 water year (lower panel), based on linear regression model with autoregressive errors of a lag-1, using mean daily water level (m d^{-1}) as a predictor. For the time-series plot (upper and lower left columns), the predicted values are shown by open red circles and the observed values are shown by open black circles.

Discussion

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

Overall rates of metabolism in the Murrumbidgee remain slightly lower than other published data for the Murray-Darling Basin and previous studies from the Murrumbidgee (Vink, Bormans et al. 2005). As noted by Wassens, Thiem et al. (2015), the discrepancy with the findings by Vink (2005) may be explained by differences in methodology (Song, Dodds, et al. 2016). This issue will be addressed in the 2016-17 Murrumbidgee LTIM Selected Area evaluation report. If rates of metabolism in the Murrumbidgee River have been reduced by the loss of nutrients and energy provided during overbank flood events then environmental flows that re-engage lateral and longitudinal connections, flushing nutrients and energy from adjacent floodplain soils into the river, will boost river productivity.

Rates of metabolism were relatively consistent between the two monitored zones despite the overall difference in flow height and variability. There was an apparent overall increase in GPP and decline in ER at the Narrandera site during 2015-16 that shifted net ecosystem metabolism toward primary production (P:R ratio >1). At this early stage in the metabolism monitoring program, we are unable to explain this shift, although apparent differences in flow height between the two years suggests a possible link with hydrology (see below). Overall, flow regulation is thought to favour increased primary production and that increased lateral carbon inputs should drive the system towards net heterotrophy (P:R <1; Robertson et al. 1999).

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

Rates of metabolism varied across time at both study sites, with peak values loosely coinciding with both high and low flows. However, we found little evidence of a strong predictive relationship between flow and metabolism, particularly in the Carrathool zone. The overarching mechanisms by which flow is expected to influence metabolism are 1) wetland and riparian reconnection events that increase the supply of bioavailable nutrients and carbon that support increased rates of production and 2) high flows that scour river biofilms, resuspending nutrients previously tied up in biomass and detritus held in biofilms and by resetting biofilm community succession (Battin, Kaplan et al. 2008). Low flows also create conditions that favour higher rates of production (Humphries, King et al. 1999). The relationship between flow and metabolism is therefore unlikely to be a consistent linear trend, and we might expect step-changes to rates of metabolism at thresholds where adjacent wetlands are reconnected with the river, when benthic shear stress exceeds that needed to scour the benthos, or when light saturates the water column. We note that high-flow events are generally absent from the current dataset while there were periods when flows were reduced. This may account for the observed negative relationships between flow and GPP (Narrandera zone, 2014-15) and ER (Narrandera zone, 2015-16).

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

5.17 Riverine microinvertebrates

Prepared by Dr Kim Jenkins

Introduction

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

Commonwealth environmental water was not directly targeted at in-channel watering outcomes during 2014-15 and 2015-16 however the transfer of water to floodplain habitats and an in-channel watering action in 2015 to Yanco Creek contributed to increased flow and hydrological variability, providing baseline information to inform the use of environmental flows to support vertebrate food sources and maintain water quality in the river. 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 both 2014 and 2015. 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 both years there were 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 and Timms 1983, Shiel and Dickson 1995, Shiel 1995). A maximum of 30 individuals of each taxa per sample were measured for length and width.

Data analysis

Daily stream gauging data from Narrandera (WaterNSW gauge 410005) and Carrathool (gauge 410078) was used to graphically represent daily water level changes in respective hydrological zones. To determine differences in benthic microinvertebrate density and length between zones, years and over time within each year, data were analysed using a three-way fixed factor (with year, zone and time(year) as factors) Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008). Raw data were used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$.

Results

In both years, densities of microinvertebrates were two orders of magnitude higher in benthic (<3000/L) than pelagic (<10/L) habitats within the Murrumbidgee River (Figure 5-5). Pelagic densities were consistently an order of magnitude below the lowest prey density threshold suggested for successful feeding by larval fish and so we focussed our analysis only on benthic microinvertebrates. There were no significant differences between zone for densities of total microinvertebrates and all other taxonomic groups apart from copepods that were significantly higher in the Carrathool than Narrandera zone (Term 1, Table 5-4, Figure 5-5 and Figure 5-6). Nevertheless, in both years higher peak densities in cladocerans and ostracods were observed in Carrathool zone, at the Yarradda and McKenna's sites, with high variability among sites over time.

Both cladocerans and ostracods were significantly higher in 2014-15 than 2015-16, due to some extremely high peaks in density in December 2014 (Term 2 Table 5-4, Figure 5-6). Although other taxa showed similar trends, they did not differ significantly between years. Cladoceran and copepod densities were significantly different among trips nested within year (Table 5-4, Terms 2 and 3, Figure 5-6). This was due to densities of both peaking earlier in 2015-16 than in 2014-15, as well as the copepod peak in 2014-15 being higher than both the peals in 2015-16 (Figure 5-6). The patterns in cladoceran densities was also significantly different among trips between zones (Term 5, Figure 5-6).

Patterns in biovolume (length x width x density) reflect patterns for density (Figure 5-5 and Figure 5-7) with a later peak in December 2014 than in 2015 when biovolume peaked in early November. Biovolume was higher in the Carrathool than Narrandera zone (Figure 5-7).

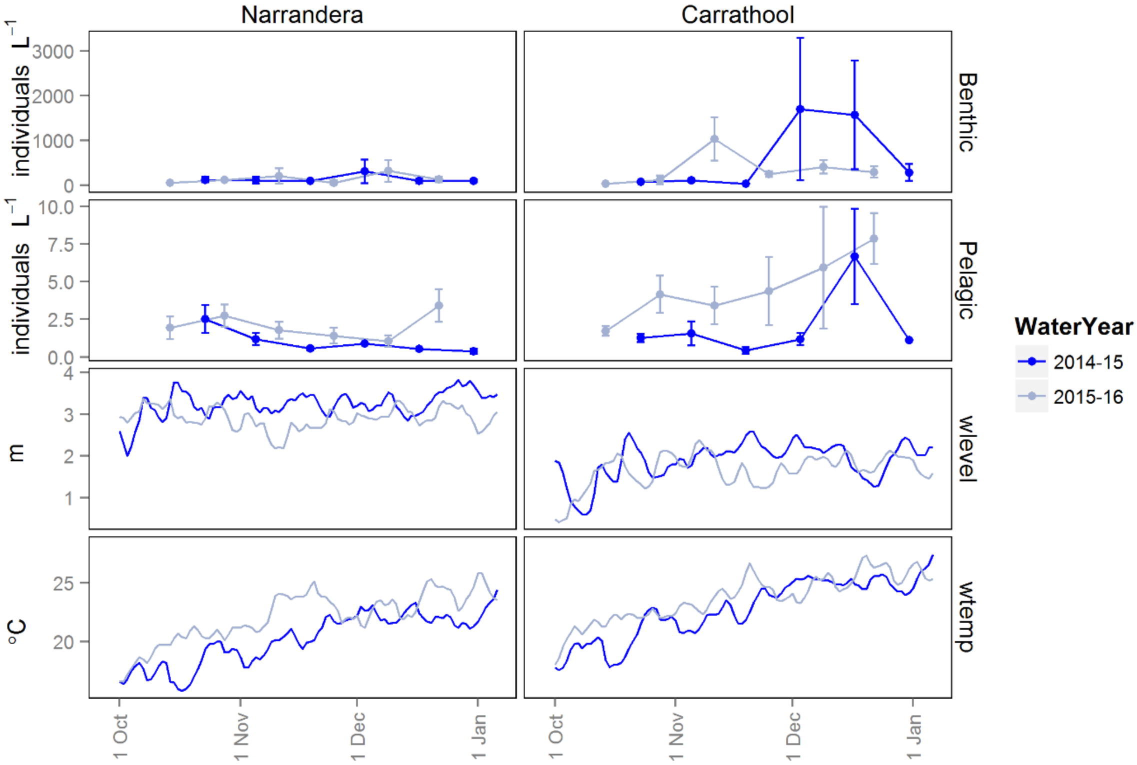


Figure 5-5. Mean densities of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in Narrandera and Carrathool zones in 2014-15 (dark blue) and 2015-16 (light blue). Water level (third row) and water temperature (fourth row) are also shown. Errors are standard errors.

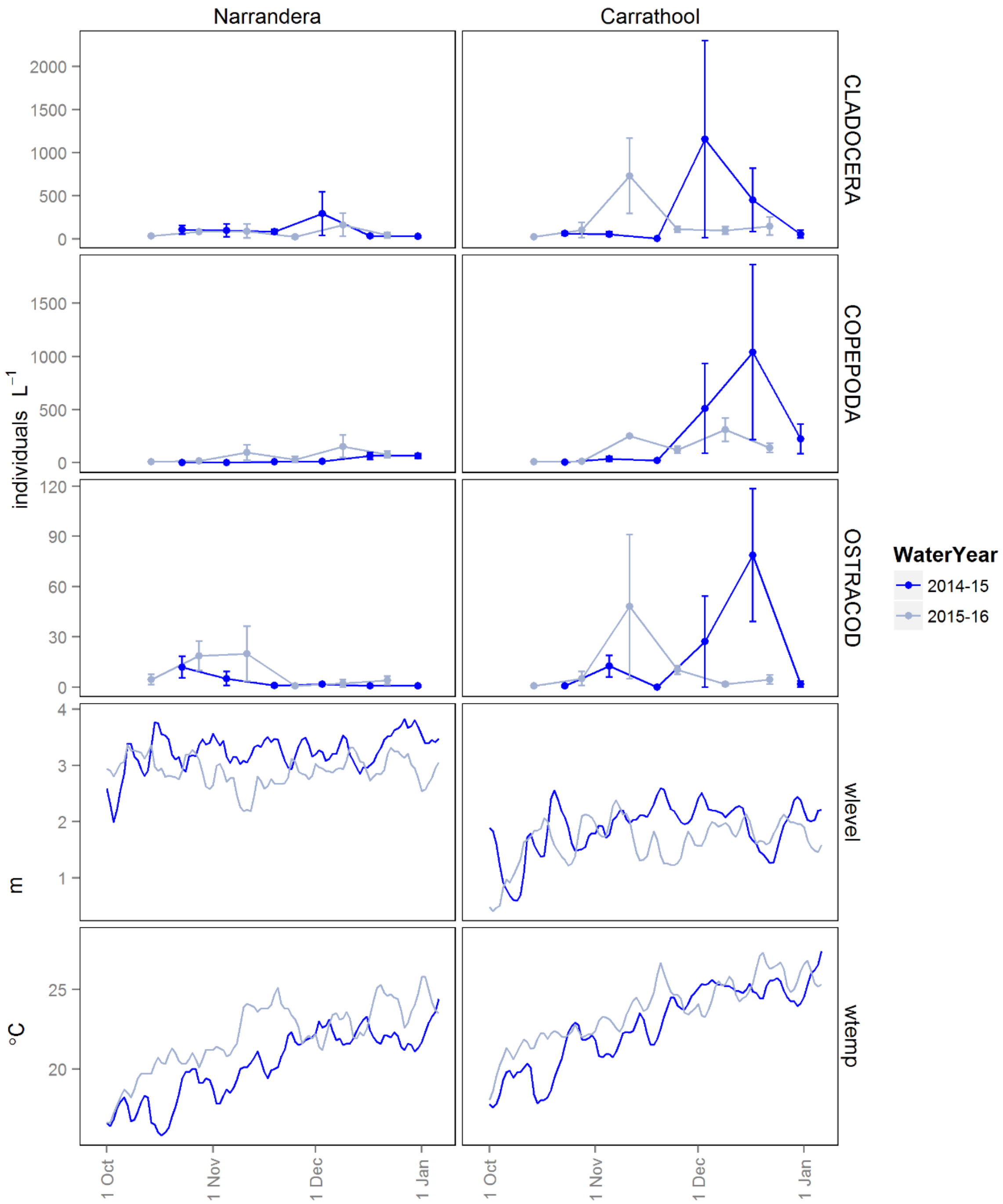


Figure 5-6 Mean densities of the main taxonomic groups of benthic microinvertebrates across sampling trips in Narrandera and Carrathool zones in 2014-15 (dark blue) and 2015-16 (light blue). Data are shown for cladocerans (first row), copepods (second row) and ostracods (third row). Water level (sixth row) and water temperature (seventh row) are also shown. Errors are standard errors.

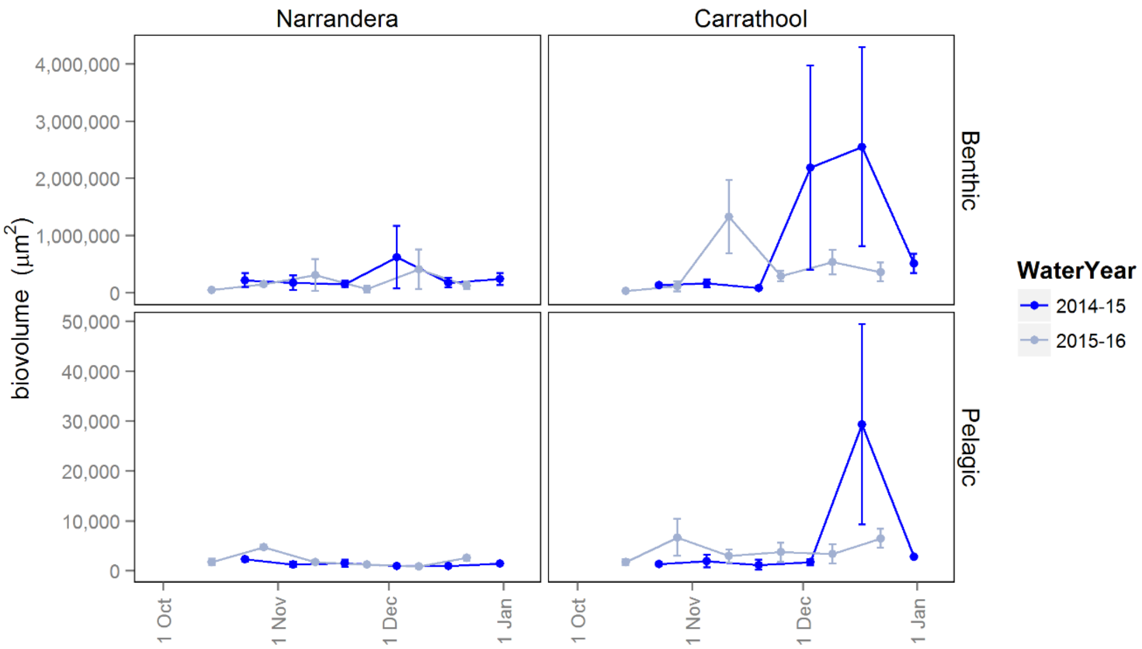


Figure 5-7 Mean biovolume (length x width x density) of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in Narrandera and Carrathool zones in 2014-15 (dark blue) and 2015-16 (light blue).

Table 5-4 PERMANOVA results for densities of microinvertebrates, cladocerans, copepods and ostracods in each zone, microhabitat (benthic vs pelagic) and survey period. F is Pseudo-F.

Term	**Microinvertebrate density**		**Cladocera density**		**Copepod density**		**Ostracod density**	
	F	p	F	p	F	p	F	p
1. Zone (ZO)	3.100	0.075	1.892	0.11	6.602	**0.002**	0.444	0.676
2. Year (YR)	0.590	0.489	8.740	**0.001**	2.364	0.067	3.538	**0.034**
3. Trip (Year) TR(YR)	0.955	0.426	2.291	**0.011**	4.105	**0.001**	1.191	0.254
4. ZO x YR	0.475	0.524	1.892	0.126	0.882	0.45	0.992	0.373
5. ZO x TR(YR)	0.609	0.881	1.830	**0.029**	1.256	0.184	1.494	0.086

Discussion

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

The delivery of Commonwealth environmental water to creeks and wetlands in the mid to lower Murrumbidgee resulted in peaks in flow within the Murrumbidgee River in the Carrathool Zone and to a lesser extent in the Narrandera Zone (See Figure 5-5). Peaks in benthic microinvertebrate densities in the Carrathool Zone were recorded 7-10 days after river levels peaked as water levels were falling (Figure 5-5 and Figure

5-6). In 2014-15 this occurred in mid-December for chydorids, ostracods and copepods, while in 2015-16 this occurred in mid-November.

The peak in benthic microinvertebrate densities in 2015-16 coincided with peaks in Australian smelt and cod species captured in light traps (see Section 5.18). However peak numbers of cod species and perch captured in drift nets occurred two weeks earlier in late October, suggesting peak densities of larval fish and microinvertebrates were offset. This mismatch in timing between peaks was more apparent in 2014-15 when larval fish numbers peaked in early to mid-November (see Section 5.18) well before the peak in microinvertebrate densities in early to mid-December (see Figure 5-5 and Figure 5-6).

Densities of pelagic microinvertebrates were two to three orders of magnitude lower than benthic densities throughout the 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.

River levels in the Narrandera zone were at least 1 metre higher than in the Carrathool zone and there was less variability in river level (Figure 5-5). It appears that the higher river level in the Narrandera zone may impact development of a productive and diverse microinvertebrate community. In contrast in the Carrathool zone with lower more variable river levels, pronounced peaks in microinvertebrate densities were recorded in both 2014-15 and 2015-16. This is likely due to drying and then rewetting of edge sediments stimulating nutrient release that then supports peak densities of microinvertebrates. In addition, when river levels are higher and flow faster it is likely that benthic microinvertebrates may be flushed from this habitat. However, further studies with additional zones are needed to replicate these observations. In addition, before, during and after monitoring as river levels rise, peak and fall would help unravel if these aspects of hydrology are driving the patterns observed in microinvertebrate community dynamics.

5.18 Riverine and larval fish

Introduction

Flow plays a critical role in the early life-cycle of native fish, and the duration, magnitude and timing of flows strongly influence adult spawning and subsequent survival and growth of larvae (King, Gwinn et al. 2015). The larvae stage is the most critical and vulnerable part of a fish's life history. Larval fish survival is highly dependent on hydrology which influences habitat availability (Copp 1992), water temperature (Rolls, Growns et al. 2013), dispersal (Gilligan and Schiller 2003) and microinvertebrate abundance for first feed (King 2004). Commonwealth environmental water targeting native fish has the capacity to positively influence reproductive opportunities, enhance larval survival, and hence, increase recruitment to the wider population. Understanding the critical links between flow, fish spawning and larval fish survival can assist the management of environmental flows to support and enhance native fish populations.

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

Commonwealth environmental water was not directly targeted at in-channel watering outcomes during 2015-16, however the transfer of water to wetland and floodplain habitats resulted in the presence of Commonwealth Water during in-channel monitoring activities.

Methods

Larval fish were collected using methods described by (Wassens, Jenkins et al. 2014). Larval fish sampling was undertaken at six riverine sites, with three sites selected within each of two hydrological zones (Figure 5-8). Eight larval drift nets and ten quatrefoil light traps were set overnight at each riverine site. Equipment and methods were consistent with those described by Hale, Stoffels et al. (2013), with the exception being that five additional larval drift nets were set at each site to adequately detect commonly encountered larvae such as Murray cod (*Maccullochella peelii*). Sampling was undertaken fortnightly from 13 October until 24 December 2015, 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 year (2014-15; (Wassens, Thiem et al. 2015)). Eggs were live-picked and enumerated from drift net samples in the field, and a subset of these were hatched in river water at ambient temperatures. Larvae were subsequently identified to species in the laboratory. With the exception of juvenile Murray River crayfish (*Euastacus armatus*) and freshwater yabby (*Cherax destructor*), entire samples collected from both light traps and drift nets were preserved in 90% ethanol for later laboratory identification using keys described in Serafini and Humphries (2004).

A sub-sample of 26 larvae hatched from live-picked eggs and 26 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 PCR amplification. Genetic assignment of golden perch and silver perch generally conformed to laboratory identification based on morphological characteristics, and species assignment to egg captures was scaled for each site and trip based on the ratios of hatched and identified larvae and eggs. A sub-sample of five larval cod (*Maccullochella* spp.) captured in light traps from the Narrandera zone during the first two sampling events were also submitted to AGRF to differentiate between Murray cod and trout cod

(*Maccullochella macquariensis*) captures, as both species occur within this zone. Four samples were confirmed to be trout cod and one Murray cod. Although, given that drift net samples were not submitted for DNA, and represent the predominant method of capture, samples were pooled at the genus level (i.e. *Maccullochella* spp.) due to difficulties with species identification, as per previous short-term intervention monitoring (Wassens et al. 2013, 2014).

Data analysis

Data were standardised to a single value per species, site, sampling event and method (i.e. total catch for each species from a site was pooled by sampling method) and are represented as catch per unit effort (CPUE; number of larvae per light trap hour or the number of larvae per cubic metre of water filtered). Juveniles and adults were excluded from analysis and reporting. Daily stream gauging data from Narrandera (WaterNSW gauge 410005) and Carrathool (gauge 410078) was used to represent daily water level changes in respective hydrological zones. To determine differences in larval fish CPUE between zones (Narrandera and Carrathool) and years (2014-15 and 2015-16), data were analysed using a two-way fixed factor (with zone and year as factors) Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, SIMPER tests were used to identify individual species contributions to average dissimilarities.

A linear mixed-effect modelling approach was undertaken to examine the (binary) probability of periodic species spawning (golden perch and silver perch) in response to abiotic factors (hydrology and temperature). Briefly, model-selection was undertaken examining a suite of hydrological (water level, cumulative water level and changes in water level) and climatic (water temperature, changes in water temperature) variables for each hydrological zone during each of the sampling events within both watering years. Only linear associations were considered during this early developmental stage of the project and the top predictor combinations are presented graphically.

Category 1 Fish Community data collected from the focal zone in both March 2015 and March 2016 (encompassing Yarradda, Bringagee and McKennas larval sampling sites) as per Hale, Stoffels et al. (2013) are presented to examine whether spawning in either watering year translated into young-of-year recruitment. Specifically, length-frequency plots are presented to indicate the presence of new recruits as a proportion of the sampled population.

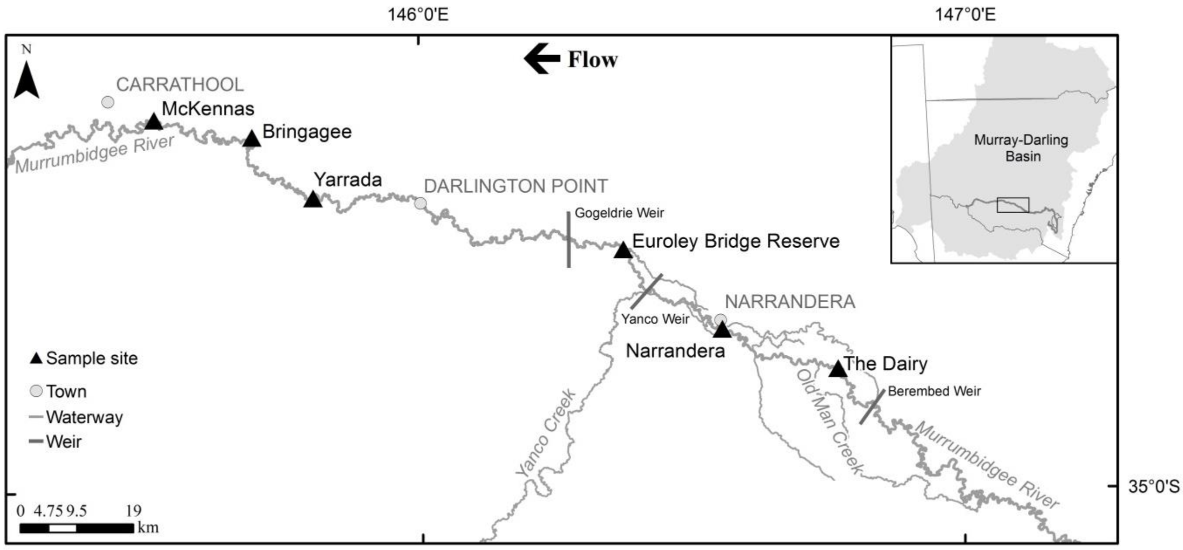


Figure 5-8 Locations of larval fish in-channel sampling sites on the Murrumbidgee River, encompassing Narrandera (The Dairy (DAI), Narrandera (NRD) and Euroley Bridge (EUB)) and Carrathool (Yarradda (YRR), Bringagee (BRI) and McKennas (MKR)) hydrological zones.

Results

A combined total of 4,291 eggs and larvae were collected during the 2015-16 sampling. At least nine native fish species (Australian smelt (*Retropinna semoni)*, bony herring (*Nematalosa erebi)*, carp gudgeon (*Hypseleotris* spp.), flat-headed gudgeon (*Philypnodon grandiceps)*, golden perch (*Macquaria ambigua)*, Murray cod (*Maccullochella peelii)*, Murray-Darling rainbowfish (*Melanotaenia fluviatilis)*, silver perch (*Bidyanus bidyanus)* and trout cod (*Maccullochella macquariensis)*) and one alien species (common carp (*Cyprinus carpio)*) spawned in the Murrumbidgee River in 2015-16 (Table 5-5). Additionally, early stage juvenile Murray River crayfish and freshwater yabby were captured in drift nets (Table 5-5). Cod species (*Maccullochella* spp.) were captured in the greatest abundance (*n*=1925), and occurred at all combinations of sites and using both methods (Table 5-5). Australian smelt larvae were also abundant (*n*=802) and were captured at all sites primarily in light traps. Both silver perch and golden perch eggs were captured in both hydrological zones using drift nets. Silver perch eggs were captured at all sampling sites and in a higher abundance

(n=1191) than golden perch eggs (n=144) which were captured at four sites. One golden perch larvae (post-flexion stage estimated at ~20 days post-hatch) was captured at McKennas in the Carrathool zone in mid-November 2015.

Catch per unit effort of larvae and eggs did not differ significantly between years (*Pseudo*-$F_{1,67}$ = 0.618, P =0.648), although did differ significantly between hydrological zones (*Pseudo*-$F_{1,67}$ = 4.832, P =0.001). There was no significant difference in the interaction between year and zone (*Pseudo*-$F_{1,67}$ =1.680, P =0.164). SIMPER analysis indicated that the observed differences among zones were primarily driven by variability in the abundance of Australian smelt, cod species and carp gudgeon larvae, with the abundance of all three higher in the Carrathool zone.

Distinct peaks were evident in the timing of collection of larvae and eggs of most fish species in 2015-16. Australian smelt larvae were more abundant in the Carrathool zone, and catch data displayed similar bi-modal peaks to 2014-15, with highest catches in early October and early November. Carp gudgeon larvae likewise were more abundant in the Carrathool zone, and captures peaked in December when water temperatures consistently exceeded 25 °C (Figure 5-9 and Figure 5-10). Conversely, captures of cod larvae peaked in mid-November 2015 in the Narrandera zone (water temperature 24 °C) and late October – mid-November 2015 in the Carrathool zone (23 °C) (Figure 5-9 and Figure 5-10). Bony herring larvae were only captured in the Carrathool zone, in November and December. Flat-headed gudgeon larvae were captured at multiple sites in both the Narrandera and Carrathool zones in both November and December. Murray-Darling rainbowfish were only captured in the Narrandera zone using light traps in both November and December. Trout cod metalarvae were captured in light traps in the Narrandera zone only, and these captures were in late October 2015. Common carp eggs were captured at the Dairy site in the Narrandera zone in late October, and larvae were captured at Narrandera zone sites Euroley Bridge and Narrandera in mid- and late-October, respectively.

Golden perch eggs were collected from one site in the Narrandera zone on weeks one (15 October 2015; water temperature 20 °C), two (29 October 2015; water temperature 21 °C) and three (12 November 2015; water temperature 24 °C). In the Carrathool zone, golden perch eggs were collected from two sites (Bringagee and Yarradda) on 28 October 2015 (22 °C; Figure 5-9). A golden perch larva was captured from McKennas site in the Carrathool zone on 10 November 2015. Predictive models indicated a weak negative relationship between the probability of golden perch spawning and ten day cumulative river levels (Figure 5-11a) and also a negative relationship with increasing water temperatures (Figure 5-11b). Silver perch eggs were collected from all sites in the Narrandera zone and in five of six sampling weeks, and captures peaked on 26 November 2015 (water temperature 21 °C; Figure 5-9). In the Carrathool zone, silver perch eggs were collected from two sites in week two (27–28 October 2015; water temperature 22 °C) and from all three sites in week five (8-9 December 2015; water temperature 25 °C), with peaks on the earlier sampling trip. No silver perch larvae were captured. Predictive models indicated a strong positive relationship between the probability of silver perch spawning at both higher river levels (Figure 5-11c) and water temperatures (Figure 5-11d).

All fish captured as eggs and/or larvae in the Carrathool zone during 2015-16 were represented in the fish community sampling undertaken in March 2016, with the exception of flat-headed gudgeon (Table 5-6). Four additional species were captured during March surveys including un-specked hardyhead, common carp, eastern gambusia and goldfish (Table 5-6). New recruits of the most abundant species were captured in the river with the exception of Murray-Darling rainbowfish (Figure 5-12) and golden perch (Figure 5-13). Additionally, no silver perch new recruits were captured.

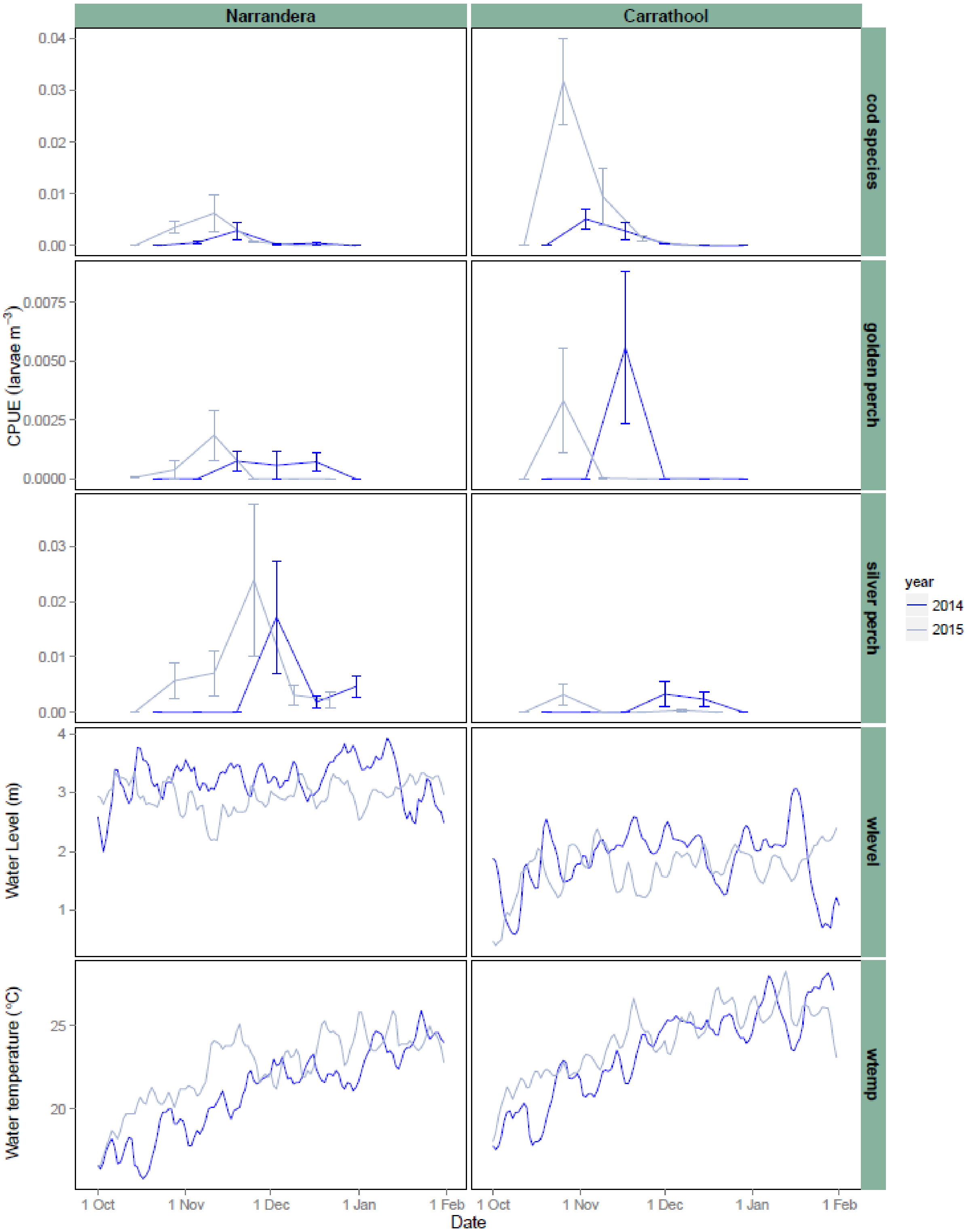


Figure 5-9 Larval drift net catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones in 2014 and 2015. The three most abundant species are represented, with captures of cod species represented by larvae, and golden and silver perch by eggs.

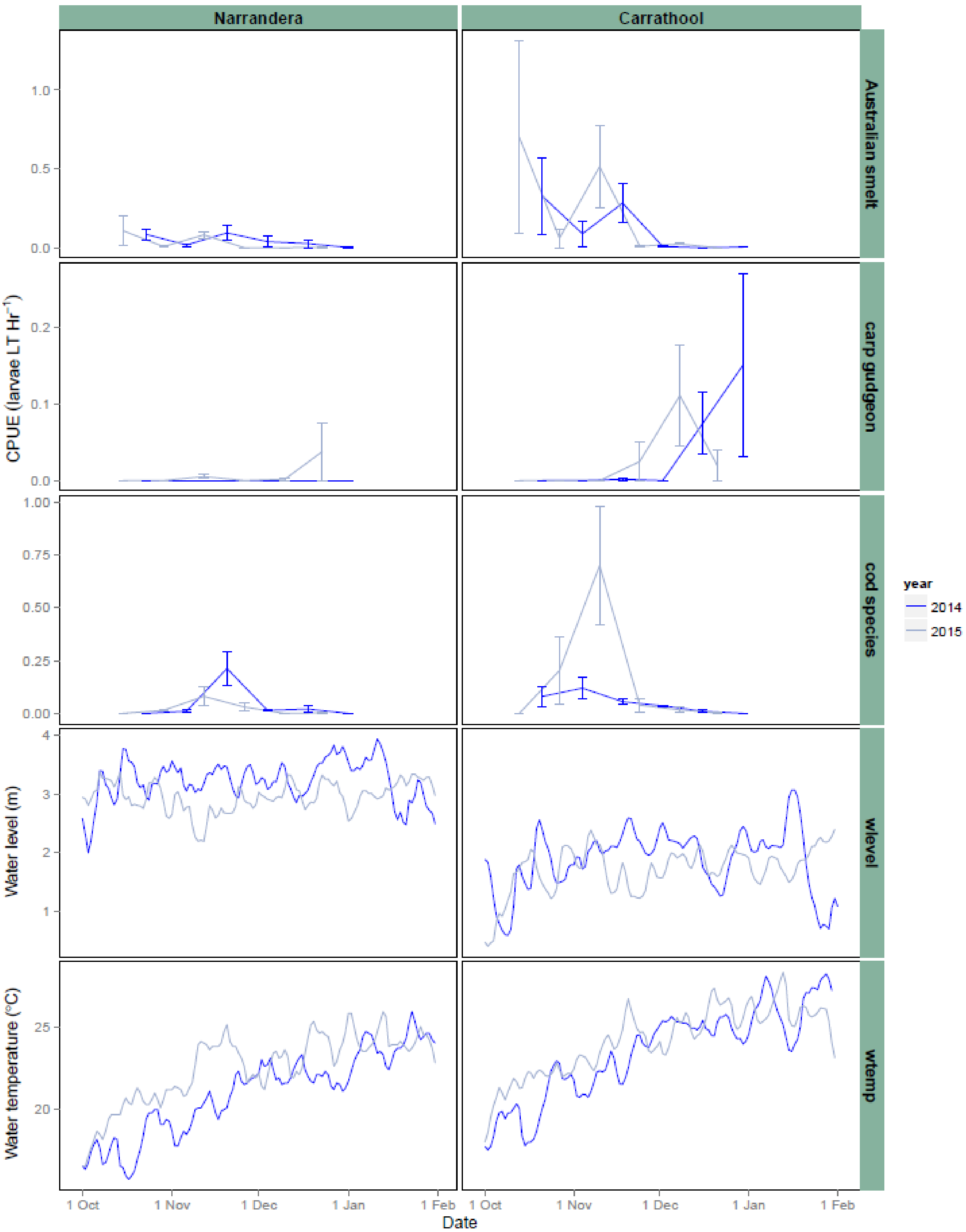


Figure 5-10 Larval light trap catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones in 2014 and 2015. Only captures of the three most abundant species larvae are represented.

