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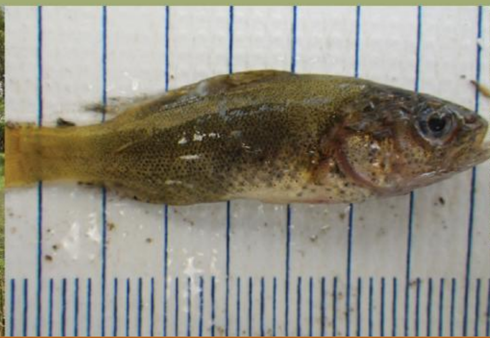

Commonwealth Environmental Water Office long-term intervention monitoring program Murrumbidgee River systems selected area

2014-15 Technical Report

Long Term Intervention Monitoring Murrumbidgee Selected Area 2014-15 technical report. Final, March 2016.

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Table of contents

Abbreviations

AGRF	Australian Genome Research Facility
ANAE	Australian National Aquatic Ecosystem
ANOVA	Analysis of Variance
ANOSIM	Analysis of Similarities
C1	Category 1 LTIM standard methods
C3	Category 3 LTIM standard methods
CAMBA	China-Australia Migratory Bird Agreement
CEWH	Commonwealth Environmental Water Holder
Chl *a*	Chlorophyll-*a*
CPUE	Catch Per Unit Effort
CSU	Charles Sturt University
CTF	Commence-To-Fill
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DTM	Digital Terrain Model
EC	Electrical Conductivity
EPBC	Commonwealth *Environment Protection & Biodiversity Conservation Act 1999*
ER	Ecosystem Respiration
EWA	Environmental Water Allowance
FMA	NSW *Fisheries Management Act 1994*
GIS	Geographic Information System
GLM	Generalised Linear Model
GPP	Gross Primary Production
GS	General Security
IMEF	Integrated Monitoring of Environmental Flows
JAMBA	Japan-Australia Migratory Bird Agreement
LiDAR	Light Detection And Ranging (DTM)
LTIM	Long Term Intervention Monitoring
ML	Megalitre
NC	Nimmie-Caira system (Lowbidgee floodplain)
NOx	Oxidised nitrogen
NTU	Nephelometric Turbidity Units
OEH	Office of Environment and Heritage, NSW
PCR	Polymerase Chain Reaction
PERMANOVA	Permutational ANOVA
PLS-PM	Partial Least Squares Path Modelling
RB	Redbank system (Lowbidgee floodplain)

SIMPER	Similarity of Percentages Analysis
SRA	Sustainable Rivers Audit
SUPPL	Supplementary environmental water allowance
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
TSC	NSW *Threatened Species Conservation Act 1995*
UNSW	University of New South Wales
YOY	Young-Of-the-Year fish

Table of Figures

List of tables

1 Introduction

This technical report provides a detailed assessment of ecological outcomes for each of the indicators monitored under the Murrumbidgee selected area Long Term Intervention Monitoring Project. Monitoring outcomes are evaluated in the Murrumbidgee selected area synthesis report.

Environmental Watering actions and objectives 2014-15

Nine water use actions were identified during 2014-15 by the Commonwealth Environmental Water Holder (CEWO 2014). Four of these actions were implemented and three were monitored as part of the Mururmbidgee Long-Term Intervention Monitoring Project in 2014-15 (

).

- **Action 1 – mid-Murrumbidgee River Wetlands (did not proceed)**
- **Action 2 – mid-Murrumbidgee River Wetlands infrastructure assisted delivery (implemented)** aimed to refill wetlands in the mid-Murrumbidgee floodplain that have infrastructure to allow delivery to these wetlands with the aim of continued improvement in vegetation condition and provision of habitat for wetland dependent fauna.
- **Action 3 – Murrumbidgee River Native Fish Fresh (did not proceed)** no Commonwealth environmental water specifically targeted these flows
- **Action 4 – mid-Yanco Creek Anabranches and Wetlands (not monitored)** aimed to maintain river red gum and other wetland vegetation by reconnecting and refilling the anabranch creeks and lagoons located in the mid-Yanco Creek system.
- **Action 5 – Restoring natural flow variability (did not proceed)**
- **Action 6 – Lowbidgee wetlands (implemented)** aimed to inundate wetlands on the Lowbidgee floodplain to maintain, improve and potentially recover wetland vegetation diversity and condition in lignum, black box, river red gum and associated wetland understorey communities and for the provision of habitat for wetland dependent fauna.
- **Action 7 – Western Lakes (not monitored)** aimed to inundate wetlands and lakes located on the western edge of the Lowbidgee floodplain with a focus on the recovery of riparian and wetland vegetation and provision of waterbird and aquatic fauna habitat.
- **Action 8 – Contingency to support significant breeding (not monitored)** to maintain wetland water levels and acceptable levels of water quality to support the completion of significant waterbird breeding events
- **Action 9**- **Murrumbidgee River water quality and habitat - return flows for 2014-15 (implemented)** aimed to contribute to maintenance or improvement of water quality primarily to support native fish condition and reproduction by returning flows from the North Redbank system.

Table 1 Summary of Commonwealth environmental watering actions and expected outcomes. Also see Murrumbidgee Monitoring and Evaluation plan (M&E Plan) (Wassens *et al.* 2014a)

Target asset	**Expected outcomes for 2014-15**	**Basin Plan (bold) and longer term objectives (M&E Plan)**
LTIM MONITORED SITES/ACTIONS		
Yarradda Lagoon Action 2 Zones Mid-Murrumbidgee (Yarradda Lagoon)	Primary – protect and maintain wetland and riparian native vegetation Secondary – provide feeding habitat for waterbirds, native fish, other aquatic vertebrates (turtles, frogs) and invertebrates.	Vegetation diversity Fish diversity Waterbird diversity Other vertebrate diversity Microinvertebrates
Mid North Redbank and Return Flows (only the return flows were monitored for this action) Action 9	Mid North Redbank - protect, maintain, and in some cases improve the condition and extent of floodplain, riparian and wetland native vegetation - maintain and improve the diversity and condition of native aquatic fauna including fish, waterbirds, frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit – support habitat requirements for waterbird, frog and native fish Return flows - support ecosystem functions, such as mobilisation, transport and dispersal of biotic and abiotic material (e.g. macroinvertebrates, nutrients and organic matter) through longitudinal and lateral floodplain-river connectivity	Water quality Ecosystem function Biotic dispersal and movement Sediment transport Nutrient and carbon cycling Microinvertebrates
Yanga National Park Action 6 Zones Redbank (Mercedes, Piggery, Two Bridges, Waugorah Lagoon) Nimmie-Caira (Avalon, Nap Nap, Eulimbah, Telephone Creek)	Primary - protect, maintain, and in some cases improve the condition and extent of floodplain, riparian and wetland native vegetation - maintain and improve the diversity and condition of native aquatic fauna including fish, waterbirds, frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit – additional water supplied to support identified waterbird (egret) breeding event Secondary – support ecosystem functions – provide habitat for native fish, frogs and other vertebrates – support habitat requirements for waterbird, frog and native fish	Vegetation diversity Fish diversity Waterbird diversity Other vertebrate diversity Microinvertebrates

Table 1 continued. Summary of Commonwealth environmental watering actions and expected outcomes. Also see Murrumbidgee Monitoring and Evaluation plan (M&E Plan)(Wassens *et al.* 2014a)

SITES/ACTIONS NOT MONITORED AS PART OF LTIM

Upper North Redbank	Primary - protect, maintain, and in some cases improve the condition and extent of floodplain, riparian and wetland native vegetation - maintain and improve the diversity and condition of native aquatic fauna including fish, waterbirds, frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit Secondary – support ecosystem functions – support habitat requirements for waterbird, frog and native fish	Vegetation diversity Waterbird diversity Other vertebrate diversity Waterbird diversity Fish diversity Ecosystem function
Sandy Creek	Primary – protect and maintain wetland and riparian native vegetation Secondary – provide feeding habitat for waterbirds – provide feeding habitat for frogs	Vegetation diversity Waterbird diversity Other vertebrate diversity Waterbird diversity
Juanbung	Primary – water stressed river gum floodplain and riparian native vegetation Secondary – provide feeding habitat for waterbirds – provide feeding habitat for frogs	Vegetation diversity Waterbird diversity Other vertebrate diversity Waterbird diversity
Paika Lake	Primary – Maintenance of open water habitat for waterbirds Secondary – inundate fringing aquatic vegetation communities – Support habitat requirements for waterbird, frog and native fish	Vegetation diversity Waterbird diversity Fish diversity Waterbird diversity
Yanco Creek	Primary - protect, maintain, and in some cases improve the condition and extent of floodplain, riparian and wetland native vegetation - maintain and improve the diversity and condition of native aquatic fauna including fish, waterbirds, frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit Secondary – Support habitat requirements for waterbird, frog and native fish – provide feeding longitudinal and lateral connectivity	Vegetation diversity Other vertebrate diversity Fish diversity Waterbird diversity Biotic dispersal and movement

Water use

The Lowbidgee wetlands in the Nimmie-Caira, north Redbank, south Redbank (Yanga National Park), and Western Lakes zones as well as the Yanco Creek system, Yarradda Lagoon and Sandy Creek in the mid-Murrumbidgee wetlands were targeted for environmental watering during the 2014-15 period of the ecological monitoring using a combination of environmental water holding entitlements: Commonwealth Environmental Water (CEW which comprised of General and High Security (GS and HS) and Lowbidgee and Murrumbidgee supplementary (SUPP) entitlements), NSW Adaptive Environmental Water (AEW), planned NSW Environmental Water Allocation (EWA), NSW The Living Murray (TLM) and NSW Lowbidgee supplementary (SUPP) (Table 2). Watering of the Lowbidgee wetlands occurred during winter and late spring-summer for the Nimmie-Caira using NSW environmental water allocations whilst watering to Redbank wetlands occurred from mid-Spring-through to Winter 2015 using a combination of CEW and NSW allocations. The mid-north Redbank return flows occurred from Autumn 2014 to Summer 2015. The Western Lakes were watered during aumtumn/winter 2015 while the mid-Murrumbidgee watering occurred during summer (Yarradda) and autumn (Sandy Creek) 2015 (OEH 2015) (Table 2 Figure 6b).

Table 2 Murrumbidgee environmental water use by entitlement (updated to 30/06/14) (Murrumbidgee 2014-15 Water use Acquittal Report)

Wetland Zone	Start – End Date	Event Name	Water Use Volume (ML) NSW AEW	NSW EWA	NSW LTIM	CEWH GS	CEWH SUPP	NSW SUPP	Total Volume delivered (ML)
Nimmie-Caira	06/07/14-30/08/14	Nap Nap Swamp to Waugorah Ck		630				18565	19195
	04/07/14-30/08/14	Uara Creek to Yanga						21757 LSAL	21757
	04/07/14-30/08/14	North Caira Floodways						7849 LSAL	7489
	22/10/14-31/12/14	Kia Lake		10000					10000
	20/10/14-28/02/15	Telephone Bank Swamp		4930					4930
	27/11/14-28/02/15	Nimmie-Caira Southern Bell Frog Wetlands		2000				3113 LSAL	5113
	23/03/15-30/04/15	Nimmie Creek		343					343
Western Lakes	25/05/15-25/06/15	Paika Lake		1459	1535	8498			11492
Redbank	12/08/14-31/01/15	Mid North Redbank, return flows	3136	13204		40000			56340
	01/10/14-30/06/15	Upper North Redbank		6648		20000			26648
	04/05/15-29/06/15	Juanbung		4667		5688			10355
	23/10/14-31/03/15	Yanga National Park	6280	19070		70000	4512 LSAL		99862
	20/02/15-13/04/15	South Yanga	7885	5893					13778
Yanco	23/06/15-30/06/15	Yanco Creek		245			2462	1372	5732
Mid-Murrumbidgee	03/12/14-31/01/15	Yarradda Lagoon				1150			1150
	22/03/15-01/04/15	Sandy Creek		130		250			380
	12/09/14-01/01/15	MIA wetlands		2472					2472
	02/12/14-01/01/15	Coonancoocabil wetlands		720					720
	09/02/15-08/03/15	Old Man Creek		840					840
	10/03/15-01/04/15	Gras Innes and Oak Creek		1278					1,278

Commonwealth environmental water contributed to eight watering actions within the Murrumbidgee Valley in 2014-15. These actions were anticipated to achieve the following expected outcomes:

- protect, maintain, and in some cases improve the condition and extent of floodplain, riparian and wetland native vegetation
- maintain and improve the diversity and condition of native aquatic fauna including fish, waterbirds, frogs, turtles and invertebrates through maintaining

suitable habitat and providing/supporting opportunities to move, breed and recruit
- support the habitat requirements of waterbirds
- support the habitat requirements of native fish
- support the habitat requirements of other vertebrates
- support ecosystem functions, such as mobilisation, transport and dispersal of biotic and abiotic material (e.g. macroinvertebrates, nutrients and organic matter) through longitudinal and lateral hydrological connectivity
- improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

2 Summary of monitoring activities -Murrumbidgee Selected Area

Wetlands make up over 4 per cent (370,000 ha) of the Murrumbidgee 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 per cent of the total catchment area)(Hardwick *et al.* 2012). Monitoring activities under the current program are stratified within broad ecological zones (zones) that represent areas with common ecological and hydrological attributes.

In the Murrumbidgee River, monitoring activities are undertaken within three zones, Narrandera (187km), Carrathool (358km) and Balranald (241km) (Figure 1). The major monitoring emphasis is on the Narrandera and Carrathool zones. The LTIM monitoring program consists of six core monitoring locations in the Murrumbidgee River in the Narrandera (n=3) and Carrathool (n=3) zones targeting larval fish, microinvertebrates, nutrients, carbon and Chlorophyll-a, with additional sites making up the category 1 and category 3 fish community monitoring locations (Table 3; see Figure 1).

On the floodplain six ecological zones have been identified; the mid-Murrumbidgee wetlands (82,800 ha), Redbank (92,504 ha), Nimmie-Caira (98,138 ha), Pimpama–Wagourah (55,451 ha), Fiddlers-Uara (75,285 ha), and Western Lakes (3459 ha) (Wassens *et al.* 2014a). Monitoring for the LTIM program includes 12 fixed wetland sites focused on three zones; the Redbank (n=4), Nimmie-Caira (n=4) and the mid-Murrumbidgee (n=4) (Figure 2; Table 4). The wetland monitoring program covers waterbird diversity, vegetation diversity, frogs, fish community, microinvertebrates, nutrients, carbon and chlorophyll-a with monitoring undertaken four times per year in September 2014, November 2014, January 2015 and March 2015.

Table 3 Summary of monitoring activities and location in the Murrumbidgee River (see Figure 1)

Site Name	Zone	ANAE classification	Stream metabolism	Nutrients carbon	Microinvertebrate	Larval fish C1	Larval Fish SA	Fish community (C1)	Fish community (C3)
Baupie Escape (River)	Balranald	Permanent lowland streams							X
Glen Avon (River)									X
Maude									X
Nap Nap									X
Redbank Weir									X
Willow Isles									X
Wynburn									X
Yarradda (River)	Carrathool	Permanent transitional zone streams		X	X	X	X	X	X
McKennas (River)		Permanent lowland streams	X	X	X	X	X	X	X
Bringagee				X	X	X	X	X	X
Birdcage								X	X
Gundaline claybar								X	
Gundaline US								X	
Hay Boat Ramp									X
Pevensey									X
Rudds Point								X	
Toganmain DS								X	
Toganmain Homestead								X	
Toganmain US								X	
Wyreema									X
The Dairy	Narrandera	Permanent lowland streams		X	X		X		X
Euroley Bridge				X	X		X		X
Narrandera			X	X	X		X		X
Buckingbong Station									X
Berembed Weir DS									X
Gogeldrie Weir US									X
Lamonts Beach									X

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

Table 4 Summary of monitoring activities and locations across three wetland zones in the Murrumbidgee floodplain (see Figure 2

Site Name	Zone	ANAE classification	Nutrients , carbon, chl a	Microinvertebrate	Fish community (C3)	Frogs	Waterbird Diversity	Vegetation Diversity
Gooragool Lagoon	mid-Murrumbidgee	Permanent floodplain wetland	X	X	X	X	X	X
McKennas Lagoon		Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Sunshower Lagoon		Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Yarradda Lagoon		Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Avalon Swamp	Nimmie-Caira	Temporary floodplain lakes	X	X	X	X	X	X
Eulimbah Swamp		Temporary floodplain wetland	X	X	X	X	X	X
Nap Nap Swamp		Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Telephone Creek		Permanent floodplain wetland	X	X	X	X	X	X
Mercedes Swamp	Redbank	Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Piggery Lake		Permanent floodplain tall emergent marshes	X	X	X	X	X	X
Two Bridges Swamp		Intermittent river red gum floodplain swamp	X	X	X	X	X	X
Waugorah Lagoon		Permanent floodplain wetland	X	X	X	X	X	X

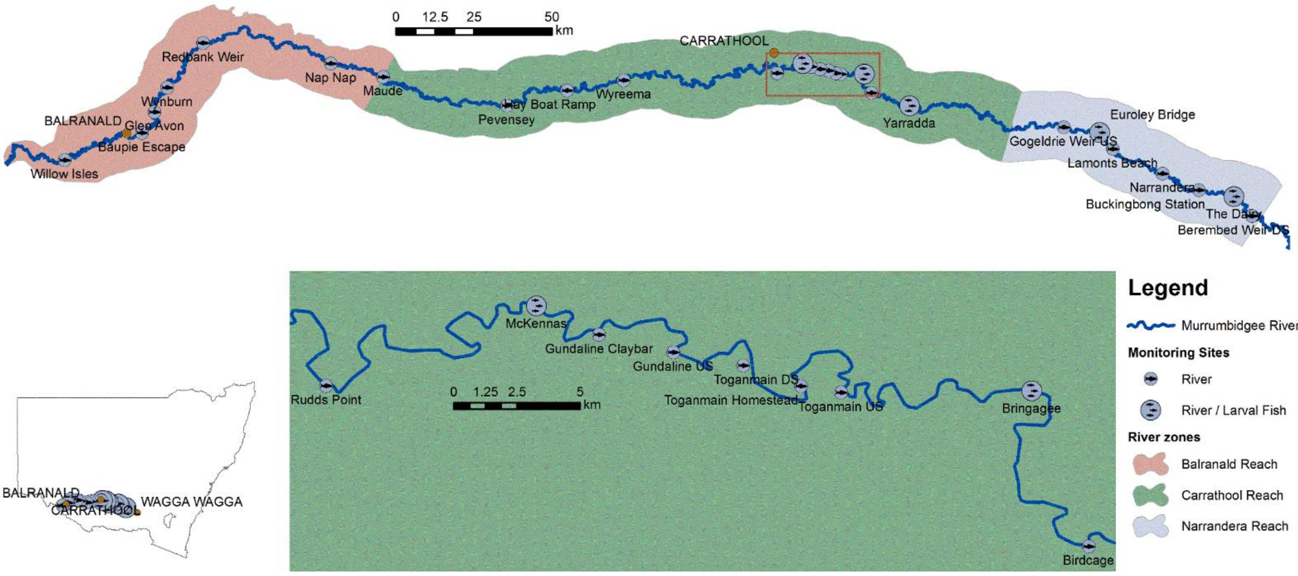


Figure 1 Distribution of riverine zones and key monitoring locations in the Murrumbidgee Selected Area.