Table 5-5 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 for each year.

		Hydrological zone											
		Narrandera						**Carrathool**					
		The Dairy		**Narrandera**		**Euroley Bridge**		**Yarradda**		**Bringagee**		**McKennas**	
	LH stage	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Native fish species													
Australian smelt	larvae	63	14	47	15	35	82	225	551	23	60	113	80
bony herring	larvae								5		1		1
carp gudgeon	larvae		1		21			72	55	31	24	12	3
cod species	larvae	112	107	74	113	43	78	95	446	176	606	309	575
flat-headed gudgeon	larvae		1		4				1		2		1
golden perch	eggs	48			55		8		56	330	25	19	
	larvae	1		41									1
Murray-Darling rainbowfish	larvae				1		5						
silver perch	eggs	84	194	172	700	264	220	75	53	6	2	18	22
trout cod	larvae		3		1								
unidentified	eggs	5		16		10	1	7		18		6	
	larvae		6	83	15	20	15		4		13	2	13
Alien fish species													
common carp	eggs		29										
	larvae				1	1	1			16		1	
redfin perch	larvae									1			
Other													
Murray River crayfish	juveniles	2	1	3	2	2	1				1		
freshwater yabby	juveniles			1		1		3	1	1	4	5	4

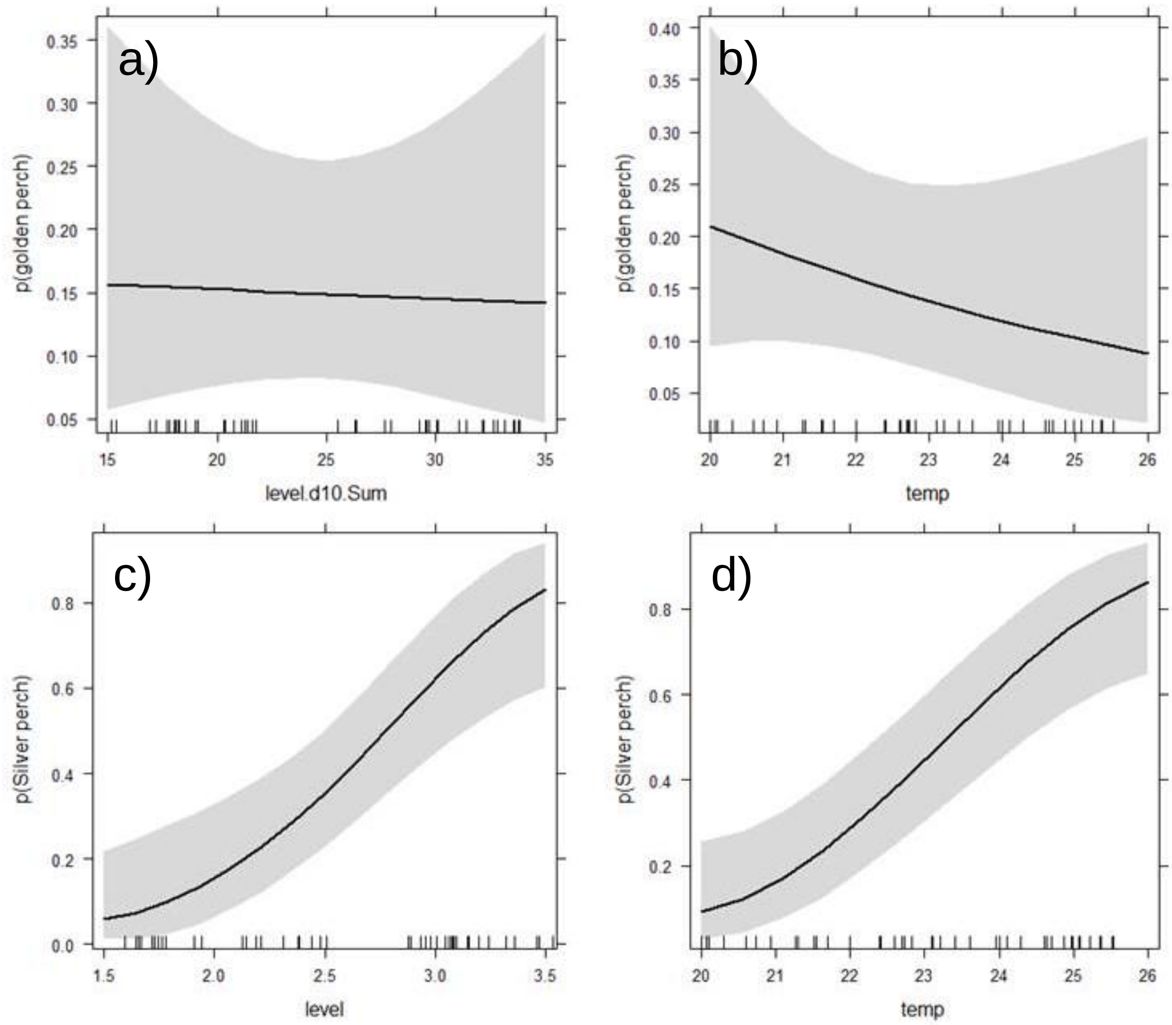


Figure 5-11 Predictive relationships generated from top-ranked models describing the spawning probably (p; y-axis) for a) golden perch in relation to water level (cumulative 10 day sum), b) golden perch in relation to daily water temperature (°C), c) silver perch in relation to daily water level (m) and d) silver perch in relation to daily water temperature (°C). Data were collected over two watering years (2014-15 and 2015-16) using larval drift nets in the Murrumbidgee River and probabilities are based on the presence/absence of drifting egg captures.

Table 5-6 Summary of fish captured during Category 1 standardised sampling in 2015 and 2016 in the Murrumbidgee LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	**2015**				**2016**			
	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**
native species								
Australian smelt	109	26		**135**	335	4		**339**
bony herring	438	2		**440**	360			**360**
carp gudgeon	9	205	18	**232**	22	704	39	**765**
golden perch	39			**39**	28			**28**
Murray cod	126	5		**131**	155			**155**
Murray-Darling rainbowfish	162	401		**563**	131	136		**267**
silver perch	1			**1**				**0**
un-specked hardyhead	4	2		**6**	4			**4**
alien species								
common carp	112			**112**	63			**63**
eastern gambusia	8	735	1	**744**	11	493	1	**505**
goldfish	11			**11**	3			**3**

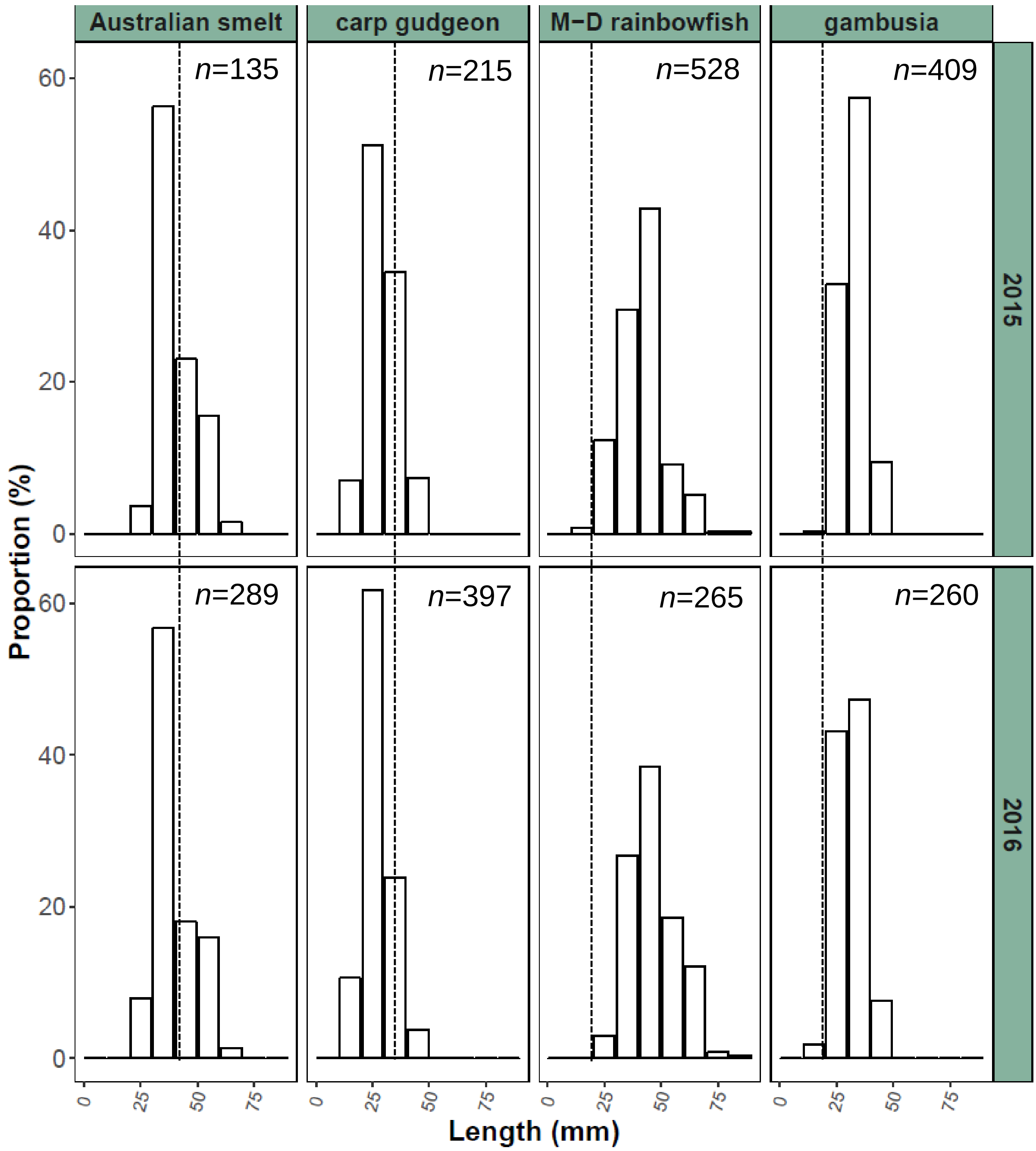


Figure 5-12 Length-frequency comparison between 2015 and 2016 of the four most abundant small-bodied fish species captured during Category 1 fish community sampling in the Murrumbidgee River. The dashed line indicates approximate size at sexual maturity.

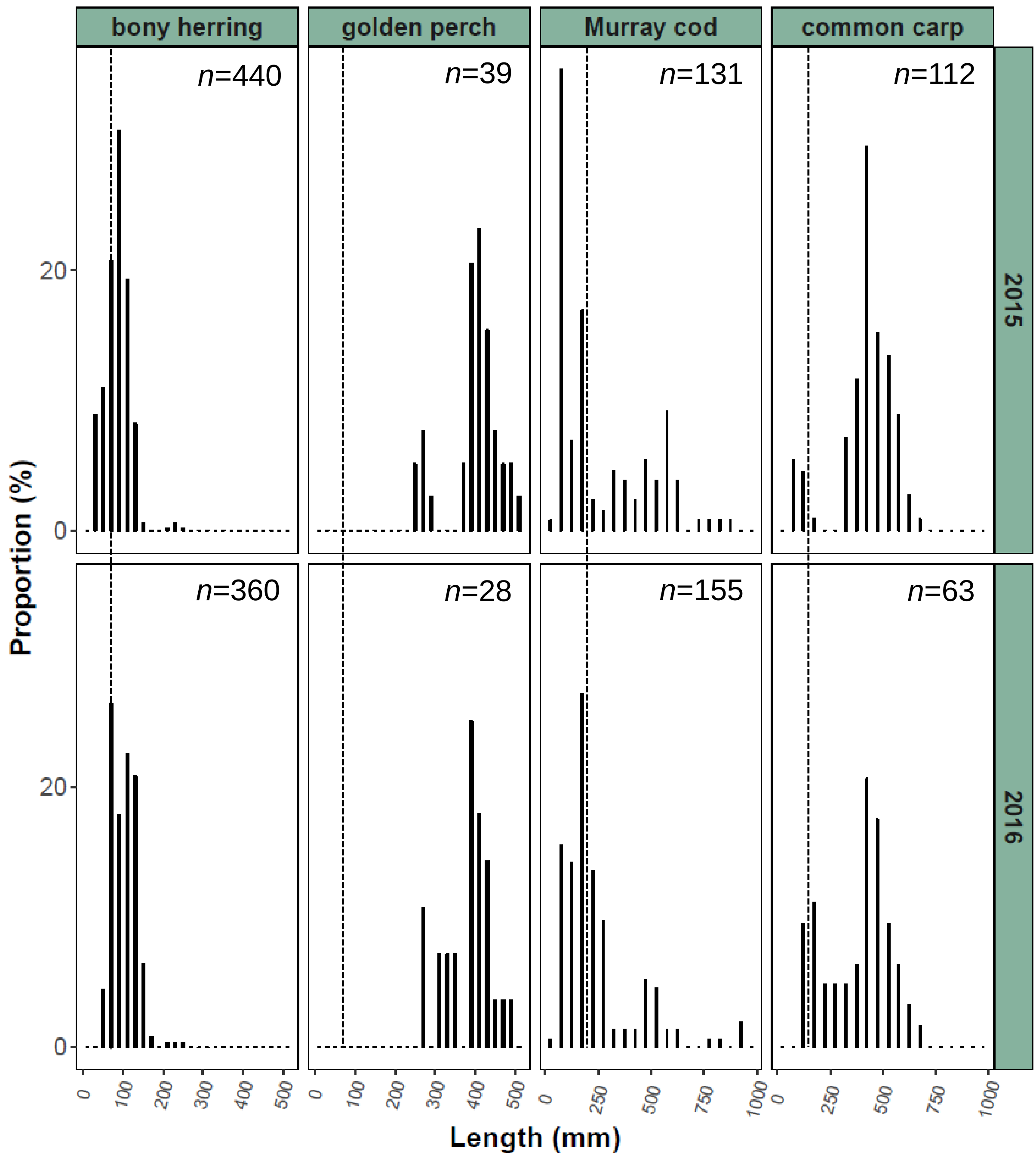


Figure 5-13 Length-frequency comparison between 2015 and 2016 of the four most abundant medium-large bodied fish species captured during Category 1 fish community sampling in the Murrumbidgee River. The dashed line indicates approximate size at one-year of age.

Discussion

What did Commonwealth environmental water contribute to native fish reproduction?

Commonwealth environmental water was delivered to Yanco Creek as well as wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee regions targeting a range of expected ecosystem outcomes. Whilst Commonwealth environmental water was not directly targeted at in-channel watering outcomes, the transfer of water to floodplain habitats impacted in-channel hydrology and we predicted that in-channel freshes resulting from water transfers would promote spawning in golden perch and silver perch. We also predicted that any flows including base-flows and larger events would enable spawning in non-flow-cued spawning species.

Delivery of Commonwealth environmental water coincided with spawning in at least nine native species of fish across the two hydrological zones. River blackfish and un-specked hardyhead were the only previously encountered native species not captured as eggs or larvae, although both are relatively uncommon in the selected area. The timing of egg and larvae capture was generally consistent with observations from 2014-15 and is also consistent with our understanding of the life-history requirements of the species encountered. The abundance of larvae was not significantly different between years, although significant difference between hydrological zones were evident in both years and these differences were driven by a higher abundance of Australian smelt, carp gudgeon and cod species in the Carrathool zone. Trout cod and common carp larvae are likely under-represented by the current temporal design of the sampling program, as both species generally spawn at cooler water temperatures prior to field sampling in October. Similarly, a number of species have a protracted spawning window (e.g. carp gudgeon, unspecked hardyhead) and are likely to continue spawning into late summer and early autumn and thus are likely underrepresented.

We predicted that in-channel freshes would promote spawning in golden perch and silver perch. Model predictions based on two years of monitoring in the Murrumbidgee selected area indicate an increasing probability of silver perch spawning with increasing river levels. This result is consistent with the recent findings of King, Gwinn et al. (2015) whereby silver perch spawning intensity increased with increasing discharge in the Murray River. In contrast, the best hydrological predictor of golden perch spawning was a 10-day cumulative river level, and model predictions indicated a weak negative association with the probability of golden perch spawning. This finding contradicts recent evidence from King, Gwinn et al. (2015) although it is worthwhile noting that spawning in both species has occurred independently of any discernible river level rise and at stable bankfull summer irrigation flows in the Murray River (e.g. Gilligan and Schiller 2003, King, Crook et al. 2005, Koster, Dawson et al. 2014). Further, the data input for the current models reflect only the small period of time for which sampling has been undertaken and the associated abiotic conditions during that time. The evidence presented to date 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. For example, the broad definition of in-channel freshes is generally met all summer in the Murrumbidgee and mid-Murray rivers as a result of irrigation releases. Therefore the appropriate hydraulic conditions may be present for a protracted period rather than a defined, discrete event such as a rise. In the absence of these high irrigation flows, it may be that a delivered 'rise' is required to meet the threshold requirement of appropriate in-channel hydraulics (i.e. in-channel freshes). Further, golden perch have been observed to exhibit substantial flexibility in both spawning and recruitment responses (e.g. (Mallen-Cooper and Stuart 2003 , Balcombe, Arthington et al. 2006, Balcombe, Arthington et al. 2006)). We anticipate that the continued monitoring of flow-cued spawning responses will strengthen the predictive relationships within the Murrumbidgee Selected Area and facilitate transferable information to other un-monitored sections of the Murrumbidgee River.

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

5.19 Wetland hydrology

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

Introduction

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

Flooding is the most influential driver of floodplain wetland ecosystems (Bunn and Arthington 2002). Floodplain wetlands in semi-arid regions are governed by variable flow regimes that produce diverse inundation patterns over large areas and time scales (Thomas, Kingsford et al. 2015). Aspects of the flood pulse that may have ecological significance include the inundation magnitude (extent), duration, timing, inter-flood dry interval and frequency of pulses (Walker and Thoms 1993). Inundation extent is a useful indicator of environmental watering outcomes in floodplain wetlands where flooding from river flows varies widely in space and over time (Thomas, Kingsford et al. 2015). Extent provides a measure of the inundated area of the floodplain and an inundation map shows where the area is located in the landscape. A time series of inundation maps enables us to measure how long a wetland area has been inundated and how many times it has been inundated. Importantly, inundation is useful in explaining the variability of ecosystem response, particularly in floodplain wetlands that are large, complex mosaics of diverse habitats.

In 2015-2016, the fourth year since large flows and flooding in 2012, Commonwealth environmental water was delivered to wetlands of the Murrumbidgee Selected Area, (Figure 5-14). Commonwealth environmental water actions to the Mid-Murrumbidgee and Lowbidgee wetlands occurred during spring to summer. The water action to the Western Lake zone occurred in autumn and a later autumn-winter action targeted wetlands in the Nimmie-Caira zone. All water actions had inundation objectives for targeted wetland assets which ranged from increasing inundation extents in core wetland and refuge habitats, maintaining inundation extents to increase periods of inundation duration, minimising inundation of wetlands on flow paths and allowing wetlands to dry out.

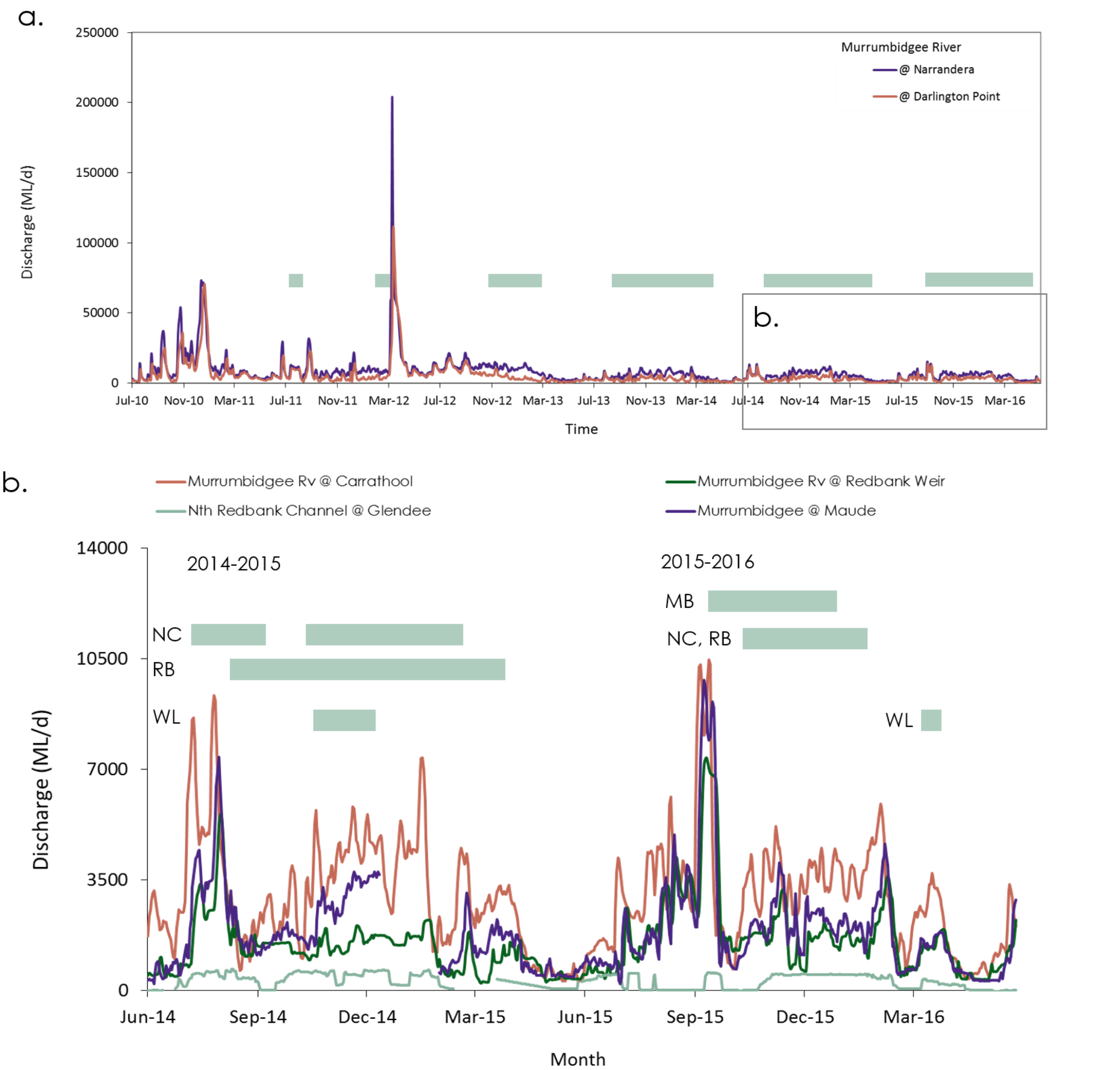


Figure 5-14 a. Mean daily discharge in the Murrumbidgee River at Narrandera and Darlington Point between 1 July 2010 to 30 June 2016. Note that the 2012 peak is truncated and actually reached 200,000 ML/d. Horizontal bars show Commonwealth and NSW environmental water actions in 2011-12, 2012-13, 2013-14, 2014-15 and 2015-16. b. Mean daily discharge in the Murrumbidgee River at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glendee in relation to the timing of environmental water delivery to wetland zones Mid-Murrumbidgee (MB), Nimmie-Caira (NC), Redbank (RB) and Western lakes (WL) during the survey period, 1 July 2014 to 30 June 2016.

Methods

To detect and classify for floodplain wetland inundation we use the Landsat satellite sensor (Landsat 8 operational land imager, OLI) images as our data source. Images are automatically downloaded by NSW OEH from the Unites States Geological Survey's (USGS) Earth Explorer website (http://earthexplorer.usgs.gov) as 30m resolution orthorectified images. NSW OEH processes these images to standardised surface reflectance (Flood, Danaher et al. 2013). Each Landsat scene location is designated by the satellite path (p) and row (r): Lowbidgee is located on p094r084 and Yarradda Lagoon is located on p093r084. We use observations from August 2015 to April 2016 because in the May and June 2016 p094r084 scenes cloud obscured the Lowbidgee wetlands. Inundation extents could not be estimated for this time coincident with the Nap-Nap to Waugorah water action. Landsat scenes for other observation dates (November and December) were affected by some cloud, but the overall effect on the analysis results was minimal.

In the Lowbidgee, inundation states were determined by combining water and vegetation indices to classify imagery into areas of open water, water mixed with vegetation, and dense cover vegetation that is inundated (Thomas, Kingsford et al. 2015). This method has been previously used to monitor inundation extents in the Lowbidgee floodplain (Spencer, Wassens et al. 2011, Thomas, Lu et al. 2012, Thomas, Cox et al. 2013, Thomas and Heath 2014). For observation dates affected by some cloud we reclassify areas of cloud shadow that were incorrectly detected as water using a cloud mask, initially automated (Goodwin, Collett et al. 2013) but manually edited at the wetland site scale. For Yarradda Lagoon we classified for water using a new water index (Fisher, Flood et al. 2016). While several of the p093r084 observation dates were cloud affected, the impact was minimised by our small area of interest, i.e. Yarradda Lagoon. For each observation, inundated pixels are allocated a value of one (1). In the Lowbidgee, we also separated agricultural inundation from floodplain wetland inundation.

Data analysis

We used inundation map observations and inundation event maps to estimate inundation extents. An inundation map observation provides a snapshot of inundation extent and distribution at one point in time. An inundation event map shows the total area of floodplain inundated at least once during the event time period. To create inundation event maps we allocate inundation maps to a water action by selecting the observation dates that occur after the start of the water action. We used a spatial overlay to count the number of times a pixel was inundated. All counts greater than zero were then recoded to a new value of one to create a map of the cumulative area of the floodplain inundated at least once by the water action.

Flows in the Lowbidgee are managed to inundate specific wetlands that may be long distances from each other, and often the existing agricultural infrastructure is used to move water across the floodplain. Due to the complexity in the system, for similar water actions, inundation outcomes vary spatially. For this reason we tabulated inundated areas from inundation observation maps and inundation event maps using the delineated Lowbidgee Water Management Areas (WMA) (Thomas, Heath et al. 2014), which are nested within the Murrumbidgee Selected Area zones. The WMAs compartmentalise the floodplain into units based on the characteristics of the ecosystem (wetland vegetation), hydrology (flow paths) and infrastructure (structures). For each inundation map observation and each inundation event map, we summed the inundated areas from each relevant Water Management Area to estimate the inundation outcome extent from each water action.

For confined wetlands with distinct boundaries (e.g. Eulimbah Swamp and Tarwillie Swamp) inundation duration (in months) was estimated by spatially overlaying each inundation map and then drawing in inundation observations from previous years. In this process the total area of the Lowbidgee floodplain inundated during the 2014-2015 and 2015-2016 water years was utilised. These inundation extents represent the cumulative area of the floodplain that was inundated at least once in each water year.

Water depth gauges placed in monitored wetlands continuously recorded water depths across the entire reporting period. The data derived from the gauges enables accurate analysis of site conditions at a fine temporal scale: analysis of inundation effects on ecological data collected at the sites proceeds based on these point data. Analysis of the wetlands derived from satellite imagery provides spatially extensive data that is more appropriate to monitoring inundation resulting from specific water actions. Therefore, the majority of the description of the hydrological monitoring, in terms of its overall impact on wetlands, is based on inundation mapping rather than point measures of specific wetland depths.

Results

Table 5-7 Summary of watering actions undertaken in the Murumbidgee catchment in 2015-16

Relevant Watering Action (s) in 2015/16	Start-End Date	CEW Water Use	Total EWater Use	Specified objective for each watering action	Measured outcomes for individual watering action*
Yarradda Lagoon	02/09/15-7/12/15	1,394.3	1,394.3	Inundate Yarradda Lagoon wetland habitat to the mature tree line	87 ha
North Redbank	21/10/15-10/02/16	25,000	54,000	Inundate at low levels core wetland habitat across North Redbank	4,908 ha
Yanga NP waterbird support	17/11/15-17/12/15	10,000	11,605	Maintain inundation extents in Tarwillie swamp and minimise incidental inundation of adjacent wetland vegetation	2,555 ha
Nimmie-Caira refuge	17/10/15-09/02/16	18,000	68,528	Inundate core refuge habitat through the Nimmie-Caira floodways to Waugorah Lagoon, Eulimbah and Monkem-Talpee Creek system	7,589 ha^
Juanbung	04/11/15-17/02/16	10,000	10,000	Inundate floodplain wetland habitat of the Juanbung Swamp (North Redbank)	864 ha
Hobblers-Penarie	15/03/16-13/4/16	5,000	5,910	Inundate Hobblers Lake and Penarie Creek	99 ha
Nap Nap Swamp to Waugorah#	6/5/16-30/6/16	9,557	15,274	Inundate refuge habitat from Nap Nap to Waugorah Lake	-#

* Measured as the cumulative total area of floodplain inundated from the water action

^ Includes the areas of Tala Lake and Yanga Lakes (~2,000 ha)

Cloud cover prevented estimates of inundated areas

The total area of the Lowbidgee floodplain inundated in 2015-2016 (21,137 ha) was about half the area of floodplain inundated in 2014-2015 (41,999 ha) (Figure 5-15). This difference is due to comparatively large inundated areas in the Redbank, Nimmie-Caira and Fiddlers zones in 2014-2015. In 2015-2016, almost half of the inundated area in the Redbank zone can be attributed to Commonwealth environmental water actions (Redbank action). Most (~85%) of the 2015-2016 inundated area in the

Nimmie-Caira zone can be attributed to combined Commonwealth and NSW environmental water actions as there were some locations of the floodplain already inundated prior to water actions within the water year. Most of the inundated area in the Western lakes zone is located in Paika Lake (480 ha) in which water had persisted from previous years. At monitoring sites with depth gauges, temporally precise records of wetland depths supplemented the inundation mapping (Figure 5-16).

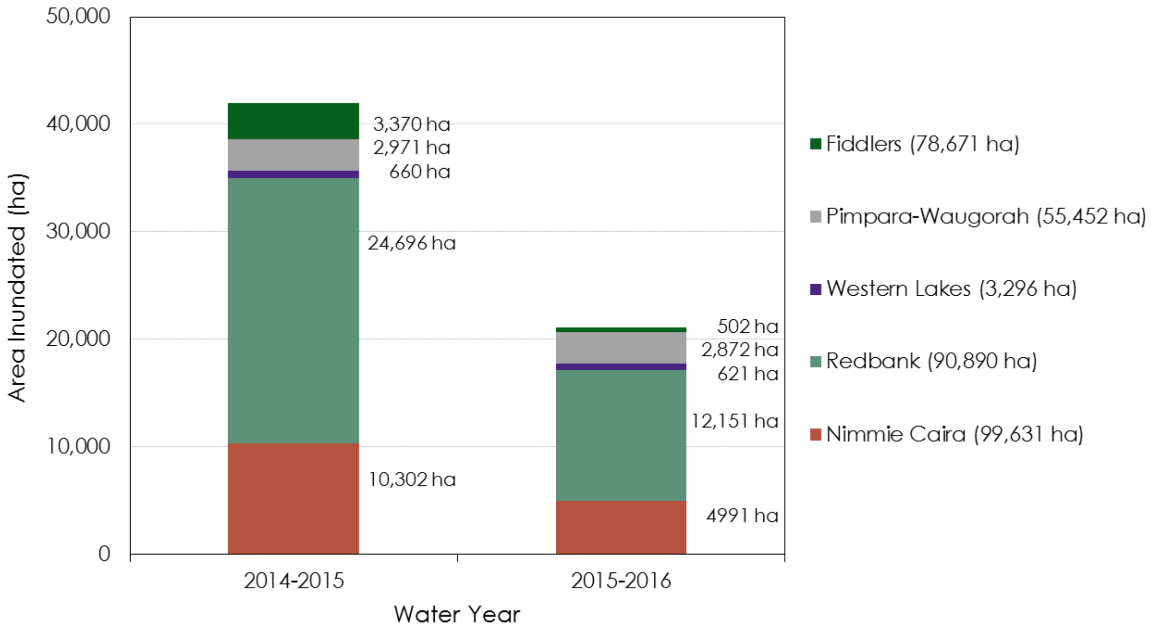


Figure 5-15 Cumulative total area (ha) of the floodplain inundated for the Lowbidgee floodplain and wetland zones for the 2014-2015 and 2015-2016 water years.

In summary, the total area of the Lowbidgee floodplain influenced by inundation from Commonwealth environmental water actions in the 2015-2016 water year was about 16,000 ha (75% of the inundated floodplain)(Table 5-7).

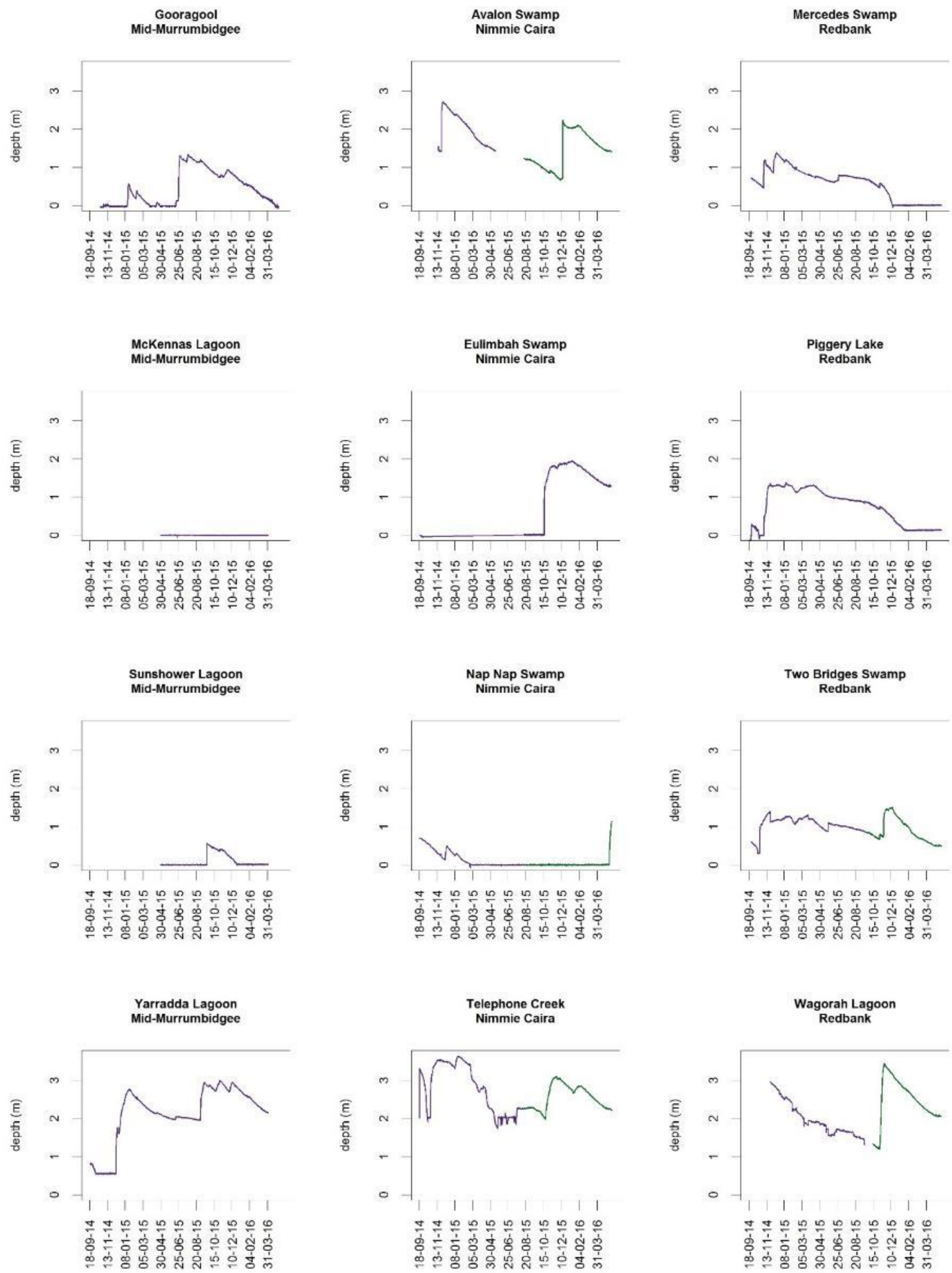


Figure 5-16 Water depth at wetlands' deepest points of the twelve wetland monitoring sites. Watering actions at sites correspond with rapid increases in depth. A change in colour of the plotted line indicates a repositioning of the depth gauge to more optimal location; corrective actions resulted in negligible impact on the continuity of the data series.

What did Commonwealth environmental water contribute to wetland inundation in Yarradda Lagoon?

Commonwealth environmental water filled Yarradda Lagoon to about 50% (87 ha) of its delineated boundary (177 ha) (Figure 5-17 and Figure 5-18). The peak of inundation was in December 2015 and then this contracted to just over 20% during the early months of 2016. Based on an overlay assessment with high resolution Satellite Pour l'Observation de la Terre SPOT 5 imagery, inundation extents aligned with the mature tree line.

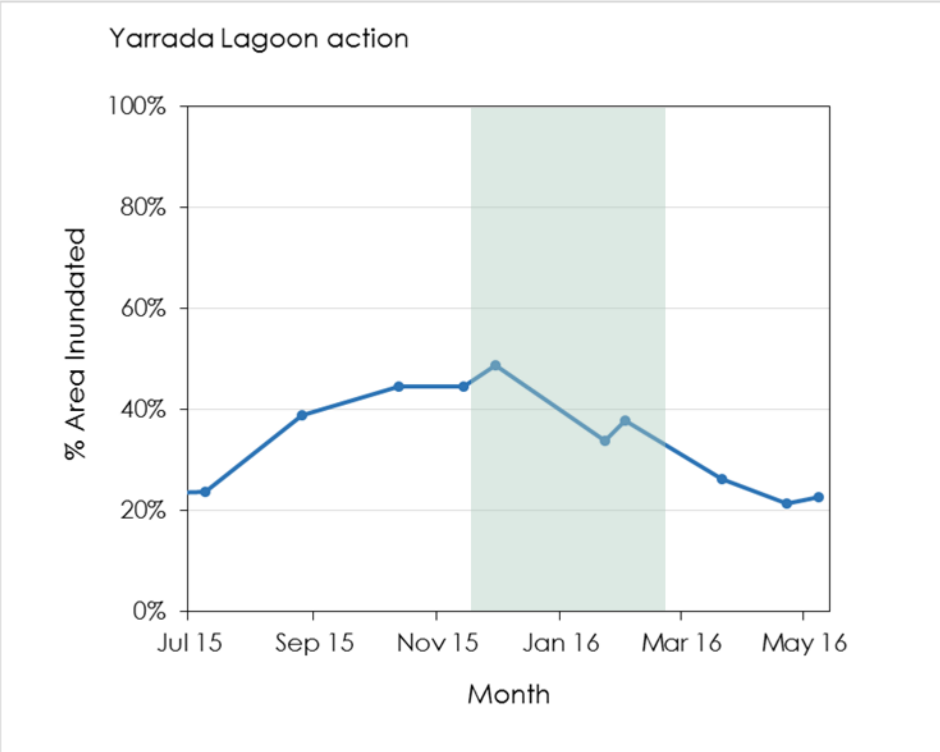


Figure 5-17 Inundation outcome shown as the percentage of Yarradda Lagoon area (177 ha) inundated from the Yarradda Lagoon water action (green bar)

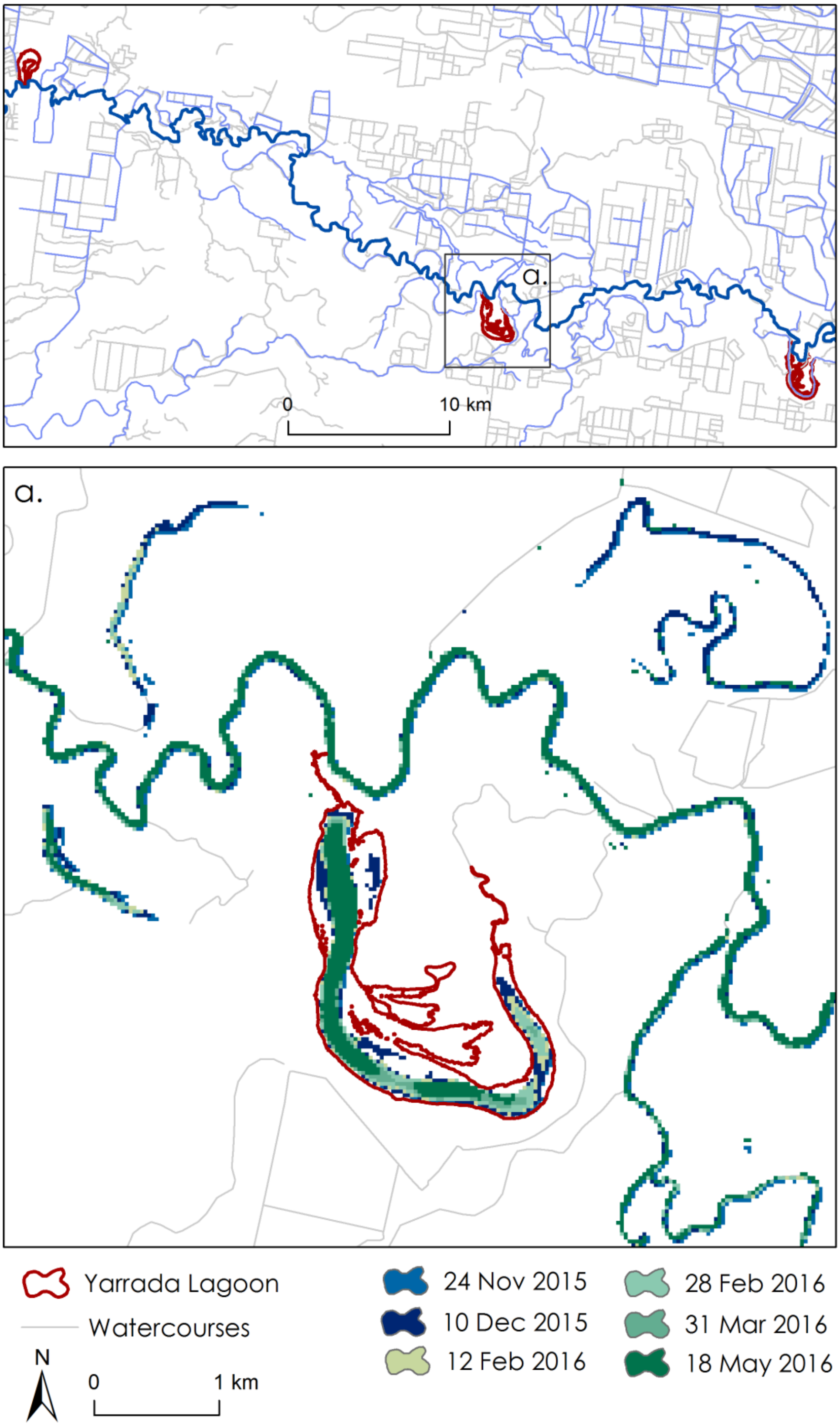


Figure 5-18 Inundation outcomes for Mid-Murrumbidgee Yarradda Lagoon watering action (02/09/15-20/12/15) showing maximum inundation conditions in December 2015 (dark blue) and recession over the following months to May 2016.

What did Commonwealth environmental water contribute to inundation in core wetland habitats across North Redbank?

Commonwealth environmental water (25,000 ML) and NSW environmental water (29,000 ML) contributed to inundating core wetland habitat in the North Redbank region. Prior to the watering action, about 740 ha of core wetlands were inundated (Figure 5-19 and Figure 5-20). By 1 December 2015, the inundated area increased in extent to almost 2,000 ha as a result of the environmental water action, mostly in the southern section of North Redbank from Narwie to Balranald Common. At the same time, there was a contraction in the pre-watering period inundation of adjacent wetland locations (Figure 5-20). Inundation expanded to almost 4,000 ha through January and February as extents progressed south and as a result of targeted watering in the upper North Redbank region. Inundation contracted in the autumn months of March and April 2016. Overall, the total area of floodplain inundated by the North Redbank water action was 4,908 ha.

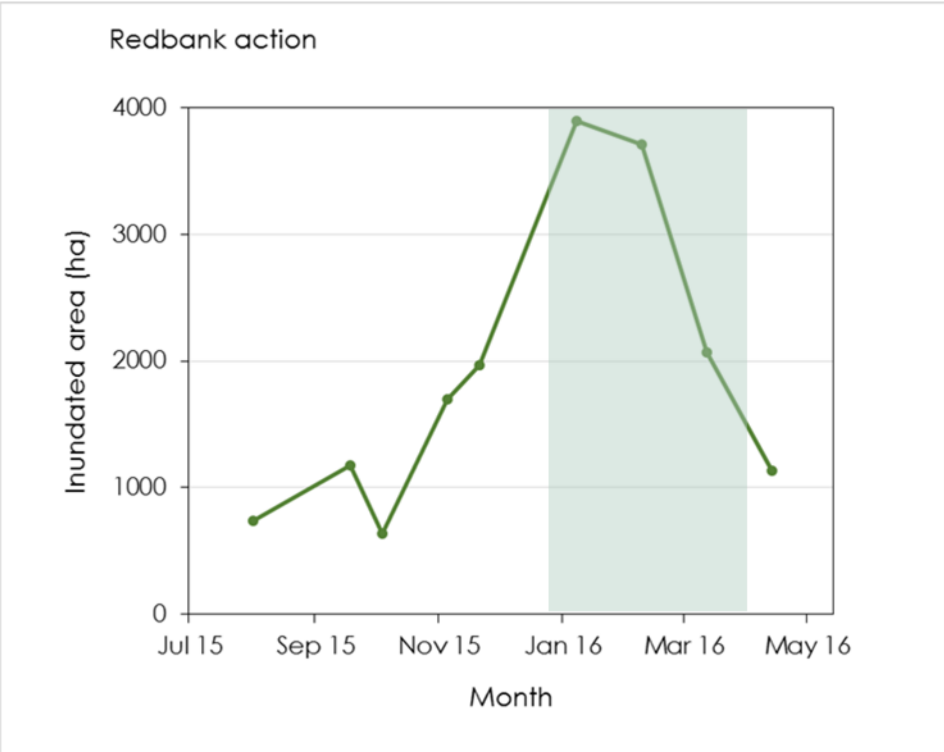


Figure 5-19 Inundated area (ha) outcomes from the North Redbank water action (green bar) located in the North Redbank region

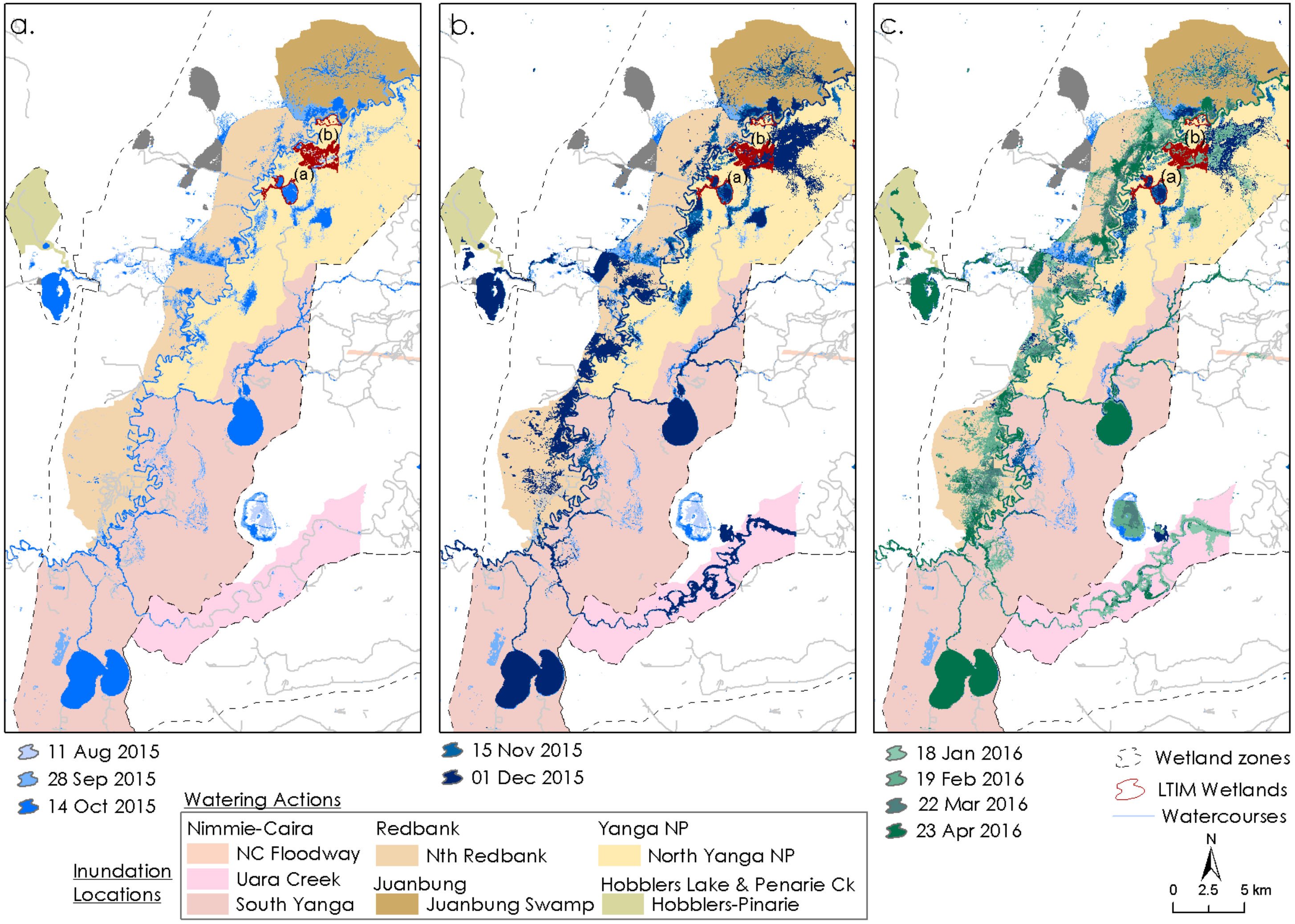


Figure 5-20 Inundation outcomes located around the Redbank zone from the watering actions: North Redbank (21/10/15-10/02/16); Juanbung (04/11-17/02/16); Nimmie-Caira (17/10/15-09/02/16); Yanga NP (17/11/15-17/12/16) and Hobblers-Penarie (08/03/16-29/03/16) showing: a. pre-watering inundation conditions, and cumulative outcomes during b. Nov-Dec 2015 and then c. Jan-Apr 2016 in the LTIM surveyed wetlands (a) Piggery Lake, (b) Two Bridges.

What did Commonwealth environmental water contribute to in maintaining inundation extents in Tarwillie Swamp of Yanga National Park?

Commonwealth environmental water was delivered using the most direct flow path to Tarwillie Swamp. As a result, there was only a small 300 ha expansion of inundated area (to about 2,300 ha) by 1 December 2015 (Figure 5-21 and Figure 5-22). The inundation expansion was confined to the flow path region in North Yanga around the east of Two Bridges and in Two Bridges Swamp. By mid-January this inundated area started receding and was dry by March 2016 (Figure 5-22 and Figure 5-21). Adjacent wetlands (e.g. Piggery Lake) were not inundated by this watering action and were able to dry out over summer (Figure 5-21 and Figure 5-22), having been continuously inundated for more than 12 months prior (since late November 2014). Inundation extent in Tarwillie Swamp remained about the same as the pre-watering extents (~150 ha) through November to January and then started to recede in February 2016 until it was dry by April 2016 (Figure 5-22). By mid-January 2016, about 80% of the 150 ha of Tarwillie Swamp had been inundated for just over 12 months (since late November 2014). Overall the total area of floodplain wetland inundated by the Yanga National Park action was 2,555 ha.

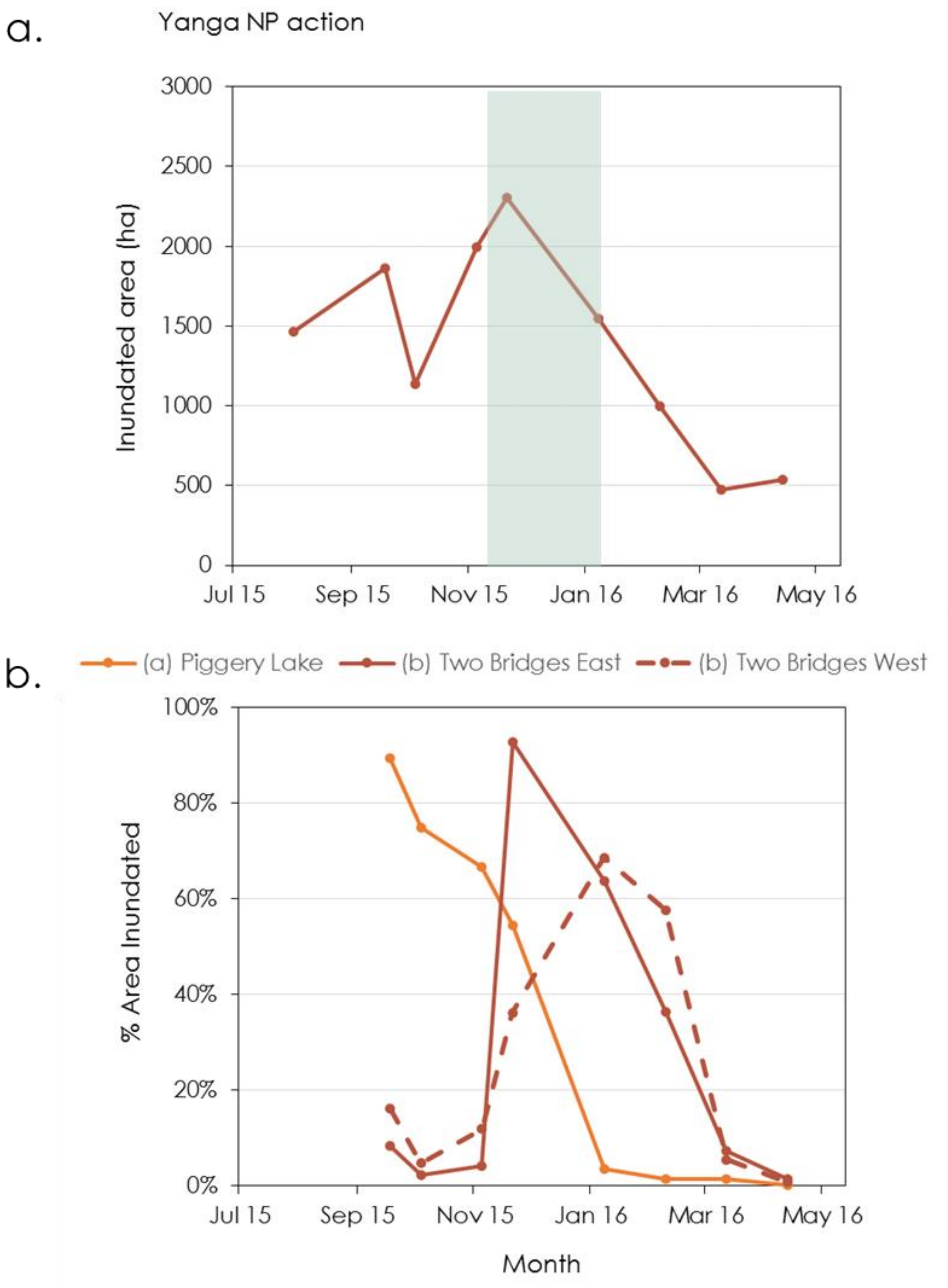


Figure 5-21a. Inundated area (ha) outcomes from the Yanga National Park water action (green bar) located in the North Yanga region, and b. the inundation outcome shown as the percentage of wetland area inundated for (a) Piggery Lake and the east and west sections of (b) Two Bridges Swamp

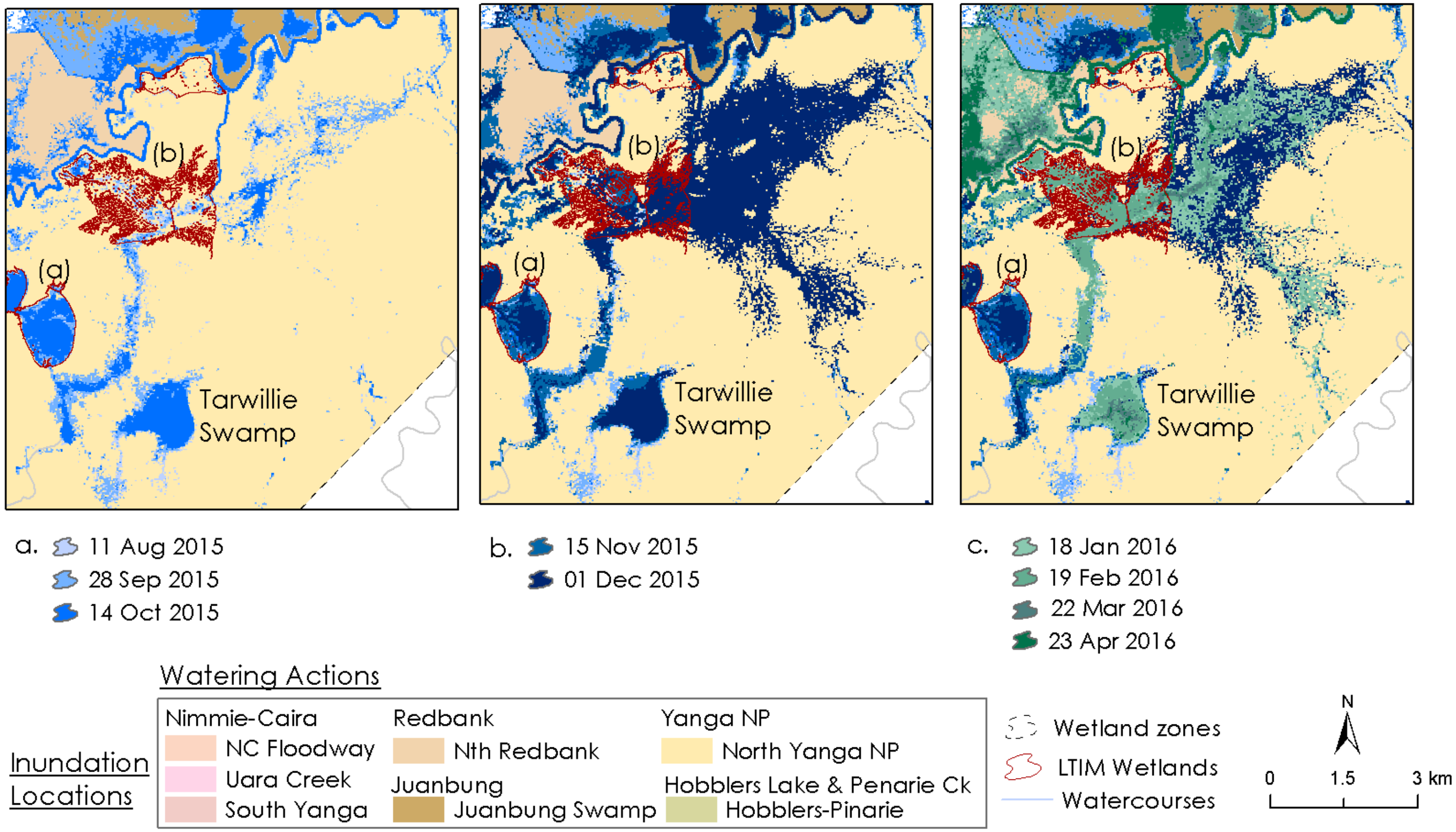


Figure 5-22 Inset of inundation outcomes located in the North Yanga National Park from the Yanga NP waterbird support watering action showing a. pre-watering inundation conditions, and cumulative outcomes during b. Nov-Dec 2015 and then c. Jan-Apr 2016 in the LTIM surveyed wetlands (a) Piggery Lake and (b) Two Bridges, and in Tarwillie Swamp

What did Commonwealth environmental water contribute to inundated area in refuge habitat through the Nimmie-Caira floodways to Waugorah Lagoon and Monkem Creek system?

Commonwealth environmental water contributed just over a quarter (18,000 ML) of the total environmental water volume (68,528 ML) for this water action. Inundation outcomes were evident in the targeted wetland assets of the Nimmie-Caira zone (Eulimbah Swamp and Telephone Creek), and Waugorah Lagoon (Figure 5-24) and the Monkem-Talpee Creek system in Yanga National Park (Figure 5-24). Prior to the Nimmie-Caira water action, Eulimbah Swamp and Waugorah Lagoon were mostly dry while Telephone Creek was about 60% inundated (Figure 5-23, Figure 5-24 and Figure 5-25). Waugorah Lagoon was inundated to 60% of its wetland extent in December 2015 and then contracted to less than 20% by January 2016 (Figure 5-23 and Figure 5-25). Eulimbah Swamp was fully inundated by late November/early December 2015 with associated inundation of the adjacent floodway downstream. Eulimbah Swamp remained mostly full until late March 2016 resulting in an inundation duration of about 4 months (Figure 5-23 and Figure 5-25). Telephone Creek remained mostly (>85%) full from November 2015 to late April 2016 resulting in an inundation duration of about 5.5 months. The Monkem Creek system was wet prior to the environmental water action and this was maintained through to mid-February (Figure 5-20). The NSW EWA contributed to inundation in the Uara Creek system reaching about 630 ha in mid-November 2015 and then expanding to about 1000 ha in January 2016 with rapid contraction of about half the inundated area over the next month to then being almost dry by late April 2016 (Figure 5-20). Overall, the total area of floodplain inundated by the Nimmie-Caira water action was 7,589 ha noting that this also includes the areas of Tala Lake (633 ha) and Yanga Lakes (1,335 ha) (total = 1,968 ha).

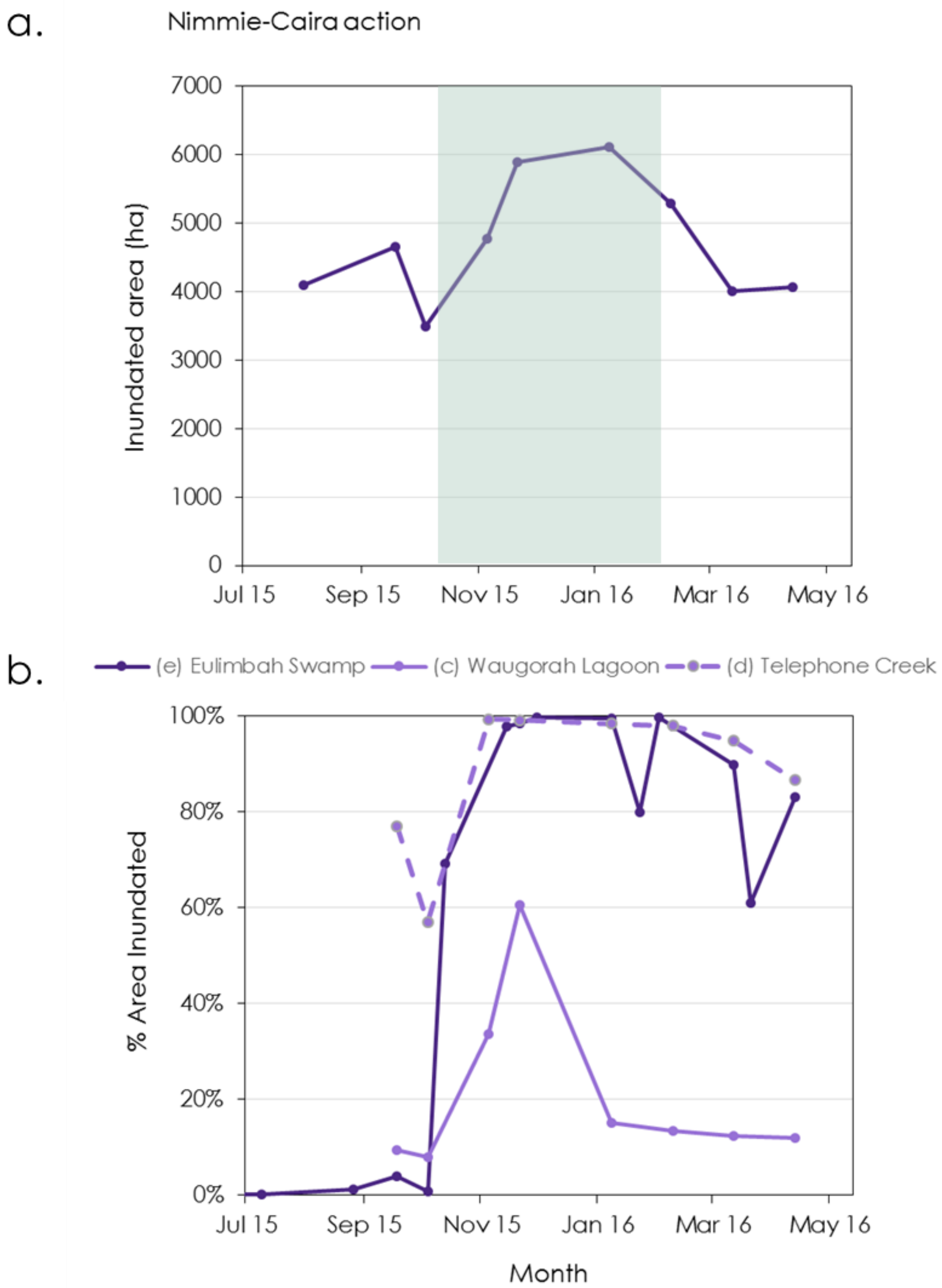


Figure 5-23 a. Inundated area (ha) outcomes from the Nimmie-Caira water action (green bar) located in the Nimmie-Caira zone and parts of Yanga National Park, and b. the inundation outcome shown as the percentage of wetland area inundated for (c) Waugorah Lagoon, (d) Telephone Creek and (e) Eulimbah Swamp.

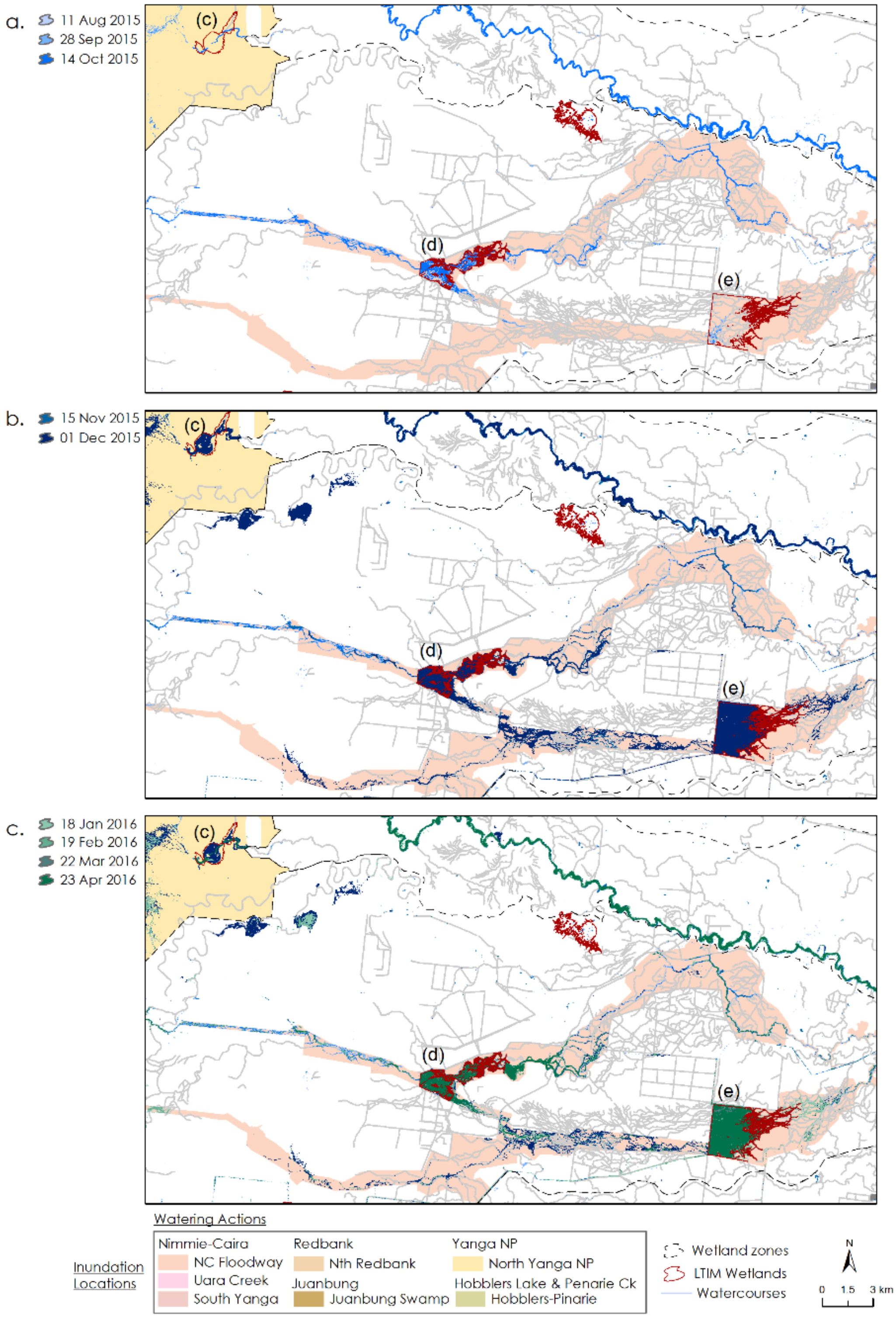


Figure 5-24 Inundation outcomes located around the Nimmie-Caira zone from the Nimmie-Caira watering actions (17/10/15-09/02/16) showing: a. pre-watering inundation conditions; and cumulative outcomes during b. Nov-Dec 2015 and then c. Jan-Apr 2016 in the LTIM surveyed wetlands (c) Waugorah Lagoon, (d) Telephone Creek and (e) Eulimbah Swamp. NB Waugorah Lagoon inundation is located in North Yanga NP but was inundated during this time by the Nimmie-Caira watering action.