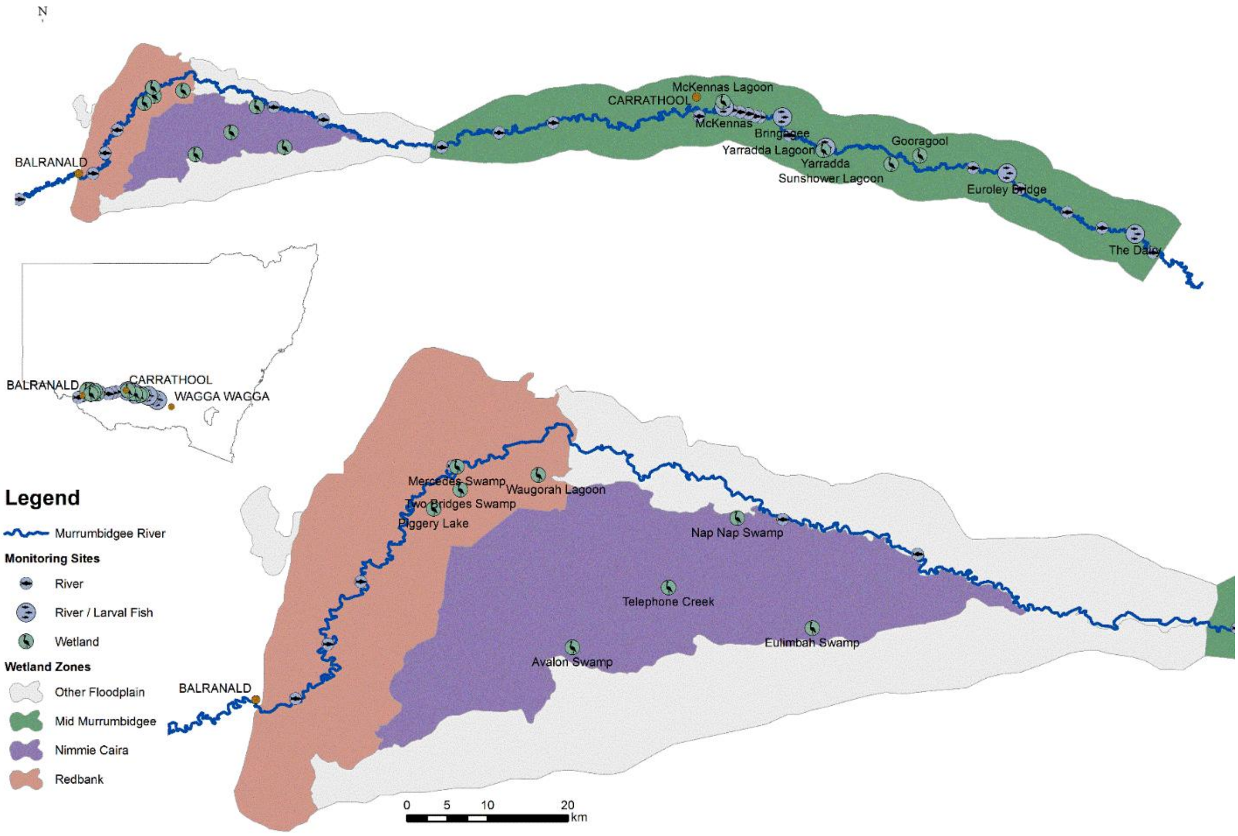


Figure 2 Distribution of wetland zones and key monitoring locations in the Murrumbidgee Selected Area

3 Ecosystem responses to Commonwealth environmental water

Southern bell frog at Avalon Swamp November 2014

3.1 Ecosystem type

Introduction

Project work associated with Ecosystem Type and Wetland Hydrology have been closely linked during this first year of the LTIM program. A key objective of this work has been to define wetland boundaries, which are required to guide much of the fieldwork and analysis effort. While the Australian National Aquatic Ecosystem (ANAE) database has been developed using the best available mapping and attribute data (Brooks *et al.* 2014) further investigation to map wetlands and describe their attributes has been necessary to produce accurate descriptions of Murrumbidgee LTIM wetland field sites (Table 5). All wetland sites selected as field sites in the Murrumbidgee LTIM were subject to the analysis to ensure a consistent set of data across all sites.

Table 5 Wetland sites for which boundaries were produced along with their ANAE data.

Zone	Vegetation description	Site	ANAE ID	ANAE Current Type
Redbank	Flooded river red gum forest open spike rush wetlands	Piggery Lake	13317	Pp2.1.1: Permanent floodplain tall emergent marshes
		Mercedes Swamp	13315	Pt1.1.1: Intermittent River red gum floodplain swamp
		Two Bridges Swamp	13314	Pt1.1.1: Intermittent River red gum floodplain swamp
		Wagourah Lagoon	13311	Pp4.1: Permanent floodplain wetland
Nimmie-Caira	lignum and lignum-black box with river red gum fringing permanent creek lines	Avalon Swamp	8048	Lt2.1: Temporary floodplain lakes
		Telephone Creek	13396	Pp4.1: Permanent floodplain wetland
		Nap Nap Swamp	13397	Pt1.1.1: Intermittent River red gum floodplain swamp
		Eulimbah Swamp	13395	Pt4.1: Temporary floodplain wetland
Mid-Murrumbidgee	River red gum forest fringing oxbow lagoons	McKennas Lagoon	13308	Pt1.1.1: Intermittent River red gum floodplain swamp
		Yarradda Lagoon	33239	Pt1.1.1: Intermittent River red gum floodplain swamp
		Sunshower Lagoon	32870	Pt1.1.1: Intermittent River red gum floodplain swamp
		Gooragool Lagoon	32869	Pp4.1: Permanent floodplain wetland

In work completed this year, the wetland boundaries were accurately delineated using remotely sensed light detection and ranging (LiDAR) data (Digital Terrain Models, DTMs) and validated with modelled inundation data already produced by NSW OEH, per the standard method, *"If the ecosystem is not mapped then record coordinates (GDA94) of the centre of the ecosystem and either locate compatible GIS mapping or delineate the boundary of the ecosystem using remote sensed data*".

With the wetland boundaries defined, detailed bathymetric maps for each wetland were derived from the DTM and a series of metrics describing inundation patterns were developed and will be further validated by ground-truthing in 2015-16. Using these series, wetland hydrology data products will be produced from depth logger data collected at each of the twelve LTIM wetland monitoring sites.

3.2 Wetland mapping

In the Murrumbidgee catchment, wetlands vary from large open water lakes and small oxbow lagoons, with relatively well defined sills and boundaries, to shallow vegetated swamps and marshes with complex bathymetry and poorly defined boundaries. Within the oxbow lagoons of the mid-Murrumbidgee zone it is possible to identify the perimeter of a lake or lagoon from a single date moderate resolution satellite image such as SPOT-5 and Landsat 7 ETM+. In the Lowbidgee floodplain, however, the perimeter of an individual wetland is ambiguous and not easily distinguishable from a single image date, because at any one point in time there is a mosaic of wetland vegetation types and a gradient of flooding. The presence of levee banks and regulatory structures also influence flooding patterns.

A LiDAR derived 1m DTM representing a bare earth surface (without buildings or vegetation) was used as the basis of wetland boundary measurements in the Murrumbidgee Selected Area. Good quality LiDAR was captured between February and September 2008 during a very dry period and is available to the project team through NSW OEH. The spatial accuracy of the DTM is ±0.60 m horizontal and ±0.15 m vertical, which provided sufficient accuracy to derive rates of rise and fall to within 0.2 m.

Rough boundary polygons were drawn around wetland areas guided by a visualisation of the DTM within a Geographic Information System (GIS) incorporating expert knowledge of the system. High elevation areas such as levees or river banks in addition to natural breaks between adjacent wetland systems were incorporated into this rough boundary. Using a novel set of algorithms produced using a suite of software tools (ArcGIS 10.2.2, Python 2.7.5 and R 3.1.3) accurate wetland boundaries based on the DTM were then determined. The series of procedures was consistent for every wetland site. The wetland boundaries were validated using images displaying inundation modelling based on time series of Landsat images, produced in a completely independent process (Figure 3, Figure 4).

The full set of defined wetland boundaries overlaid on the ANAE wetland boundaries map are displayed in Figure 5. While a good level of agreement was produced for some of the wetlands, e.g. Avalon Swamp, and Yarradda Lagoon, a high level of improvement was produced for many of the areas, particularly those that are represented within the ANAE as arbitrary circles at the approximate locations of the wetlands, e.g. Eulimbah Swamp, Nap Nap Swamp and Telephone Creek. These accurate boundary shapefiles will be utilised in future spatial analyses of wetlands, including modelling of hydrology metrics.

Further to the validation process, expert knowledge within the team was utilised to assess ANAE classification types of the 12 wetland areas in conjunction with Landsat imagery and flood frequency maps. Classification types as currently recorded within the ANAE were found to be as accurate as could be conveyed (within the constraints of the system) for all 12 wetland sites.

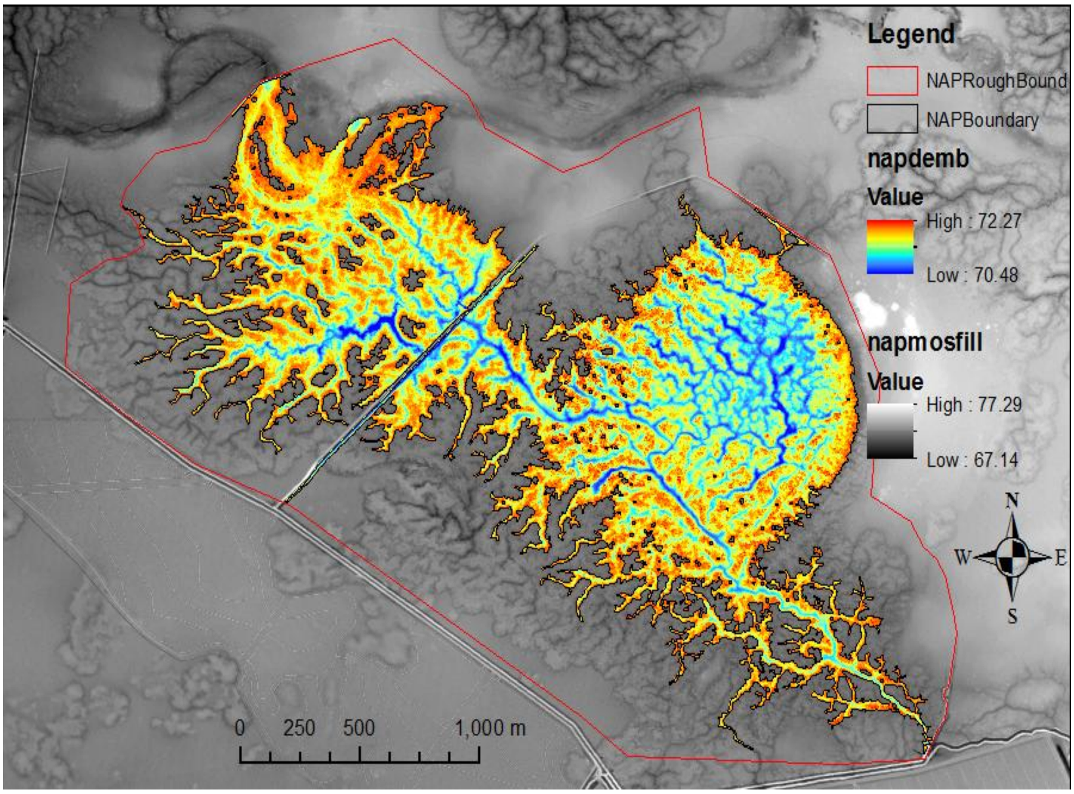
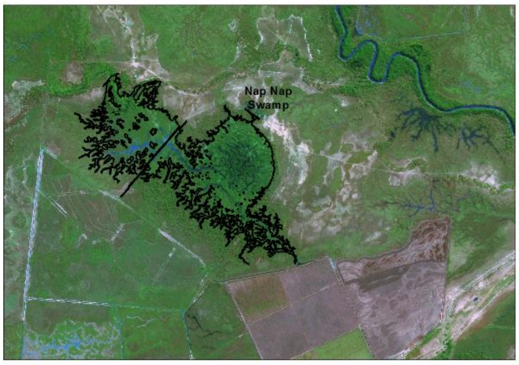


Figure 3 Wetland boundary for Nap Nap Swamp (Nimmie-Caira zone) (black solid line) with bathymetry (coloured) shown with greyscale digital terrain map and rough boundary (red solid line).

(a) 

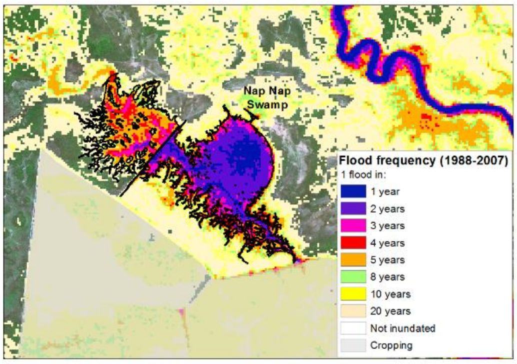
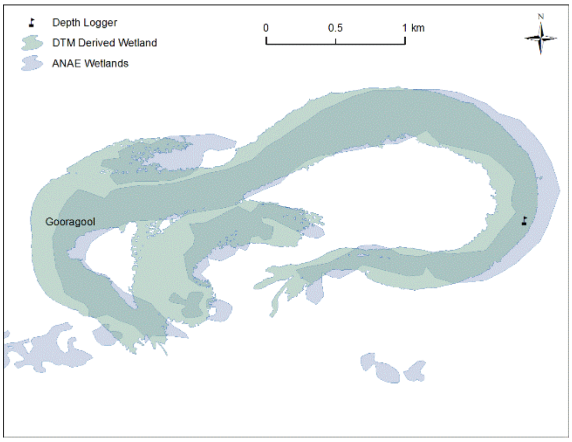
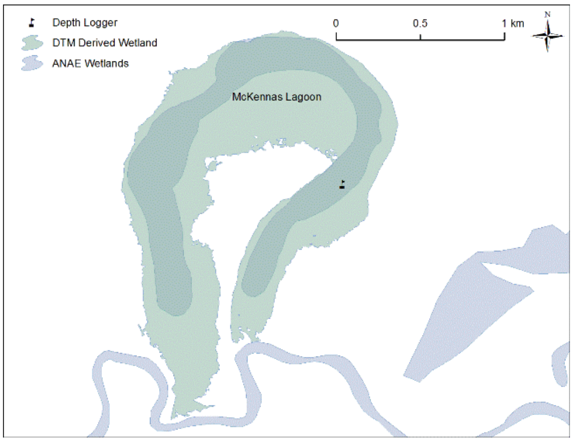
(b) 

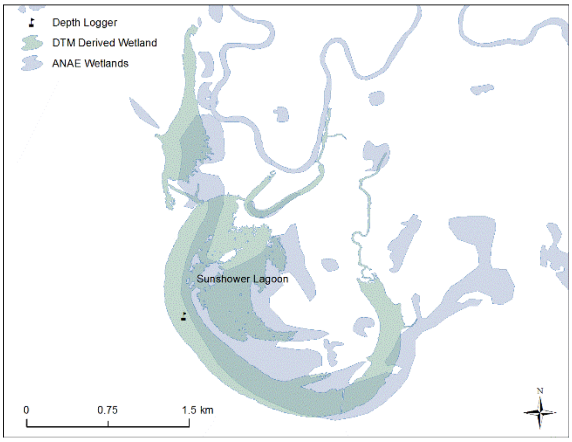
Figure 4(a) Wetland boundary for Nap Nap swamp shown with (a) true colour Landsat image and (b) flood frequency map of the surrounding area.



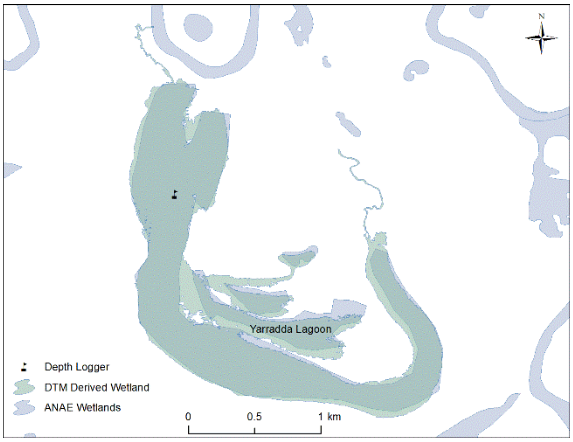
(a)Gooragool Lagoon



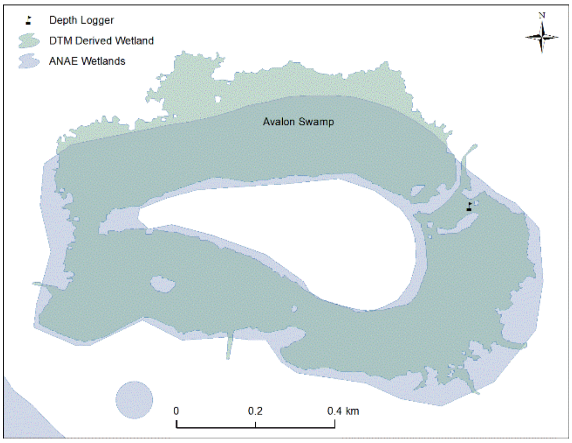
(b) McKenna's Lagoon



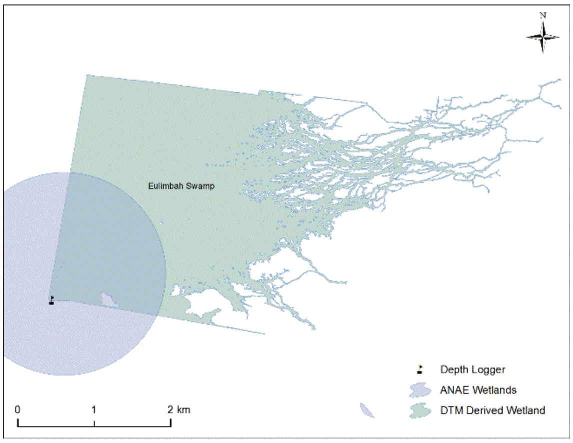
(c) Sunshower Lagoon



(d)Yarradda Lagoon

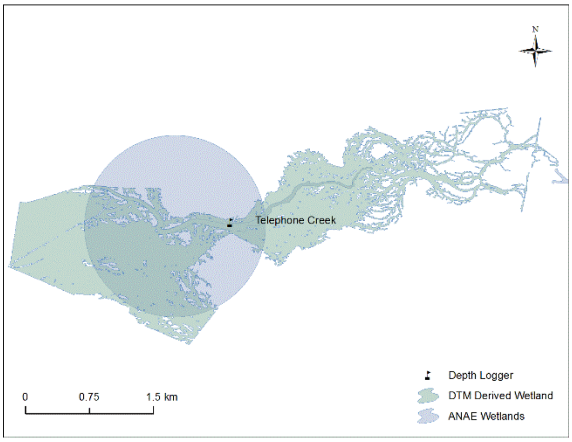


(e)Avalon Swamp

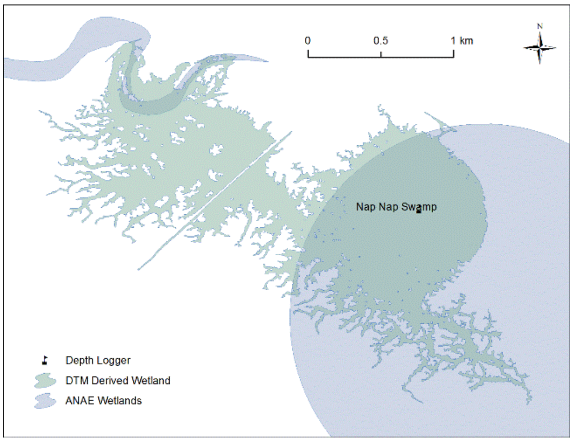


(f)Eulimbah Swamp

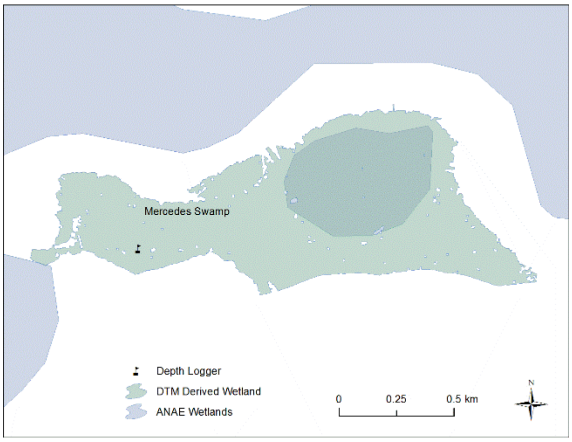
Figure 5 Wetland boundaries derived using a digital terrain model compared to the ANAE database wetland boundaries.



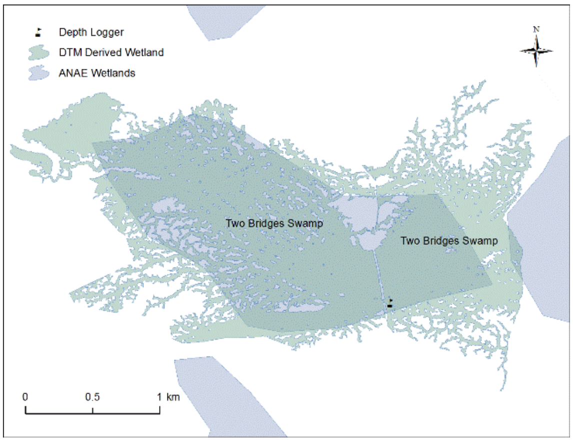
(g) Telephone Creek



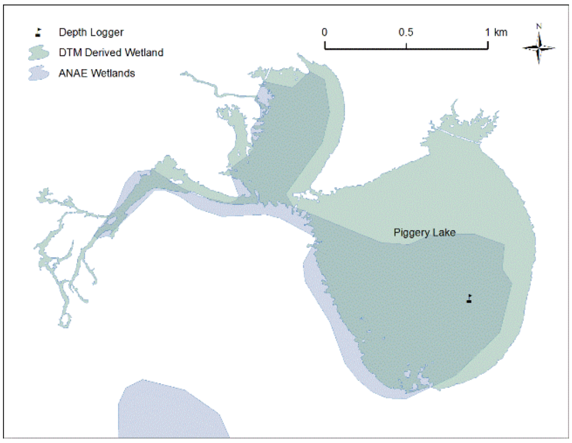
(h)Nap Nap Swamp



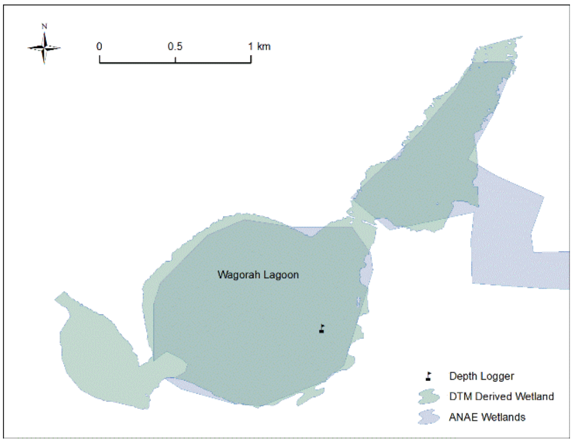
(i) Mercedes Swamp



(j) Two Bridges Swamp



(k) Piggery Lake



(l) Wagourah Lagoon

Figure 5 (cont) Wetland boundaries derived using a DTM compared to the ANAE database wetland boundaries.