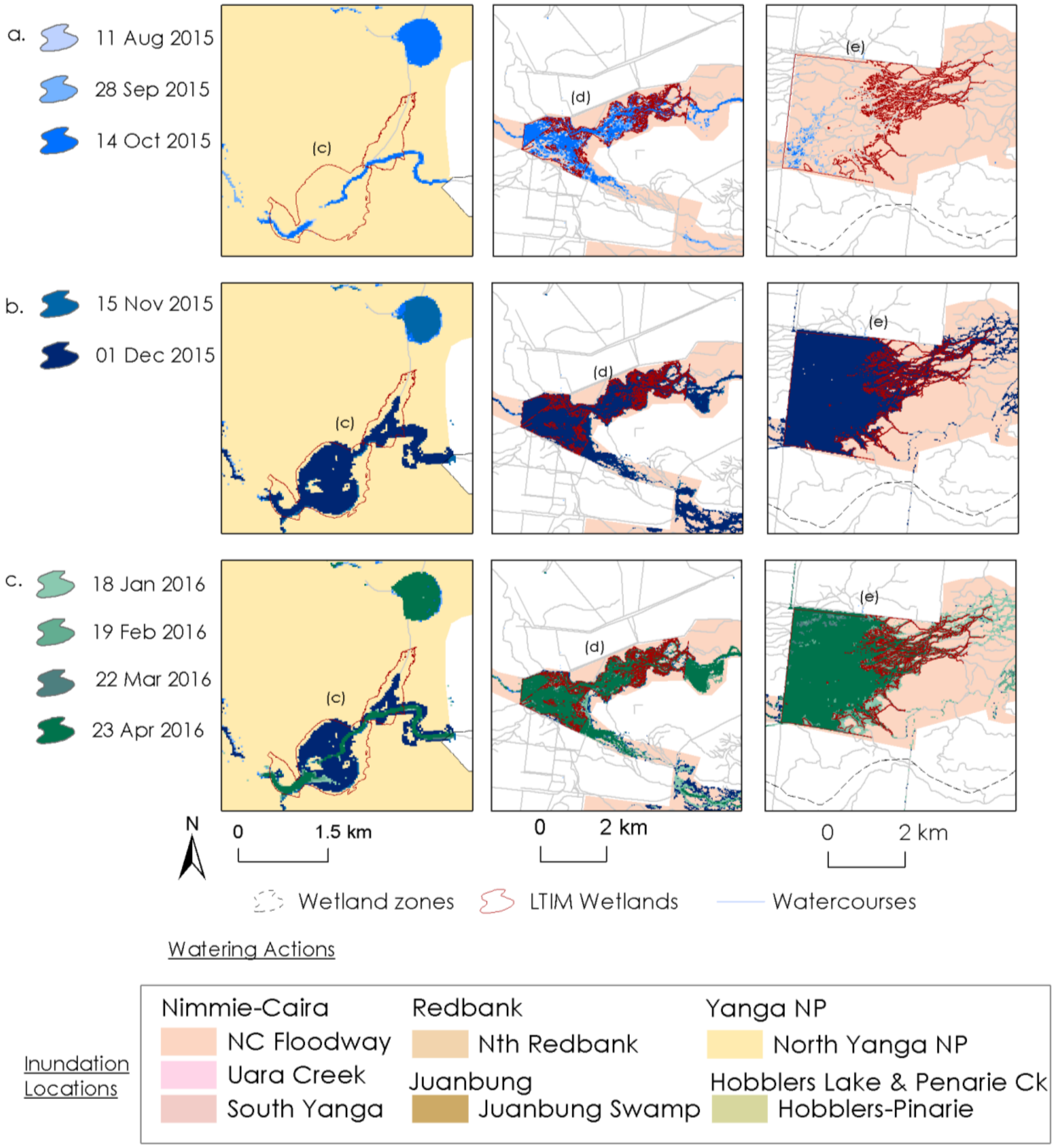


Figure 5-25 Inset of inundation outcomes located around the Nimmie-Caira zone from the Nimmie-Caira watering action (17/10/16-09/02/16) showing a. pre-watering inundation conditions, b. post-watering Nov-Dec 2015 and c. post-watering Jan-Apr 2016 in the LTIM surveyed wetlands (c) Waugorah Lagoon, (d) Telephone Creek and (e) Eulimbah Swamp. Note that the Waugorah Lagoon is located in North Yanga NP but was inundated during this time by the Nimmie-Caira watering action.

What did Commonwealth environmental water contribute to inundated areas of the Juanbung Swamp floodplain wetland habitat?

Inundation outcomes for this Commonwealth environmental water action (10,000 ML) were evident in the targeted Juanbung Swamp (Figure 5-26 and Figure 5-27). As a result of the water action 680 ha were inundated in mid-November. There was evidence of hydrological connectivity with the upper north Redbank at this time, after which, by early December, inundation had contracted in Juanbung Swamp to be confined to its narrow braided creek system and wetlands close to the Murrumbidgee River (Figure 5-27). Floodplain wetland inundation of about 300 ha was maintained for a duration of about 4.5 months (Oct 2015 to mid-Feb 2016). Overall, the total area of floodplain inundated in Juanbung Swamp by the Juanbung water action was 864 ha.

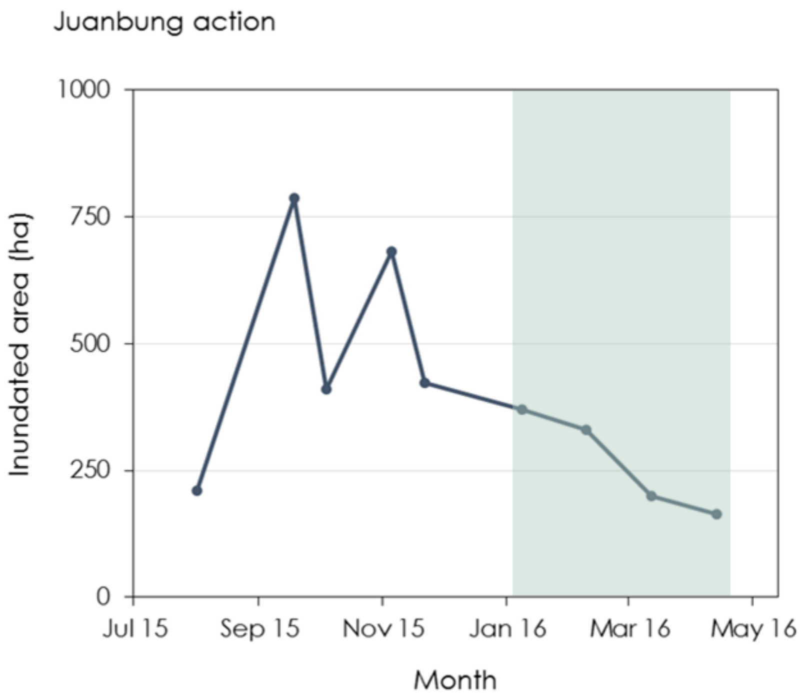


Figure 5-26 Inundated area (ha) outcomes from the Juanbung water action (green bar) located in the Redbank zone

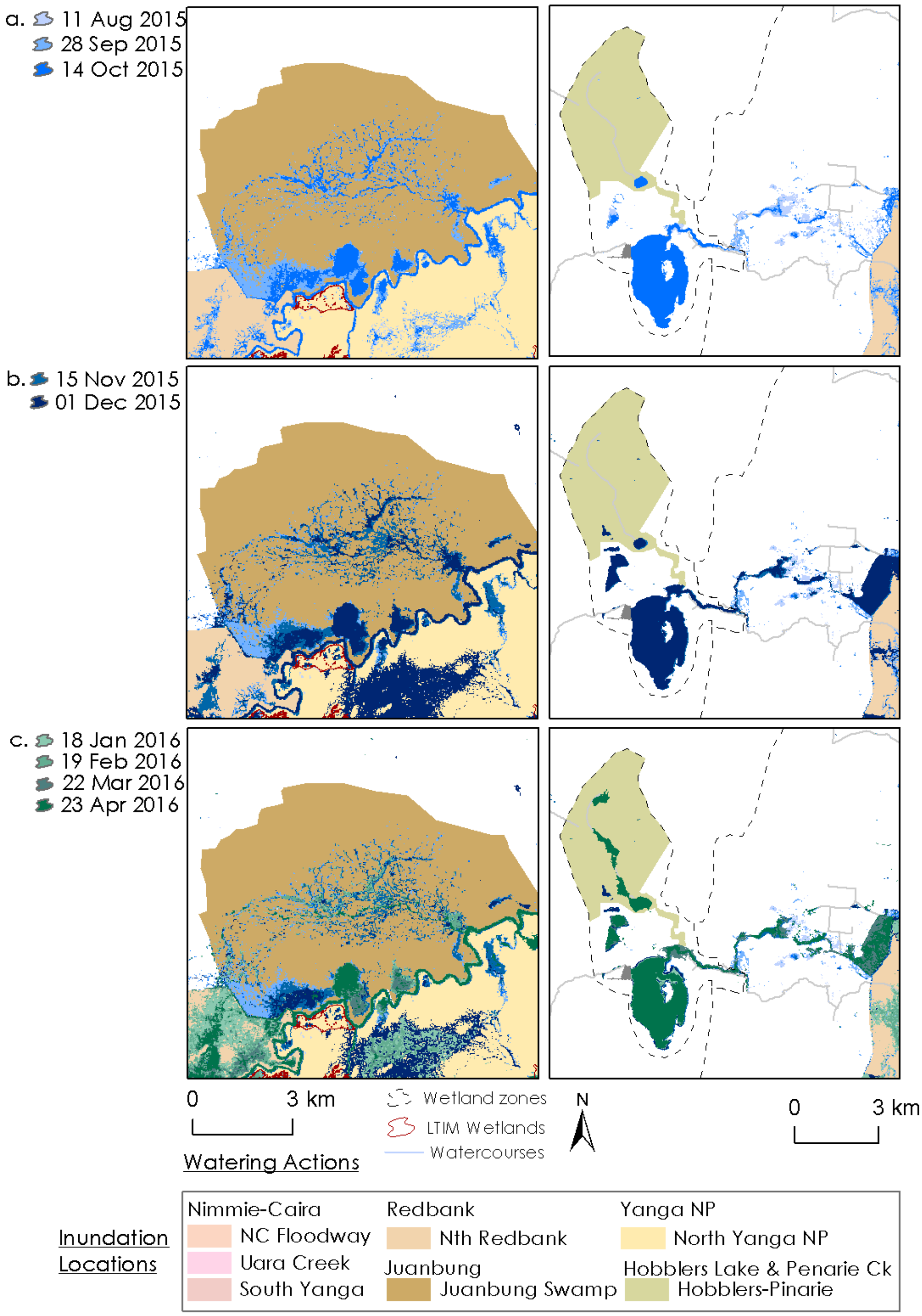


Figure 5-27 Inset of inundation outcomes located in Juanbung Swamp located in the Redbank zone (left) and located in the Hobblers Lake-Penarie Creek system of the Western Lakes zone (right) showing: a. pre-watering inundation conditions; b. post-watering, Nov-Dec 2015; and c. post-watering, Jan-Apr 2016

What did Commonwealth environmental water contribute to inundated areas in Hobblers Lake and Penarie Creek?

Commonwealth environmental water contributions were the larger proportion for this water action. Prior to the water action, Hobblers Lake had residual water present for 3.5 months (mid-August 2015 to end of November 2015) (Figure 5-28 and Figure 5-27). In January and February 2016, Hobblers Lake was dry, but by March 2016 Hobblers Lake was inundated across an area of 10 ha, expanding to 30 ha in late April 2016 when inundation extended into the Penarie Creek system, giving a total of 99 ha (Figure 5-28 and Figure 5-27).

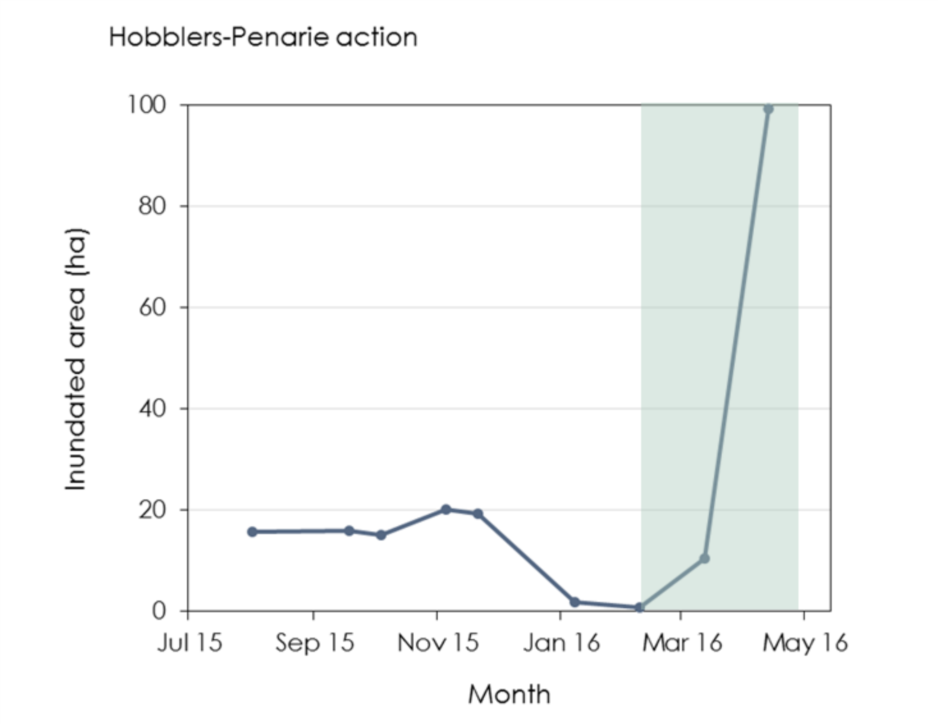


Figure 5-28 Inundated area (ha) outcomes from the Hobblers-Penarie water action (green bar) located in the Western Lakes zone

Discussion

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee in order to "inundate wetland and refuge habitat" in the Murrumbidgee Catchment.

What did Commonwealth environmental water contribute to inundated area?

All Commonwealth water actions achieved the expected inundation objectives for targeted wetland assets. These inundation outcomes ranged from increasing inundation extents in core wetland and refuge habitats, maintaining inundation extents to increase periods of inundation duration, minimising inundation of wetlands on flow paths and allowing wetlands to dry out. The 2015-2016 total inundated area of the Lowbidgee floodplain was half the total inundated area in 2014-2015, but the Commonwealth environmental water actions influenced about 75% of the 2015-2016 total inundated area.

Increased inundation extents were achieved in the core wetlands of the North Redbank region, increasing lateral connectivity between wetland habitats throughout the region. Connectivity with Juanbung Swamp as a result of the Juanbung water action was also evident, although inundation mapping suggested that this did not last very long. Inundation extents in Yarradda Lagoon were increased as planned. The aim of the water action to reach levels that align with the mature tree line to provide waterbird habitat was achieved. For refuge habitats, inundation extents were also increased, as expected, in wetlands located across the Nimmie-Caira zone such as Telephone Creek and Eulimbah Swamp, and in Waugorah Lagoon.

Maintaining inundation duration is critical for the completion of the life history stages of flora and fauna, especially during dry periods. Commonwealth environmental water was successfully used to maintain the water levels, or inundation extent, in Tarwillie Swamp to support a waterbird breeding event. This water action effectively extended inundation duration of the core wetland area (~120 ha) to just over 12 months. Inundation duration outcomes were evident in refuge habitats across the Nimmie-Caira with most of Eulimbah Swamp inundated for 4 months and most of Telephone Creek inundated for 5.5 months.

Maintaining the spatial variability of inundation patterns is important for the persistence of the wet-dry mosaic of diverse habitats across wetland landscapes. Commonwealth environmental water actions facilitated the drying of wetland vegetation that had their water regime requirements met in previous years. Understanding the variability in vegetation and fauna inundation requirements will help to inform environmental water actions to maintain a diverse wetland mosaic across the landscape.

5.20 Wetland water quality

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

Introduction

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

In 2015-16 environmental watering aimed to *improve aquatic habitat, water quality and riparian vegetation* at sites in the Nimmie-Caira system. Water quality was also indirectly targeted in the mid-Murrumbidgee wetlands (Yarradda Lagoon) where flows aimed to *support known native fish and frog community established in 2014-15* and in Yanga national park where flows were delivered to *provide habitat for native fish, frogs and other vertebrates*. To evaluate these objectives we compared observed ranges of 1) physicochemical parameters and 2) concentrations of carbon, nutrients and chlorophyll-a against previously collected data and against other wetlands in the Murrumbidgee catchment.

Methods

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

Results

Overall, physicochemical conditions fell within the range of values observed previously across the Murrumbidgee wetlands (Figure 5-29). Notable exceptions include high turbidity at Avalon Swamp during January 2015 (900 NTU) and high turbidity and electrical conductivity at Piggery Lake during September 2014 (1000 NTU and 1.307 mS cm^{-1}, respectively).

The use of Commonwealth environmental water in the Murrumbidgee wetlands during 2015-16 supported adequate physicochemical conditions for colonisation by aquatic biota.

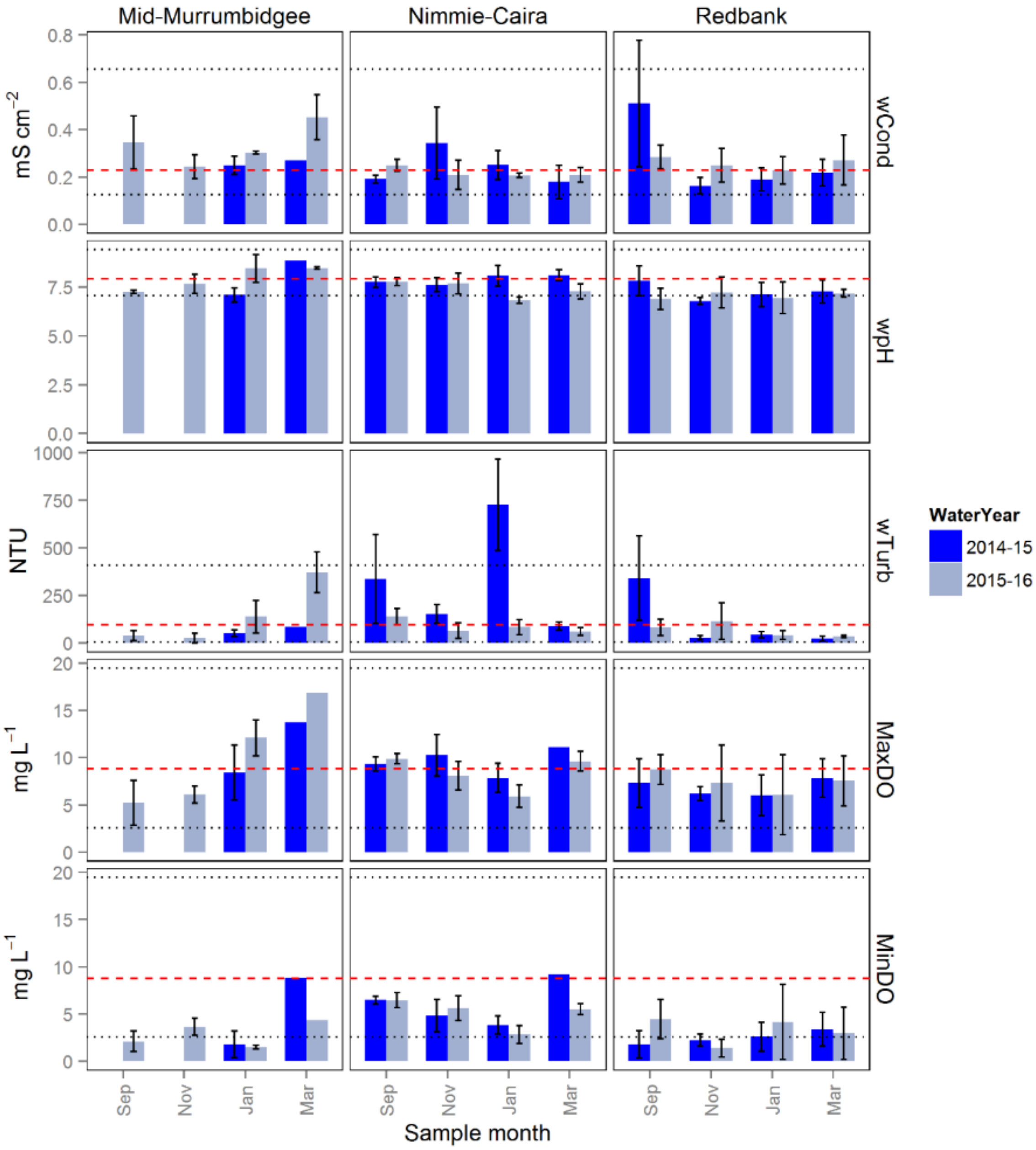


Figure 5-29 Mean ± standard error for physicochemical parameters (minimum dissolved oxygen – MinDO; maximum dissolved oxygen – MaxDO; turbidity – wTurb; pH –wpH; and conductivity – wCond) measured during September, November, January and March sample occasions in 2014-15 and 2015-16. The number of samples on each occasion ranges between 0 and 4 depending on the number of sites that received environmental water. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for wetlands across all sites in the Murrumbidgee (

Table 5-8).

Table 5-8 Median, 5^{th} and 95^{th} percentile and number of samples for water quality measurements collected across all wetlands in the Murrumbidgee catchment prior to 2014.

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

Measured nutrient and carbon concentrations also fell within the expected ranges, based on previous records Figure 5-30. High values for all measured variables in Redbank wetlands during September 2014 were attributed to Piggery Lake having dried to <1% of total fill volume. Chlorophyll-a concentrations exceeded the 95^{th} percentile of past data at Yarradda (174 mg L^{-1}, Plate 5-1) and Gooragool (447 mg L ^{1}) lagoons during March 2016.

No significant differences among sites, zones or sample occasions were observed during the data analysis. The use of Commonwealth environmental water in the Murrumbidgee wetlands during 2015-16 supported nutrient and carbon concentrations within expected ranges.

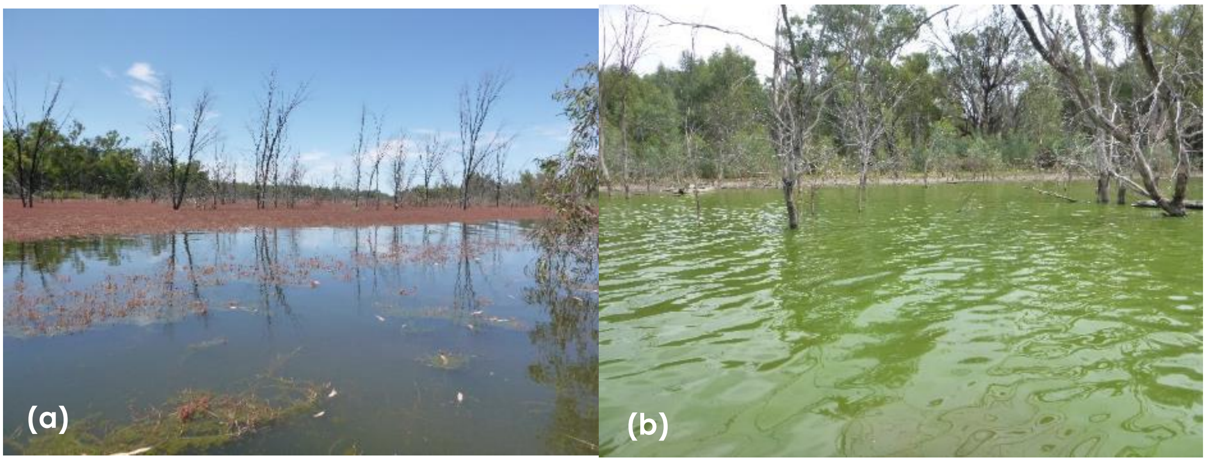


Plate 5-1 Yarradda Lagoon showing wetland condition during (1) November 2015 and after (2) March 2016. Note the presence of dense red myriophyllum (*Myriophyllum tuberculatum*) during November and the bright green hue of water during March. High concentrations of chlorophyll-a are not uncommon in wetlands.

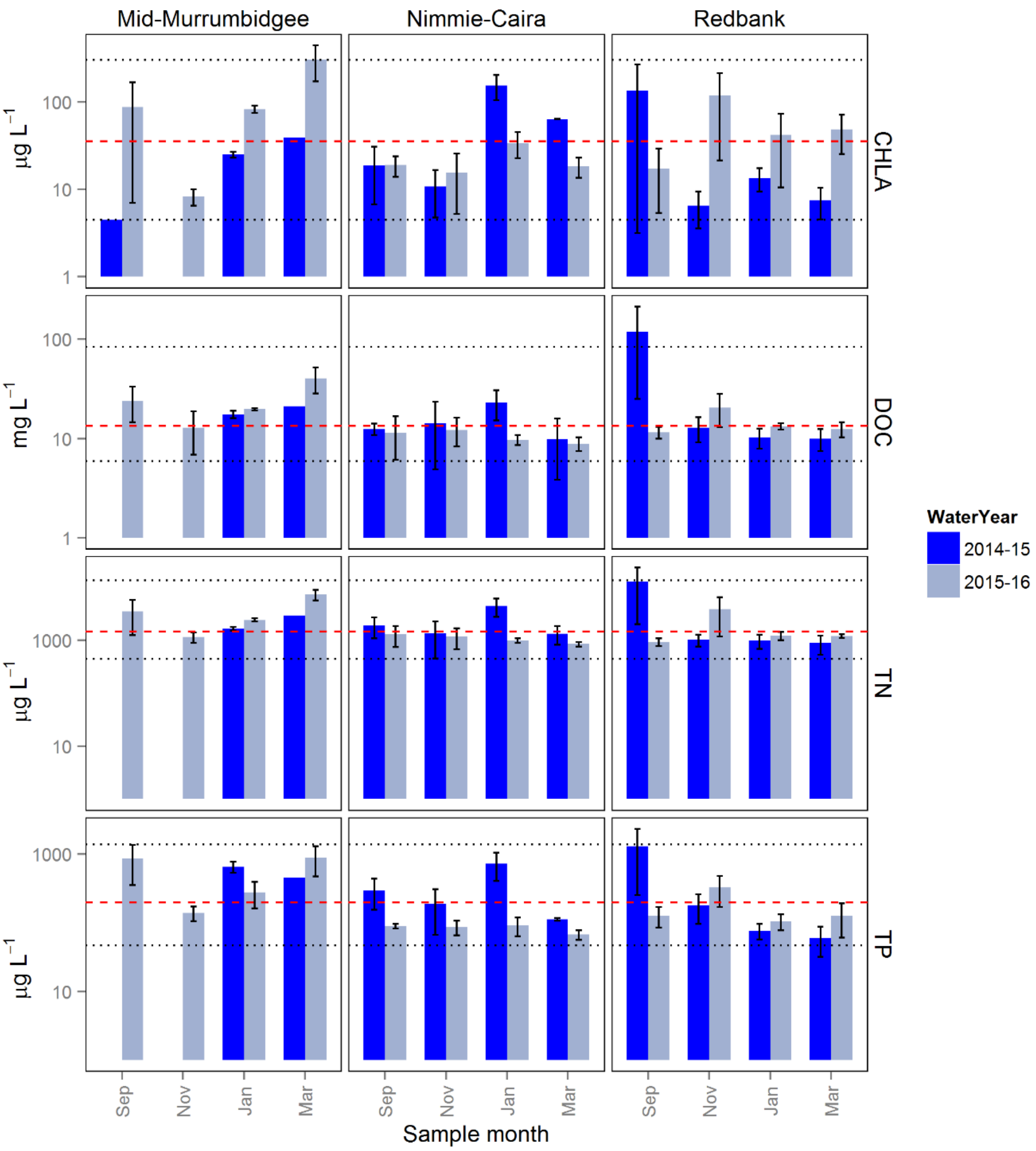


Figure 5-30 Mean ± standard error for total phosphorus (TP), total nitrogen (TN), dissolved organic carbon (DOC) and chlorophyll-a (CHLA) measured during September, November, January and March sample occasions in 2014-15 and 2015-16. The number of samples on each occasion ranges between 0 and 4 depending on the number of sites that received environmental water. Dashed (red) lines indicate median and dotted (black) lines 5th and 95th percentiles of pre-2014 data collected for wetlands across all sites in the Murrumbidgee (Table 5-8).

Discussion

What did Commonwealth environmental water contribute to suitable physicochemical conditions for wetland fauna?

Overall, physicochemical conditions were within the range of values observed previously across the Murrumbidgee wetlands. High turbidity has been reported previously at Avalon Swamp and this does not appear to prevent occupation by native fauna (Wassens, Jenkins et al. 2014, Wassens, Thiem et al. 2015). The high conductivity at Piggery Lake is equivalent to a salinity level of approximately 660 mg L ^{1}. This is within the known salinity tolerances of freshwater aquatic biota (James, Cant et al. 2003). Moderately high turbidities were also reported for Yarradda (263 NTU) and Gooragool (478 NTU) lagoons during March 2016 which are attributed to high densities of phytoplankton (see chlorophyll-a below).

There are no published water quality guidelines for wetlands in south-eastern Australia. For dissolved oxygen, minimum thresholds of 4 mg L^{-1} and 2 mg L^{-1} are often used to indicate when particular taxa might begin to be impacted (Howitt, Baldwin et al. 2007). For this study, 5th and 95th percentile ranges have been calculated from daytime spot measurements, and therefore minimum night-time dissolved oxygen is expected to be lower. These dissolved oxygen results are consistent with other wetlands in south-eastern Australia where native fish are known to exhibit physical and behavioural adaptations to low dissolved oxygen (McNeil and Closs 2007, McMaster and Bond 2008).

The use of Commonwealth environmental water in the Murrumbidgee wetlands during 2015-16 supported adequate physicochemical conditions for colonisation by aquatic biota. There is no evidence that water quality is changing among years in response to repeated watering.

What did Commonwealth environmental water contribute to wetland nutrient and carbon concentrations?

Measured nutrient and carbon concentrations also fell within the expected ranges, based on previous records. Persistently high values for the Redbank Zone during the 2014-15 water year can be attributed to Piggery Lake having dried to <1% of total fill volume during September 2014. High chlorophyll-a values were reported for Yarradda (174mg L^{-1}) and Gooragool (447 mg L^{-1}) lagoons during March 2016. Both lagoons had dried down considerably at this time and increased temperature, solar exposure, and evapo-concentration are expected to be the main drivers for increased concentrations. High DOC concentrations have previously been observed in association with high chlorophyll-a in drying wetlands with the source of high carbon concentrations likely to be algal in origin rather than leaf leachates (Wassens, Bindokas et al. 2013, Wassens, Jenkins et al. 2014). The overarching objective for Yarradda Lagoon is to maintain a permanent fish and frog refuge to improve ecological outcomes.

5.21 Wetland microinvertebrates

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. In both 2014-15 and 2015-16, 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).

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. The density of the major microcrustacean groups, such as copepods, cladocerans and ostracods can differ significantly between wetlands and the river channel (Jenkins, Iles et al. 2013) between the benthic (bottom) and pelagic (open water) microhabitats (King 2004), and over time. Assessing if microinvertebrate community density and composition differ markedly between river and wetland habitats can be a useful indicator of the health of the system and whether there is an adequate supply of prey to support river and wetland food-webs. By monitoring microinvertebrate communities in river sites nearby to wetlands, we can assess whether re-connection events lead to mixing of riverine and wetland communities which may boost riverine productivity.

In 2015-16 environmental water was delivered to wetlands in the Nimmie-Caira, Redbank and mid-Murrumbidgee systems. In 2014-15 Commonwealth environmental water was delivered to wetlands in the mid-Murrumbidgee and Lowbidgee floodplain. We monitored benthic and pelagic microinvertebrate communities in wetlands and three river comparison sites coinciding with the wetland fish and tadpole monitoring in September to March in each water year.

Based on recent environmental watering of these sites (2013-14), we hypothesised that environmental water delivered to wetlands would transport microinvertebrates as well as trigger their emergence and community establishment with densities and community composition changing over time in relation to wetland filling and draw-down. We expected there would be modest increases in microinvertebrate productivity at sites that had been more frequently watered.

Methods

Wetland microinvertebrates were sampled four times per year (September, November, January and March), beginning in September 2014 and most recently sampled in March 2016. Sampling was conducted across all twelve wetland sites (Section 4.1) on each occasion. Microinvertebrate samples were not collected when there was less than 10cm of surface water. Benthic and pelagic samples were collected following the methods described by Wassens, Jenkins et al. (2014). Laboratory methods follow those reported in the riverine microinvertebrate section.

Data analysis

To test for differences between zones and sample occasions data were analysed using a three-way permutational analysis of variance (PERMANOVA; Anderson, Gorley et al. 2008) with zone, water year and sample occasion as fixed factors. Sample occasion were nested within water year. Data were not transformed prior to analysis. Resemblance matrices were calculated using a Euclidian distance measure. Post-hoc tests were used to further isolate significant terms, using Monte-Carlo tests where numbers of unique permutations were low. Results were considered significant at $P<0.05$. All data were analysed using Primer 6 with PERMANOVA (Primer-E Ltd.).

Results

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

The inundation of wetlands in the mid-Murrumbidgee, Nimmie Caira and Redbank zones with Commonwealth environmental water contributed to high levels of secondary productivity with densities of microinvertebrates between 500-1000/L throughout spring and summer (Figure 5-31). Densities of microinvertebrates were higher in benthic than pelagic habitats and although wetland pelagic densities were less than 500 /L (100-400/L), they were considerably higher than pelagic densities in riverine habitats (< 100/L, Section 5.3). Copepods dominated densities, typically occurring between 5 and 1500/L, in all wetlands, with cladocerans also occurring in densities above 100/L on half the sampling occasions and ostracods in lower densities (Figure 5-32).