3.3 Hydrology

Wetland hydrology - Inundated areas

Nimmie-Caira

Environmental water events using NSW water holding entitlements targetted the main floodways and wetlands of the Nimmie-Caira in July-August 2014 (see Table 2). Included in these targets were the LTIM surveyed wetland sites (a) Telephone Creek, (b) Nap Nap Swamp, (c) Avalon Swamp and (d) Eulimbah Swamp (Figure 6 and Figure 7)

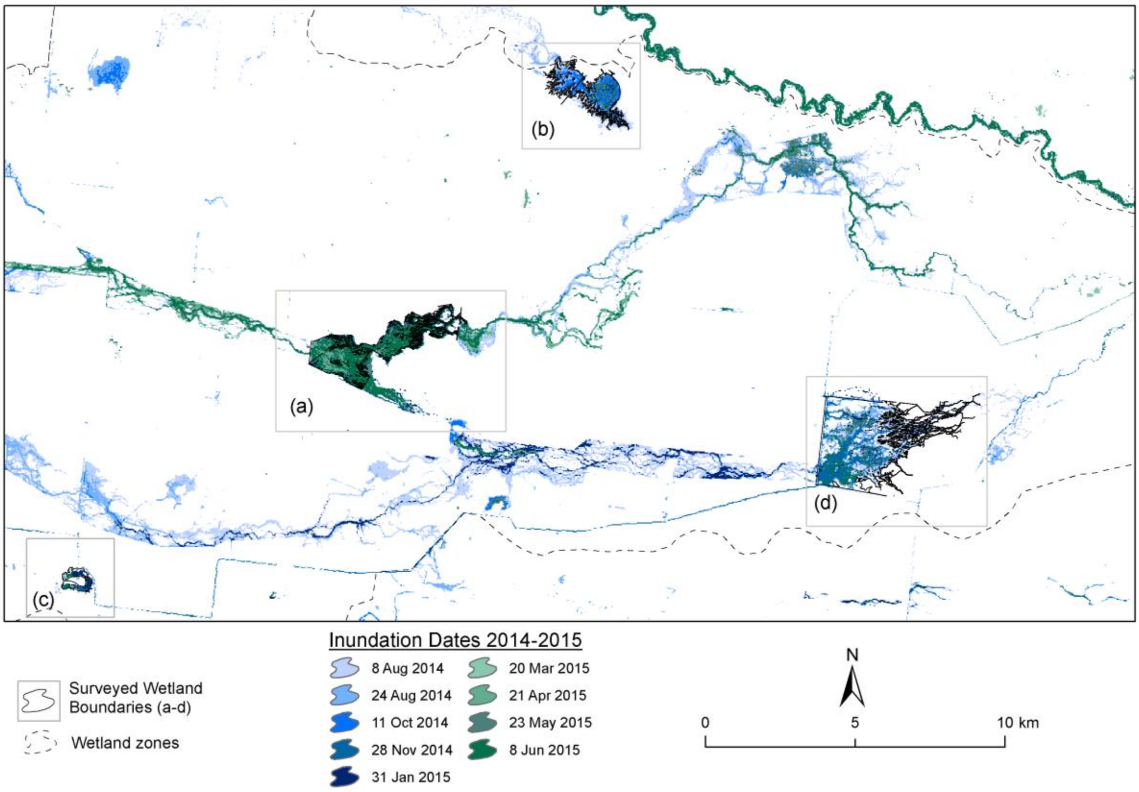


Figure 6 Distribution of inundated areas derived from Landsat satellite imagery dates in the Nimmie-Caira wetland zone during environmental watering action periods (August 2014-April 2015) and in relation to surveyed wetlands: insets (a) Telephone Creek (b) Nap Nap Swamp, (c) Avalon Swamp and (d) Eulimbah Swamp

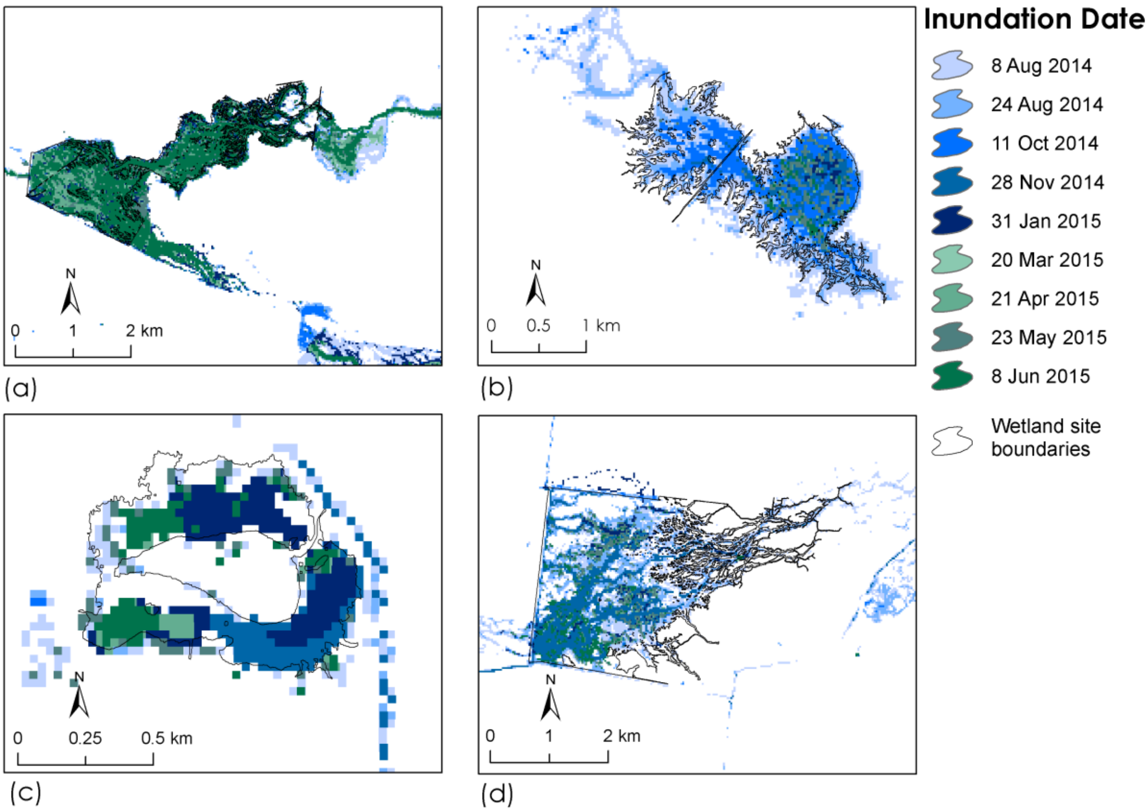


Figure 7 Distribution of inundated areas in the LTIM surveyed wetlands of the Nimmie-Caira wetland zone (a) Telephone Creek (b) Nap Nap Swamp, (c) Avalon Swamp and (d) Eulimbah Swamp during environmental watering action periods between August 2014 and June 2015.

Both Telephone Creek and Nap Nap Swamp were inundated to over 90 per cent of their wetland boundary during August 2014 with areas in Nap Nap Swamp steadily receding over the summer months (Figure 8). Telephone Creek was specifically targetted between October 2014 and Febuary 2015, remaining more than 90 per cent inundated to the end of January 2015 and at least 50 per cent inundated during the winter. Avalon Swamp was inundated to almost 50 per cent of its area at the end of January as a result of environmental watering to Southern Bell Frog wetlands during the summer months (Table 2). Eulimbah Swamp was inundated to almost 70 per cent of its area in July-August 2014 as a result of environmental watering (inundated areas steadily receded to below 20 per cent during October but increased again to just under 50 per cent of its area by the end of January 2015 as a result of environmental watering)(see Figure 8).

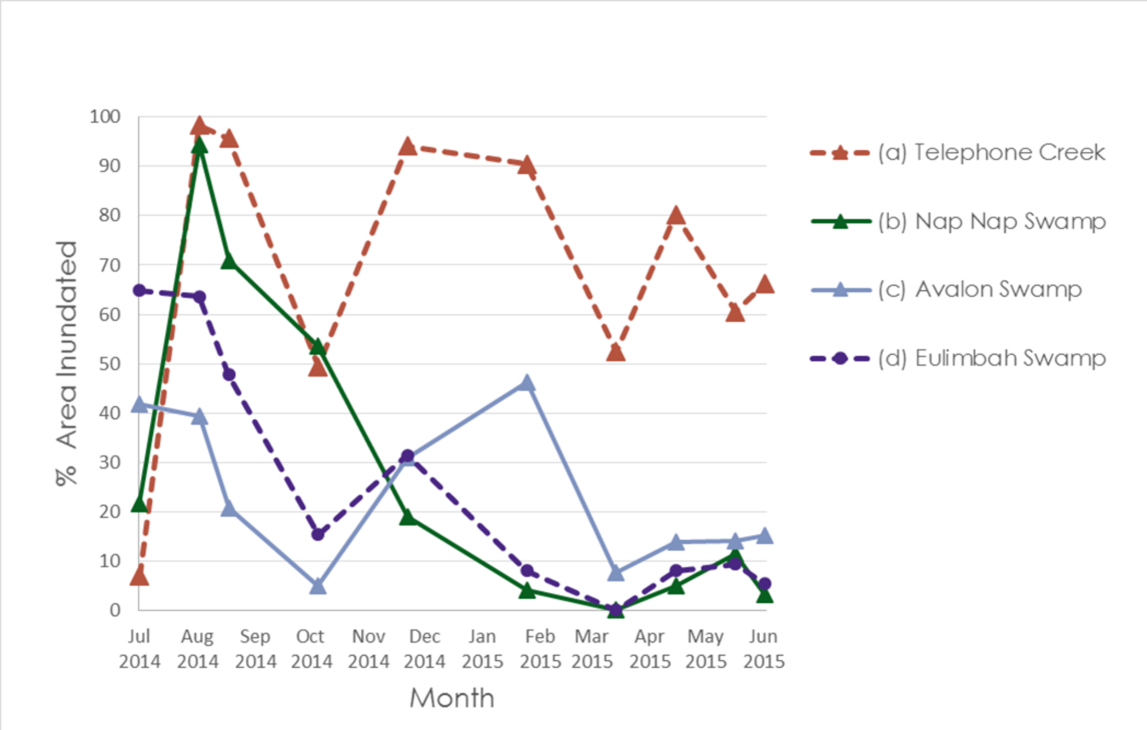


Figure 8 Percentage area inundated of the LTIM surveyed wetlands in the Nimmie-Caira wetland zone of the Lowbidgee during NSW environmental water actions in 2014-15.

Redbank (including return flows)

The mid-North Redbank return flows watering action began mid-August and ended at the end of January 2015 inundating a cumulative total area of floodplain of 4,452 ha (Table 2 and blue areas in south-west quarter of Figure 9). This was as a result of a total of 56,340 ML of environmental water entitlements from CEW GS (40,000 ML), NSW AEW (3,136 ML) and NSW EWA (13,204 ML). In the upper north Redbank a mostly CEW GS watering action of 20,000 ML combined with 6,648 ML of NSW EWA inundated a cumulative total area of 2,791 ha between October 2014 and June 2015 (Table 2).

South Redbank (Yanga National Park) was targeted for environmental watering using a total of 99,862 ML mostly through CEW GS (70,000 ML) usage combined with CEW SUPP (4,512 ML), NSW AEW (5,611 ML) and NSW EWA (19,739 ML). About a cumulative 11,870 ha of the Yanga National Park was inundated during the period from late October 2014 to the end of March 2015 (Table 2 and Figure 9). This environmental water action inundated the surveyed LTIM wetlands sites Mercedes Swamp, Two Bridges Swamp and Piggery Lake (Figure 10).

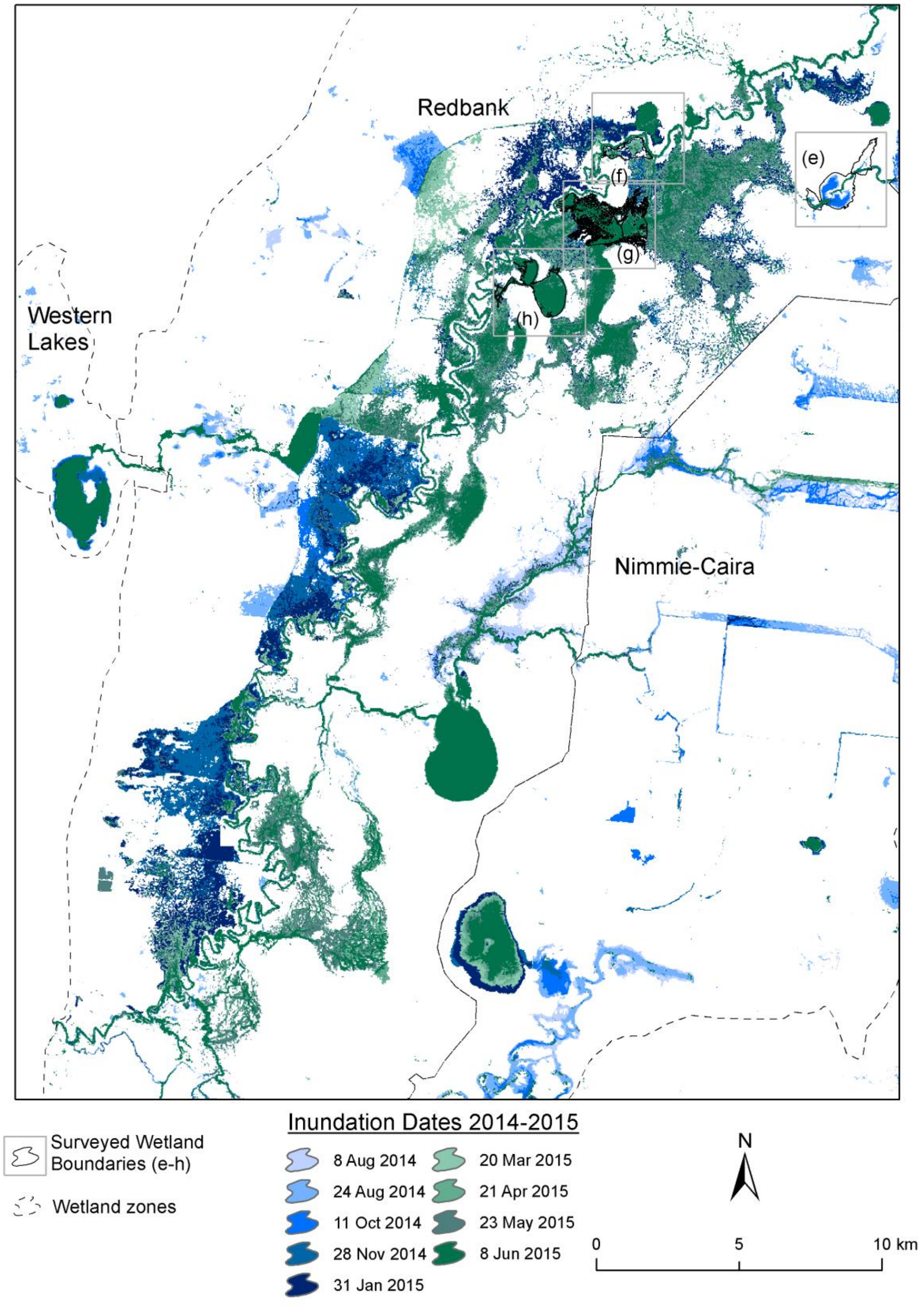


Figure 9 Distribution of inundated areas derived from Landsat satellite imagery dates in the Redbank and Western Lakes wetland zone during environmental watering action periods (August 2014-June 2015) and in relation to surveyed wetlands: insets (e) Waugorah Lagoon (f) Mercedes Swamp, (g) Two Bridges Swamp and (h) Piggery Lake (see Figure 10)

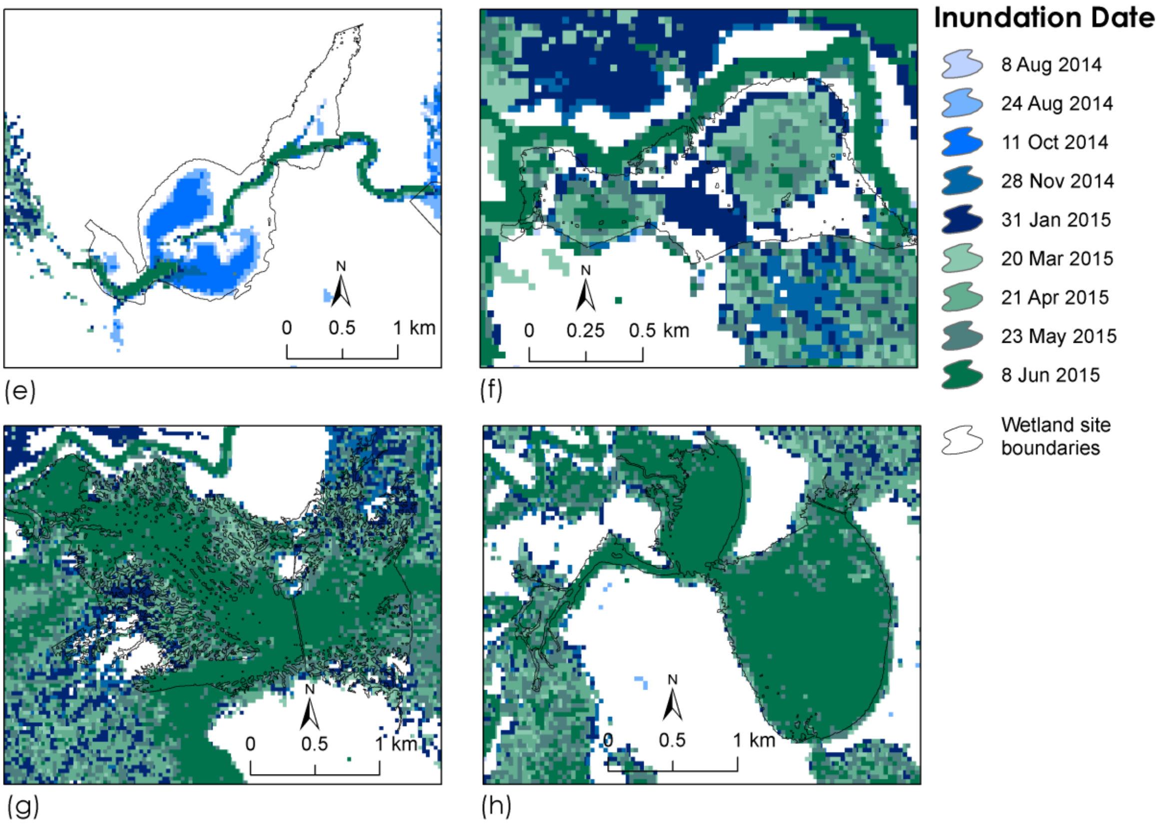


Figure 10 Distribution of inundated areas in the LTIM surveyed wetlands of the Redbank wetland zone (e) Waugorah Lagoon (f) Mercedes Swamp, (g) Two Bridges Swamp and (h) Piggery Lake during environmental watering action periods between August 2014 and June 2015.