Densities of benthic microinvertebrates were significantly different among zones, driven by the pattern for copepods (Term 1, Table 5-9, Figure 5-31 and Figure 5-32). Both total microinvertebrates and copepods had the highest densities in both years in the mid-Murrumbidgee and Nimmie-Caira compared to the Redbank wetlands (Figure 5-31). There were no significant differences between years or among trips nested within year in densities of microinvertebrates (Figure 5-31 and Figure 5-32). Nevertheless, densities tended to be lowest in all wetlands in March, declining from the highest values in September in the Redbank wetlands, but with no apparent pattern in the other zones (Figure 5-31 and Figure 5-32).

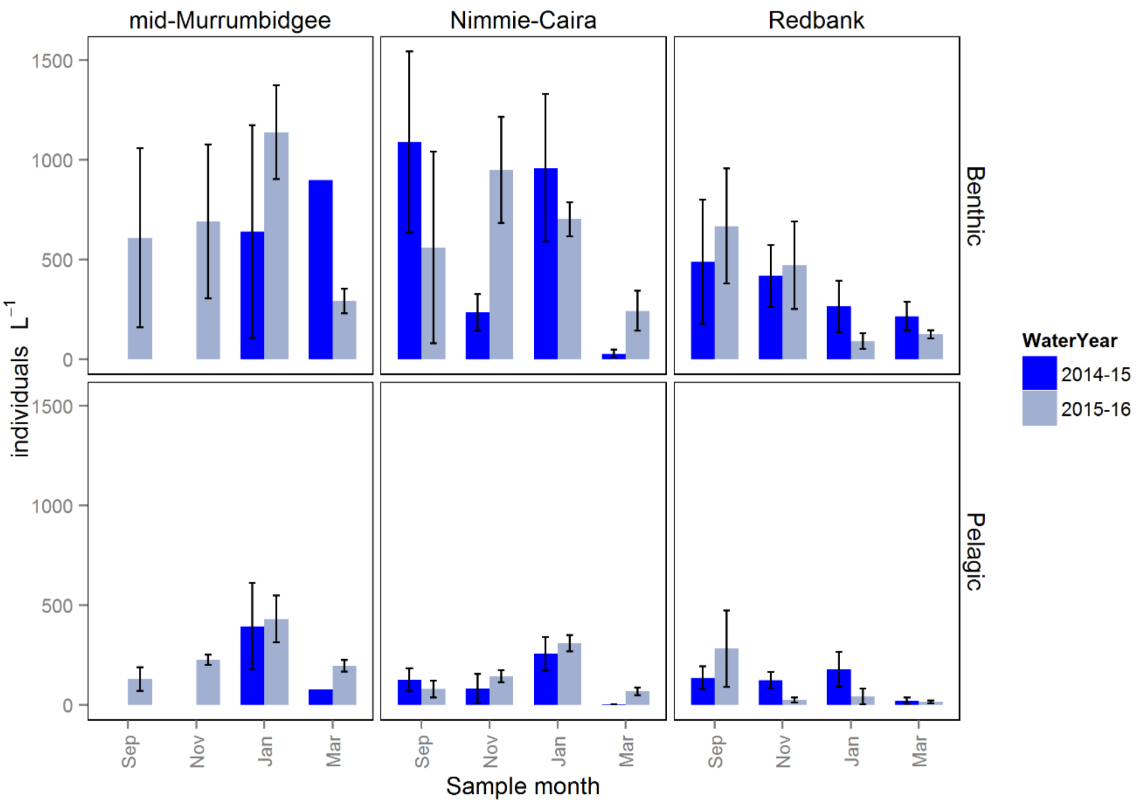


Figure 5-31 Mean densities of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) and 2015-16 (light blue). Errors are standard errors. In September and November 2014-15 wetlands in the mid-Murrumbidgee were dry and not available to sample.

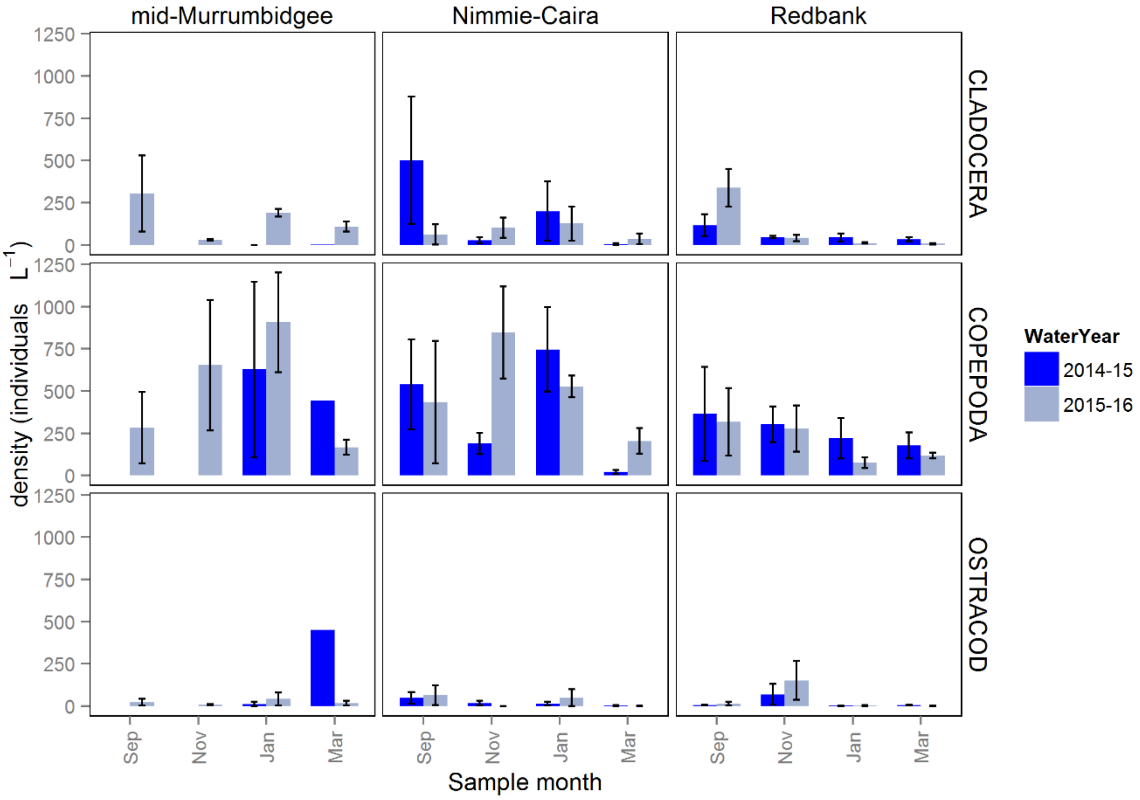


Figure 5-32 Mean densities of the main taxonomic groups of benthic microinvertebrates across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) and 2015-16 (light blue). Data are shown for cladocerans (first row), copepods (second row) and ostracods (third row). Errors are standard errors.

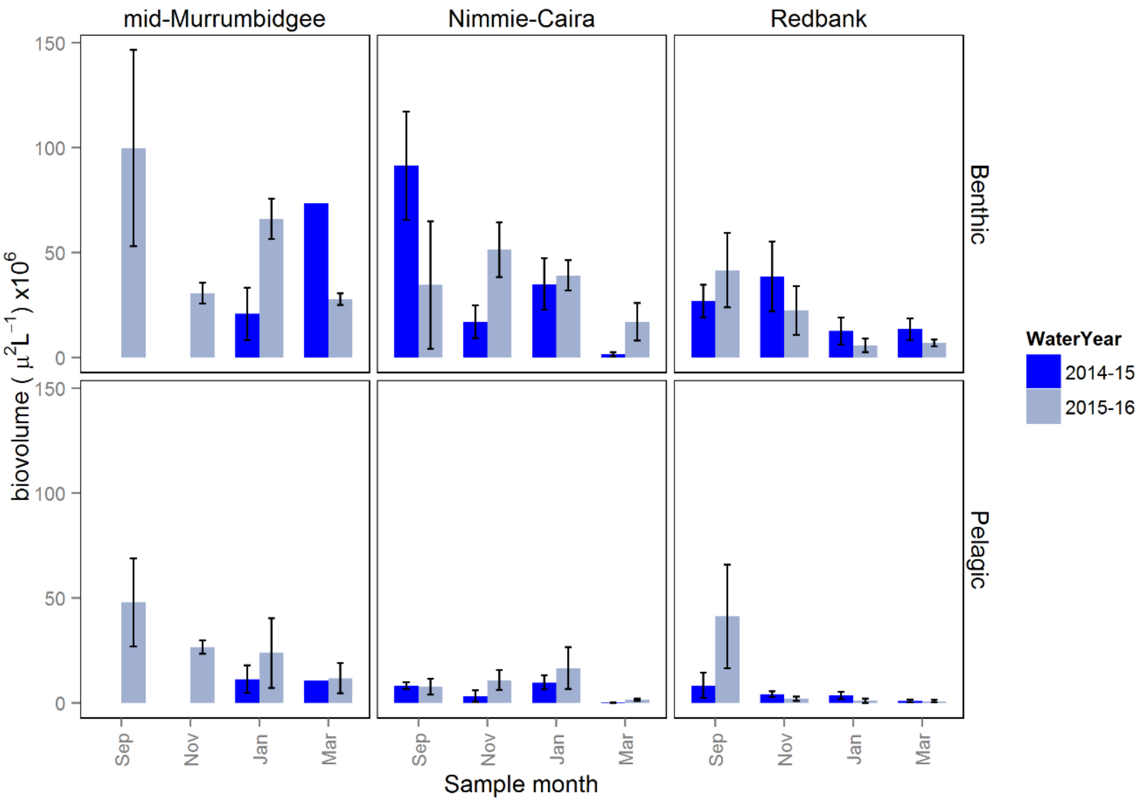


Figure 5-33 Mean biovolume (length x width x density) of benthic (first row) and pelagic (second row) microinvertebrates across sampling trips in mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 (dark blue) and 2015-16 (light blue).

Table 5-9 PERMANOVA results for densities of microinvertebrates, cladocerans, copepods and ostracods in each zone, year and across sampling trips. F is Pseudo-F.

Term	Microinvertebrate density		Cladocera density		Copepod density		Ostracod density	
	F	p	F	p	F	p	F	p
1. Zone (ZO)	2.26	**0.06**	0.81	0.579	2.63	**0.025**	1.61	0.155
2. Year (YR)	9.22E-2	0.964	2.17	0.092	5.86E-2	0.994	1.48	0.173
3. Trip (Year) TR(YR)	1.22	0.273	1.52	0.088	1.31	0.224	0.77	0.716
4. ZO x YR	0.96	0.434	2.85	**0.013**	1.05	0.38	1.31	0.254
5. ZO x TR(YR)	1.24	0.221	1.10	0.346	1.06	0.4	0.81	0.717

Discussion

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

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee in order to restore flow events that are affected by river regulation and/or extraction, to support habitat, food resources and breeding requirements of waterbirds, native fish and other vertebrates. Inundation of these wetlands in both 2014-15 and 2015-16 triggered a rapid and productive response in microinvertebrates with high densities throughout September, November and January. The peak densities (>1000/L) recorded across the two years of LTIM sampling were in the mid-Murrumbidgee in January 2016, matching densities recorded in the Nimmie-Caira in September 2014 and January 2015.

It is likely that high temperatures in January contributed to increased productivity in wetlands, although it is not clear why the Redbank wetlands did not show this pattern in either year. The peak in the Lowbidgee River sites in 2014-15 matched peaks observed in the independently sampled larval fish riverine sites. Wetlands receiving Commonwealth environmental water via infrastructure in 2014-15 in the mid-Murrumbidgee (Yarradda Lagoon) had similar densities of microinvertebrates as those in the Lowbidgee floodplain (Nimmie-Caira refuge watering) and were higher than wetlands in the Redbank zone (Yanga Waterbird and Nap Nap Waugorah), indicating that the mode of water delivery had little impact on microinvertebrate density or diversity.

Environmental watering of the mid-Murrumbidgee and Lowbidgee systems in 2014-15 and 2015-16 facilitated ecosystem functioning, enhancing habitat suitability for high ecological value species that rely on wetland food-webs. It will be interesting to see whether this same productivity is maintained or improved following repeated inundation in successive years. It will be valuable to examine the relationship between the high densities of microinvertebrates and the fish and waterbird species that prey upon them.

5.22 Vegetation diversity

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

Introduction

The hydrological regime is the principle driver of the composition and diversity of wetland plant communities. The persistence of water dependant species, and growth following environmental watering is influenced by a range of hydrological metrics (Brock and Casanova 1997, Casanova and Brock 2000). Over longer time periods inundation history at a wetland (how regularly the site received water in the past) and the length of time the wetland had been dry can influence the types of species that have persisted and the rate of establishment following inundation (Reid and Capon 2011). At shorter time scales, the length of time the wetland contained water prior to sampling and water depth will influence which species have established. Season and temperature can also influence the growth of water dependent species with growth increasing through summer.

Plant species richness is driven by species persistence (the ability of a species to survive and reproduce within a wetland) and dispersal (the capacity of seeds or propagules to enter the wetland from surrounding areas) (Wright, Flecker et al. 2003). For wetland plants, persistence is influenced by long-term inundation frequency, with extended dry periods potentially leading to losses from both the extant species pool and the seedbank (Brock, Nielsen et al. 2003). Seeds and propagules can enter wetlands from surrounding areas via water (Reid, Reid et al 2015) or in some cases can be carried by waterbirds (Figuerola, Green et al 2003). For healthy wetlands the rates of extinction are low and while dispersal occurs it may not necessarily add to the species richness of the wetland, for example dispersal of species that are already established in the wetland will potentially increase genetic diversity within the population but will not lead to a change in species richness overall. Considering this, while some natural variability in species richness as a result of wetting and drying transitions and annual variability in wetland hydrology may influence the types of species dominating the wetland community in a given year, long-term patterns of species richness in healthy wetlands is expected to remain relatively stable. However in degraded wetlands, for example areas that have been dry for extended periods and are currently being restored through environmental watering, species richness is expected to gradually increase due to dispersal of species from surrounding areas and reestablishment through the seedbank. Depending on the long-term patterns of inundation, it is normal for healthy wetlands to regularly transition between wet and dry phases with each phase supporting its own unique set of plant species (Rhazi, Grillas et al. 2009). However it is important to make a distinction between this transitional dry phase community that forms on mudflats and water margins during the wetland drying phase, and the terrestrial community that can eventually establish when wetlands are subject to extended long dry periods.

Methods

Monitoring of vegetation communities is undertaken four times per year (September, November, January and March) and commenced in September 2014 as per Wassens et al (2014). Surveys are conducted at twelve wetlands, with data collected along two to three set transects each containing three or five meter quadrats. Data on the percentage cover of each species, open water, bare ground, leaf litter, and logs > 10cm, tree canopy crown cover, water depth (cm) and soil moisture is also recorded in each quadrat.

Data analysis

Comparisons of community structure were undertaken using Primer version 6 (PRIMER). The percentage cover of each species was square root transformed before analysis. Analysis of similarities (ANOSIM) was used to compare community composition between sites, water years and wet-dry phases. SIMPER is used to identify the species contribution most to differences between sites (Anderson 2005). Species richness (SR) was calculated in PRIMER, individual plants that could only be identified to genus were excluded from the analysis. Generalised Linear Models were used to compare mean patterns of species richness at the wetland scale between wet and dry phases, zones and water years, as well as water depths between zones and water years

Results

Hydrological conditions

When considered together the mean water depth along each vegetation survey transect there was no significant differences between zones (GLM F =1.035, p= 0.357) and water years (GLM F =1.780, p= 0.183), but there was a significant interaction between zone and water year (GLM F = 4.627, P = 0.011). Water depths were lower in the mid-Murrumbidgee and Nimmie-Caira in 2014-15 compared to 2015-16, while water depths in the Redbank zone were higher in 2014-15 reflecting limited watering at two of the four Redbank sites in 2015-16 (Figure 5-34).

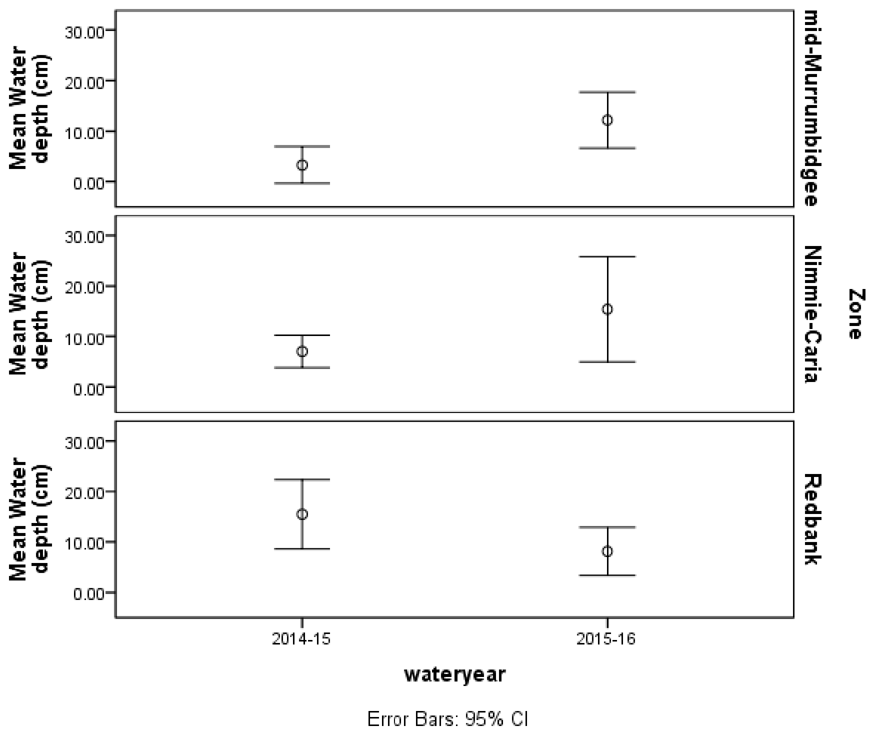


Figure 5-34 Mean water depth (cm) along each survey transect across sites in each monitoring zone and water year

What did Commonwealth environmental water contribute to vegetation species diversity?

Since September 2014, 208 species (147 native and 61 exotic) have been recorded with 43 water dependant species recorded following Commonwealth and state environmental watering actions. Species richness differed between the 12 monitoring sites and was highest at Telephone Creek in the Nimmie-Caira, which also contained the nationally listed species Mossgiel daisy (vulnerable EPBC Act). Species richness did not differ significantly between 2014-15 and 2015-16 (GLM F=0.385, p = 0.535) or between wetlands in their wet and dry phases (GLM F=0.0.901, p = 0.440). However there was some variability at individual wetlands. For example Nap Nap Swamp had higher species richness in 2014-15 when it received environmental water than in 2015-16 when the site was dry (Figure 5-35), while the opposite trend was observed for Gooragool Lagoon which had a lower species richness following environmental watering.

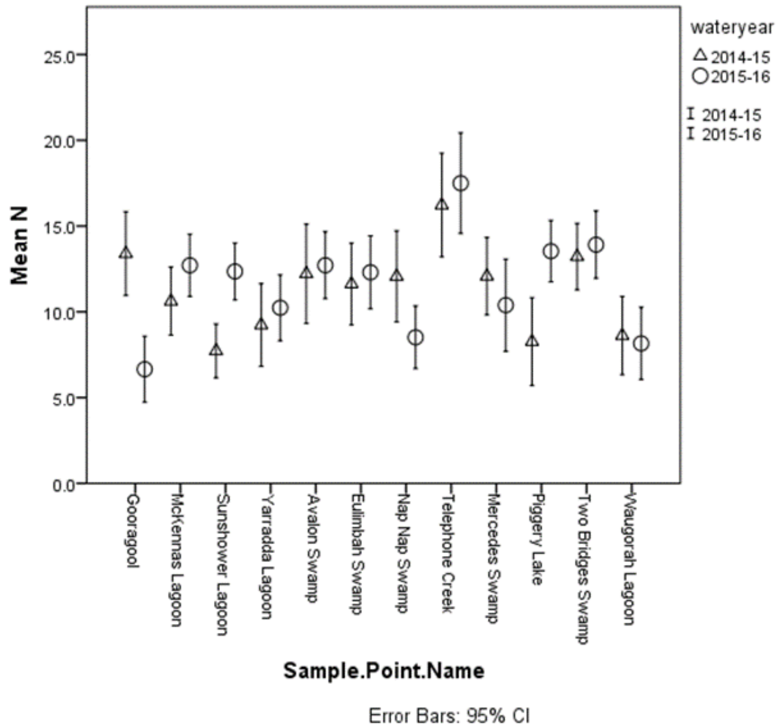


Figure 5-35 Patterns of species richness at each of the 12 monitoring locations in 2014-15 and 2015-16

What did Commonwealth environmental water contribute to vegetation community diversity?

The composition of wetland vegetation communities differed significantly between each of the 12 wetlands (ANOSIM Global R 0.687, p = 0.001), that is each of the wetlands targeted with environmental water supported its own assemblage of plant species and this relationship held during both the wet and dry phases. This can be seen in the MDMS plot (Figure 5-36) where each point represents the vegetation community during each survey occasion. Overall, sites that underwent a wet and dry phase transition have a wider spread of points than sites that remained dry throughout (for example Mckennas) but despite this there is still clear groupings, with limited overlap of points drawn from each site. These differences between individual sites were somewhat stronger than when sites were grouped within the three monitoring zones (mid-Murrumbidgee, Nimmie-Caira and Redbank), although monitoring zones still represent significantly different communities (ANOSIM 0.477, p = 0.001).

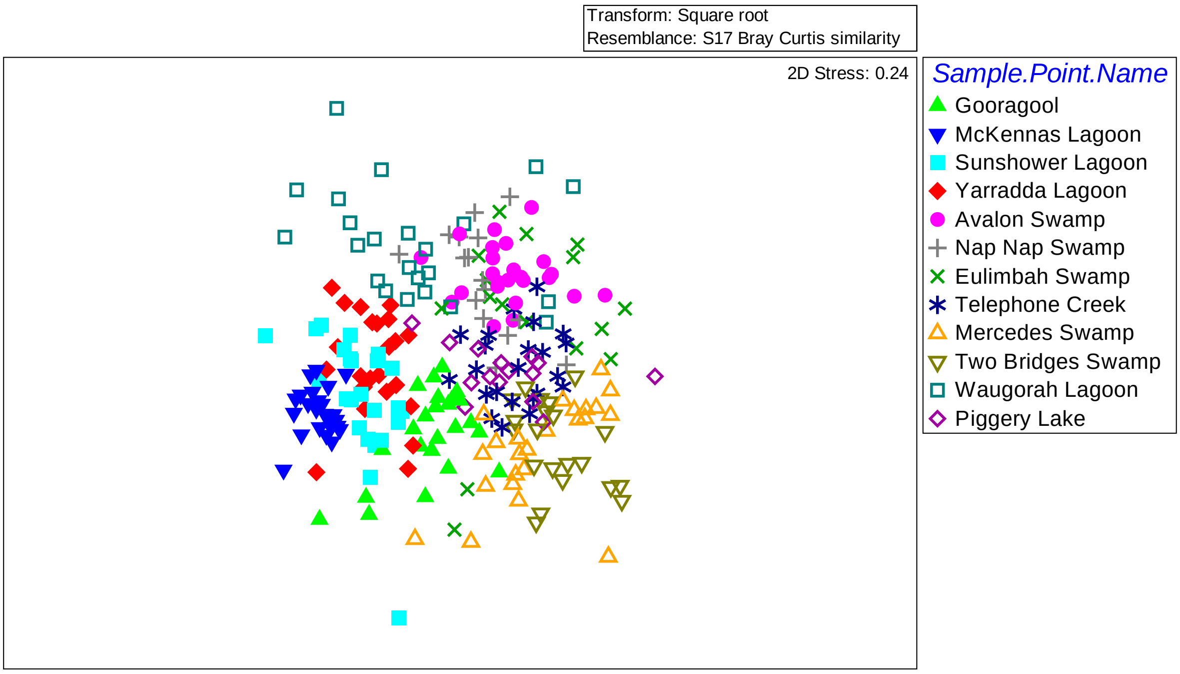


Figure 5-36 MDS plot of vegetation communities across the 12 monitoring locations in 2014-15 and 2015-16. Points that are close together have more similar communities then those which are further apart.

Did the percentage cover of plant functional groups change in response to environmental watering?

Due to the high level of variability in the types of species present at each wetland, we classed each species in to its functional group (Casanova and Brock 1997). The dominance of terrestrial species is clearly apparent at wetland sites that did not receive water in either 2014-15 or 2015-16 (McKenna's and Sunshower) (Figure 5-37). Other wetlands including Yarradda Lagoon show a strong increase in the percentage cover of species within the amphibious functional groups following environmental watering in December 2014 which was maintained by follow up watering in 2015. Many of the wetlands in the Nimmie-Caira systems were dry in September 2015 and this is reflected in the high percentages of terrestrial species at Avalon, Eulimbah, Nap Nap and Telephone Creek. Of these wetlands only Telephone Creek received substantial inundation, while Avalon and Eulimbah received partial fills, Nap Nap remained dry throughout 2015-16 and this is reflected in the increasing cover of terrestrial species.

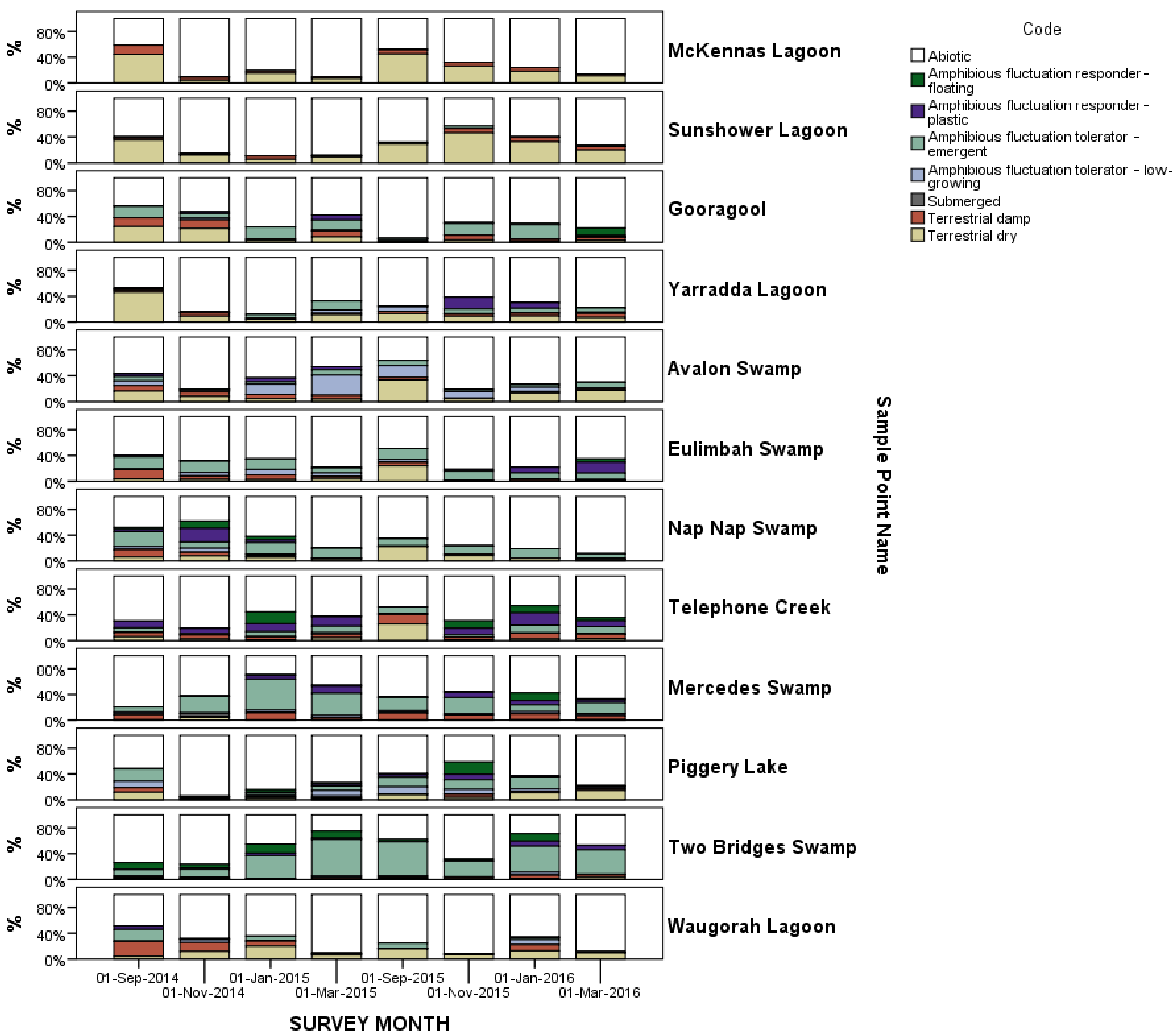


Figure 5-37 Changes in percentage cover of plant functional groups and abiotic factors (bare ground, open water and leaf litter) between September 2014 and March 2016. See (Brock and Casanova, 1997).

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

Community composition differed significantly between wet and dry sites (ANOSIM Global R 0.132, P = 0.001). Key understory species most abundant at sites during their wet stage were common spike rush (*Eleocharis acuta*), nardoo (*Marsilea drummondii*), water primrose (*Ludwigia peploides ssp.montevidensis*), and tall spike rush (*Eleocharis sphacelata*). Other species including common sneeze weed (*Centipeda cunninghamii*) had similar abundances at wetlands during both the wet and dry phase, whereas the introduced weed spear thistle (*Cirsium vulgare*) was most abundant at dry sites (Table 5-10).

Table 5-10 SIMPER comparison of species contributing to the differences in community composition between wet and dry sites (top 60% of species included for clarity). Average abundance represents how abundant the species was at sites while they were wet and while they were dry. The percent contribution (Contribution %) represents how much that species contributes to the differences between wet and dry sites (higher percentage means a greater contribution)

Species	Average Abundance				
	Wet	Dry	Contribution %	Cumulative contribution	Association
Eleocharis acuta	1.06	0.57	4.66	4.66	Wet
Muehlenbeckia florulenta	0.79	0.51	4.32	8.98	Wet
Marsilea drummondii	0.71	0.48	3.56	12.55	Wet
*Cirsium vulgare**	0.2	0.83	3.52	16.07	Dry
Eucalyptus camaldulensis	0.42	0.88	3.47	19.53	Dry
Ludwigia peploidesssp. montevidensis	0.88	0.2	3.33	22.86	Wet
Eleocharis sphacelata	0.65	0.22	3.31	26.17	Wet
Azolla filiculoides	0.78	0.18	3.24	29.41	Wet
Centipeda cunninghamii	0.63	0.62	3.17	32.58	Both
Dysphania pumilio	0.15	0.66	2.65	35.23	Dry
*Annual Exotic Grass**	0.25	0.63	2.6	37.83	Dry
Eleocharis pusilla	0.46	0.28	2.18	40.01	Wet
Atriplex semibaccata	0.19	0.5	2.15	42.17	Dry
Polygonum aviculare	0.12	0.52	2.13	44.3	Dry
Alternanthera denticulata	0.42	0.29	2.11	46.42	Wet
Medicago polymorpha	0.21	0.4	1.82	48.23	Dry
Myriophyllum papillosum	0.38	0.13	1.61	49.84	Wet
Paspalidium jubiflorum	0.32	0.17	1.52	51.36	Wet
Calotis scapigera	0.09	0.33	1.44	52.8	Dry
Pseudoraphis spinescens	0.3	0.06	1.33	54.12	Dry
Persicaria decipiens	0.3	0.1	1.3	55.43	Dry
Sclerolaena muricata	0.15	0.16	1.21	56.64	Dry
Chamaesyce drummondii	0.12	0.21	1.19	57.83	Dry
Heliotropium europaeum	0.04	0.26	1.15	58.98	Dry

* Denotes introduced species

Case studies

Outcomes of Yarradda Lagoon watering

In 2015-16 Commonwealth environmental water was used to top-up Yarradda Lagoon with the objective of “maintain wetland and riparian native vegetation”. Yarradda Lagoon had been dry for an extended period between 2002 and 2010. It filled in 2010 as a result of heavy rainfall across the catchment and retained water until early in 2012. The wetland remained dry through 2013 and most of 2014, initially receiving NSW environmental water in December 2014. We used SIMPER to identify which species contributed most to differences in the composition of the vegetation communities before and after environmental watering. Prior to watering the key species included spear thistle (*Cirsium vulgare*), creeping knotweed (*Persicaria prostrata*), river red gum seedlings *(Eucalyptus camaldulensis*)*,* prickly lettuce *(*Lactuca serriola) and burr medic (*Medicago polymorpha*)(Table 5-11). As expected, after environmental watering there were major changes in the composition of the plant communities with red water milfoil (*Myriophyllum verrucosum*), hairy panic (*Panicum effusum*) and spiny mudgrass (*Pseudoraphis spinescens*) establishing. The aquatic community continued to develop over 2015-16 with tall spike rush (*Eleocharis sphacelata*) and fringe lily (*Nymohoides crenata*) recorded.

Table 5-11 SIMPER comparisons of Yarradda Lagoon in its wet and dry phase. Shading indicates that species have a higher average abundance during the wet phase (top 70% of species included for clarity). * denotes exotic species. Average abundance represents how abundant the species was at sites while they were wet and while they were dry. The percent contribution (Contrib %) represents how much that species contributes to the differences between wet and dry sites (higher percentage means a greater contribution)

Species	Average abundance			
	Dry	Wet	Contribution %	Cumulative contribution
*Cirsium vulgare**	2.49	0.7	9.97	9.97
*Medicago polymorpha**	2.05	0.38	8.24	18.21
Pseudoraphis spinescens	0.18	1.44	6.52	24.73
Myriophyllum verrucosum	0	1.3	6.2	30.93
Persicaria prostrata	1.35	0.71	5.75	36.68
Panicum effusum	0	1.09	5.2	41.88
Centipeda cunninghamii	0.83	1.24	5	46.88
Grass*	0.98	0.35	4.49	51.37
Eucalyptus camaldulensis	1.2	0.73	3.5	54.88
Chamaesyce drummondii	0.26	0.53	2.84	57.72
*Trifolium arvense**	0.7	0.06	2.77	60.49
*Lactuca serriola**	0.56	0.11	2.54	63.03
Atriplex semibaccata	0.42	0.4	2.26	65.3
Dysphania pumilio	0.12	0.45	2.25	67.55
Eleocharis acuta	0.46	0.23	2.23	69.78

Nimmie-Caira

Unlike Yarradda Lagoon which had been subject to disturbance as a result of extended drying periods that far exceeded its natural inundation frequency, the wetlands monitored in the Nimmie-Caira have received regular inundation that more closely aligns with the long-term water regime. All four of the monitoring sites received environmental water in either 2014-15 or in 2015-16 (Table 5-12), vegetation transects at Avalon and Nap Nap were inundated in 2014-15 only while transects in Telephone Creek and Eulimbah were inundated in both years. Despite differences in the types of plants present at the four wetlands, there was still a significant difference between the wet and dry communities (ANOSIM Global R. 0.125, $p = 0.009$). Species contributing the most to difference in the wet and dry phase communities across the Nimmie-Caira sites were identified using SIMPER (Average dissimilarity = 79.43). As wetlands dried native species including nardoo (*Marsilea drummondii*), *sneezeweed (Centipeda* *cunninghamii), climbing saltbush (Rhagodia spinescens), and lesser joyweed (Alternanthera denticulata)* all increased in abundance. Following inundation water dependant species including water primrose (*Ludwigia peploides ssp. montevidensis)* Azolla *(Azolla filiculoides)* and common watermilfolil *(Myriophyllum papillosum*) established.

Table 5-12 SIMPER comparisons of wetlands in their wet and dry phases in the Nimmie-Caira. Shading indicates that species has a higher average abundance during the wet phase (top 60% of species included for clarity) * denotes exotic species

Species	Average abundance			
	Dry	Wet	Contribution %	Cummulative contribution
Muehlenbeckia florulenta	2.22	1.93	7.28	7.28
Marsilea drummondii	1.38	1.01	6.35	13.63
Ludwigia peploidesssp.montevidensis	0.19	1.65	6.18	19.81
Azolla filiculoides	0.02	1	3.99	23.8
Centipeda cunninghamii	1.14	0.79	3.99	27.79
Eleocharis pusilla	0.72	0.75	3.91	31.69
Paspalidium jubiflorum	0.08	0.59	2.26	33.96
Rhagodia spinescens	0.49	0.04	2.18	36.14
Heliotropium europaeum	0.52	0.04	2.12	38.27
Myriophyllum papillosum	0	0.54	2.09	40.36
Dysphania pumilio	0.57	0.14	2.04	42.4
Chenopodium nitrariaceum	0.42	0.17	2.01	44.42
Juncus usitatus	0.22	0.45	1.99	46.41
Alternanthera denticulata	0.4	0.31	1.95	48.35
Senecio runcinifolius	0.44	0.39	1.88	50.23
Eleocharis acuta	0.03	0.49	1.75	51.98
*Verbena supine**	0.41	0.17	1.66	53.64
Mentha australis	0.38	0.19	1.64	55.29
Juncus flavidus	0.09	0.43	1.62	56.9
Myriophyllum verrucosum	0.06	0.37	1.59	58.49
*Medicago polymorpha**	0	0.43	1.44	59.93

Discussion

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee in order to "Protect and maintain the health of existing extent of riparian, floodplain and wetland native vegetation communities". The outcomes of environmental watering on plant communities are considered in the context of two broad evaluation questions and two predictions specific to the watering actions carried out in 2015-16.

Environmental watering supported the establishment and growth of 43 water dependent species, thereby contributing these additional species to the overall regional species pool. However species richness did not differ significantly between 2014-15 and 2015-16 or between wetlands in their wet and dry phases. This is expected for wetlands in the Nimmie-Caira and Redbank where wetlands are already in good condition and additions of new aquatic species are uncommon. This pattern is also consistent with other studies in the Lowbidgee (Capon and Reid 2016). Species richness is a relatively simple measure of the number of species present at a given time. When considering the response to environmental watering it maybe more informative to identify species that make significant contribution to the composition and character of the vegetation community at each wetland and to target watering actions to ensure that the water regime supports condition for their growth and reproduction.

To date there has been limited studies available on which we can infer relationships between the hydrological characteristics of individual wetlands and the structure and persistence of key floodplain species. Environmental watering actions targeting Yarradda Lagoon clearly supported the establishment of important aquatic species including spiny mud grass and tall spike rush both of which were absent from surveys conducted when the wetland last contained water in 2010-2012 (Wassens, Bindokas et al. 2013). This increase in abundance of key water dependant species demonstrates that the current environmental watering strategy at Yarradda Lagoon has been successful and should be continued.

Vegetation community diversity describes the range of different communities that are targeted by environmental water in a given year. The 12 monitoring sites represented a small fraction of a range of different wetland types, geomorphologies and long-term inundation histories that occur through the Murrumbidgee floodplain. Monitoring focused on three key wetland types: open oxbow lagoons, spike-rush- river red gum wetlands and lignum-black box wetlands; however, even within these broad groupings there is considerable differences in the composition of the communities between individual sites. Community composition was more similar for sites that belonged within the same geographic zone (mid-Murrumbidgee, Nimmie-Caira and

Redbank) with the exception of Waugorah Lagoon which is located within the Redbank zone. Waugorah Lagoon supports vegetation communities that are consistent with those in the Nimmie-Caira. Watering actions were conducted in the Nimmie-Caira with the objective of "improving aquatic habitat, and riparian vegetation" it is import to note that the monitored wetlands in the Nimmie-Caira have been regularly watered and are in good condition, therefore a significant change in vegetation diversity or abundance is not expected following environmental watering because the rates of species additions and deletions are very slow. Instead the focus of watering should be to maintain the unique character of individual wetlands in the Nimmie-Caira, thereby supporting community diversity and species richness across the floodplain. This can be achieved by describing the long-term hydrological regime of the target wetlands and managing watering actions in a manner that is sympathetic to the long-term inundation regime and the requirements of dominant aquatic plant species.

5.23 Wetland fish

Prepared by Dr Skye Wassens (CSU) and Dr Jason Thiem (DPI Fisheries)

Introduction

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

Four watering actions were monitored as part of the LTIM project that have objectives relating to native fish communities in wetlands. In the Redbank system, the Yanga National Park action inundated Two Bridges swamp with the objective to "provide habitat for native fish, frogs and other vertebrates" while the Nap Nap – Waugorah action targeted flood ways through the Redbank zone including Waugorah Lagoon, as well as the northern section of the Nimmie-Caira. The Nimmie-Caira SBF refuge (south Caira channel) and Nimmie-Caira refuge (north Caira channel) inundated Eulimbah Swamp and Telephone Creek and maintained a small area of water in a dam associated with Avalon Swamp in the Nimmie-Caira zone with the objectives "maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbird" and "Support the habitat requirements of native fish and turtles". In the mid-Murrumbidgee, wetland pumping was undertaken at Yarradda Lagoon with the objective of "support known native fish and frog community established in 2014-15" while NSW environmental water was used to maintain Gooragool Lagoon.

Methods

Since 2014, wetland fish have been monitored across the 12 LTIM surveyed wetlands four times per year (September, November, January and March). Detailed survey methodology is contained in Wassens, Jenkins et al. (2014). Wetland fish are surveyed using a combination of large (n=2) and small (n = 2) fyke nets which are set overnight. The fish Catch-Per-Unit Effort (CPUE) is based on the number of fish collected per hour, with this value adjusted for differences in the width of the net wings and water depth where the net is set (nets can only be set when water depths are above 30cm). In 2015-16 two sites (McKennas in the mid-Murrumbidgee and Nap Nap in the Nimmie-Caira) were dry throughout the monitoring period.

Data analysis

Differences in fish species richness and abundance (CPUE) between monitoring zones and sample occasions where tested using Generlised Linear models. Where data were not normally distributed, patterns were tested using Kruskal-Wallis one-way analysis of variance. Changes in the length-frequency distributions between the the September and November (pooled results) and the January-March (pooled sample results) sampling periods were tested using Mann-Whitney U tests for the native species captured in wetlands of the Murrumbidgee catchment in 2015-16.

Results

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

Seven native and four exotic species were captured across 10 LTIM surveyed wetland sites that contained water between September 2015 and March 2016. Murray cod juveniles were collected at Eulimbah Swamp in the Nimmie-Caira for the first time, increasing overall number of native species from six in 2014-15 to seven in 2015-16.

Carp gudgeon were the most abundant (based on CPUE) native species occurring across all three monitoring zones, while bony herring and Australian smelt were also widespread across zones but with far lower abundances (Figure 5-38 a and b). While there were some changes overtime, within each zone the abundance of native species did not change significantly between sampled occasions (based on Kruskal-Wallis tests). This outcome may have been influenced by the smaller number of sites that contained water within each zone in 2015-16 compared to previous years, which makes it difficult to delineate statistically significant relationships.

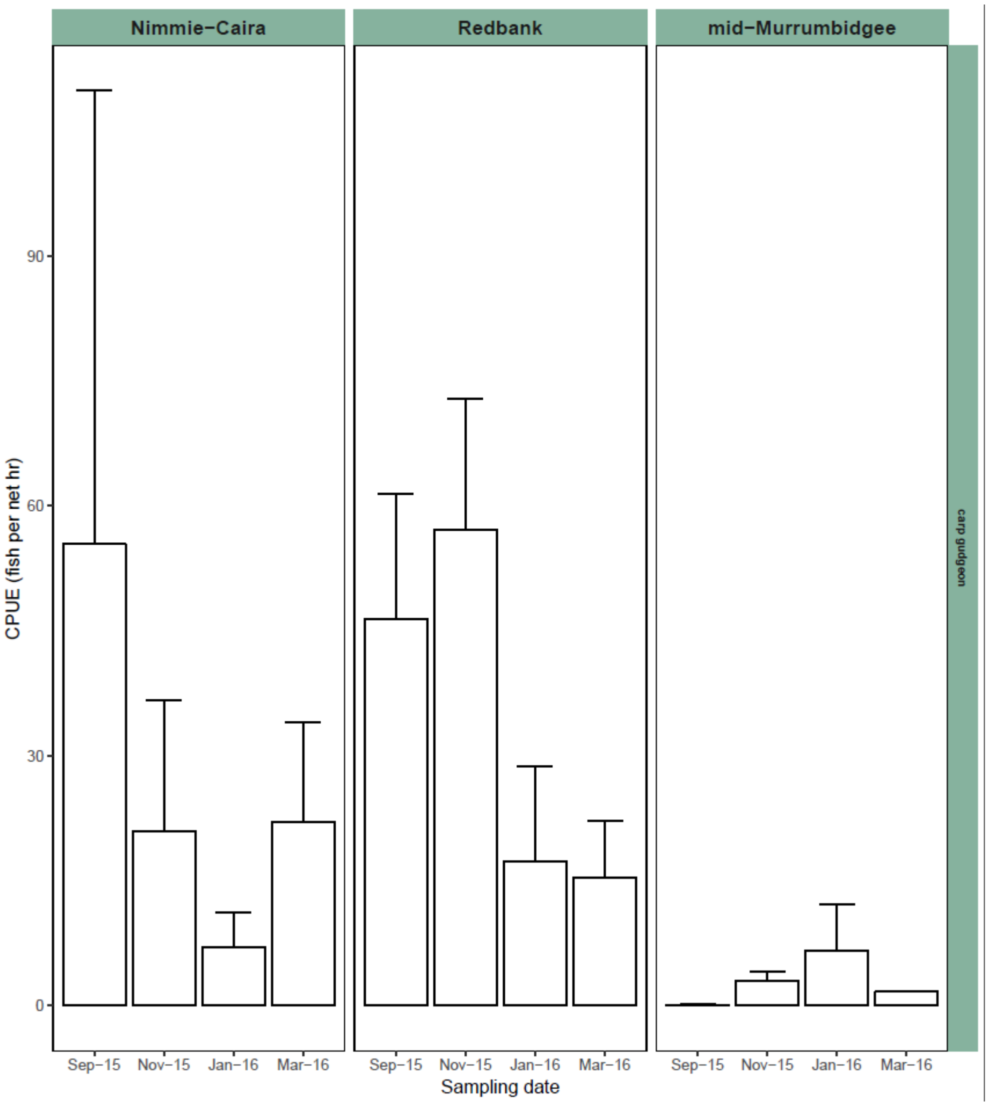


Figure 5-38(a) Mean catch per unit effort (fish per net hour)((CPUE) (± SE) of carp gudgeon over the four sample periods in 2015-16.

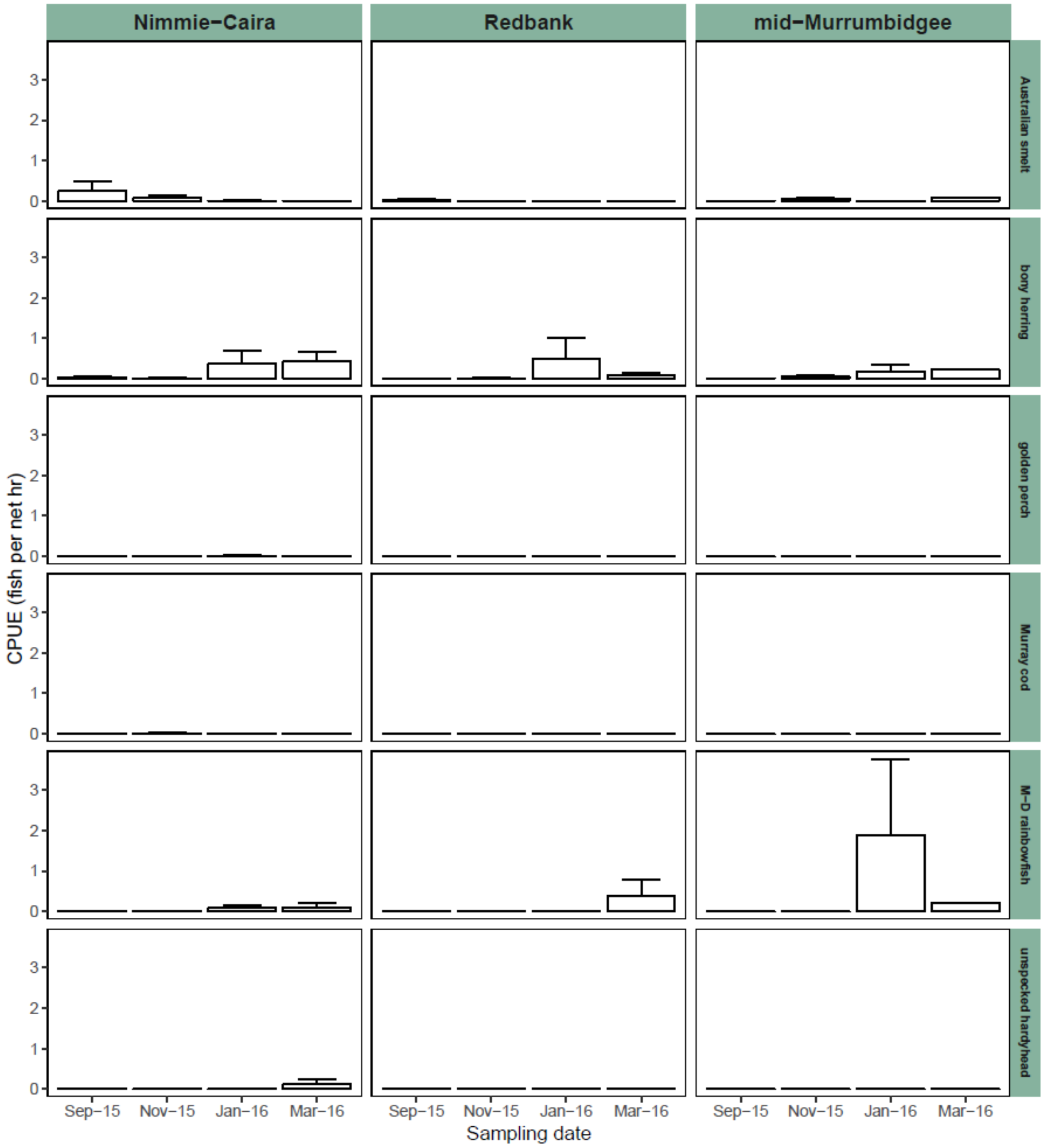


Figure 5-38 (b) Mean catch per unit effort (fish per net hour)((CPUE) (± SE) of native fish species excluding carp gudgeon over the four sample periods in 2015-16.

As in previous years (Wassens, Thiem et al. 2015) exotic fish species were widespread through the monitoring locations, with gambusia, common carp, goldfish and oriental weatherloach (*Misgurnus anguillicaudatus*) the most commonly recorded exotic species (Figure 5-39). Carp, goldfish and gambusia occurred at all monitoring locations while weatherloach were restricted to five locations (three in Redbank: Two Bridges, Mercedes and Piggery and two in the Nimmie-Caira: Nap and Telephone Creek). As was the case for native species, there were no significant trends associated with changes in the abundance of exotic species over time within each zone.

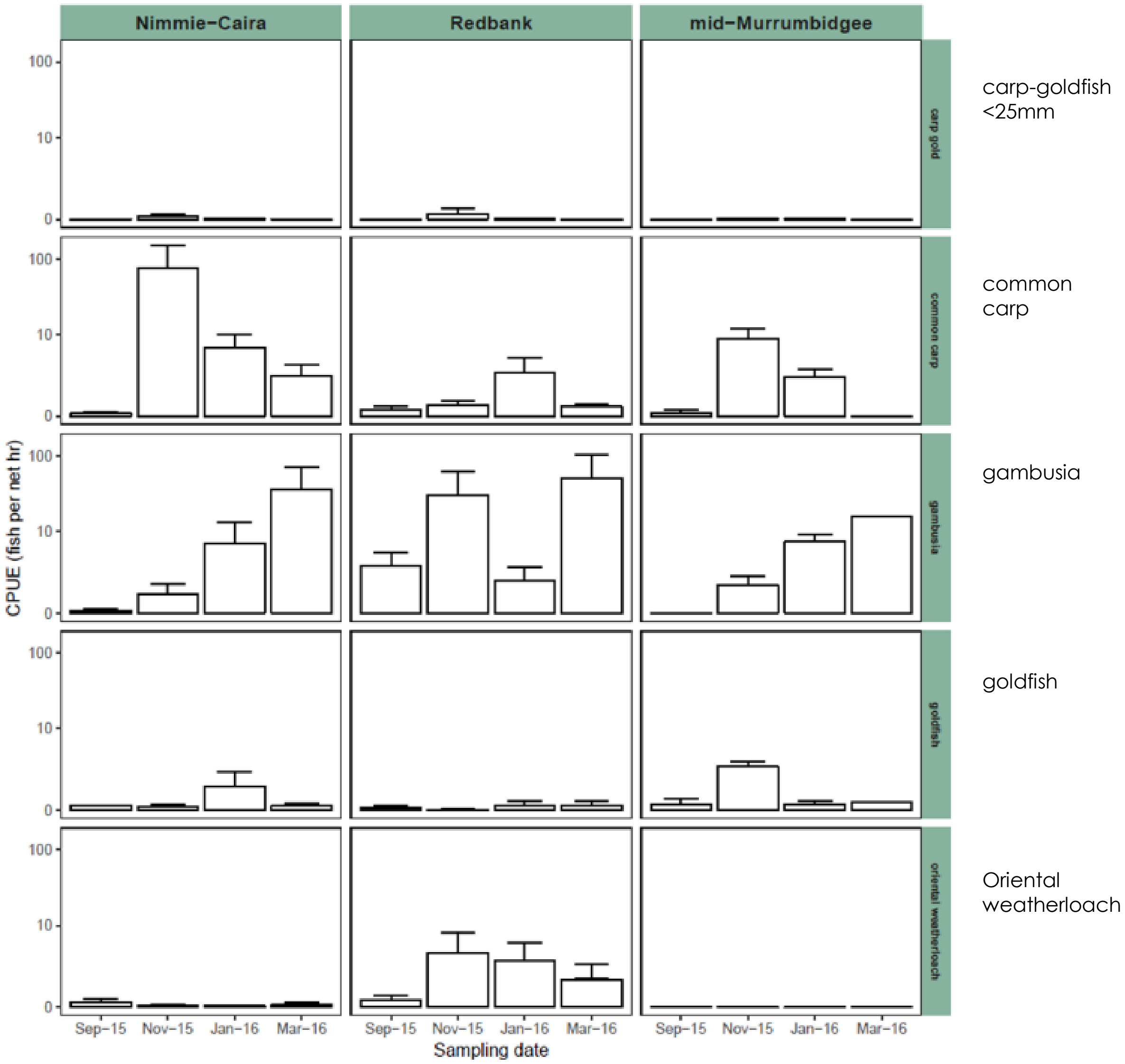


Figure 5-39 Mean catch per unit effort (CPUE) (±SE) of exotic fish species over the four sample periods. Note the log10 scale.

Species richness

The native species richness differed significantly between sites (GLM f = 4.238, p <0.001), zones (GLM f=4.391, p = 0.007) and water years (GLM f = 5.116, p= 0.027). There was a slight but non-significant interaction between site and water year (GLM f = 1.995, p= 0.08) reflecting differences in watering strategies between sites in each water year. Yarradda Lagoon which received water via pumping in 2014-15 and 2015-16 with the objective of "support known native fish and frog community established in 2014-15" alongside a brief natural reconnection, had an increase in the number of native fish species from two (carp gudgeon and bony herring) in 2014-15 to four in 2015-16 with Murray darling rainbowfish and Australian smelt also detected (Figure 5-40).

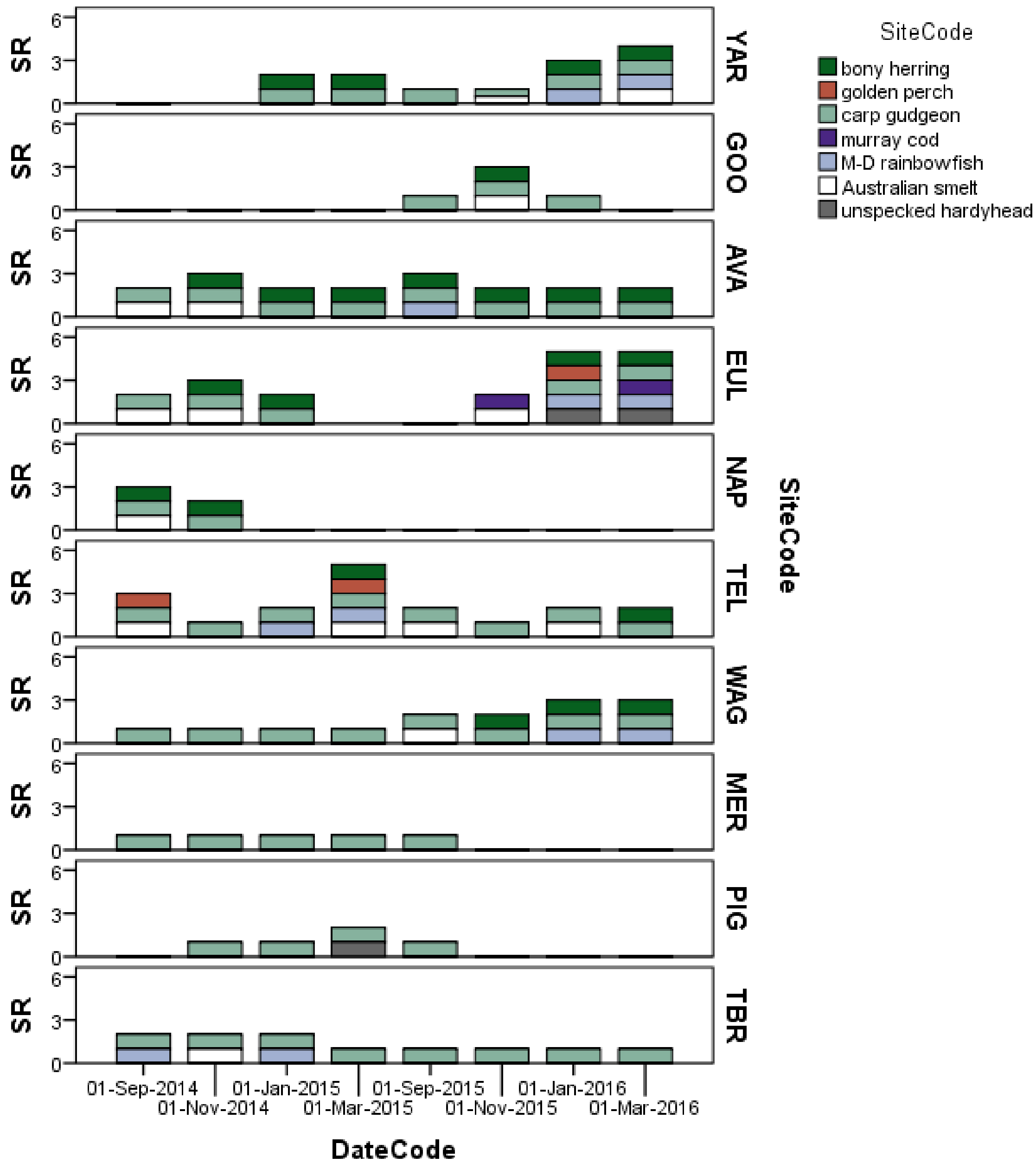


Figure 5-40 Change in native species richness between September 2014 and March 2016 at each monitoring site (note that McKenna's and Sunshower were too dry to set nets in both water years and have been excluded from this analysis). Nil Species richness value indicate that the site was dry or that water levels at the site were too low to set nets.

Watering actions targeting Eulimbah Swamp and Telephone Creek in the Nimmie-Caira and Waugorah Lagoon in the Redbank zone with the objectives of "maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbird" and "Support the habitat requirements of native fish and turtles" were also associated increases in native species richness. At Eulimbah the number of native species increased from three in 2014-15 to seven with Murray cod, unspecked hardyhead, golden perch and Murray Darling rainbow fish recorded at the swamp in 2015-16. Native species have also increased at Waugorah Lagoon from one species (carp gudgeon) in 2014-15) to three in 2015-16 with Murray Darling rainbow and Bony herring also recorded. When considered across all sites, exotic species richness also differed significantly (GLM f = 5.670, p <0.001) and there was a significant interaction between site and water year (GLM f = 2.217, p =0.038) which suggests that the number of exotic species is changing at different rates over time.

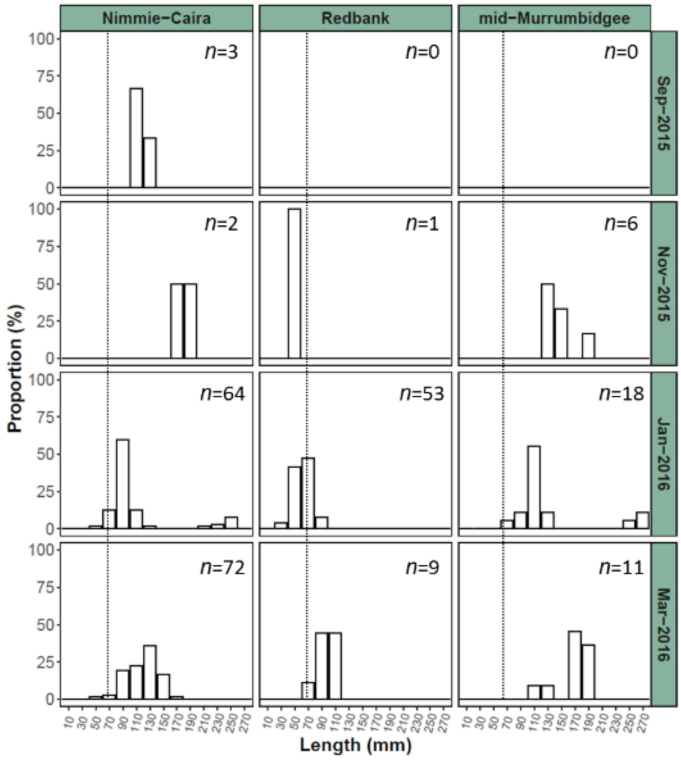
What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?

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

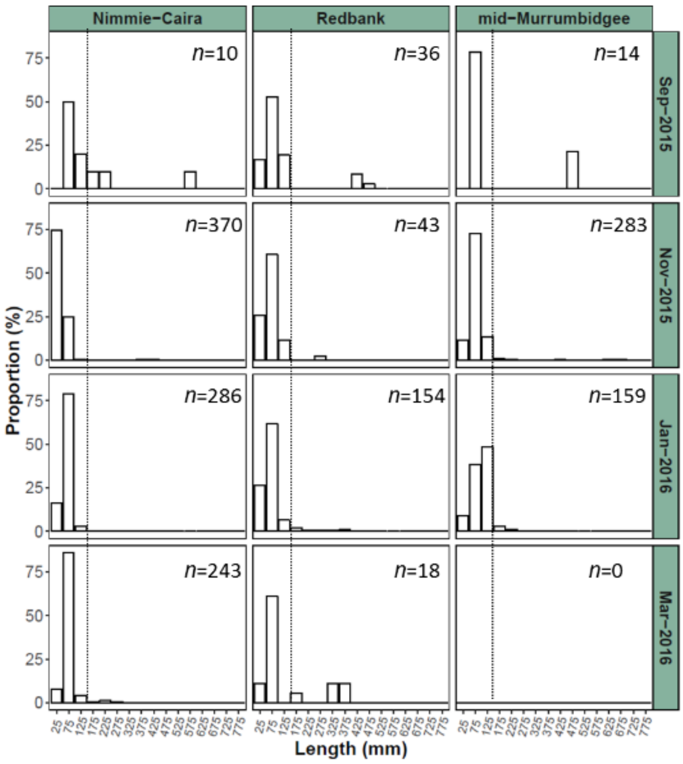
Size distributions of key native species collected in spring (September and November 2014) and summer (January and March 2015) were compared within each zone using the Mann-Whitney U test. In the mid-Murrumbidgee (Yarradda Lagoon) and Nimmie-Caira (Nimmie-Caira refuge north and south watering actions) the size structure of the Australian smelt was skewed towards smaller individuals in spring (September and November) with a shift towards larger individuals with the March survey (Table 5-13; Figure 5-41). In contrast, carp gudgeon populations showed a shift from smaller to larger individuals in the mid-Murrumbidgee, and a shift from larger to smaller individuals in the Nimmie-Caira and Redbank (Yanga waterbird action). Bony herring size distributions did not differ significantly between spring and summer samples in the mid-Murrumbidgee or Redbank, while in Nimmie-Caira larger individuals dominated the population in spring with smaller individuals occurring in summer. Trends in the size distributions of exotic species also differed between zones, with common carp size distributions changing from smaller to larger individuals in the mid-Murrumbidgee and Nimmie-Caira, but not Redbank. While oriental weather loach size distributions did not differ in Redbank but did undergo a shift towards larger individuals in the Nimmie-Caira (see Table 5-13; Figure 5-41).

Table 5-13 Length-frequency distribution Mann-Whitney U test comparisons between the September and November (pooled results) and the January-March (pooled sample results) for the native species captured in wetlands of the Murrumbidgee catchment in 2015-16. Null values indicate that sample size was too small to undertake analysis. Significant differences are indicated in bold.

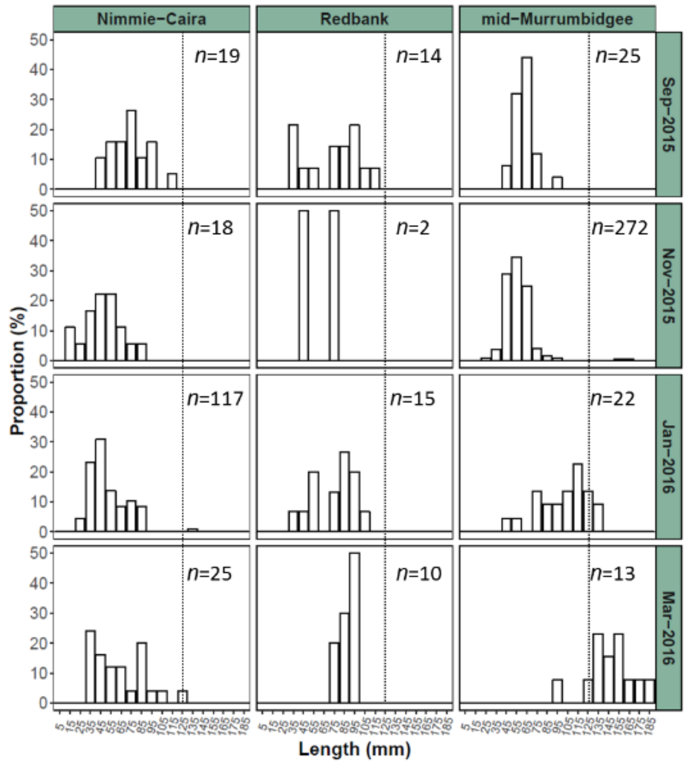
Species	Mid-Murrubidgee		Redbank		Nimmie-Caira	
	MW	*P*	*MW*	*P*	*MW*	*P*
Australian smelt	**3.103**	**0.002**	-	-	**1.627**	**0.087**
bony herring	-0.744	0.480	0.716	0.603	**-2.035**	**0.042**
carp gudgeon	**13.189**	**<0.001**	**-3.332**	**0.001**	**-12.007**	**<0.001**
Murray-Darling rainbowfish	-	-	-	-	-	-
golden perch	-	-	-	-	-	-
common carp	**8.533**	**<0.001**	**-4.798**	**<0.001**	**18.977**	**<0.001**
gambusia	0.594	0.553	**-10.995**	**<0.001**	**8.608**	**<0.001**
goldfish	8.452	<0.001	1.435	0.151	**-2.051**	**0.040**
oriental weatherloach	-	-	-0.876	0.381	**2.596**	**0.009**



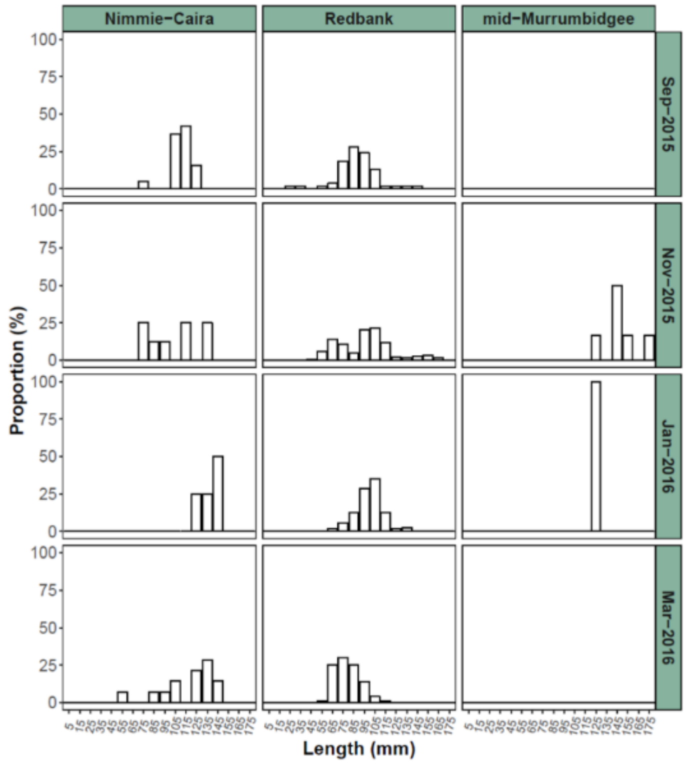
bony herring



common carp



goldfish



oriental weatherloach

Figure 5-41 Size frequency distributions for each sample occasion in 2015-16 across the three sampling zones. Charts only included for species where there were more than 50 individuals collected. Dashed line indicates size at sexual maturity.

Discussion

Four watering actions that have outcomes targeting fish communities were undertaken in 2015-16, overall these actions were successful in achieving their stated objectives for the native fish species that were present (Table 5-14). But overall wetland fish communities are in poor condition dominated by opportunistic generalist species with floodplain specialist species such as Murray hardyhead absent from the mid-Murrumbidgee and Lowbidgee floodplains.