Both Two Bridges Swamp and Piggery Lake were almost fully (100 per cent) inundated by late November 2014 (Figure 11). Piggery Lake retained a 90 per cent inundated area for six months and in Two Bridges it was for two months steadily receding over the next four months (Figure 11). In Mercedes Swamp, inundated area peaked to almost 70 per cent of its boundary in late January 2015 and then receded steadily over the next six months (see Figure 10 and Figure 11). Whilst Waugorah Lagoon is located in the Redbank wetland zone, its inundation was as a result of the Nimmie-Caira environmental watering action (Nap Nap Swamp to Waugorah Creek) which occurred from July 2014 and August 2014 (Table 2) hence the largest percentage area inundated (about 40 per cent) in July –August 2014 for Waugorah Lagoon (see Figure 10 and Figure 11).

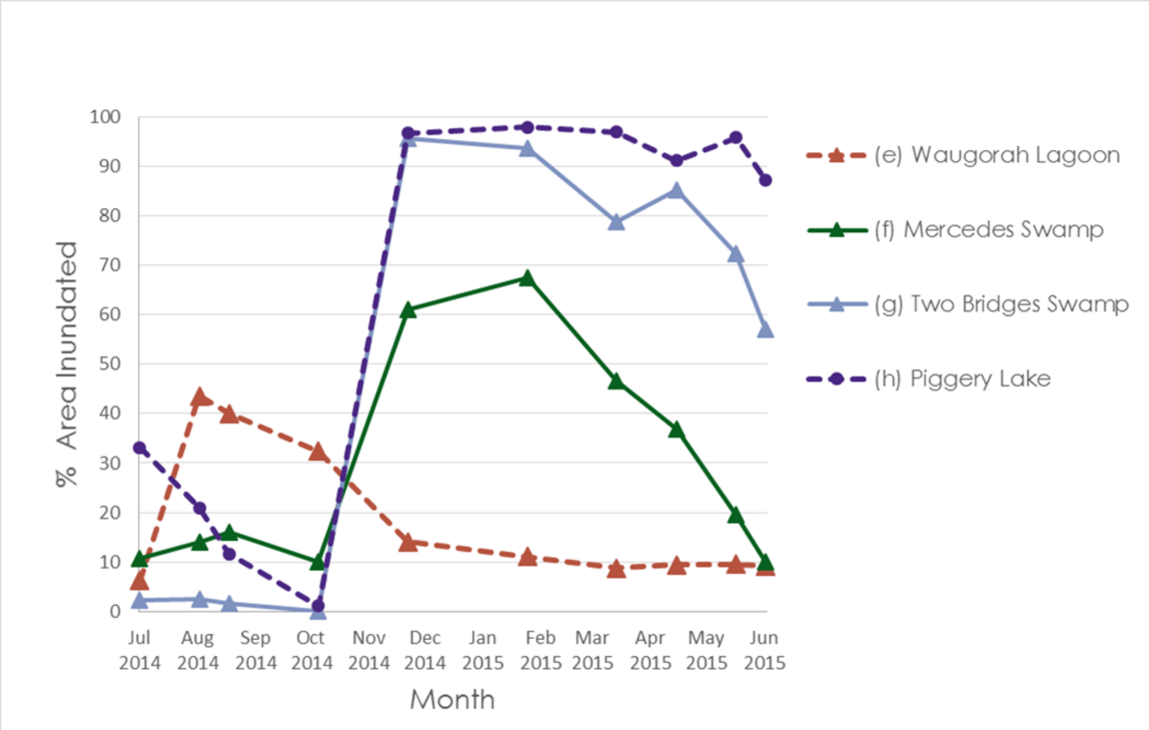


Figure 11 Percentage area inundated of the LTIM surveyed wetlands in the Redbank wetland zone of the Lowbidgee from Commonwealth and NSW environmental water during 2014-15.

Western lakes

Paika Lake (and Paika Creek) were targetted for environmental watering in late May – June 2015 using a combindation of water holder entitlements totalling 11,492ML (8,498 ML CEW general security, 1,459 ML NSW Adaptive Environmental Water and 1,535 ML NSW The Living Murray) and inundated a cumulative total of 385 ha of wetland area (Table 2 and Figure 9).

Water depths

Water level loggers were deployed across all 12 wetlands. Where practical, depth loggers were deployed using existing stations which are placed at the deepest point of the wetlands in locations close to the main inflow locations. In some cases, deeper locations within the wetlands exist, but were deemed to be too disconnected from the main inflows to be selected for the depth logger locations.

In the Lowbidgee floodplain (Action 6) across the eight Lowbidgee wetland sites, two are nominally permanent (Wagourah Lagoon in the Redbank and Telephone Creek in the Nimmie-Caira zone), with both characterised by areas of deep persistent water with large areas of connected, temporary floodplain. The remaining sites are seasonally inundated with relatively short inter-flood periods. In 2014-15 the inundation patterns varied between sites both within and between zones. In September 2014, three sites, Piggery Swamp, Two Bridges in the Redbank zone and Avalon Swamp and Eulimbah in the Nimmie-Caira zone were largely dry with small residual pools (Figure 12). By November all of the wetlands in the Redbank and Nimmie-Caira zone had received water, with water levels typically declining over January and March 2015. Yarradda Lagoon in the mid-Murrumbidgee received water in December 2014 and Gooragool Lagoon intermittently received draining water from surrounding irrigation areas (see Figure 12). Sunshower and McKenna's lagoons in the mid-Murrumbidgee were not inundated during 2014-15.

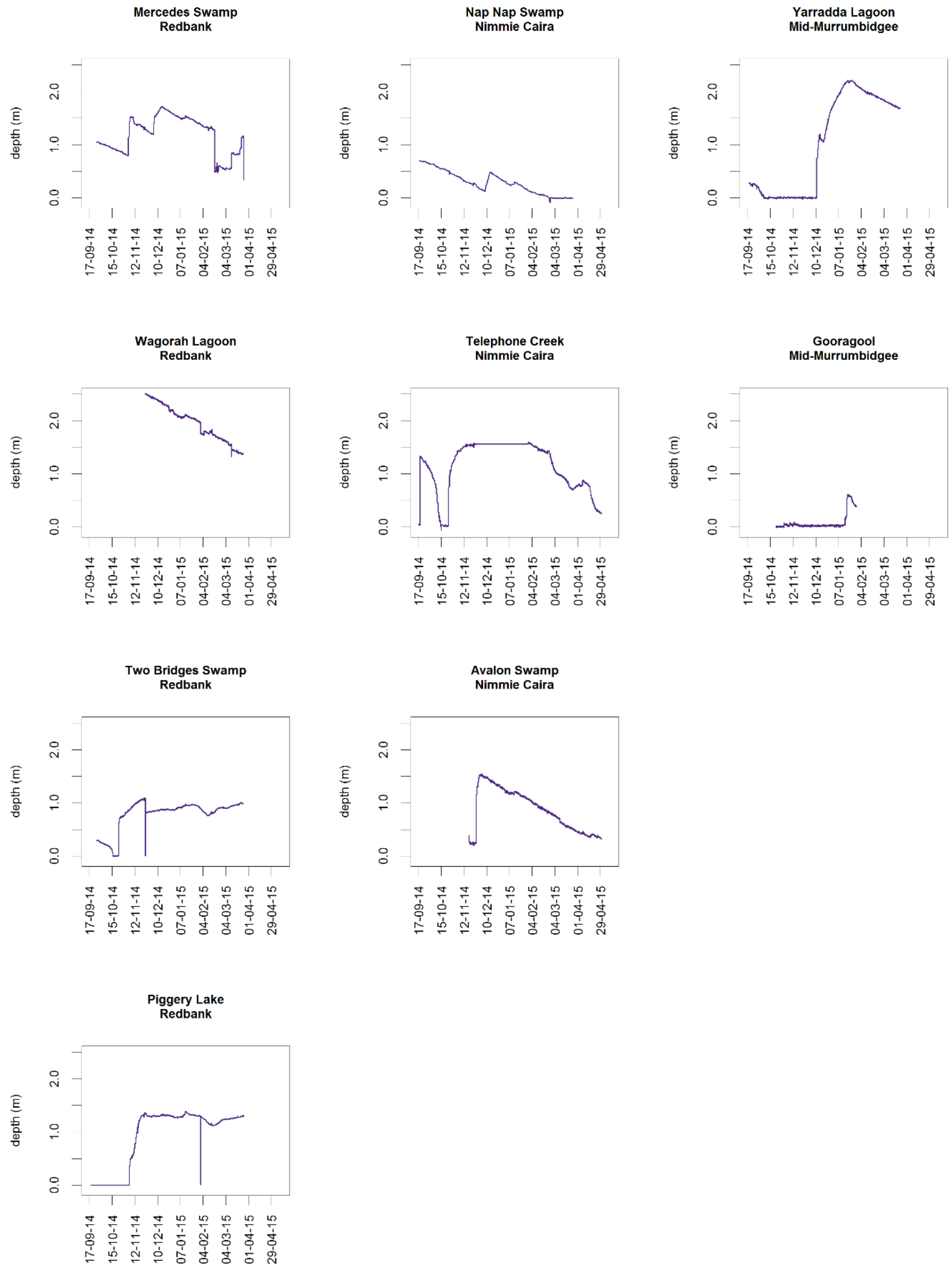


Figure 12 Wetland hydrographs indicating the timing of inundation for individual wetlands as demonstrated by a rapid rise in water depth.

River Hydrology

The Murrumbidgee River is heavily regulated and has a very well developed network of gauges maintained by NSW DPI Water within the main river channel and key off-takes (Sinclair Knight Merz 2011). For the purpose of the LTIM program, monitoring zones within the Murrumbidgee Selected Area were specifically defined with a view of reducing hydrological heterogeneity and aligning key monitoring activities with the existing gauge network (Figure 13). Monitoring of water quality, nutrients, larval fish and microinvertebrates is undertaken within two of these zones; Narrandera and Carrathool.

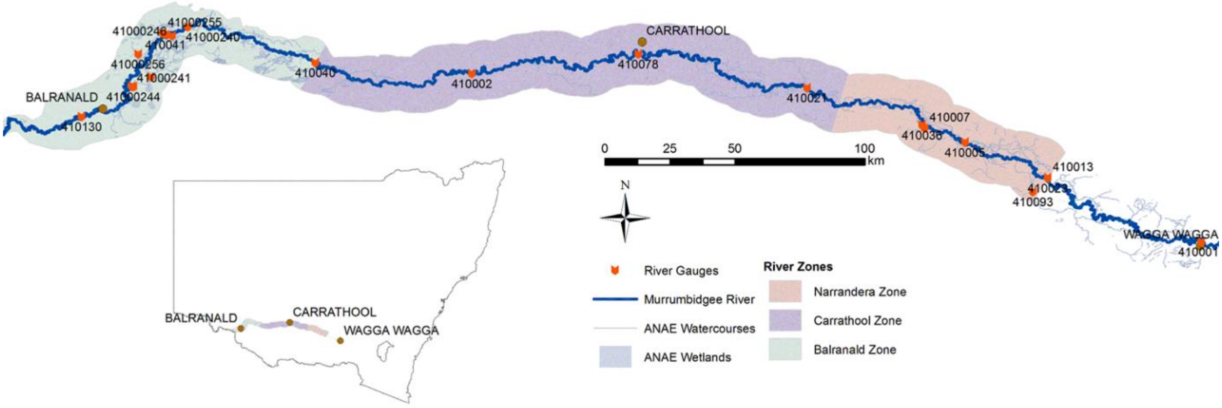
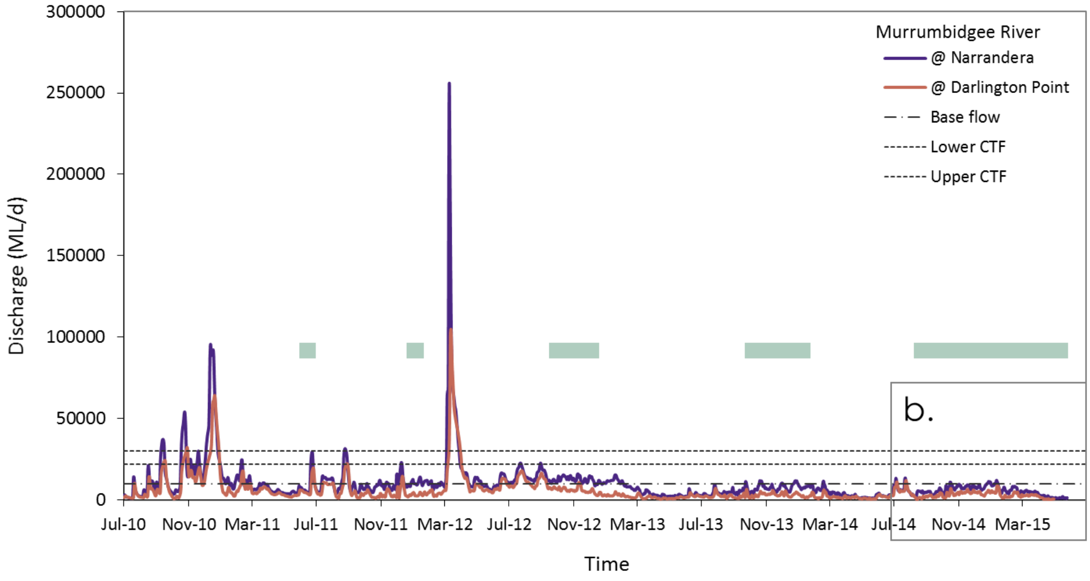


Figure 13 Distribution of gauges across the Murrumbidgee selected area.

a.



b.

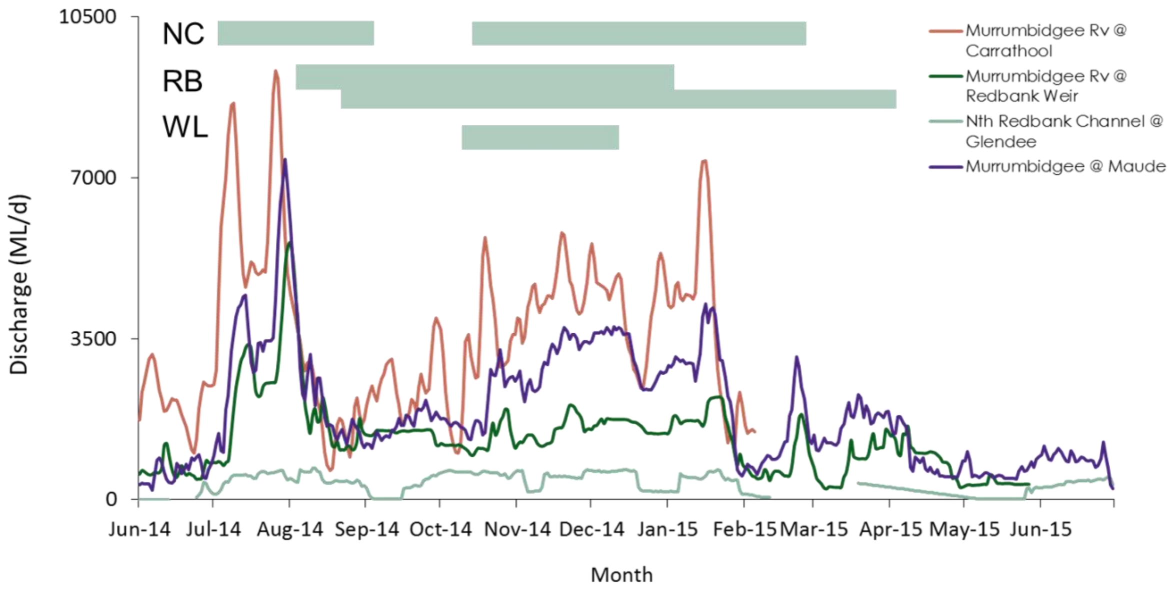


Figure 14 (a) Mean daily discharge in the Murrumbidgee River at Narrandera and Darlington Point between 1 July 2010 to 30 June 2015 with base flows (dash-dot line) and upper and lower commence to fill (CTF) levels. Horizontal bars show Commonwealth and NSW environmental water actions in 2011-12, 2012-13, 2013-14 and 2014-15. (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 Nimmie-Caira (NC), Western lakes (WL) and Redbank (RB) during survey period (1 July 2014 to 30 June 2015).

Environmental watering actions occurred throughout most of the 2014-15 watering year (October 2014 to June 2015) which was the third year since widespread flooding during 2012 (Figure 14). The Murrumbidgee flow gauges at Carrathool, Redbank Weir and downstream of Maude Weir and on the North Redbank Channel at Glendee show the 2014-15 flow volumes in relation to the timing of environmental water delivery (Figure 14).

While the shapes of the hydrographs were broadly consistent between the two monitoring zones, discharge was higher and more variable during the LTIM monitoring periods between October 2014 and January 2015 (mean 7,844 ML/D, SD ± 1884) within the Narrandera zone than in the Carrathool zone (mean 3,913 ML/D, SD ± 345) (Figure 15).

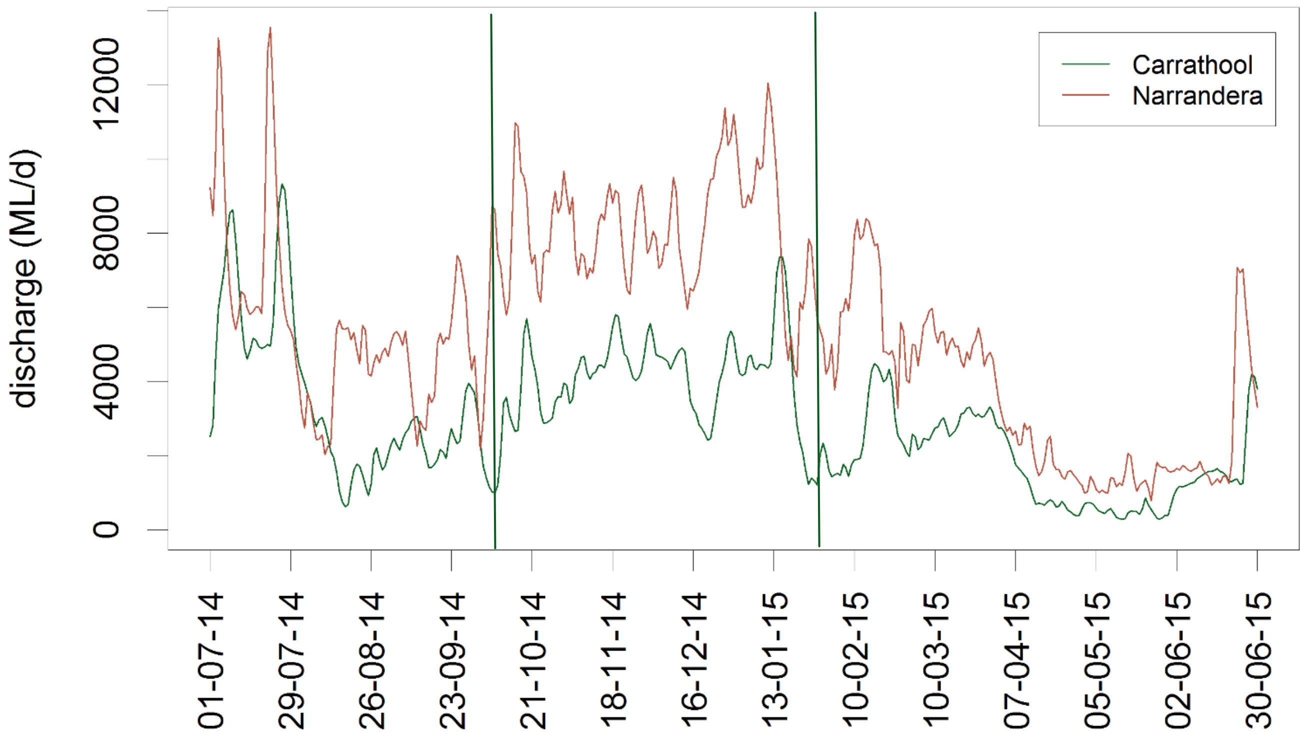


Figure 15 River discharge at Narrandera and Carrathool zone from 1 July 2014 to 30 June 2015, vertical lines indicate key in-channel monitoring periods.

3.4 Water quality

Outcomes summary

The physiochemical (also abiotic) properties of water are naturally variable over time, reflecting changes in air temperature, discharge, patterns of wetting and drying, aquatic photosynthesis and salinisation. Aquatic organisms present within a wetland are adapted to tolerate a degree of variability in physicochemical conditions (Poff *et al.* 1997), however exceeding tolerance limits can cause sub-lethal impacts (i.e. impaired growth or reproduction) or mortality (Heugens *et al.* 2001; Bunn *et al.* 2002). In this manner, water quality is an important covariate influencing the suitability of habitats for aquatic fauna.

During 2014-15, water quality (physicochemistry) was measured alongside both wetland fish, frog and nutrient monitoring and river larval fish monitoring. Environmental water was not specifically targeted at in-channel flows at locations where annual monitoring was carried out. We expected water quality to improve at wetland sites where environmental water was delivered.

Key findings

- Environmental watering actions contributed to improved water quality at sites where residual drying had caused water quality to deteriorate

Introduction

The physiochemical (also abiotic) properties of water are naturally variable over time, reflecting changes in air temperature, discharge, patterns of wetting and drying, aquatic photosynthesis and salinisation. Aquatic organisms present within a wetland are adapted to tolerate a degree of variability in physicochemical conditions (Poff *et al.* 1997), however exceeding tolerance limits can cause sub-lethal impacts (i.e. impaired growth or reproduction) or mortality (Heugens *et al.* 2001; Bunn *et al.* 2002). In this manner, water quality is an important covariate influencing the suitability of habitats for native wetland fauna.

Methods

Water quality parameters, temperature (°C), electrical conductivity (EC, µS/cm), turbidity (NTU), pH and dissolved oxygen (mg/L), were routinely measured in association with both larval fish monitoring (fortnightly between October 2014 and January 2015) and wetland monitoring (September 2014, November 2014, January 2015 and March-May 2015). At each site water quality was measured using a calibrated water quality meter (Horiba U-52G). To capture the range of variability in wetland dissolved oxygen, dissolved oxygen was measured continuously at ten minute intervals at each wetland over twelve hours using a dissolved oxygen datalogger (D-Opto, Zebra Tech).

To determine if return flows significantly increased concentrations of measured water quality parameters, data were analysed using two-way permutational analysis of variance (PERMANOVA; Anderson et al. 2008) with zone and trip date as fixed factors. Data were not transformed prior to analysis. Resemblance matrices 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 analyses were performed using Primer 6 with PERMANOVA (Primer-E Ltd.).

Results

Mid-Murrumbidgee River

All river sites exhibited similar trends with respect to temperature, conductivity, turbidity and dissolved oxygen. Discharge was higher and water temperature slightly lower in the upstream Narrandera zone (DAI, NRD, EUB), relative to the downstream Carrathool zone (BRI, YRR, MKR) (Figure 16). Daily river temperature increased steadily between October 2014 and January 2015, and was above the threshold for cod spawning (>16 °C) before sampling commenced on 20 October 2014.

Conductivity was within the expected range of values for inland waters (0.125 – 2.200 mS/cm; ANZECC water quality guidelines (2000)) across all river sites. Values fell initially, declining until early December 2014 and then increased steadily for the remainder of the study. It is not clear whether this increase was related to high flow events (January 2015), reduced flow (February-April 2015) or because both high and low flows were increasing conductivity. Dissolved oxygen remained high or saturated throughout the study, declining slowly across time.

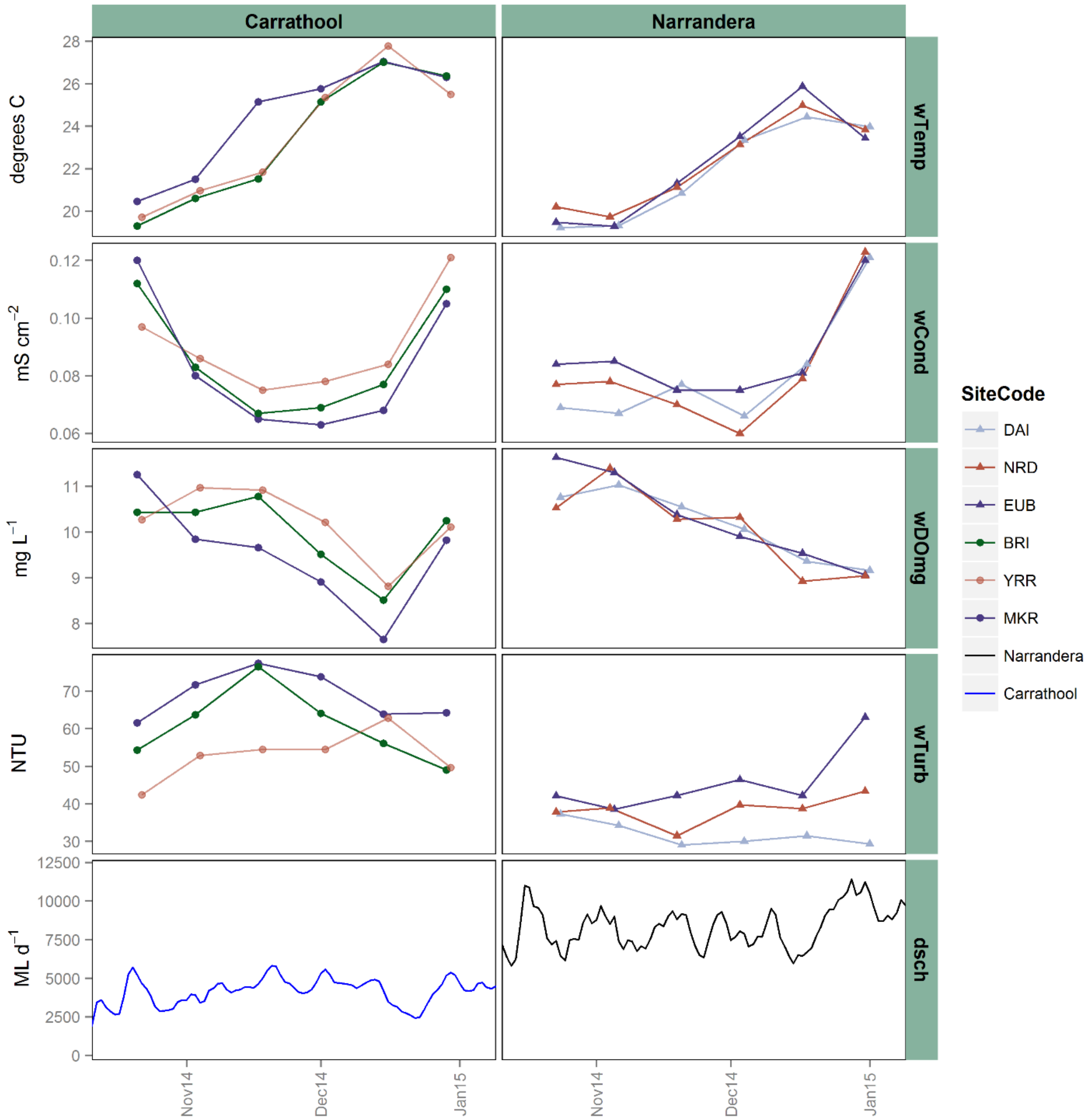


Figure 16 Time series plots of measured water quality parameters and river discharge (mean daily flows) at larval fish monitoring sites (fortnightly measurements between 20 October 2014 and 1 January 2015). Shapes indicate sites from the Narrandera (triangle) and Carrathool (circle) reaches. Additional monthly samples were collected at MKR as part of the Category 1 metabolism monitoring. Discharge measurements are for the gauges at Narrandera and Carrathool.

Wetlands

During late September many wetlands contained residual water from previous years watering actions. Overall, water quality was highly variable across time and between sites, reflecting wetland condition, stage of drying and the long-term hydrological regime of individual wetlands. Turbidity did not differ significantly among zones (Pseudo-F = 2.6892, P-perm = 0.171), although values were typically greater in the Nimmie-Caira. High conductivity and turbidity were observed at Piggery Lake (27/9/14) and, to a lesser degree, Two Bridges Swamp (26/9/14), but overall there were no significant differences in conductivity between zones (Pseudo-F = 0.1011, P-perm = 0.894), or over time (Pseudo-F = 0.5971, P-perm = 0.655). Subsequent environmental flows in early November saw water quality improve at these sites. Nap Nap Swamp, which was inadvertently partially drained at the end of November, recorded increased conductivity and turbidity during November and January. Note that the site was partially rewetted during the intervening period.

Maximum daytime dissolved oxygen did not differ significantly among sites (Pseudo-F = 2.8704 P-perm = 0.079). Overall, values were typically within the range tolerated by most aquatic species (i.e. >4 mg L^{-1}), with lower values recorded at Two Bridges and Mercedes swamps. Minimum night time dissolved oxygen was significantly lower at in Redbank compared with Nimmie-Caira (Pseudo-F = 5.7968, P-perm = 0.008; pairwise P-perm = 0.005), becoming hypoxic (<2 mg L^{-1}) for short periods. During the single sample occasion at Gooragool Lagoon, minimum night time dissolved oxygen was also hypoxic. As noted in 2013-14, diurnal hypoxia is common in forested wetlands (Wassens *et al.* 2014b).

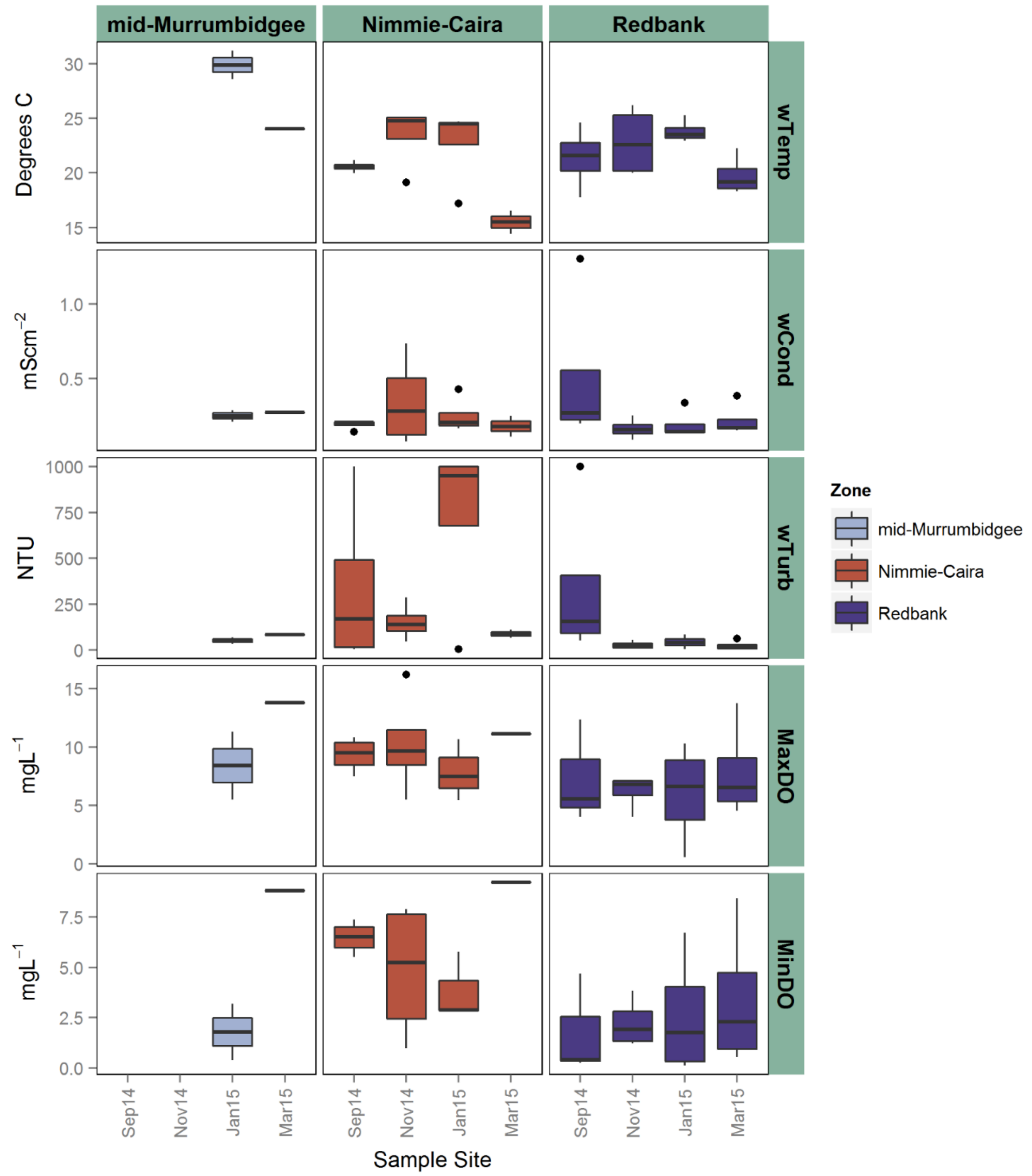


Figure 17 Boxplots (showing the full range of variation from minimum to maximum and the typical value (mean)) of water quality parameters (temperature, conductivity, turbidity, maximum dissolved oxygen, minimum dissolved oxygen) in wetlands of the mid-Murrumbidgee, Nimmie-Caira and south Redbank between October 2014 and May 2015.

Discussion

Overall, observed water temperatures were lower across sampled wetlands in 2014-15 than in 2013-14 (Wassens *et al.* 2014b), reflecting a milder summer. Extreme water quality conditions (supersaturation of oxygen and high water temperature) associated with warm weather were less common during the 2014-15 wetlands sampling.

Providing environmental water to wetlands during 2014-15 led to an improvement of water quality conditions at sites where residual water was in the latter stages of drying. Desiccation leads to evapo-concentration of particles in suspension and dissolved salts or compounds. The increased concentration of salt and particulates can impact on wetland fauna through increased salinity and turbidity, while increased nutrient loadings can boost microbial and algal productivity, causing rapid changes to dissolved oxygen. Piggery Lake and Two Bridges Swamp were in the latter stages of drying when environmental flows commenced in November 2014, and subsequent watering ameliorated potential impacts to wetland species.

3.5 Nutrients, carbon and productivity

Outcomes summary

Concentrations of nutrients, carbon and chlorophyll-a as well as rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) are key covariates that account for variability in primary producers (e.g. photosynthetic algae and plants) and dependent higher-trophic indicator organisms such as invertebrates and fish (Wassens *et al.* 2013a). Flow plays a critical role in supporting ecosystem metabolic processes both in rivers and wetlands.

Samples of nutrients, carbon and chlorophyll-a were collected fortnightly between October 2014 and January 2015 at six sites across the Narrandera and Carrathool zones of the Murrumbidgee River. While in wetlands, concentrations of nutrients, Dissolved Organic Carbon (DOC) and chlorophyll-a were sampled every 2 months across ten sites between September 2014 and March 2015.

Relevant objectives relating to environmental water delivery to the Lowbidgee Floodplain (*Action* 6) include the **provision of habitat to support the survival and maintain condition of native fish, waterbirds, and other aquatic vertebrates.** In 2014-15 there were no environmental watering actions specifically targeting in-channel or wetland nutrients, carbon and chlorophyll-a and rates of GPP and ER. However, environmental water deliveries to the Lowbidgee floodplain contributed to patterns of in-channel hydrological variability, providing baseline information to help explain the potential role of environmental flows in maintaining ecological beneficial concentrations of nutrients, carbon and chlorophyll-a and rates of GPP or ER.

Key findings

- There were two notable peaks in nutrient levels which coincided with increasing water levels in the Murrumbidgee River. This was explained by increasing water levels during bulk water deliveries which resulted in the inundation of dry sediments and the release of nutrients.
- Peak GPP and ER coincided with both freshes and low-flow events in-channel, suggesting that the frequency of bankside sediment inundation may be manipulated to promote enhanced productivity outcomes in-stream.

- The use of Commonwealth environmental water in the Lowbidgee wetlands enabled the development of productive wetland ecosystems capable of supporting diverse food webs, including algae and microinvertebrates that support biota at higher trophic levels such as fish and waterbirds.

Introduction

Nutrients and carbon (and their chemical forms) are a key factor driving primary productivity, for example the growth of photosynthetic algae and plants (Kobayashi *et al.* 2013). This, in turn, feeds the complex food-web of algae and microinvertebrates that support biota at higher trophic levels such as fish and waterbirds. Communities of phytoplankton (diatoms and algae in the water column) can expand rapidly when temperatures and nutrients increase, driving changes in food resource availability. As producers of oxygen, changes in phytoplankton abundance and activity can also affect water quality.

Environmental flows in both rivers and wetlands facilitate chemical and physicochemical changes in aquatic ecosystems, in turn driving the availability of nutrients and carbon, as well as the biomass and community composition of phytoplankton (and other algae) (Robertson *et al.* 1999b; Kobayashi *et al.* 2009; Kayranli *et al.* 2010). While excessive concentrations of nutrients and carbon can sometimes contribute to a temporal decline in water quality, the ecological benefits of environmental water to hydrologically stressed floodplain river systems outweighs such potential extreme responses (Wassens *et al.* 2013a; Cook *et al.* 2015).

Commonwealth environmental watering actions relating to the mobilisation of nutrients and energy include *Actions* 6 (watering wetlands in the Lowbidgee system) "**provision of habitat to support the survival and maintain condition of native fish, waterbirds, and other aquatic vertebrates"** and *Action* 9 (Murrumbidgee River water quality and habitat). Environmental water was not specifically targeted at in-channel flows at locations where annual monitoring was carried out, although the delivery of environmental water to the Lowbidgee floodplain (*sensu* Action 6) will have increased flows in the channel.

We expected that where environmental watering has contributed to small in-channel freshes concentrations of nutrients, carbon and chlorophyll-a, as well as ecosystem metabolism, would increase and that there would be modest concentrations of C, N and P relative to previous water years. Action 9 is discussed further in Section 3.7.

Methods

Nutrients, DOC and Chlorophyll-a were sampled fortnightly at six sites within the Murrumbidgee River; three in the Narrandera Zone (Dairy Reserve, Narrandera and Euroley Bridge) and three in the Carrathool Zone (Yarradda, Bringagee and McKenna's) between 20 October 2014 and 31 January 2015 (see Figure 1). Nutrients, DOC and Chlorophyll-a were also sampled across three wetland zones – mid-Murrumbidgee (n=4), Nimmie-Caira (n=4) and Redbank (n=4), with sampling undertaken on four occasions (September 2014, November 2014, January 2015 and March 2015)(see Figure 2). Two sites in the mid-Murrumbidgee were dry throughout 2014-15 and as a result water samples were only collected from two of the four wetlands in this zone.

Methods for nutrient, carbon and chlorophyll-a sampling are described in (Wassens *et al.* 2014a). Wetland water samples were analysed for chlorophyll-a, DOC, total nitrogen and phosphorus. Unlike river samples, wetland nutrients were analysed in the laboratory using Hach nutrient test kits (Hach Pacific PTY Ltd.).

Ecosystem metabolism was measured using the LTIM Category 1 open-system method (Hale *et al.* 2014). Metabolism was measured at one site in the Carrathool (October – April) and one site in the Narrandera zone (October – January) concurrent with the larval fish monitoring and as part of the LTIM Category 1 and Category 3 ecosystem metabolism monitoring. Because of the difference in LTIM Category 1 and 3 monitoring periods, Category 3 data from Narrandera is only available for a three month period coinciding with larval fish monitoring in this zone.

Differences in nutrient, DOC and chlorophyll-a concentrations among zones were tested using a two-way permutational analysis of variance (PERMANOVA, (Anderson *et al.* 2008)) with zone and trip number as fixed factors. Distance measures were calculated using Euclidian distance. Data were not transformed prior to analysis. Results were considered significant at $p<0.05$.

Results

River sampling – nutrients, carbon and chlorophyll-a

Over the three month sampling period samples from the Narrandera Reach had higher concentrations of nitrogen (N) (Pseudo-F = 18.906, P-perm = 0.001) and phosphorus (P) (Pseudo-F = 6.8759, P-perm = 0.001) and occasionally showed lower concentrations of DOC than the Carrathool Reach (Pseudo-F = 6.2872, P-perm = 0.001). The ratio of nitrogen to phosphorus (see NPrat, Figure 19) is used to estimate the relative availability of either N or P (Keck *et al.* 2012). Further examination showed relatively high N: P ratios for the Murrumbidgee River (2014-15), indicating that there was relatively less available phosphorus in the Narrandera zone than the Carrathool zone (Figure 18).

DOC concentrations peaked across all sites in early January 2015, at the end of the larval fish sampling program, coinciding with increased nitrogen and phosphorus in the Narrandera reach. This peak in nutrients coincides with increased flow during January which was more pronounced in the Narrandera zone than in the Carrathool zone. Although Chlorophyll-a concentration was significantly higher in the Carrathool zone (Pseudo-F = 7.3995, P-perm = 0.005), there was a high degree of variability among sites. Overall concentrations were typically lowest at McKenna's (MKR) and highest at Yarradda (YRR) river sites, both of which are located in the Carrathool zone.