Table 5-14 summary of outcomes for each of the monitored watering actions undertaken in 2015-16 as they relate to wetland fish

Watering action	Expected outcomes for wetland fish	LTIM sites receiving water	Outcomes
Yanga National Park waterbird support	– provide habitat for native fish, frogs and other vertebrates	Two Bridges	Overall species richness was low in Redbank, with only one of the three spike rush wetlands receiving water in 2015-16.
Nimmie-Caira Nimmie-Caira refuge (north Caira channel) **Nimmie-Caira SBF refuge (south Caira channel**	– maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbird	Eulimbah Avalon Telephone Creek	Overall, species richness has increased in the Nimmie-Caira with Murray cod juveniles recorded in Eulimbah swamp in 2015-16. The strategy of maintaining refuge for southern bell frogs is also likely to support native fish population in this system.
Nap Nap - Waugorah	– Support the habitat requirements of native fish and turtles.	Waugorah Lagoon	Native species richness has increased in Waugorah lagoon between 2014-15 and 2015-16. Waugorah lagoon also supported higher abundance of native species than other sites in the Redbank zone, highlighting the importance of this system as native fish refuge.
Yarradda Lagoon	– support known native fish and frog community established in 2014-15.	Yarradda Lagoon	Native species richness has increased in Yarradda lagoon between 2014-15 and 2015-16 with the detection of Murray-Darling rainbow fish

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

The Murrumbidgee River is an important source of colonising individuals to wetlands, but the conditions present in the wetland during the water year can influence the establishment and persistence of populations. While temporary habitats are critical for growth and reproduction of many wetland species, permanent habitats are also important because they allow aquatic species to survive on the floodplain between water years. Watering actions undertaken to create refuge habitat in the Nimmie-Caira and Nap-Nap to Waugorah Lagoon supported an increase in native fish diversity, in particular native species richness has increased at Eulimbah Swamp in the Nimmie-Caira and Waugorah Lagoon in the Redbank system, and southern bell frogs were also recorded at these sites. Gradual increase in species richness may indicate that the strategy of maintaining refuges is having a positive impact on species richness at some sites. Environmental watering actions at Yarradda Lagoon which were undertaken with the objective of supporting known native fish and frog community established in 2014-15 have successfully achieved this goal. No native species have been lost from the wetland and the detection of Murray-Darling rainbow fish in 2015-16, which may have entered the wetland during a period of higher river flows that briefly reconnected the wetland, increased species diversity there.

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

Native fish communities were dominated by one larger bodied (bony herring) and two small bodied (Australian smelt and carp gudgeon) native fish. There was evidence of juveniles being present for all three species, but size structure of the population differed between zones. For bony herring, catches were made up of individuals of reproductive size (adults) in September and November, with small numbers of individuals below reproductive size occurring in January. Combining January and March samples in order to undertake the Mann-Whitney tests may have masked the occurrence of juveniles in the populations. Small peaks in the occurrence of juvenile Australian smelt occurred in the Nimmie-Caira and mid-Murrumbidgee in November 2015, suggesting that breeding either occurred following initial inundation of the wetlands or that smaller individuals were transported into the wetlands during water delivery. Australian smelt and carp gudgeon are short lived species and respond rapidly to wetland watering events, but due to their short lifespan, turnover of individuals between water years may be limited. This means that gradual increases in abundance between water years are not necessarily expected for these small bodied native species.

5.24 Wetland frogs and turtles

Prepared by Dr Skye Wassens (CSU)

Introduction

The availability of standing water is critical to the survival of frog populations through floodplain wetland systems. Environmental watering actions can be used to maintain frog populations via two key mechanisms: providing refuge habitat that support frog populations during periods of low water availability and through the provision of breeding habitat that allows frog populations to reproduce. Many of the frog species that occupy floodplain habitats have limited capacity to survive extended dry periods, so the maintenance of refuge habitat is critical for the long-term persistence of populations, especially for the vulnerable southern bell frog (*Litoria raniformis*). While persistent water is important for keeping frogs alive during dry periods, breeding success is typically greater in areas of shallow, temporary habitat. Therefore watering actions targeting breeding outcomes should seek to increase the area of inundation within and around wetlands.

The overriding objective of Commonwealth environmental water as it relates to frogs is to "support the habitat and breeding requirements of native fish and other vertebrates". However, individual watering actions: Nimmie-Caira southern bell frog refuge (north Caira channel), Nimmie-Caira southern bell frog refuge (south Caira channel) and Nap Nap – Waugorah were carried out with specific objectives to "maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbirds" and "support the habitat requirements of southern bell frogs (EPBC Act Vulnerable)(Table 5-16)." These watering actions inundated four LTIM surveyed wetlands in 2015-16 including Telephone Creek, Eulimbah Swamp, Avalon Swamp (dam area only) and Waugorah Lagoon. The Redbank watering action inundated one LTIM surveyed site (Two Bridges Swamp). Water was pumped into Yarradda Lagoon in the mid-Murrumbidgee to "support known native fish and frog community established in 2015-16".

Methods

Since 2014, frogs and tadpoles have been monitored across the 12 LTIM surveyed wetlands four times per year (September, November, January and March). Detailed survey methodology is contained in Wassens, Jenkins et al. (2014). Adult frogs are surveyed after dark using two timed 20 minute transects where all frogs observed or heard calling are recorded. Tadpoles are surveyed alongside wetland fish, using a combination of two large and two small fyke nets which are set overnight. The tadpole Catch-Per-Unit Effort (CPUE) is based on the number of tadpoles collected per hour, with this value adjusted for differences in the width of the net wings and water depth where the net is set (nets can only be set when water depths are above 30cm). In 2015-16 two sites (McKennas Lagoon in the mid-Murrumbidgee and Nap Nap Swamp in the Nimmie-Caira) were dry throughout the monitoring period.

Data analysis

Spearman's rank correlations were used to identify significant relationships between the percentage wetland inundation on each survey occasion between September 2014 and March 2016 and frog and tadpole abundance. Mann-Whitney U test were used to compare size distributions of the three turtles species detected during the 2014-15 and 2015-16 water year.

Results

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

Six frog species were recorded at 10 of the 12 wetlands in 2015-16, no frogs were recorded at McKennas Lagoon or Nap Nap Swamp which were dry throughout 2015-16 (Figure 5-42). There were continued improvements in species diversity following environmental watering at the site level. At Yarradda Lagoon *Limnodynastes interioris* was recorded in 2014-15 and again in 2015-16, while the vulnerable (EPBC Act) *Litoria raniformis* adults, tadpoles and recent metamorphs were recorded in 2015-16 only. Yarradda Lagoon also had large increases in the abundance of other frog species including the inland banjo frog and Peron's tree frog between 2014-15 and 2015-16.

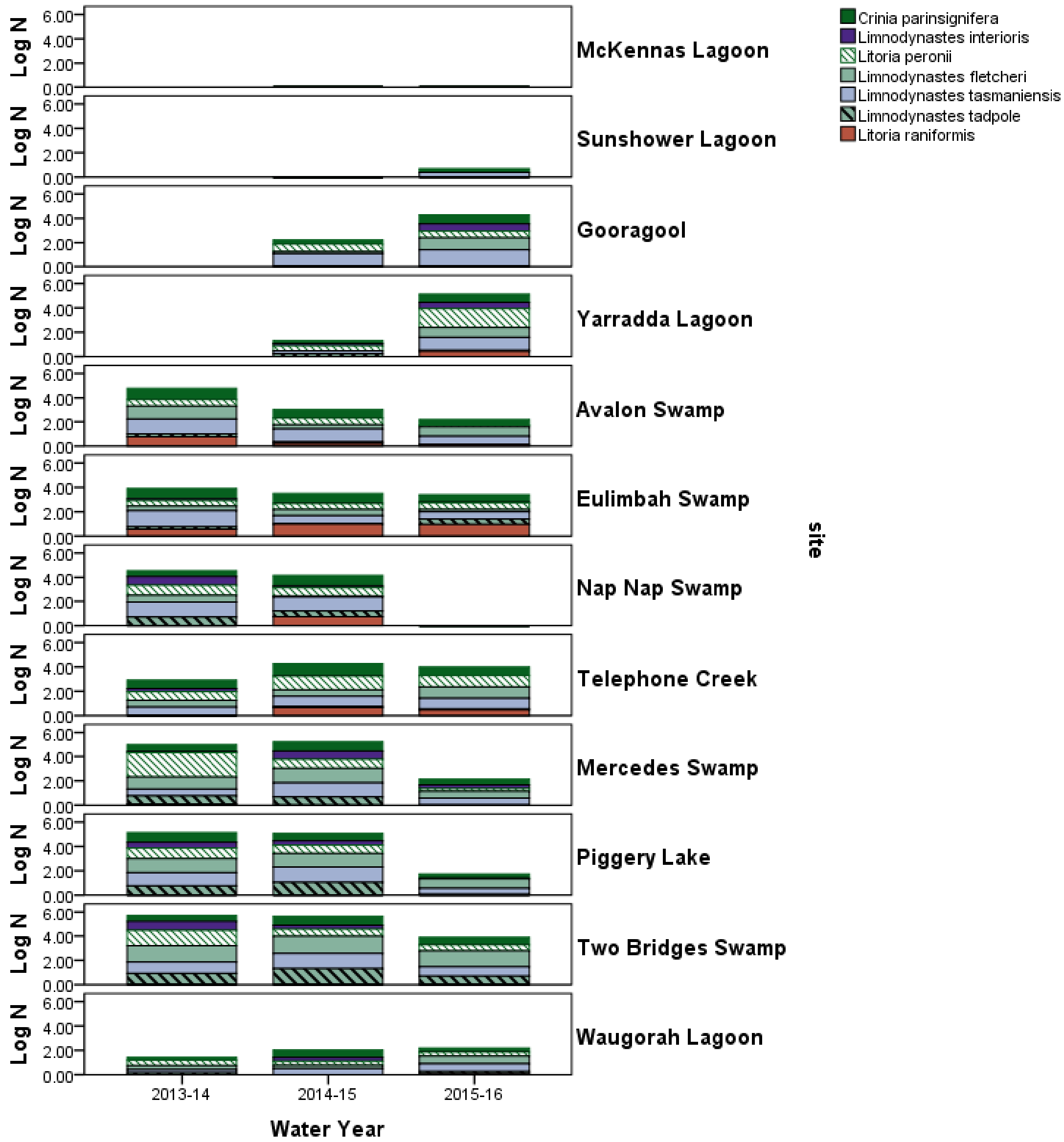


Figure 5-42 Changes in (Log) total abundance of frogs observed in the monitoried sites (2013-14; see (Wassens, Jenkins et al. 2014, Wassens, Thiem et al. 2015)). Note that McKennas, Sunshower, Yarradda and Gooragool lagoons were dry in 2013-14.

Turtles

Three turtle species were recorded in wetlands between September 2014 and March 2016. The most commonly recorded species was the eastern long-necked turtle (*Chelodina longicollis*) which was recorded in 10 wetlands during 2014-15 and six wetlands in 2015-16 (Table 5-15), the broad shell turtle (*Chelodina expansa*) was recorded at one site in 2014-15 and three sites in 2015-16 while the Macquarie turtle (*Emydura macquarii*) was recorded at one site in each year. In the mid-Murrumbidgee, Yarradda Lagoon supports the highest abundances and diversity of turtle species, Avalon and Telephone Creek are important in the Nimmie-Caira and Waugorah Lagoon and Two Bridges Swamp were important in the Redbank system.

Table 5-15 Summary of turtle catches across the 10 wetland sites containing water in 2014-15 and 2015-16

		2014-15			2015-16		
Zone	site	broad shell turtle	eastern long-necked turtle	Macquarie turtle	broad shell turtle	eastern long-necked turtle	Macquarie turtle
Mid-Murrumbidgee	MCK						
	SUN				.	2	.
	GOO	.	1	.	1	.	1
	YAR	.	1	.	3	6	.
Nimmie-Caira	AVA	.	7	.	.	16	.
	EUL	.	1	.	.	.	.
	NAP	.	2	.	.	.	.
	TEL	.	3	.	.	3	.
Redbank	MER	.	7	.	.	.	.
	PIG	.	2	.	.	.	.
	TBR	.	3	.	.	14	.
	WAG	1	1	.	2	1	.

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

Calling activity

In 2015-16 calling activity was recorded at nine of the 12 monitoring sites, no calling activity was recorded at sites which were dry through 2015-16 (McKennas or Sunshower in the mid-Murrumbidgee or Nap Nap in the Nimmie-Caira). Of the sites that contained water, plains froglet (*Crinia parinsignifera*), spotted marsh frog (*Limnodynastes tasmaniensis*), barking marsh frog (*L. fletcheri*) and Peron's tree frog (*Litoria peronii)* were widespread calling at seven or more wetlands while *Litoria raniformis* and *Limnodynastes interioris* each called at three wetlands. Importantly southern bell frog (*Litoria raniformis*) actively called at Eulimbah and Telephone Creek in response to the Nimmie-Caira refuge (north Caira channel) watering action which was undertaken with the objective of "*support the habitat requirements of southern bell frogs*" and at Yarradda Lagoon following environmental watering actions undertaken with the objective of "*support known native fish and frog community*".

The percentage of the wetland inundated had a strong, significant impact on frog calling activity. Across both water years there were significant positive correlations between calling activity and the percentage of the wetland inundated for five of the six frog species recorded plains froglet ($r=0.290$, $p = 0.008$), barking marsh frog ($r=0.360$, $p = 0.001$), inland banjo frog ($r=0.172$, $p <0.001$), Peron's tree frog ($r=0.392$, $p <0.001$) and southern bell frog ($r=0.314$, 0.04).

Tadpoles

Overall fewer tadpoles were recorded in 2015-16 compared with 2014-15 (Figure 5-43). But there was a high level of variability between wetlands and survey occasions, making it difficult to resolve statistically significant patterns. *Limnodynastes* tadpoles were more abundant through sites in the Redbank zone in 2014-15, with declines largely reflecting the drying of Piggery and Mercedes Swamp. When considered across both water years, the abundance of *Limnodynastes* tadpoles increased with increasing percentage of wetland inundation ($r = 0.311$, $p = 0.04$).

Despite actively calling at Eulimbah no southern bell frog tadpoles were recorded in response to the Nimmie-Caira refuge (north Caira channel) watering action which was undertaken with the objective of "*support the habitat requirements of southern bell frogs*". However southern bell frog tadpoles were recorded at Yarradda Lagoon following environmental watering actions undertaken with the objective of "*support known native fish and frog community*". Large numbers of Peron's tree frog tadpoles were also recorded at Yarradda Lagoon in response to the summer watering (Figure 5-43).

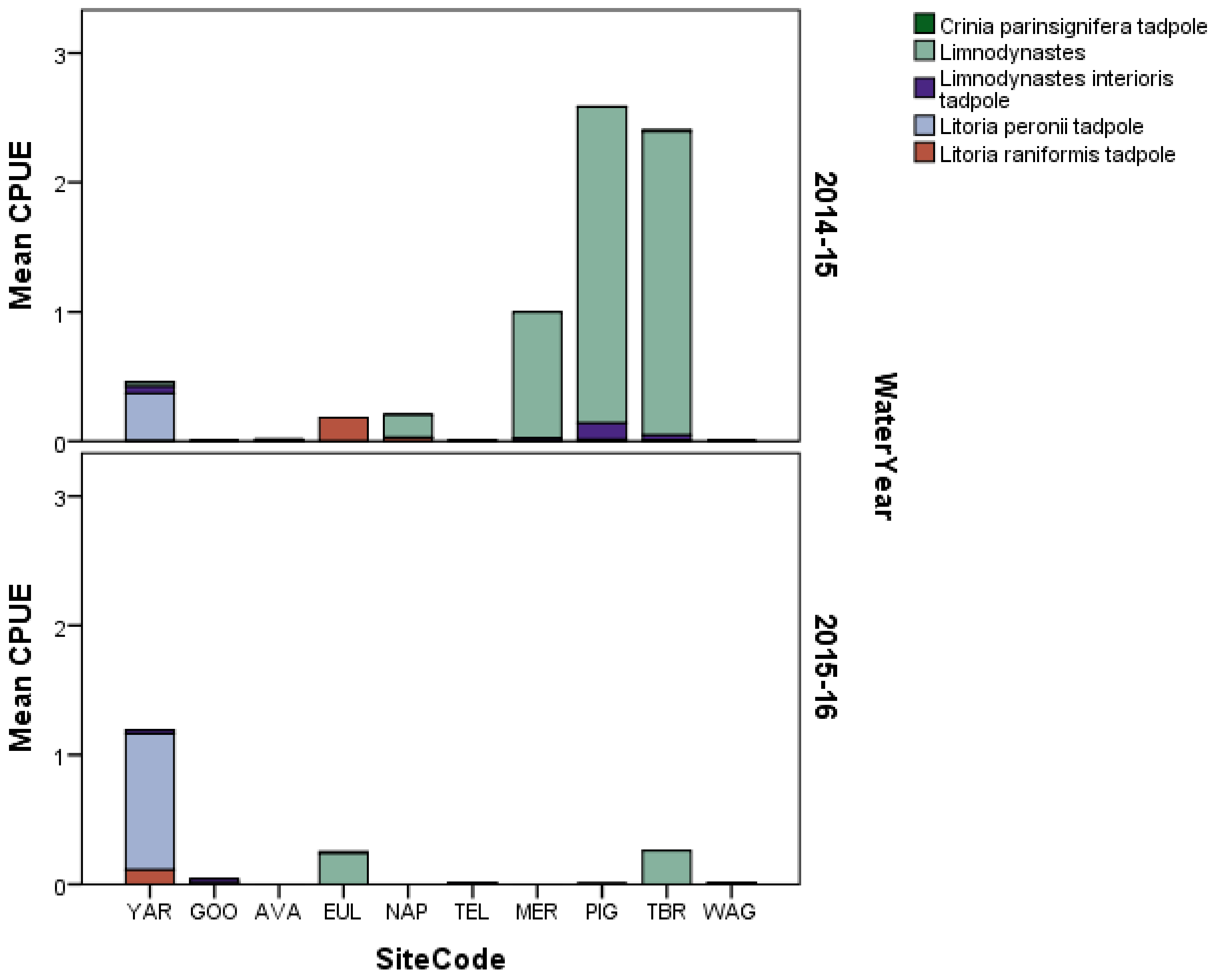


Figure 5-43 Tadpole abundance (mean Catch Per Unit Effort) of tadpoles at each site in the 2014-15 and 2015-16 water years (note that McKennas and Sunshower lagoons have been excluded from the figure as no tadpoles were recorded at these monitoring sites in either water year).

Turtles

The size of a turtle's shell is a relatively good indicator of its age, and this indicator is used as a measure of reproductive success for turtle populations. Juveniles of eastern long necked turtles (*C. longicollis)*(less than 100mm) were recorded in both 2014-15 and 2015-16, and there were no significant difference between the size structure of populations in either years Mann-Whitney U test (1.092, p = 0.0375)(Figure 5-44). The broad-shell and Macquarie turtles identified were all larger individuals (adults) and we did not identify any evidence of recruitment for these species.

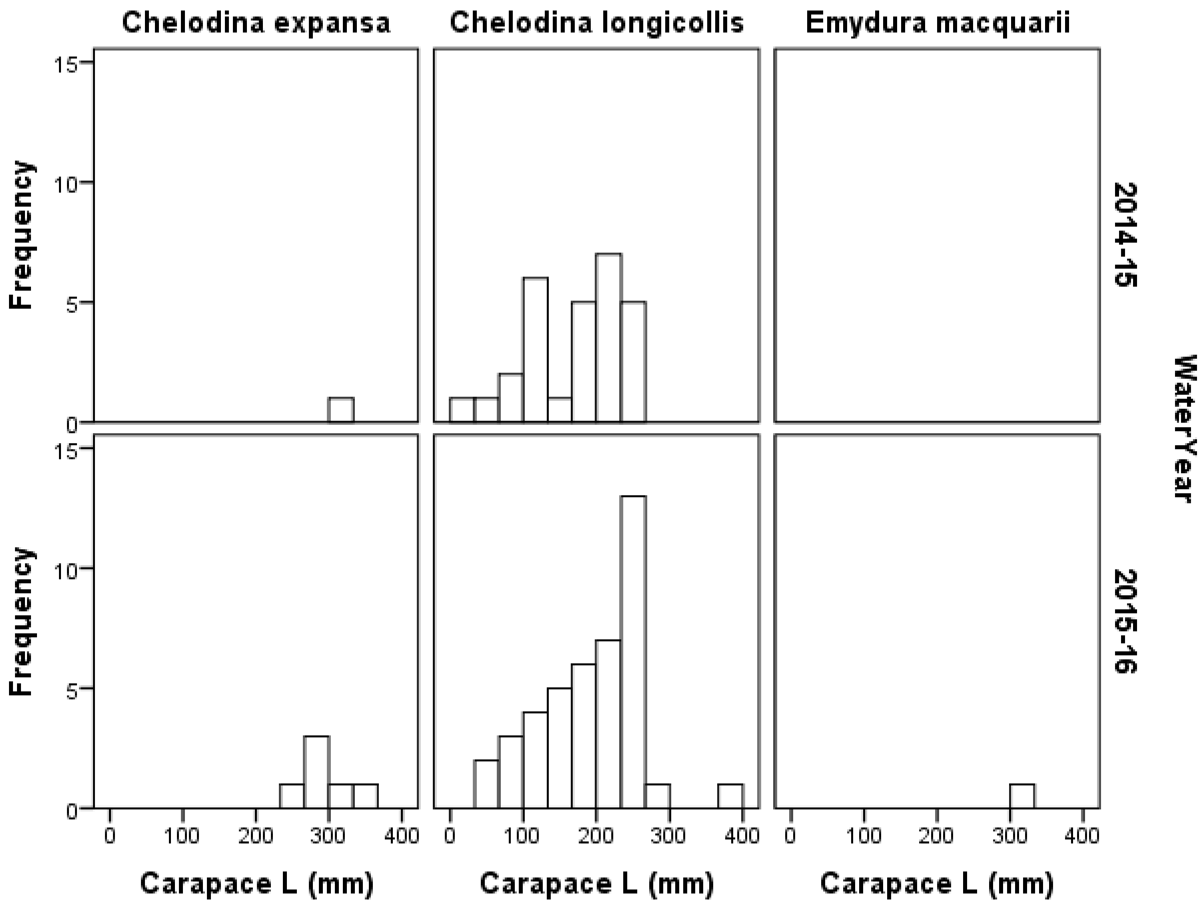


Figure 5-44 Size structure (based on Carapace length mm) of the three turtle species recorded in 2014-15 and 2015-16. Eastern long-necked turtle (*Chelodina longicollis*), broad shell turtle (*Chelodina expansa*) and Macquarie turtle (*Emydura macquarii*)

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

Refuge habitat are important for frog populations in the Murrumbidgee because they provide critical aquatic habitat to support resident populations during dry periods. Two environmental watering actions - Nimmie-Caira refuge (south Caira channel) and Nimmie-Caira refuge (north Caira channel) - were undertaken with the objectives of maintaining refuge habitat for the vulnerable southern bell frog. In 2014-15 39 adult southern bell frog and 27 tadpoles were recorded at Eulimbah Swamp following environmental watering, in 2015-16 this number had increased to 127 adults, the increase in the number of adults present at the wetland indicates that it is serving its function of supporting the resident population (Figure 5-45). In contrast Nap Nap which received water in 2014-15 but not in 2015-16 had declines in the number of individuals present despite tadpoles being recorded in 2014-15 (Figure 5-45). Adult frogs were also identified at Telephone Creek and Waugorah Lagoon which received environmental water and Avalon Swamp where refuge habitat was created by maintaining a small dam.

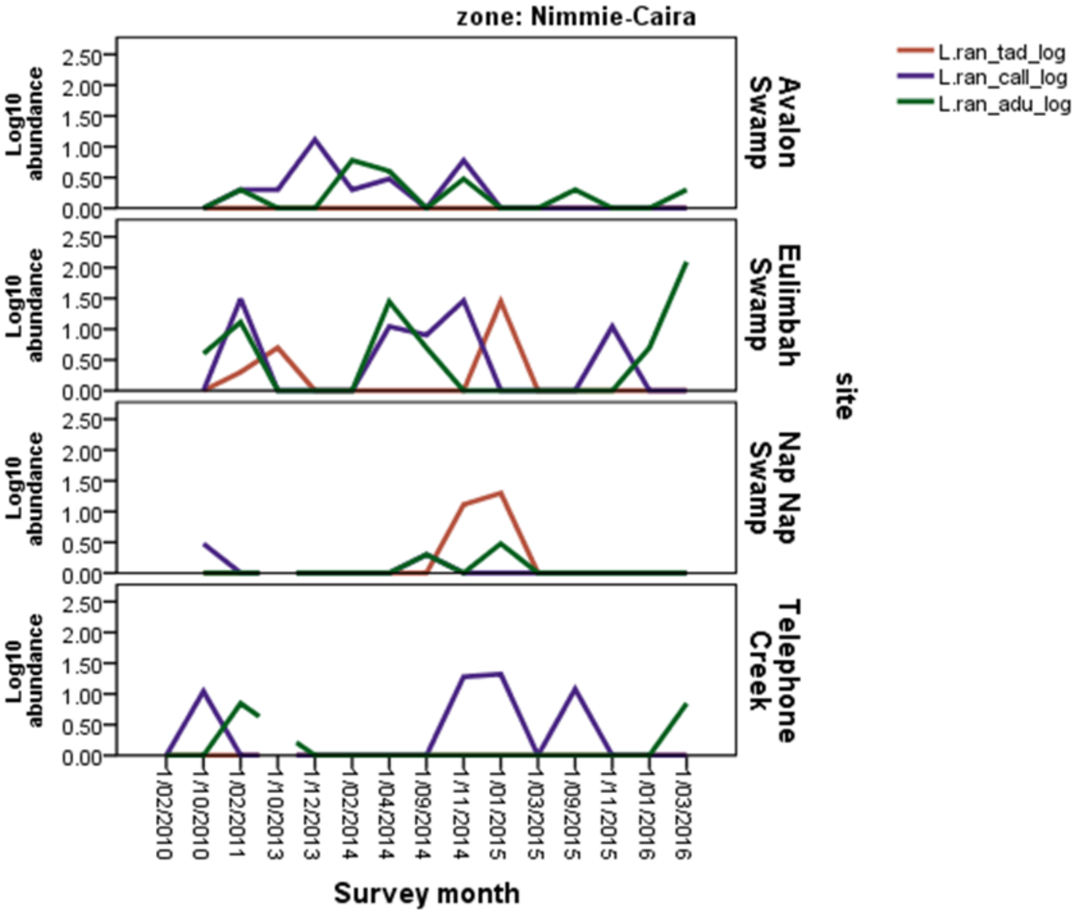


Figure 5-45 Southern bell frog abundance between 2010 and 2016 (Spencer and Wassens 2010, Wassens, Jenkins et al. 2013, Wassens, Jenkins et al. 2014, Wassens, Thiem et al. 2015) at four monitoring sites in the Nimmie-Caira.

Turtles

Permanent waterbodies are import for persistence of turtle populations, particularly in the Nimmie-Caira where wetlands are further from the Murrumbidgee River. Environmental watering actions that focused on maintaining refuge habitats as part of the Nimmie-Caira, Nap Nap-Waugorah and Yarradda actions, appear to have been successful in maintaining populations through 2014-15 and 2015-16, in particular there have been increases in the number of turtles recorded at Yarradda Lagoon and Avalon Swamp where the dam was maintained with environmental water in order to provide refuge for frogs, fish and turtles.

Discussion

Four Commonwealth environmental watering actions were carried out with the objectives of supporting frog populations through the Murrumbidgee Selected Area (Table 5-16). There was clear evidence that these watering actions supported frog populations and created opportunities for frog breeding. Most importantly, watering actions that focused on southern bell frogs (Vulnerable EPBC Act) in the Nimmie-Caira were successful in achieving their objectives and there was a clear link between the area of inundation and calling activity by southern bell frogs. There was also an increase in abundance of adult frogs late in the season at Eulimbah and Telephone Creek which were targeted with environmental water with the objective of "supporting the habitat requirements of southern bell frogs (EPBC Act vulnerable) (Eulimbah Floodway)". Southern bell frog abundance declined at Avalon and Nap Nap Swamps which were not inundated in 2015-16. Southern bell frogs were also observed at Waugorah Lagoon which received water as part of the Nap Nap–Waugorah watering action. This observation is important because southern bell frogs have been declining in the Redbank systems for a number of years. The Waugorah Lagoon system consists of a persistent lagoon which spills into an area of lignum, the watering actions in 2015-16 created suitable conditions *for* southern bell frogs with the lignum area inundated in summer, but it is likely that water did not remain in the wetland for a long enough period to support breeding. However, Waugorah Lagoon still represents an important refuge for native fish, frogs and turtles and has potential to support frog breeding in years of higher water availability.

Southern bell frog adults, tadpoles and metamorphs were also recorded at Yarradda Lagoon following repeated environmental watering activities undertaken by NSW OEH and CEWO. This is the first record of southern bell frogs at Yarradda Lagoon in a number of decades and provides clear evidence of the success of pumping actions to maintain high quality habitat in the lagoon. While natural reconnections have multiple benefits for riverine species and benefit wetland water quality in the long-term, pumping was effective in creating suitable habitat for southern bell frogs and other summer-breeding frog species.

Overall turtles were recorded at fewer wetlands in 2015-16 compared to 2014-15 which reflects the smaller number of wetlands inundated in 2015-16. Permanent habitats in Avalon Swamp in the Nimmie-Caria and Waugorah Lagoon in the Redbank systems were important refuge areas.

Table 5-16 summary of watering actions with outcomes targeting frog and turtle habitat and responses

Target asset	Expected outcomes	LTIM sites receiving water	Outcomes
Yanga National Park waterbird support	– provide habitat for native fish, frogs and other vertebrates	Two Bridges	Overall smaller numbers of individuals recorded in 2015-16 compared to previous years because a number of sites were dry. Two bridges swamp supported a high abundance of eastern long necked turtles.
Nimmie-Caira Nimmie-Caira refuge (north Caira channel) Nimmie-Caira southern bell frog refuge (south Caira channel	– maintain refuge habitat for a diverse range of native fish, frogs and turtles and waterbirds – support the habitat requirements of southern bell frogs (EPBC Act vulnerable) (Eulimbah Floodway).	Eulimbah Avalon Telephone Creek	Southern bell frogs recorded at Eulimbah and Telephone Creek, with numbers of adults increasing later in the season suggesting that these wetlands are being used as refuges in late summer. Avalon swamp supported a high abundance of eastern long necked turtles.
Nap Nap - Waugorah	– Support the habitat requirements of native fish and turtles.	Waugorah Lagoon	Southern bell frog recorded in 2015-16. Broad shell turtle recorded in Waugorah Lagoon
Yarradda Lagoon	– support known native fish and frog community established in 2014-15. – provide feeding habitat for frogs	Yarradda Lagoon	Southern bell frog, calling, tadpoles and metamorphs recorded in 2015-16. Broad shell and eastern long necked turtles recorded.

5.25 Waterbird Diversity

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

Introduction

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee zones in order to “support the habitat requirements of waterbirds” in the Murrumbidgee catchment. Wetlands in the Murrumbidgee Selected Area are recognised in the Basin-wide Environmental Watering Strategy (EWS) for their importance for maintaining total waterbird abundance and diversity, and colonial waterbird breeding within the Murray-Darling Basin (Murray-Darling Basin Authority 2014).

Waterbirds can provide useful indicators of regional-scale wetland availability and of local-scale wetland health, because their abundance, diversity and breeding activity can be related to total wetland area, the health of wetland vegetation and the abundance of food resources e.g. microinvertebrates, fish, frogs, and aquatic vegetation. This means that generally wetlands with vegetation in good health and a complexity of habitats with varying water depths tend to support the greatest diversity of waterbird species and highest waterbird abundance (Scott 1997, Kingsford and Norman 2002).

Colonial waterbird breeding can also provide a useful index of the effectiveness of environmental water delivery, because successful waterbird breeding is heavily dependent on adequately timed flows of sufficient frequency, duration, depth and extent to inundate breeding habitat and stimulate sufficient food resources (Scott 1997, Kingsford and Auld 2005). Environmental flows can be delivered to initiate and support annual small-scale waterbird breeding in the Murrumbidgee Selected Area (Spencer and Wassens 2010, Spencer, Wassens et al. 2011, Wassens, Jenkins et al. 2014, Wassens, Thiem et al. 2015) or to extend or build on natural flows to support large-scale waterbird breeding (Spencer, Wassens et al. 2011).

The timing and duration of flooding is important as breeding success is maximised when flooding coincides with spring and summer months and food availability is optimal (Scott 1997). Most waterbirds commence breeding in spring, however, the stimuli for breeding is usually a combination of season, rainfall and water, with the timing of inundation influencing the lag time between the start of flooding and the commencement of nesting (Briggs and Thornton 1999). Overall, breeding habitats need to be inundated for long enough to allow birds to achieve pre-breeding condition, pair up, build nests, lay eggs, and raise and fledge their young (Scott 1997).

In 2015-16, there were four main Commonwealth environmental watering actions that had specific watering objectives for waterbird outcomes in the Murrumbidgee Selected Area. This include delivery of Commonwealth environmental water to: support colonial waterbird breeding in Redbank (Yanga National Park); inundating neighbouring habitats in the North Redbank system to provide waterbird habitat; maintain refuge habitat across the Nimmie-Caira zone; and infrastructure assisted delivery of environmental water to Yarradda Lagoon in the Mid-Murrumbidgee to provide feeding habitat for waterbirds.

Methods

Ground surveys to assess waterbird species diversity, maximum abundance and breeding activity were conducted at the 12 LTIM surveyed wetland survey sites spread across the mid-Murrumbidgee, Nimmie-Caira and Redbank zones. Five of the LTIM surveyed sites received Commonwealth and NSW OEH managed environmental water in the 2015-16 water year. Methods followed those employed previously to survey waterbirds in the Murrumbidgee catchment and are documented in Wassens, Jenkins et al. (2014).

Complementary annual spring and event- based waterbird diversity and waterbird breeding monitoring was undertaken by NSW OEH (in collaboration with CEWO staff) across the Murrumbidgee Selected Area (Spencer, Ocock et al. 2016). The University of New South Wales also completed an aerial survey of the Lowbidgee floodplain in mid-October as part of long-term Aerial Waterbird Surveys of Eastern Australia (AWSEA program)(Porter, Kingsford et al. 2015).

Data analysis

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

Waterbird species were separated into eight functional groups as per (Hale, Stoffels et al. 2014) (see

Table 5-17) to investigate differences in bird assemblages among the surveyed wetlands. The total abundance of each functional group per hectare was calculated for each survey based on known coverage of each site in relation to the wetland boundaries determined in Wassens, Thiem et al. (2015). Across the 12 wetland survey sites approximately 152 ha of wetlands were surveyed in Redbank zone, 198 ha in the Nimmie-Caira zone and 104 ha in the mid-Murrumbidgee zone.

Multivariate analyses (Anderson) were used to investigate differences in waterbird species assemblages among the survey sites as per Wassens et al. (2014). We also used a GLM with a binomial distribution (R Development Core Team) to investigate waterbird responses among wetland zones and according to wetland conditions observed during each wetland survey (dry <10% inundated, or wet >10% inundated) as determined from water depth measurements using fixed water depth loggers deployed at each site and estimates of flooded area from inundation mapping. This approach was also used to investigate whether total species and abundance differed among sites that received environmental water (where more than >10% of each site was inundated) in 2015-16 or the previous water year, or in neither water year.