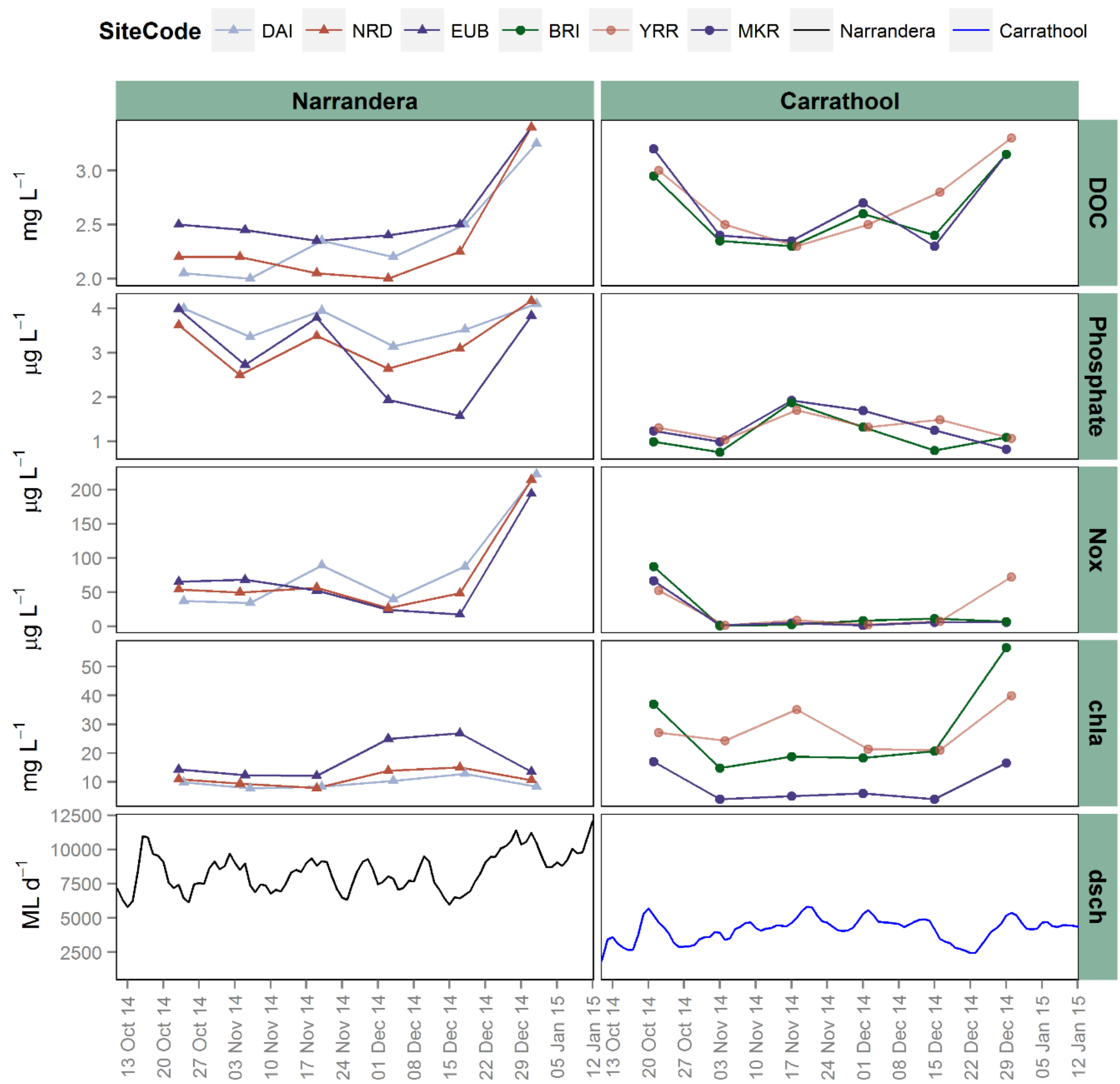


Figure 18 Line plots of dissolved organic carbon (DOC), Nitrate+Nitrite (NOx), total dissolved phosphorus (TDP), total dissolved nitrogen (TDN) and Chlorophyll-a at larval fish monitoring sites (DAI = The Dairy, NRD = Narrandera, EUB = Euroley Bridge, BRI = Bringagee, YRR = near Yarradda Lagoon, MKR = near Carrathool) in the Mid-Murrumbidgee River. Discharge data (bottom panel) is mean daily discharge for the Narrandera and Carrathool gauges.

River ecosystem metabolism

Metabolism data in the Narrandera and Carrathool zones were collected concurrently between October 2014 and January 2015. During this period, rates of GPP and ER were of similar scale across the two zones, despite the differences in river discharge (Figure 19). Overall, production was predominantly heterotrophic indicated by PRrat values of less than one, occasionally shifting briefly to net autotrophy (late October, late December, mid-January, mid-February) as indicated by PRrat values greater than one. The overall hydrological regime, which was truncated by a peak flow event in mid-January, followed by an overall reduction in flows, corresponded to a net increase in both GPP and ER in the Carrathool zone. During mid-April 2015 discharge fell further, coinciding with a net increase in productivity.

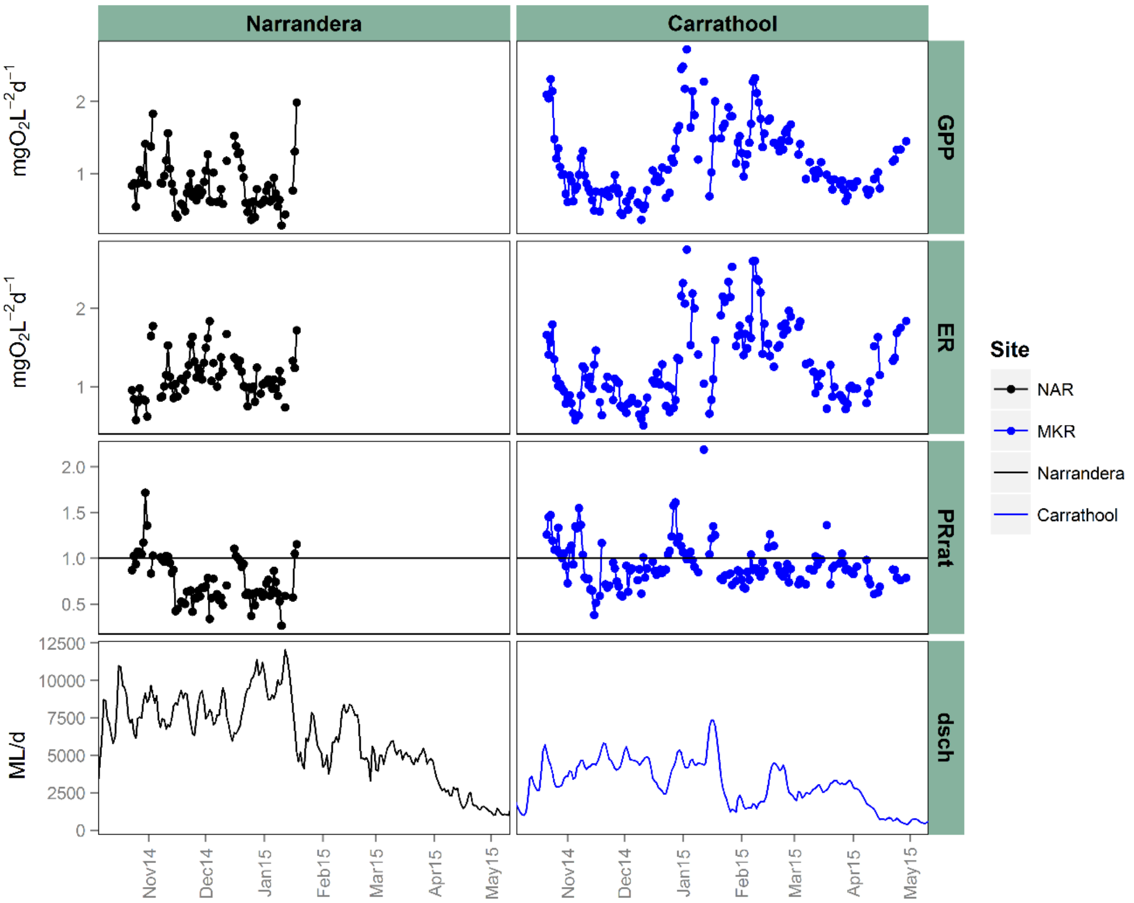


Figure 19 Ecosystem metabolism in the Carrathool (blue) and Narrandera (black) zones. Data are gross primary production (GPP), ecosystem respiration (ER) and the ratio of primary production to respiration (PRrat). The horizontal line at y=1 on the PRrat panel indicates the divide between net autotrophic production and net respiration. Discharge data (bottom panel) are taken from the Narrandera and Carrathool gauging stations.

Wetland nutrients, carbon and Chlorophyll-a

There was considerable variation in carbon concentrations and no consistent differences among wetland zones (Pseudo-F = 0.775, P-perm = 0.548), over time (Pseudo-F = 0.742, P-perm = 0.653). In general environmental water delivery (Action 6) reduced dissolved organic carbon (DOC), Nitrogen and Phosphorus concentrations in the Redbank system. High nutrient and carbon concentrations typically occurred in wetlands during their draw-down phase, either prior to environmental water delivery in the Redbank system during September 2014, or later in the season, as in the Nimmie-Caira. Overall chlorophyll-a concentrations mirrored changes in nutrient and carbon availability, with no consistent differences between zones (Pseudo-F = 1.438, P-perm = 0.243), or over time (Pseudo-F = 1.221, P-perm = 0.302). However chlorophyll-a peaked higher prior to environmental watering in the Redbank zone and during draw down in the Nimmie-Caira zone contributing to a significant interaction between zone and time (Pseudo-F = 3.524, P-perm = 0.029).

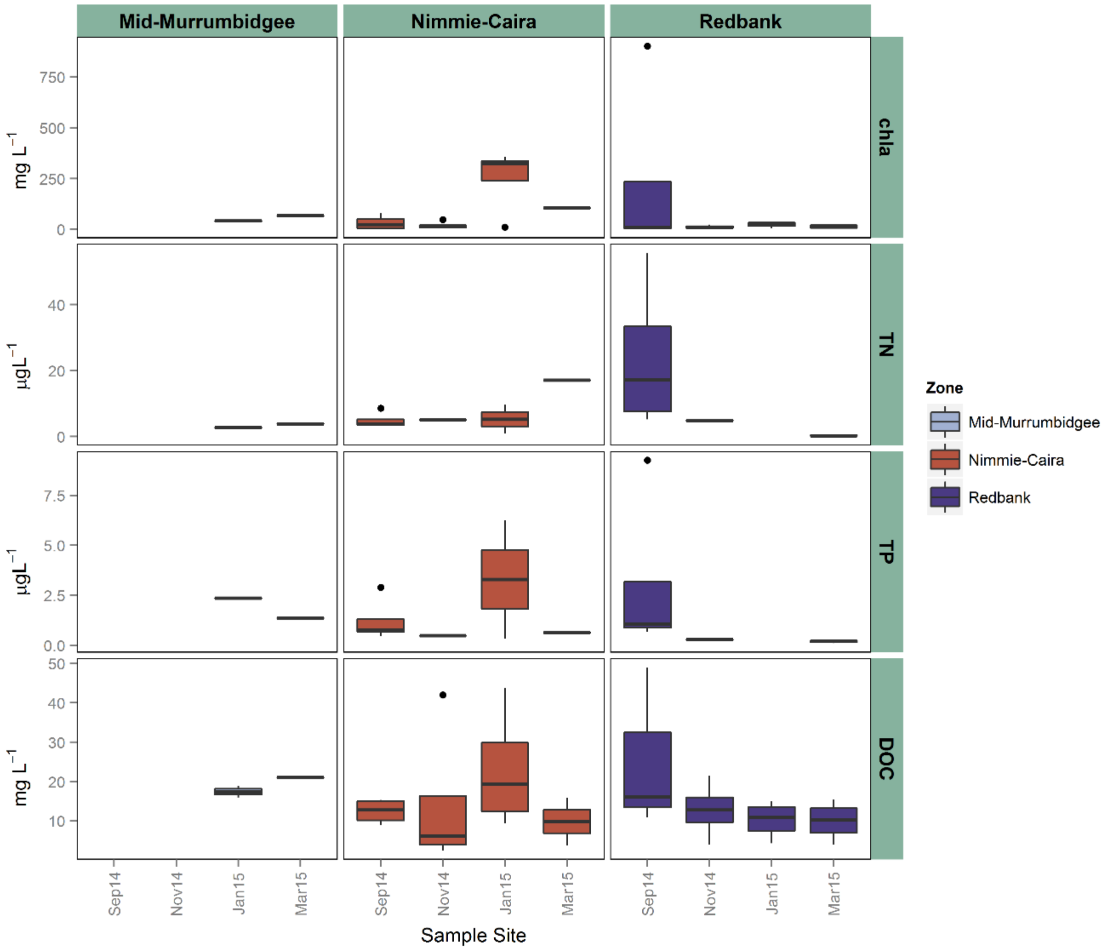


Figure 20 Box plots (showing the full range of variation from minimum to maximum and the typical value (mean)) of chlorophyll-a (chla), total nitrogen (TN), total phosphorus (TP) and dissolved organic carbon (DOC) in wetland sites. Includes all data collected across four sampling trips to each wetland between October 2014 and May 2015. The number of samples is determined by the presence of water during sampling in the mid-Murrumbidgee (Gooragool n=1, Yarradda n=2, McKenna's n=0, Sunshower n=0), Nimmie-Caira (Avalon n=4, Eulimbah n=3, Nap Nap n=3, Telephone Creek n=4) and Redbank (Mercedes n=3, Piggery n=4, Two Bridges n=4, Waugorah n=4).

Discussion

Mid-Murrumbidgee River

There were no direct environmental watering actions targeting in-channel habitats during 2014-15. Nevertheless, volumes of environmental water delivered to wetlands (Action 6) and inter-valley transfers are thought to have contributed to the overall volume, timing and magnitude of flows. Moreover, data collected during 2014-15 provides an important benchmark for detecting responses in future years and for planning future environmental watering actions.

Monitoring during 2014-15 revealed small but significant differences in both the availability of resources (nutrients and energy) and subsequent ecological processes between the two sampled river zones. Interestingly, concentrations of nutrients and chlorophyll-a generally varied in the same direction across sites within each zone suggesting that controls were operating at the zone scale (i.e. differences in flow, water temperature, or water quality discussed in Section3.4). Flow is a critical driver of metabolism (Marcarelli *et al.* 2010; Aristi *et al.* 2014). Although the observed patterns appear to broadly coincide with different hydrology both within and between zones, more data is required to understand the role of flow as a driver of these processes.

The decline in nutrient concentrations from October to November 2014 was similar to that observed in results from both 2012-13 and 2013-14 (Wassens *et al.* 2013a), indicating that this may be a seasonal trend. 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 *et al.* 2000; Knowles *et al.* 2012) and transporting nutrients into the river channel with water returning to the river. However, the lack of sufficient in-stream flows to engage adjacent riparian and floodplain habitats during 2014-15 indicates other processes are acting on seasonal nutrient dynamics.

Production in aquatic ecosystems can be limited by the availability of resources for production (nutrients and carbon) or by other physicochemical factors including temperature and light penetration. Overall, nutrient concentrations (especially PO_4) in the Carrathool reach were half that of the Narrandera reach. Phosphate (PO_4) is often reported to limit ecosystem production as is N limitation (Vink *et al.* 2005; Davis *et al.* 2006). Chlorophyll-a concentrations were relatively high in the Carrathool zone regardless of potential limiting-nutrient controls. This might be due to lower discharge, and therefore shallower water depth and greater light penetration in the Carrathool zone than in the Narrandera zone. However, data also shows that within the Carrathool zone production by algae is consistently low at the MKR site relative to the other two sites, indicating that some of these factors may vary among sites within zones.

Overall, rates of primary production (carbon produced - GPP) and respiration (carbon consumed – ER) observed during 2014-15 are less than half that reported for the Murrumbidgee system by Vink *et al.* (2005). Vink *et al.* (2005) found overall low net heterotrophy but a high contribution of phytoplankton to rates of primary production in the Murrumbidgee River. They speculated that this was because floodplain and riparian carbon inputs were either low or not biologically available as a result of flow regulation. With the low primary productivity observed consistently during 2014-15, perhaps further detailed studies are warranted to determine if these different results between the present monitoring and Vink *et al.* (2005) reflect different sampling methodologies, site selection, inter-annual variability, or a trend of decline. Persistently low productivity points to potentially impaired ecosystem processes that may impact on the entire food web.

Peak GPP and ER were observed in the Carrathool zone during late October 2014, January and late February 2015, coinciding with both small flow peaks and periods of low flow. These trends are not as apparent as those in the more variable Narrandera zone. Rising discharge, even when contained within the channel, could inundate dry sediment and with sufficient drying between wetting cycles it might provide small pulses of nutrients. Conversely, low flows may increase light availability and nutrient retention times (Hilton *et al.* 2006). Both of these processes are likely to enhance aspects of ecosystem metabolism. The high flow periods during January and late February were created by inter-valley transfers. If these kinds of flows are able to increase rates of basic ecosystem functions, pulsed flows may provide a means to promote productivity outcomes in regulated systems (sensu Watts *et al.* 2009).

These findings reveal low rates of production in the Murrumbidgee river overall as well as important differences in ecosystem structure and function between the two hydrological zones. With flow as a principal driver of these processes, we expect that environmental water deliveries can be used for the benefit of riverine biological communities, even by providing small to moderate freshes, and low flows, to enhance productivity.

Ephemeral wetlands can experience a wide range of nutrient and water quality conditions stemming from an initial pulse of nutrients upon inundation, milder conditions as rates of uptake and transformation are stabilised, and through to extreme conditions at the latter stages of drying due to evapoconcentration. The hydrological cycle of wetlands creates a window of opportunity for biota to capitalise on the boom of productivity that results from initial inundation before declining water quality conditions make wetlands uninhabitable for many species. During 2014-15, environmental watering of wetlands throughout the Murrumbidgee Catchment created available wetland habitat through the provision of water, but also ameliorated declining water quality at sites that were in the advanced stages of drying. Moreover, at sites such as Nap Nap and throughout Redbank mid-season top-up flows were able to restore or maintain conditions. Nutrient and DOC concentrations remained relatively low across all watered sites, and were typically much lower than those reported for the same sites during 2013-14 (Wassens *et al.* 2014b). This use of environmental water will have lengthened the time available for species dependent upon water to complete their lifecycles (for example Sections 3.11 and 3.12)

3.6 Microinvertebrates

Outcomes summary

Microinvertebrates play a key role in floodplain river food webs, and respond strongly to flow pulses and inundation, mediated by antecedent conditions and season (Jenkins *et al.* 2003; Jenkins *et al.* 2007). Microinvertebrate communities were monitored concurrently with larval fish in the Murrumbidgee River from October 2014 to January 2015, and in wetlands and the river from the Lowbidgee (Nimmie Caira, Redbank) and mid-Murrumbidgee coinciding with wetland fish and tadpole monitoring from September 2014 to May 2015. The key objectives of the Commonwealth environmental watering actions in 2014-15 that relate to microinvertebrates in wetlands were Action 2 (mid-Murrumbidgee) and Action 6 (Lowbidgee floodplain) to "provide feeding habitat for waterbirds, native fish, other aquatic vertebrates (turtles, frogs) and invertebrates." In 2014-15 there were no targeted in-channel environmental watering actions. However, water deliveries contributed to hydrological variability, providing baseline information to inform the use of environmental flows to support food webs and maintain water quality in the river.

Key findings

- Densities of benthic microinvertebrates in wetlands from the Nimmie Caira were high in September and again in January 2015 along with the mid-Murrumbidgee and Murrumbidgee River, while Redbank densities were highest in November 2014. The high densities in spring relate to rapid emergence and reproduction following delivery of Commonwealth environmental water **(Action 2 and 6),** demonstrating the role of this water in providing habitat to support the survival and maintain condition of native fish, waterbirds, and other aquatic vertebrates.
- High peak densities in January 2015 of copepods and cladocerans in the mid-Murrumbidgee wetlands, Nimmie Caira and Murrumbidgee River demonstrate the importance of Commonwealth environmental water providing an ongoing abundant food supply for native fish, filter-feeding

waterbirds and other vertebrates such as tadpoles during their critical growth and reproductive periods.

- In the Murrumbidgee River microinvertebrate densities were higher in the Carrathool than the Narrandera zone, largely due to the extremely high densities at the Yarradda and McKennas sites in December (respective peaks of 4886 and 3991 per litre). Densities above the critical threshold of 100/L to support larval fish feeding were also observed in the Narrandera zone, although peaks of copepods only occurred in the Carrathool zone.

Introduction

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 *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.

Commonwealth environmental watering actions relating to the productivity of microinvertebrates include Actions 2 (infrastructure assisted delivery of water to wetlands in the mid-Murrumbidgee) and 6 (watering wetlands in the Lowbidgee system) include the "provide feeding habitat for waterbirds, native fish, other aquatic vertebrates (turtles, frogs) and invertebrates". 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 overtime in relation to wetland filling and draw-down. We expected there would be modest bursts of microinvertebrate productivity relative to previous water years.

Environmental water was not specifically targeted at in-channel flows at locations where annual monitoring was carried out, although the delivery of environmental water to the Lowbidgee floodplain (*sensu* Action 6) will have increased flows in the channel. We hypothesised that environmental flows in late winter, spring and summer will inundate previously dry habitats in wetlands and also in rivers (i.e. backwaters, in-channel benches), releasing and transporting nutrients that 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) between 20 October 2014 and 1 January 2015 in association with larval fish monitoring and from 10 wetlands in the lower (Nimmie Caira and Redbank) and mid-Murrumbidgee over four surveys from September 2014 to May 2015 in association with fish and tadpole monitoring. Three additional river sites were sampled to coincide with the wetland sampling. A survey was also undertaken in May 2015 to sample wetlands in the Nimmie Caira that were not accessible in April 2015.

Benthic and pelagic samples were collected following the methods reported in 2012-13 (Wassens, Jenkins *et al*. 2014). In the laboratory, benthic and pelagic microinvertebrate samples were poured into a Bogorov tray and enumerated with the aid of a dissecting microscope (Leica M125) at a magnification of 32x to 80x. Due to high densities and dense organic matter in many benthic wetland samples we sub-sampled all samples (wetland and riverine) 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 due to high densities in wetlands (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 (wetland/river sites) and the laboratory (larval fish sites) to highlight individuals in samples with excessive sediment present. Specimens were identified with relevant guides to species where possible (Williams 1980; Smirnov *et al.* 1983; Shiel *et al.* 1995; Shiel 1995). A maximum of 30 individuals of each taxa per sample were measured for length and width. Due to observed consistency among the size of nauplii, these were not measured and an average value was used.

Results

Both river and wetland sites were dominated by three key groups of microinvertebrates, all microcrustacea: the copepods, cladocerans and ostracods. Microinvertebrate densities were often higher in wetlands compared to river sites; however peak river densities in January 2015 at larval fish monitoring sites in the Carrathool zone of the Murrumbidgee River were as high as those observed in wetlands.

Microinvertebrates at larval fish monitoring sites

The overall density from the six larval fish sites across six trips (36 samples) was 14,822. Total microinvertebrate density was significantly higher in benthic than pelagic microhabitats (Term 2, Table 6), however there was no significant difference between zones (Term 1, Table 6) or across time (Term 3, Table 6, Figure 21). This trend was reflected for the three key broad taxonomic groups; cladocerans, copepods and ostracods (Table 6, Figure 22). Furthermore, the microhabitat trend was consistent between zones and across time as indicated by the lack of significant interactions (Terms 4-7, Table 6). The non-significant result for zone and time is likely due to the influence of the extremely low density in all pelagic samples on the analysis as well as the site specific high peaks. Despite this there were notable differences between zones and over time (Figure 21 and Figure 22).

There were high peaks in benthic density (per litre), driven by pulses in copepods, particularly cyclopoids and nauplii (early (1,355), mid (295) and late (504) December at Yarradda, and mid (2,684) December 2014 at McKenna's) and cladocerans, particularly macrothricids (early December at Yarradda (3450), mid December at McKennas (1180), late October (183), early November (241) and early December 2014 (798) at DAI) (Figure 21 and Figure 22).

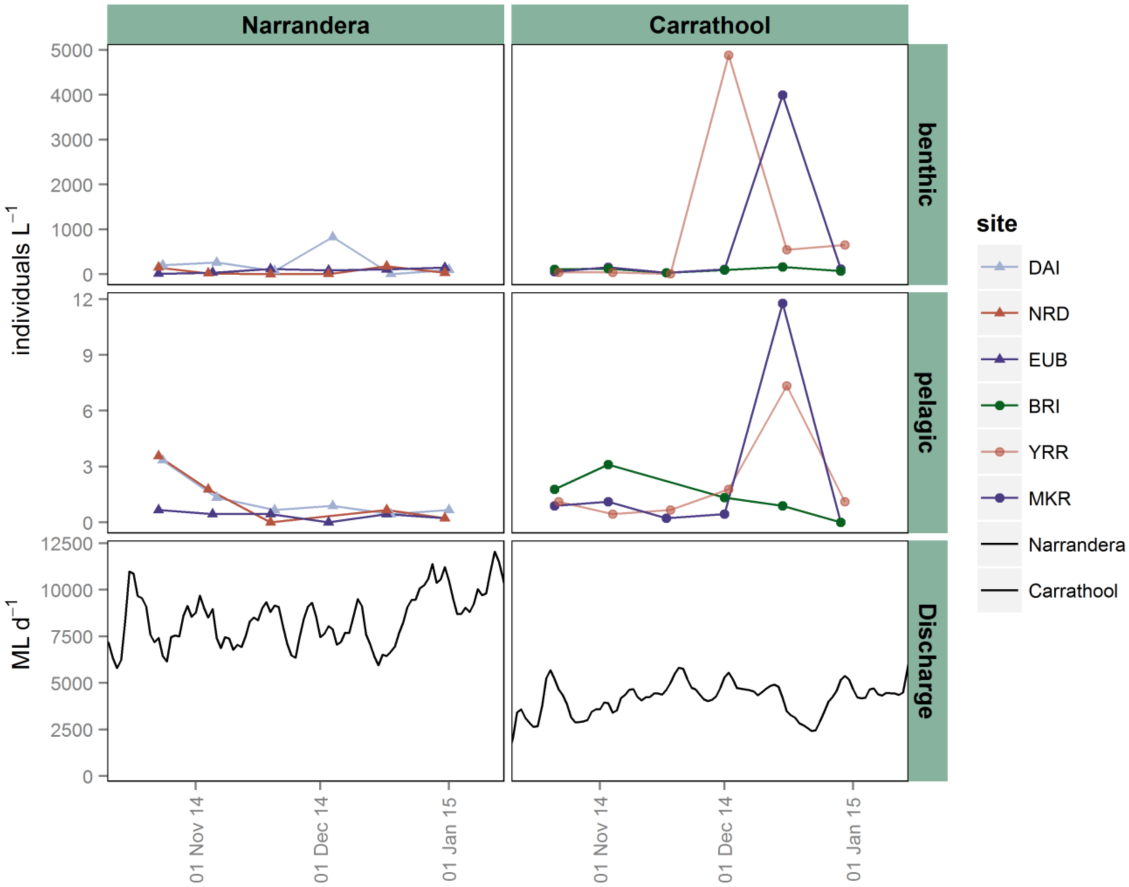


Figure 21 Benthic (upper graph) and pelagic (middle graph) microinvertebrate densities (L^{-1}) for 3 sites in the Narrandera zone (left graphs) and 3 sites in the Carrathool zone (right graphs) of the Murrumbidgee River sampled from October 2014 to January 2015. Data are plotted as scatter plots with individual data points for each site comprising a single composite sample. Benthic and pelagic samples are presented on different scales, with benthic samples typically exhibiting densities several orders of magnitude greater than pelagic samples. Discharge (lower graph) is shown for Narrandera and Carrathool gauge.

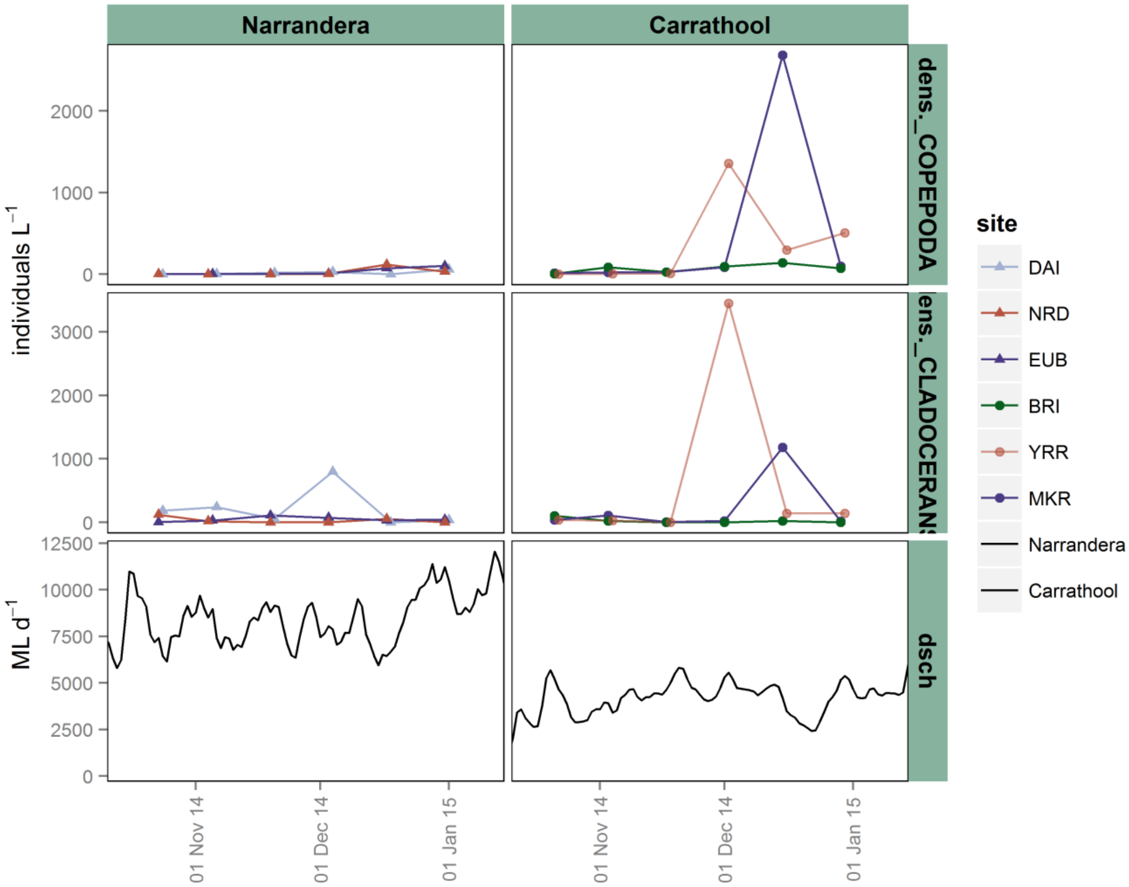


Figure 22 Benthic copepod (upper graph) and cladoceran (middle graph) densities (L^{-1}) for 3 sites in the Narrandera zone (left graphs) and 3 sites in the Carrathool zone (right graphs) of the Murrumbidgee River sampled from October 2014 to January 2015. Data are plotted as scatter plots with data points for each site comprising a single composite sample. Discharge (lower graph) is shown for Narrandera (left) and Carrathool (right) gauge.

Table 6 ANOVA results for densities of microinvertebrates, cladocerans, copepods and ostracods in each zone, microhabitat (benthic vs pelagic) and survey period.

Term	**Microinvertebrate density**		**Cladocera density**		**Copepod density**		**Ostracod density**	
	F	p	F	p	F	p	F	p
1. Zone (ZO)	0.624	0.716	1.302	0.273	1.420	0.188	0.849	0.425
2. Microhabitat (MH)	40.558	**0.001**	24.148	**0.001**	18.196	**0.001**	11.454	**0.001**
3. Time (TI)	1.102	0.342	1.638	0.059	1.579	0.065	0.908	0.517
4. ZO x MH	0.726	0.647	0.226	0.96	1.042	0.312	0.547	0.618
4. ZO x TI	1.410	0.098	0.847	0.626	1.235	0.235	0.767	0.656
4. MH x TI	1.277	0.16	1.085	0.372	2.379	**0.007**	1.187	0.331
4. ZO x MH x TI	1.417	0.076	0.652	0.875	1.051	0.392	0.712	0.709

Three taxonomic groups contributed primarily to biovolume (a measure combining length and width with density); copepods, chydroid cladocerans and macrothricid cladocerans (Figure 23). Chydorid and macrothricid cladocerans contributed to biovolume peaks at sites in both Narrandera and Carrathool zones (Figure 23). In contrast copepods only contributed to peaks in the Carrathool zone, where biovolume was an order of magnitude greater than contributed by chydorids (Figure 23).

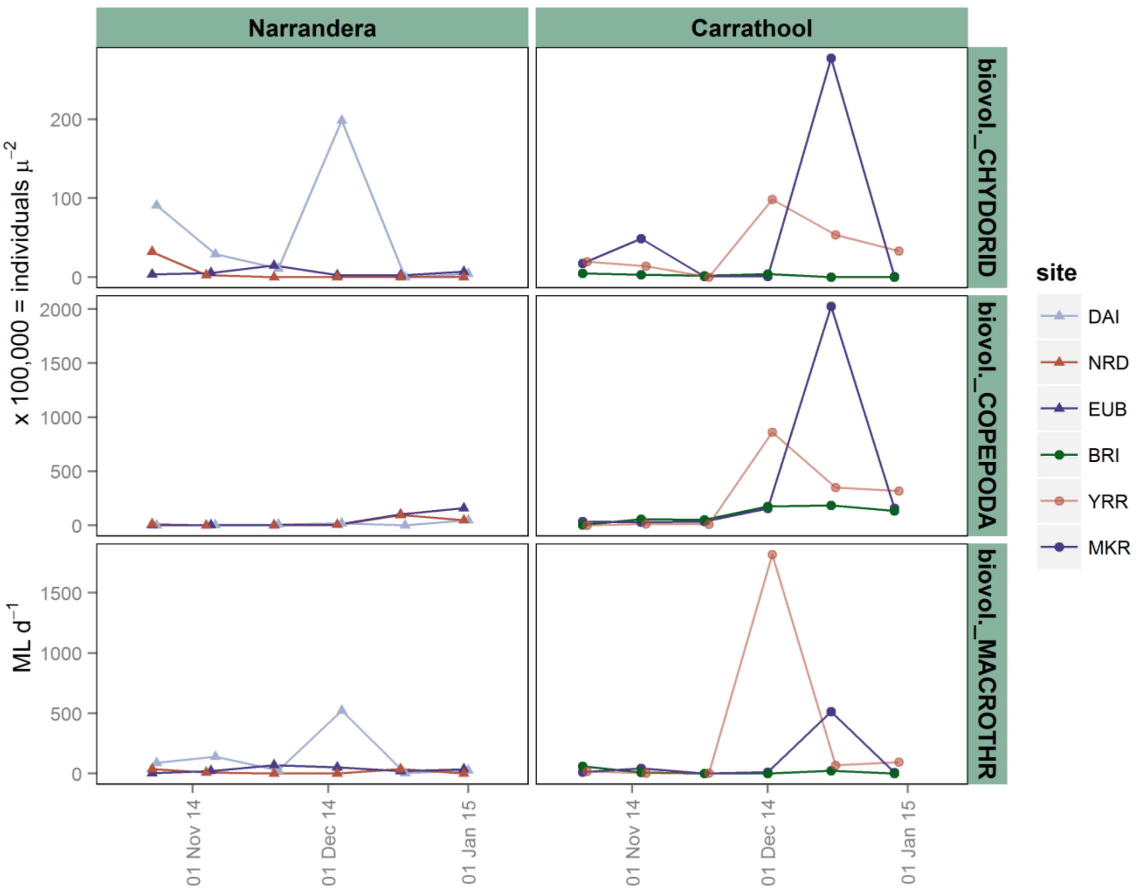


Figure 23 Benthic (left graphs) biovolume (length x width x density) for chydorid cladocerans (upper graphs) and copepods (middle graphs) and macrothricid cladocerans (lower graphs) for 3 sites in the Narrandera zone (left graphs) and 3 sites in the Carrathool zone (right graphs) of the Murrumbidgee River sampled from October 2014 to January 2015.

Microinvertebrates at wetland sites

In the wetland study, a total of 30,657 microinvertebrates from 38 taxa were recorded from benthic and pelagic habitats from 10 wetlands (103 samples). Densities of microinvertebrates were significantly different among zones, microhabitats and over time (Terms 1- 3, Table 7). Trends across time in wetlands sampled in the Nimmie Caira, mid-Murrumbidgee and Murrumbidgee River differed to those in the Redbank zone (Figure 24). In the Redbank zone, overall densities, influenced primarily by copepods and ostracods, peaked in November 2014 and then declined in January and March 2015 (Figure 24). In contrast, densities peaked in the other two wetland zones and the Murrumbidgee River (Balranald zone) in

January 2015 (Figure 24). High densities were also recorded in the Nimmie Caira in September 2014 (Figure 24). Densities were significantly higher in benthic habitats compared to pelagic habitats (Term 2, Table 7).

Copepods made a significant contribution to density (up to 1000 per litre, Figure 24), however cladocerans were also present in high densities (up to 500 per litre, Figure 24). Densities in the Murrumbidgee River also peaked in January 2015 (Figure 24)

Similarity Percentage (SIMPER) analysis supported findings from the density plots, with nauplii dominating samples from all zones (39-62%) along with cyclopoids (28-33%). In the Nimmie-Caira, calanoid copepods (8%), *Moina micrura* (1.5%) and ostracods (1.42%) also occurred. A suite of 12 cladocerans (chydorids, daphnids, bosminids, sidids and macrothricids) also contributed to similarity among samples, albeit less than 1%. In the mid-Murrumbidgee wetlands, ostracods, sidids and moinids contributed less than 1% to similarity due to the dominance of nauplii and cyclopoid copepods. In the Redbank zone, nauplii and cyclopoids dominated samples, with a suite of 16 taxa (calanoids, ostracods and 14 cladoceran taxa) contributing to similarity. Although also dominated by nauplii (38.91%) and cyclopoids (29.04%), the Murrumbidgee River community similarity included *Bosmina meriodonalis* (11%), chydorids (7%) and a Macrothricid species *Neothrix armata* (8%).

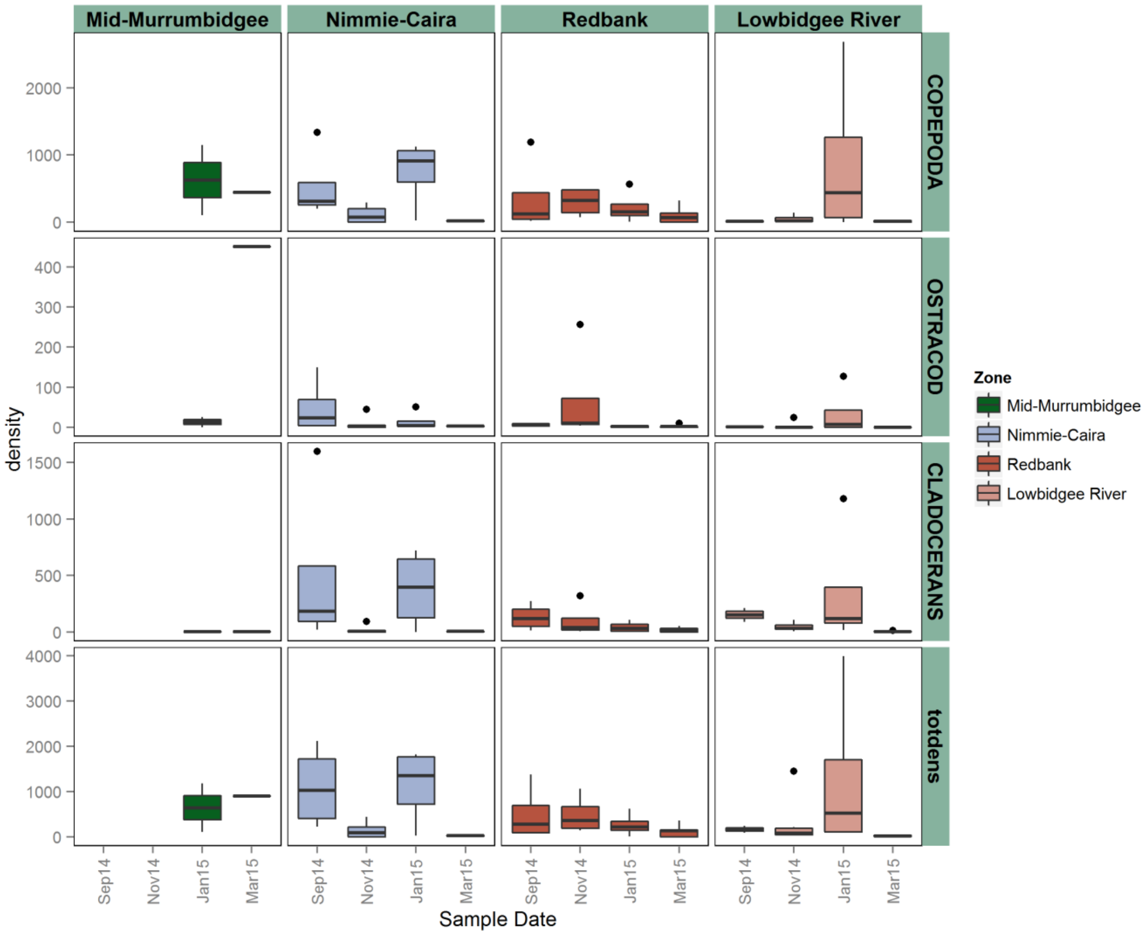


Figure 24 Boxplots of copepod (first row), ostracod (second row), cladoceran (third row), and total microinvertebrate (fourth row) benthic densities across time in each zone. Data are means and standard errors of the four wetland sites (sometimes fewer sites depending on when wetlands flooded and dried) sampled in each of the three zones (mid-Murrumbidgee, Nimmie Caira, north Redbank, Redbank and the Murrumbidgee River sites) on each sampling date.