Results

What did Commonwealth environmental water contribute to waterbird diversity?

Overall, 40 and 44 wetland-dependent bird species were recorded in the 2014-15 and 2015-2015-16 LTIM surveys, respectively (Figure 5-46). This included two waterbird species listed under threatened species legislation and two species of international significance (

Table 5-17). In 2015-16, freckled duck (*Stictonetta naevosa)* (NSW TSC Act 1995 vulnerable) were also recorded in Yarradda Lagoon (Murrumbidgee Valley National Park), in the Mid-Murrumbidgee wetland zone during complementary surveys by NSW OEH. Australasian bittern (*Botaurus poiciloptilus)* (Commonwealth EPBC Act endangered) were recorded at both Eulimbah and Telephone swamps, in the Nimmie-Caira zone.

Across the Murrumbidgee Selected Area, all functional guilds were identified in the 2014-15 wetland surveys, and only migratory shorebirds were not present during the 2015-16 LTIM wetland surveys. However, this guild was detected during complementary NSW OEH surveys of adjoining wetlands in the Western Lakes. There were no significant differences in guild assemblages across the surveyed LTIM wetlands in either water year (ANOSIM *Global R* 0.09, p = 0.8). Dabbling ducks dominated waterbird assemblages during the 2014-15 water year, while Dabbling ducks, Deep water foragers (diving ducks, coots and swans) and Piscivores (fish-eating birds) were the most abundant waterbird functional groups across the Murrumbidgee Selected Area in the 2015-16 water year (Figure 5-47 and Figure 5-48). In 2015-16, the most abundant and widespread waterbird species were grey teal (*Anas gracilis)* (Dabbling ducks), Eurasian coot (*Fulica atra)* (Deep water foragers) and little black cormorants (*Phalacrocorax sulcirostris)* (Fish-eating birds - Piscivores).

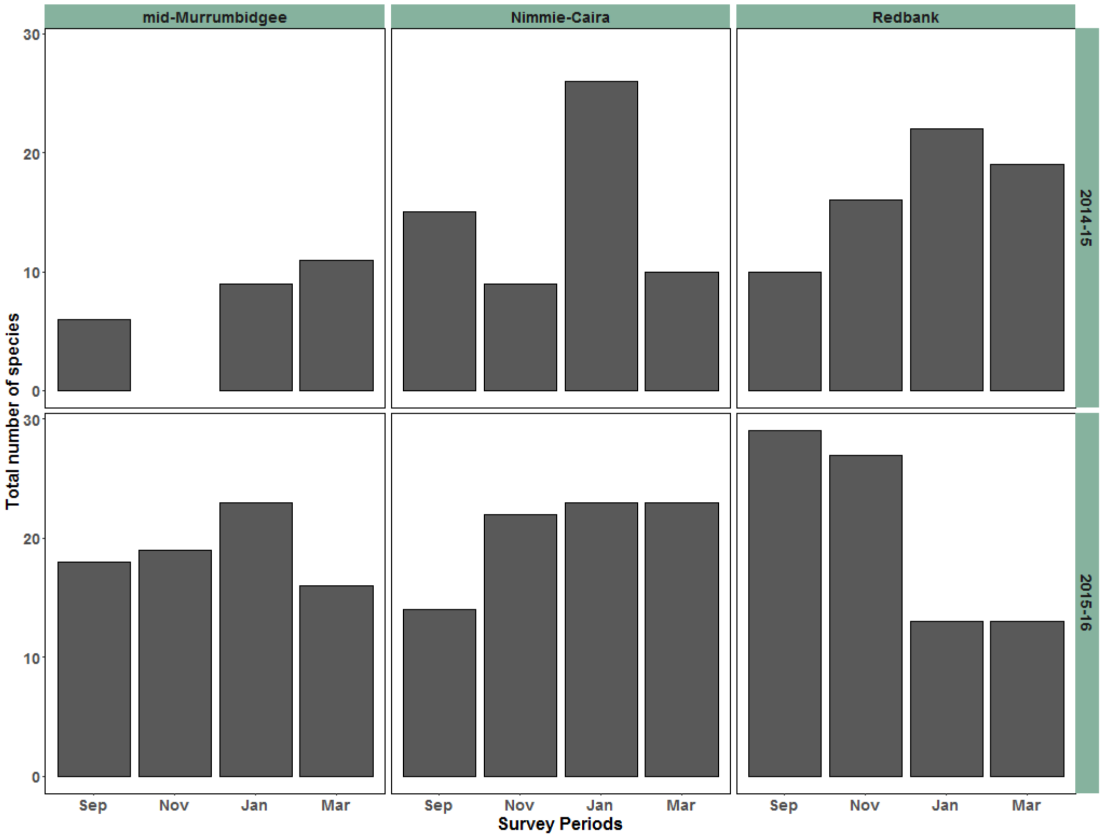


Figure 5-46 Total number of species recorded in each wetland zone in the 2014-15 and 2015-16 survey periods.

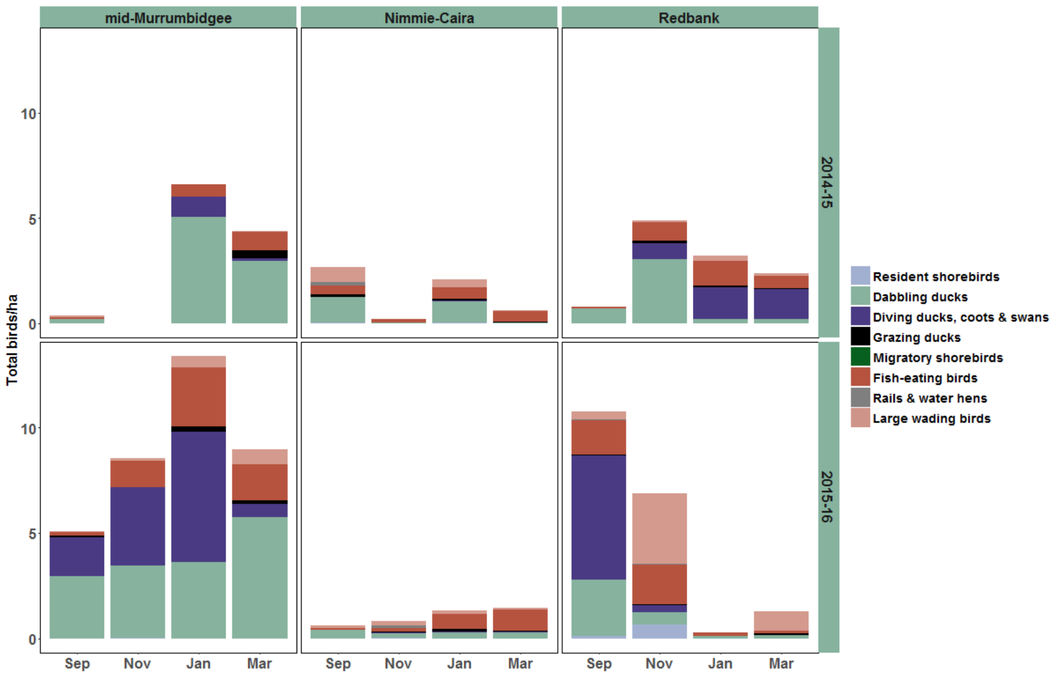


Figure 5-47 Total number of birds per ha grouped by functional guild, recorded across each wetland zone in the 2014-15 and 2015-16 survey periods. Note that reed-inhabiting passerines and raptors were not recorded in sufficiently large numbers to be displayed here. (Functional groups are described in

Table 5-17).

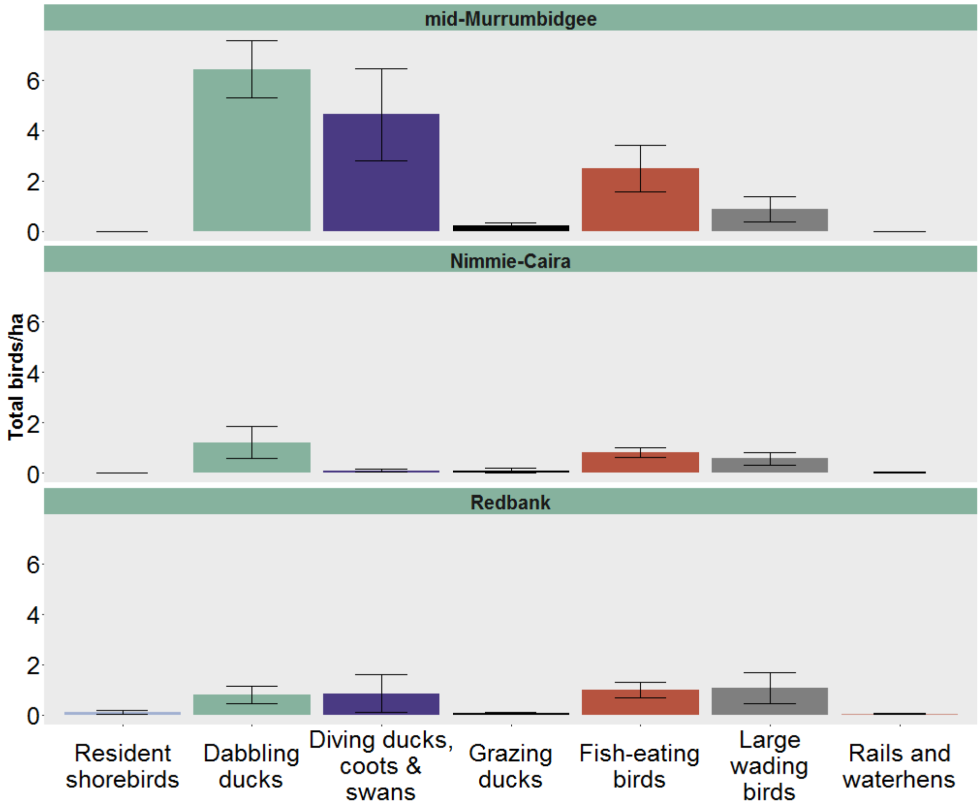


Figure 5-48 Mean total number of birds per ha (+/- SE) in each functional group in each wetland zone in the 2015-16 survey period. Note that reed-inhabiting passerines, raptors and migratory shorebirds were not recorded in large numbers and so are not displayed here. (Functional groups are described in

Table 5-17).

We predicted that there would be local increases in waterbird diversity and abundance in response to the delivery of environmental water and this was supported by observations in the LTIM surveyed wetland sites in 2015-16. Overall, total species diversity and abundance of waterbirds was greater in the LTIM surveyed wetlands that were inundated compared to those that remained dry in 2015-16 (GLM diversity Z value = 7.2, p >0.001; abundance Z value = 8.3, p >0.001) (Figure 5-49). LTIM surveyed sites that received environmental water in 2015-16 had higher species richness and total waterbird abundance than sites that did not receive environmental water in 2015-16 (GLM diversity Z value = 6.9, p>0.001; abundance Z value = 6.4, p >0.001). Waterbird diversity was also higher in sites that received environmental water in 2014-15 compared to sites that remained dry in both water years (GLM diversity Z value = 3.9, p> 0.001) (Figure 5-50).

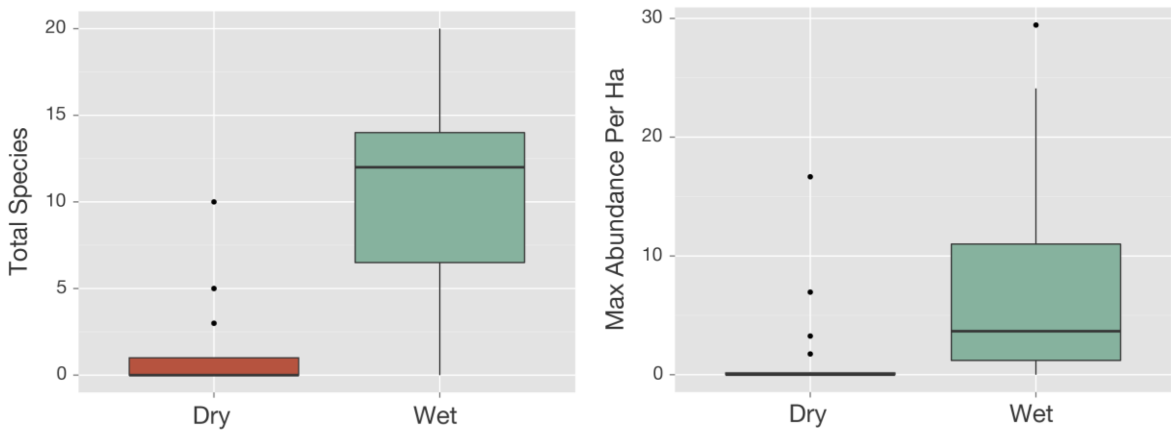


Figure 5-49 Comparison of total species diversity (*left*) and waterbird abundance (max. count/ha) (*right*) recorded in surveyed LTIM wetlands in 2015-16 that were inundated compared to drier sites (<10% inundated).

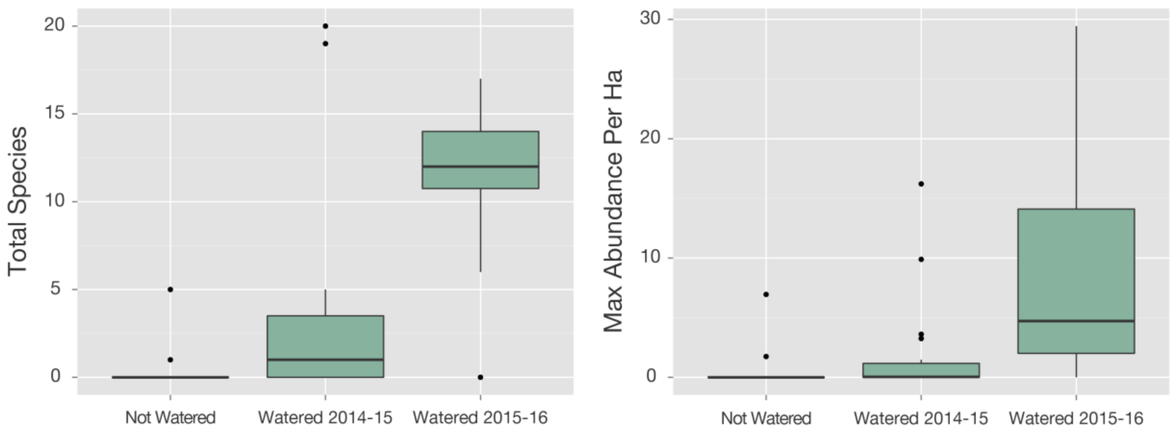


Figure 5-50 Comparison of total species diversity (*left*) and waterbird abundance (max. count/ha) (*right*) recorded in surveyed LTIM wetlands in 2015-16 that received environmental water compared to sites that were not inundated in 2015-16 but received environmental water in 2014-15, and sites that did not receive environmental water in either water year.

Redbank watering actions

The total number of species recorded increased in the Redbank zones between water years (28 species in 2014-15, 35 species in 2015-16) (see Figure 5-46).

Nimmie-Caira refuge watering action

The Nimmie-Caira zone supported at least 33 species. Including the endangered Australasian bittern (EPBC Act) which was heard calling from areas of lignum during the November, January and March LTIM surveys of Eulimbah Swamp and Telephone Creek, in the Nimmie-Caira, in response to the delivery of environmental water to both sites. Species richness was similar between water years (32 species in 2014-15, 33 species in 2015-16). Wetland zones supported diverse waterbird assemblages in both survey years (see Figure 5-47). Inundated area was limited in the Nimmie-Caira zone in both the 2014-15 and 2015-16 water years and so total waterbird abundance was low in the surveyed wetlands. There were significant differences in total abundance of waterbirds between the Nimmie-Caira and other wetland zones in the 2015-16 survey year (GLM Z value = 3.5, $p > 0.001$). A higher proportion of survey occasions in the Nimmie-Caira sites recorded dry conditions (<10% inundated dry) in the 2015-16 (56% of surveys) compared to the 2014-15 surveys (38% of surveys).

Mid-Murrumbidgee (Yarradda Lagoon) watering action

The total number of species recorded increased in the mid-Murrumbidgee wetland zone in 2015-16 surveys (30 species) compared to the 2014-15 surveys (19 species). This response was largely the result of infrastructure-assisted delivery of Commonwealth environmental water to Yarradda Lagoon where 23 waterbird species were recorded during the LTIM surveys in 2015-16.

What did Commonwealth environmental water contribute to waterbird breeding?

There were two watering actions specifically targeting waterbird breeding - Redbank (Yanga National Park) waterbird contingency and the Nimmie-Caira refuge action (see

Table 2-2). Breeding activity was detected in 19 waterbird species in total through the 2015-16 LTIM wetland surveys and complementary NSW OEH surveys across the Redbank, Nimmie-Caira and mid-Murrumbidgee zones (see

Table 5-17). Small numbers of non-colonial waterbird broods were recorded in the LTIM surveyed wetlands, Yarradda Lagoon (mid-Murrumbidgee) and Telephone Creek (Nimmie-Caira), this included small numbers of broods of grey teal, Pacific black duck (*Anas superciliosa)* (Dabbling ducks) (Yarradda Lagoon and Telephone Creek), Australian shelduck (*Tadorna tadornoides),* Australian wood duck (*Chenonetta jubata)* (Grazing ducks). At least 15 pairs of black swan (*Cygnus atratus)* (Diving ducks and swans), and small numbers of masked lapwing (*Vanellus miles)* (Resident shorebirds), Eurasian coot and Australian shelduck were also observed nesting or with advanced young at Piggery Lake (Plate 5-2) (Redbank), in spring 2015, which received environmental water in 2014-15.

NSW OEH and CEWO staff recorded small-scale colonial-nesting waterbird breeding in six wetlands (eight colonial waterbird species) in the Murrumbidgee Selected Area 2015-16. Five of these sites received Commonwealth environmental water in 2015-16: Tarwillie and Glenn Dee swamps (Redbank), Eulimbah and Telephone swamps (Nimmie-Caira) and Yarradda Lagoon (mid-Murrumbidgee).

Redbank watering actions

Two watering actions were undertaken in the Redbank zone - the Redbank (Yanga National Park) waterbird contingency and the Redbank (North) watering action. Delivery of Commonwealth environmental water to areas of North Redbank initiated breeding in small numbers (around 50-100 nests) of spoonbills, cormorants and darters at Glenn Dee Swamp near Redbank weir. Targeted delivery of Commonwealth environmental water was made to Tarwillie Swamp in Yanga National Park, to maintain stable water levels for around 350 nests (eight colonially-nesting waterbird species including around 250 Eastern great egret (*Ardea modesta* nests)). The results of follow up ground surveys by NSW OEH and CEWO staff indicated that these colonies completed breeding successfully (Spencer, Ocock et al. 2016).

Nimmie-Caira refuge watering

Complementary OEH and UNSW monitoring in 2015-16 detected small-scale colonial waterbird breeding that was partly successful in two LTIM wetland sites (Eulimbah and Telephone) in the Nimmie-Caira. The results of UNSW spring aerial surveys in early November indicated that a small number of straw-necked ibis (*Threskiornis spinicollis*) and Australian white ibis (*Threskiornis moluccus)* were building nests in Eulimbah and Telephone (around 80-100 birds in each site) but no active nests were observed during OEH's aerial survey in early December. Ground surveys later in the season determined that Eulimbah Swamp supported small numbers of nesting Australian white ibis and royal spoonbill (*Platalea regia)* (estimated 100 nests in total) (Plate 5-2) which had advanced chicks and fledglings in February 2016. Six colonial waterbird species were detected nesting (around 100 nests) in Telephone Creek (where the main inundation was confined to) during complementary ground surveys from January-March 2016. This included about 20 Eastern great egret (*Ardea modesta*) nests, a species listed under the Japan-Australia migratory bird agreement (JAMBA).

Yarradda Lagoon

Australasian darter (*Anhinga novaehollandiae)*, great cormorant *(Phalacrocorax carbo)*, little pied cormorant (*Microcarbo melanoleucos)* and little black cormorant nested in Yarradda Lagoon successfully (estimated 175 nests in total) in response to the delivery of environmental water over November 2015 – March 2016. Follow up OEH ground surveys and LTIM wetland surveys confirmed completion of breeding to fledgling stage.

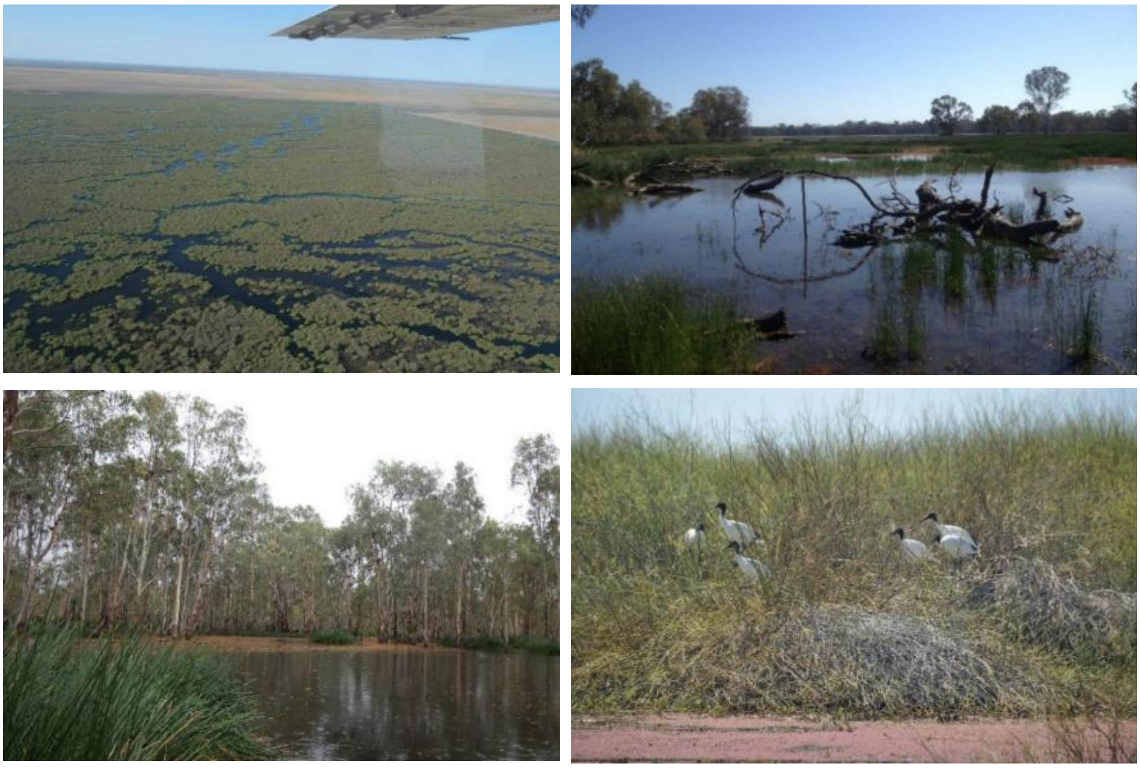


Plate 5-2 *Clockwise*: aerial view of Eulimbah swamp (Nimmie-Caira) (Credit: J. Ocock, Nov 15); Piggery Lake (Redbank) supported black swan breeding (Credit: J. Spencer, Sep 2015), and juvenile Australian white ibis in Eulimbah Swamp (Credit: J. Dyer, Mar 2015); Great egret nested in Tarwillie Swamp (Redbank) from December 2015 - March 2016 (Credit: C. Amos, Jan 2016).

Discussion

Commonwealth environmental water was delivered to wetlands through the Redbank, Nimmie-Caira and mid-Murrumbidgee as part of multiple watering actions focused on supporting the habitat requirements of waterbirds and supporting specific waterbird breeding events in the Yanga National Park (Redbank), North Redbank, Nimmie-Caira and mid-Murrumbidgee (Yarradda Lagoon). The measured outcomes relevant to each specific watering actions monitored under the LTIM project and complimentary monitoring by NSW OEH demonstrate that Commonwealth and State environmental water achieved their stated watering objectives for waterbirds in the Murrumbidgee Selected Area in 2015-16.

What did Commonwealth environmental water contribute to waterbird diversity?

As waterbirds respond to wetland inundation at large spatial scales, we evaluated the influence of wetting and drying cycles across all 12 LTIM surveyed sites between 2014 and 2016. We predicted that Commonwealth environmental water would increase the abundance and diversity of waterbirds and this was supported by our results. Environmental water provided habitat for species of conservation significance included nationally endangered Australasian bittern (EPBC Act), NSW vulnerable freckled duck and magpie goose (NSW TSC Act 1995), and JAMBA listed Eastern great egret.

Species richness and abundance was higher at sites that received water in 2015-16 when compared to wetlands that received water in 2014-15 but not 2015-16, and wetlands that no environmental water in either 2014-15 or 2015-16. However, total waterbird abundance and species richness was generally low across the three wetland zones when compared with longer term trends (Porter, Kingsford et al. 2015). The late spring inundation of monitored sites in 2015-16 was outside of the ideal timing for many waterbirds, including migratory shorebirds and the area of wetland inundated were comparatively small compared to long-term inundation patterns (Wassens, Jenkins et al. 2014). While it is important to maintain inundated habitats through summer to support waterbird breeding and other wetland dependant taxa, inundation of additional areas in spring (August-November) will increase the availability of seasonal habitat for migratory shorebirds (unvegetated muddy shorelines and open shallow lagoons and lakes) and other waterbird species and provide aquatic habitat for a longer period of the year than summer watering alone.

What did Commonwealth environmental water contribute to waterbird breeding?

Waterbirds need opportunities to breed in order to maintain and improve waterbird diversity and abundance across the MDB. Two watering actions were undertaken to support waterbird breeding in the Nimmie-Caira and Redbank systems, however these watering events were small and aimed at maintaining water levels in existing small colonies rather than triggering large-scale colonial waterbird breeding across the Murrumbidgee Selected Area. As a consequence, both colonial and non-colonial waterbird breeding activity was generally low across the Murrumbidgee Selected Area with only small or single broods of Dabbling ducks, Grazing ducks, Diving ducks and swans, and resident shorebirds detected, and active colonies being small in size (<400 nests).

Complementary monitoring (Spencer, Ocock et al. 2016) in 2015-16 identified small-scale colonial waterbird breeding at five wetlands which received Commonwealth environmental water in 2015-16. This included successful watering actions aimed at extending the duration of flooding in a key egret river red gum colony site in Tarwillie Swamp (Yanga National Park waterbird watering action). This was achieved by using small volumes of water to maintain stable water levels and prevent wetland drying over spring and summer at wetlands where colonies had established.

However, the comparatively small scale of waterbird breeding compared to long-term trends (Porter, Kingsford et al. 2015) was influenced by two key factors - the late spring inundation of habitats in the Murrumbidgee Selected Area which was outside of the preferred breeding window for many species, and the focus on small scale watering of individual sites as part of watering actions aimed at maintaining refuge habitats (Nimmie-Caira refuge watering action) without provision of large-scale watering of adjoining foraging grounds.

In the last 15-year period, large colonial waterbird and non-colonial waterbird breeding in the Lowbidgee floodplain has coincided with widespread flooding that occurred in 2000, 2005 and 2010 (Spencer, Maher et al. 2016). While small-scale colonial-waterbird breeding (<1000 nests) did occur outside of these large flood events, colonial-nesting waterbirds and non-colonial waterbird species require widespread overbank flooding to maximise opportunities to breed and for recruitment of their young. These large events are crucial for the long-term maintenance of waterbird species in the MDB. Historically adjoining habitats to the main colony sites, Eulimbah, Telephone, Nap Nap and Avalon swamps in the Nimmie-Caira zone, would have been inundated during wet years creating large areas of foraging habitat for colonial and non-colonial waterbird species and supporting the establishment of large breeding colonies. Flooding of key colony sites and also adjoining foraging grounds is necessary to support successful breeding. Sufficient food supplies need to be available prior to breeding for adult birds to build up condition, and then for the duration of the breeding event and post-fledging period to support adult birds and their young (Scott 1997, Brandis and Bino 2016).

Recommendations

Commonwealth environmental water should be prioritised for use in extending the duration of inundation and for maintaining adequate water depths in any active waterbird colony sites through to completion (minimum of three to four months from egg laying plus post-fledgling care for most species). Future planning of Commonwealth environmental water use in the Murrumbidgee Selected Area should also consider inundating habitats known to historically support colonially-nesting waterbirds which have since been degraded. This includes lignum shrubland in the Nimmie-Caira zone, and river red gum sites in south Yanga National Park and parts of the mid-Murrumbidgee zone which have not supported breeding in the last decade.

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

Table 5-17 Wetland-dependent bird species recorded in 2014-16 (see foonote below for explanatory notes).

Functional Group	Common Name^	Scientific Name	CAVS Code
Australian-breeding 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
Dabbling and filter-feeding 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, aquatic gallinules and swans	Black swan	*Cygnus atratus*	203
	Dusky moorhen	*Gallinula tenebrosa*	56
	Eurasian coot	*Fulica atra*	59
	Hardhead	*Aythya australis*	215
	Musk duck	*Biziura lobata*	217
Grazing ducks and geese	Australian shelduck	*Tadorna tadornoides*	207
	Australian wood duck	*Chenonetta jubata*	202
	Magpie goose v	*Anseranas semipalmata*	199
	Plumed whistling-duck	*Dendrocygna eytoni*	205
Migratory shorebirds	Sharp-tailed sandpiper J,C,R	*Calidris acuminata*	163
Piscivores (including grebes, cormorants, egrets, bitterns, terns and kingfisher)	Australasian bittern E e	*Botaurus poiciloptilus*	197
	Australasian darter	*Anhinga novaehollandiae*	101
	Australasian grebe	*Tachybaptus novaehollandiae*	61
	Australian pelican	*Pelecanus conspicillatus*	106
	Eastern great egret J	*Ardea modesta*	187
	Great cormorant	*Phalacrocorax carbo*	96
	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
	Sacred kingfisher	*Todiramphus sanctus*	326
	Whiskered tern	*Chlidonias hybrida*	110
	White-faced heron	*Egretta novaehollandiae*	188
	White-necked heron	*Ardea pacifica*	189
Rails and shoreline gallinules	Black-tailed native-hen	*Tribonyx ventralis*	55
	Purple swamphen	*Porphyrio porphyrio*	58
Raptor	Nankeen kestrel	*Falco cenchroides*	240
	Swamp harrier	*Circus approximans*	219
	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
Storks, cranes, ibis and spoonbills (large wading birds)	Australian white ibis	*Threskiornis moluccus*	179
	Glossy ibis	*Plegadis falcinellus*	178
	Royal spoonbill	*Platalea regia*	181
	Straw-necked ibis	*Threskiornis spinicollis*	180
	Yellow-billed spoonbill	*Platalea flavipes*	182

^Status: J = JAMBA, C = CAMBA, R = ROKAMBA (listed under international migratory bird agreements Australia has with Japan, China, Republic of Korea, respectively), listing under the NSW *TSC Act 1995* (e = endangered, v = vulnerable), and under Commonwealth *EPBC Act 1999* (E = Endangered). Functional groups as described by Hale *et al.* (2014). Nomenclature follows Christidis and Boles (2008). Individual *Census of Australian Vertebrate Species* (CAVS) codes are presented (these codes are maintained by the Australian Biological Resources Study (ABRS) that document all species known to occur in Australia).

Table 5-18 Maximum count of each species recorded in each of the wetland zones during 2014-15 and 2015-16.

Common Name	2014-15			2015-16		
	Mid-bidgee	Nimmie-Caira	Redbank	Mid-bidgee	Nimmie-Caira	Redbank
Australasian bittern E e	0	0	1	0	2	0
Australasian darter	0	8*	3*	31*	16*	2*
Australasian grebe	45*	0	4	20	11	73*
Australasian shoveler	6	0	0	0	0	8
Australian pelican	0	81	65	85	34	136
Australian pratincole	0	0	0	0	0	1
Australian reed-warbler	0	1	0	1	1	6
Australian shelduck	0	3	2	2	0*	6*
Australian white ibis	9	47	12*	8	24*	135*
Australian wood duck	38*	25	17	23*	30*	12
Black-fronted dotterel	0	7	0	0	0	0
Black-tailed native-hen	0	40	0	0	36	0
Black-winged stilt	0	4	0	0	2	101
Black swan	0	8	59	31*	8	245*
Dusky moorhen	0	0	0*	0	0	5
Eastern great egret J	2	17	8*	2	32*	43*
Eurasian coot	65	4	204	595	8	711*
Freckled duck	0	0	0	1	0	0
Glossy ibis	0	0	0	0	0	270
Golden-headed cisticola	0	0	0	0	0	1
Great cormorant	38	2	21*	65*	64*	21
Grey teal	376*	361*	318	514*	99	430*
Hardhead	32	0	15	172	0	10
Hoary-headed grebe	58	0	110	30	2	0
Intermediate egret	0	1	9*	6	13	68*
Little black cormorant	5	100*	23*	7*	80*	12*
Little egret	0	5	0*	0	4	7*
Little grassbird	0	0	0	0	1	1
Little pied cormorant	4	11*	21*	82*	52*	26*
Magpie goose v	1	0	0	0	0	0
Masked lapwing	0	2	2	2	2	7*
Musk duck	0	1	0	0	0	0
Nankeen kestrel	0	0	0	1	0	2
Nankeen night-heron	0	0	5*	0	0	0
Pacific black duck	86*	62	56	174*	75*	35*
Pied cormorant	0	0	0	7	1	0
Pink-eared duck	259	18	125	20	0	0
Plumed whistling-duck	0	47	0	0	0	0
Purple swamphen	0	0	0	0	0	9*
Red-capped plover	0	2	0	0	0	0
Red-kneed dotterel	0	3	0	0	0	0
Royal spoonbill	0	7	0	22	9*	12
Sacred kingfisher	0	0	1	2	1	0

Table 5-18 (continued) Maximum count of each species recorded in each of the wetland zones during 2014-15 and 2015-16 (*indicates breeding detected).

Common Name^	**2014-15**			**2015-16**		
	Mid-bidgee	Nimmie-Caira	Redbank	Mid-bidgee	Nimmie-Caira	Redbank
Sharp-tailed sandpiper J,C,R,	0	2	0	0	0	0
Straw-necked ibis	4	200	42	0	28	15
Swamp harrier	0	0	0	1	3	0
Whiskered tern	0	0	0	0	120	0
Whistling kite	2	0	5	1	5	4
White-bellied sea-eagle	0	2	2	1	1	3
White-faced heron	3	26	5*	10	6	6
White-necked heron	0	3	17	5	1	13*
Yellow-billed spoonbill	2	29	6	51	16	210*
Total species from LTIM surveys	**19**	**32**	**28**	**30**	**33**	**35**
Total breeding species* from all surveys	**4**	**4**	**11**	**8**	**10**	**17**

^Status: J = JAMBA, C = CAMBA, R = ROKAMBA (listed under international migratory bird agreements Australia has with Japan, China and Republic of North Korea, respectively), listing under the NSW *TSC Act 1995* (e = endangered, v = vulnerable), and under Commonwealth *EPBC Act 1999* (E = Endangered). *Breeding records were determined from the results of LTIM quarterly wetland surveys and complementary monitoring undertaken by NSW OEH (see Spencer *et al.* 2016a).

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