Table 7 ANOVA results for densities of microinvertebrates, cladocerans, copepods and ostracods in each microhabitat (benthic vs pelagic) and survey period.

Term	Microinvertebrate density		Cladocera density		Copepod density		Ostracod density		Biovolume	
	F	p	F	p	F	p	F	p	F	p
1. Zone (ZO)	3.3	**0.001**	2.075	**0.036**	4.801	**0.001**	4.666	**0.001**	4.164	**0.001**
2. Microhabitat (MH)	2.317	**0.043**	1.74	0.157	1.777	0.117	3.946	**0.014**	2.827	**0.022**
3. Time (TI)	1.6	**0.015**	1.439	0.083	1.543	**0.024**	0.901	0.589	1.81	0.006
4. ZO x MH	1.206	0.232	1.055	0.39	1.154	0.3	1.949	0.071	1.899	**0.028**
4. ZO x TI	0.941	0.569	1.546	**0.035**	1.063	0.357	1.351	0.17	0.943	0.581
4. MH x TI	0.933	0.595	0.775	0.807	1.093	0.305	0.516	0.967	1.171	0.219
4. ZO x MH x TI	0.999	0.476	1.008	0.47	1.341	0.092	0.935	0.512	0.904	0.643

Discussion

There were no environmental watering actions directly targeting in-channel habitats during 2014-15. Nevertheless, volumes of environmental water delivered to the Lowbidgee wetlands (Action 6) and inter-valley transfers contributed to the overall volume, timing and magnitude of flows. For example, the peaks in benthic microinvertebrates at two of the larval fish sites in December 2014 and January 2015 coincided with inter-valley transfers that also matched peaks in chlorophyll-a and nutrients. However, the largest peaks in microinvertebrate densities were observed in the Carathool zone where overall discharge was lower and it is likely the January 2015 peak was due to a spike in temperature coupled with lower water levels. This matches with the peak also being observed in wetlands from the Nimmie-Caira and mid-Murrumbidgee at the same time. Data collected during 2014-15 provides an important benchmark for comparison with past years, and detecting responses in future years. The extremely high densities (>3000 per litre) recorded in the Murrumbidgee River in December 2014 and January 2015 were unexpected for riverine habitats.

The differences recorded between the Narrandera and Carrathool zones in microinvertebrate community composition will help to provide insights into larval fish recruitment as two of the three primary microcrustacean groups, macrothricids and cyclopoids are key prey for larval Murray cod (King 2004). Both groups dominated communities at the Carrathool sites with copepods numbers staying low and stable across the Narrandera sites. Copepods were the dominant taxonomic group in all sampled sites (river and wetland) in 2012-13 and 2013-14 (Wassens *et al.* 2014b) so it was very surprising to not observe higher densities at Dairy, Narrandera and Euroley sites. In the Murrumbidgee River, despite a shorter targeted sampling season in 2014-15 (36 samples) the overall density from the six larval fish sites (14,822) was almost triple the density in 2013-14 (50 samples) (Wassens *et al.* 2014b).

In wetlands, Commonwealth environmental water (Action 6) contributed peaks in microinvertebrate densities in January 2015 in the Nimmie-Caira, and Lowbidgee River, but not in the Redbank zone. 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. The peak in the Lowbidgee River sites matches peaks observed in the independently sampled larval fish riverine sites.

Wetlands receiving Commonwealth environmental water via infrastructure in the mid-Murrumbidgee (Action 2) had similar densities of microinvertebrates as those in the Lowbidgee floodplain (Nimmie-Caira) and were higher than wetlands in the Redbank zone, indicating that the mode of water delivery has little impact on microinvertebrate density or diversity.

Environmental watering of the mid-Murrumbidgee and Lowbidgee systems in 2014-15 facilitated ecosystem functioning, enhancing habitat suitability for high ecological value species that rely on wetland food-webs.

3.7 Return flows

Outcomes summary

During 2014-15, parts of the north Redbank system were inundated with Commonwealth environmental water (Action 6 and Action 9). A proportion of these flows were allowed to flow back into the river (called "return flows") from a regulator located approximately half way between Redbank Weir and Balranald (the Wynburn Escape). This use of environmental water aimed to "support ecosystem functions, such as mobilisation, transport and dispersal of biotic and abiotic material (e.g. macroinvertebrates, nutrients and organic matter) through longitudinal and lateral floodplain-river connectivity". We expected that this use of environmental water would augment riverine nutrient and carbon concentrations and possibly promote changes in ecosystem processes. Monitoring focussed on quantifying the transfer of nutrients and microinvertebrates from wetlands into the Murrumbidgee River and detecting subsequent ecological responses.

Return flows were delivered as two separate actions, one in October 2014, and the other in February 2015. Each return flow was monitored on four separate occasions (Before, During 1, During 2, After).

Key findings

- River discharge levels were high during both the return flows, and as a result the nutrient levels in water being returned from wetlands was rapidly diluted upon entering the river. The small release volumes, and short release intervals of the return flows made it difficult to detect ecological responses immediately downstream of the return flow point.
- Nevertheless we detected an increase in phosphate and DOC for up to 3km downstream of the return flow in the Murrumbidgee River.
- We recommend return flows aim to increase dissolved organic carbon concentrations to above 6 mg L^{-1} in the river to trigger metabolism responses in the river.

Introduction

Returns flows are a means of replicating the two-way transfer of water, nutrients energy and biota between rivers and floodplain that historically occurred during moderate to high flows along the Murrumbidgee River (Page *et al.* 2005; Frazier *et al.* 2006). The ecological benefits of river-floodplain connections stem from complementary processes that operate in both rivers and wetlands. Rivers provide the necessary flows and seeding of water-dependent species (e.g. fish) that reproduce in wetlands. These biota are then transferred along with nutrients and carbon in energy to augment populations and processes in the river (Ward *et al.* 2001; Sheldon *et al.* 2002; Lyon *et al.* 2010).

The outcomes of return flows are influenced by three key factors: the condition of the floodplain, timing of initial inundation and subsequent releases, and the volumes of water leaving the wetlands relative to the discharge rates in the river. The condition of the floodplain is particularly important and is influenced by the flooding history (Jenkins and Boulton 2007), land-use and the degree of leaf litter accumulation. This in turn influences the amount of carbon and nutrients released during inundation (Robertson *et al.* 1999a) and the quality of vegetation communities including the presence of rhizomes and seedbanks (Capon *et al.* 2006) which can conversely determine rates of nutrient uptake and storage. These aspects determine the suitability of habitat for floodplain fauna, as well as egg banks which influence the density and composition of microinvertebrates across the floodplain (Jenkins and Boulton 2007). Managing environmental water to restore connectivity between wetlands and the river enables nutrient and carbon-rich water released from accumulated leaf litter and woody debris to move from the floodplain into the river (i.e. “return flows”), recreating some aspects of lost river-floodplain connectivity on a small scale.

This section describes the outcomes of two small experimental return flows released from the north Redbank wetland complex to the Lowbidgee River in 2014-15 under Action 9. These flows were released to “support ecosystem functions, such as mobilisation, transport and dispersal of biotic and abiotic material (e.g. macroinvertebrates, nutrients and organic matter) through longitudinal and lateral floodplain-river connectivity”. We expected that this use of environmental water would:

- Increase nutrient concentrations downstream of the escape relative to upstream control sites
- Reduce nutrient and carbon concentrations within the wetland

Depending on whether this resource provisioning was enough to stimulate productivity in the river then we might also expect:

- Increased ecosystem metabolism through the addition of limiting nutrients, increasing the concentration of water column chlorophyll-a and increasing rates of primary production and respiration at downstream control sites
- Increase the density and species richness of microinvertebrate taxa in benthic habitats of the Murrumbidgee River downstream of the escape relative to upstream control sites

We evaluated these outcomes and discuss our findings with regard to ecological outcomes and the potential management implications of similar events in the future.

Methods

Location

During 2014-15, return flows were released from the Wynburn escape as two discrete actions, one during October 2014 and the other during February 2015. The Wynburn escape regulator is perched within a levee on the northern bank of the Murrumbidgee River near Balranald, NSW (Figure 25). It is constructed from concrete, containing four 1.84m wide bays each with wooden boards that can be removed to manipulate weir height. Discharge rates from the Wynburn escape can be controlled by changing the height of the Wynburn Escape regulator or by adjusting inflow rates into the wetland complex from any of multiple regulators along the north Redbank canal.

Study design

Each of the 2014-15 return flows followed a separate strategy. During the October 2014 release the wetland was surcharged with environmental water, with releases commencing after boards were removed from the Wynburn Escape on 8 October, 2014. Discharge rates from the Wynburn Escape were maintained by providing constant inflows of environmental water, with return flows lasting for approximately 3 weeks. Flows in the river at this time were approximately 1,300 ML d^{-1}.

The February 2015 return flow coincided with reduced river discharge (mean flow = 460 ML d^{-1}), and was intended to drain water from the wetland complex without top-up flows. High densities of macrophytes growing in the wetland at this time restricted outflow volumes and the action was ceased after approximately 1.5 weeks due to insufficient water.

Monitoring of both return flows was conducted across six sites (Figure 25). One site was located within Wynburn Swamp, in the North Redbank system, immediately behind the Wynburn escape. Five river sites were located in the adjacent Murrumbidgee River, two upstream and three downstream of the Wynburn Escape. River sites were spaced at 1km intervals with the first downstream site located 1km downstream of the escape point to allow for adequate mixing (D. Baldwin, pers. com.). Sites were monitored once before (Before) each release, twice during (During 1 and During 2), and once after (After). Samples were collected at approximately fortnightly intervals during October and weekly during the shorter release in February.

Prior to the October return flow, dissolved oxygen dataloggers (D-Opto, Zebra Tech) were deployed at each of the six sites, monitoring dissolved oxygen and water temperature continuously at ten minute intervals for the duration of each release period. A single depth logger (UD-20-1, Hobo Pacific) was deployed in the wetland immediately behind the regulator. Dissolved oxygen data were collected to evaluate the risk of a hypoxic blackwater event in the Murrumbidgee River associated with return flows and to calculate daily rates of ecosystem metabolism following methods described in Section 3.5 Nutrients, carbon and productivity.

On each sample occasion, duplicate water samples were collected and later analysed for water nutrients, chlorophyll-a and DOC following the methods described in Section 3.5 and water quality were collected following the methods described in Section 3.4 Water Quality. Benthic microinvertebrate samples were collected and processed following the methods described in Section 3.6 Microinvertebrates. Discharge in the escape canal was estimated on each sample occasion using an electromagnetic flow meter (Marsh McBirney Flow Mate 2000).

Data analysis

Metabolism data were affected by flow height changes, particularly during the second shorter return flow, and data were only available for approximately 60 per cent of days. Average rates of GPP and ER were calculated from all available data for 1 week prior to each sample occasion, except for the During 1 sample for the February release which was only 4 days after the previous sample.

Data were analysed using two-way permutational analysis of variance to determine if return flows significantly increased concentrations of dissolved nutrients, DOC, chlorophyll-a, microinvertebrates and rates of metabolism (PERMANOVA; Anderson et al. 2008). Treatment (upstream control vs downstream treatment) and trip date (Before, During 1, During 2 and After) were fixed factors. Resemblance matrices for nutrient data were calculated using a Euclidian distance measure, Bray-Curtis dissimilarity was used for microinvertebrate data. Data for each return flow were analysed separately. 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 $P<0.05$. Nutrient data were not transformed prior to analysis, microinvertebrate data were log x+1 transformed to reduce the influence of dominant species. All data analyses were performed using Primer 6 with PERMANOVA (Primer-E Ltd.).

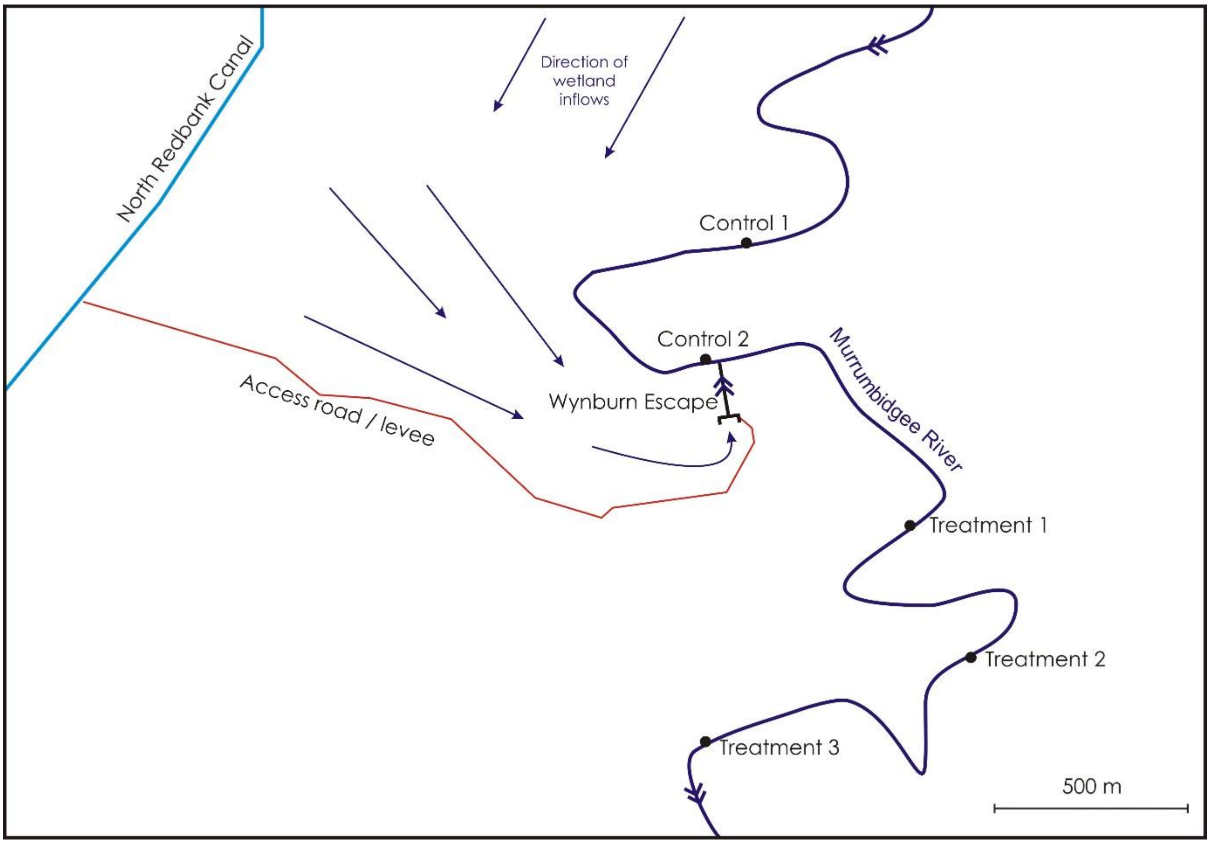


Figure 25 Sites monitored during the 2014-15 return flows. Treatment sites (n=3) are located downstream if the junction between the escape canal and the Murrumbidgee River. Control sites are located upstream (n=2). An additional site is located within the wetland immediately behind the Wynburn Escape. Environmental water was delivered by inundating the North Redbank wetland complex by providing inflows from the North.

Plate 1 The Wynburn Escape regulator photographed from the wetland (left of frame). The 50 m long escape canal is to the right of frame. The weir structure is overarched by a disused bridge. Wooden boards are used to regulate weir height. At this time the escape was approximately 15cm below spill-height.

Results

Release volumes

Wynburn Swamp was filled leading up to October 2014, reaching peak height during late September (at approximately 1.25m). At this time the weir leaked a small amount of water, estimated at less than 2 ML d^{-1}. The first release commenced on 8 October 2014, with initial discharge rates estimated at approximately 90 ML d^{-1} on 8 October. At this time discharge in the receiving river was 1098 ML d^{-1}, with wetland water comprising ~ 7 per cent of river water below the release point. Return flows were later decreased to protect the bankside levee, and remained at approximately 3 per cent of river volume for the duration of the action (Table 8). The total use estimated for the first release was 1,800 megalitres.

Multiple weir height changes meant that discharge during the second release cannot be interpolated to unsampled discharges. Measured values ranged up to 49 ML d^{-1}, falling sharply without top-up flows. These weir height changes are reflected in the stepped profile of depth data seen in Figure 26. An increase in depth following the cessation of flows on 13 February 2015 indicates that recharge rates were slower than release rates.

Table 8 Summary of return flow and river discharge during the four sample occasions.

Release number	Sample date	Sample occasion	Escape discharge	River discharge	% return flow contribution to river discharge
	1/10/2014	Before	1	1349	0.0
Release 1	14/10/2014	During 1	65.8	1126	2.9
October 2014	21/10/2014	During 2	77.2	1074	3.6
	12/11/2014	Before	1	1196	0.0
	2/02/2015	Before	0	884	0.0
Release 2	7/02/2015	During 1	49.4	578	4.3
February 2015	13/02/2015	During 2	9.2	442	1.0
	17/02/2015	After	0	462	0.0

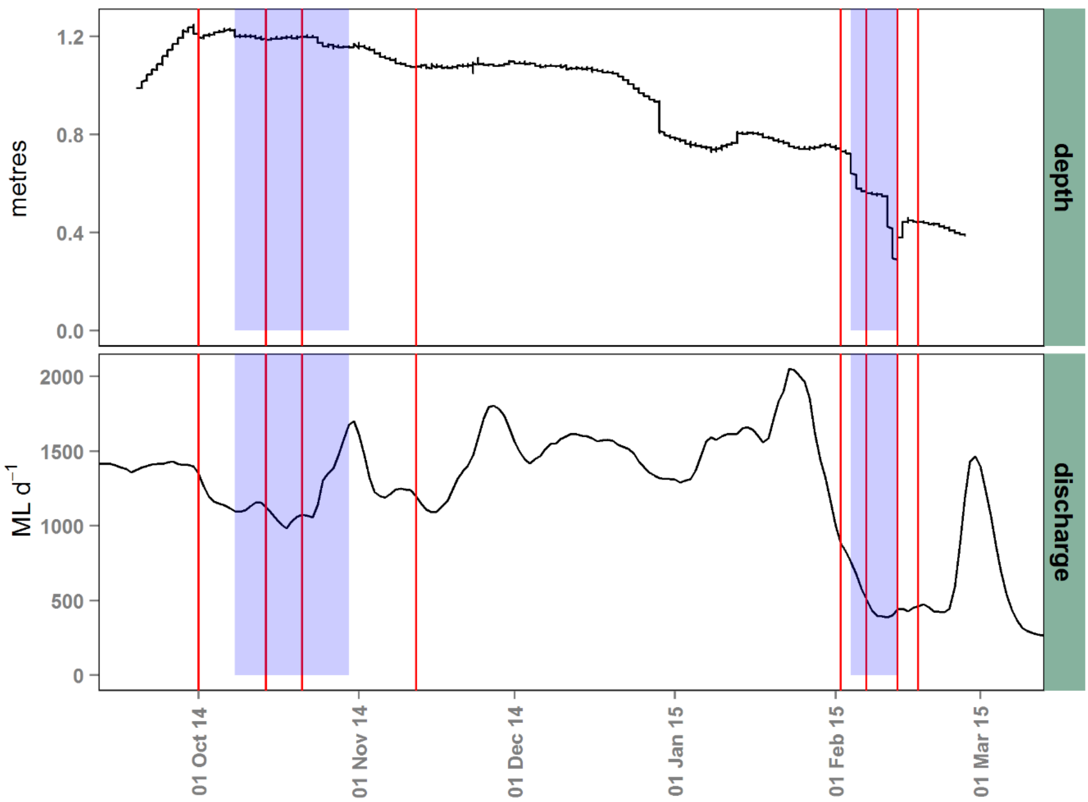


Figure 26 Water depth in Wynburn Swamp measured in the canal below the Wynburn Escape and discharge in the Murrumbidgee River between September 2014 and March 2015. Areas highlighted in blue indicate approximate beginning and end times of Release 1 and Release 2. Vertical lines show monitoring dates. Depth data was recorded hourly. Discharge is mean daily flow, adapted from the NSW Water Info website (http://waterinfo.nsw.gov.au/).

Continuous water quality monitoring

Dissolved oxygen in Wynburn swamp ranged between hypoxic and saturated, varying with diurnal cycles and temperature, reducing slowly across time (Figure 27). Temperature increased across time in both the river and wetland, with peak temperatures during early January and at times through February. Persistent daytime hypoxia (DO <2mg L^{-1}) was only observed in the wetland during the hot period in January and late February when the wetland drew down. However, overall values decreased below 4mg L^{-1} from December 2014 onwards. Dissolved oxygen levels in the river were more stable, with little diurnal variability becoming more variable as flow rates declined during early February.

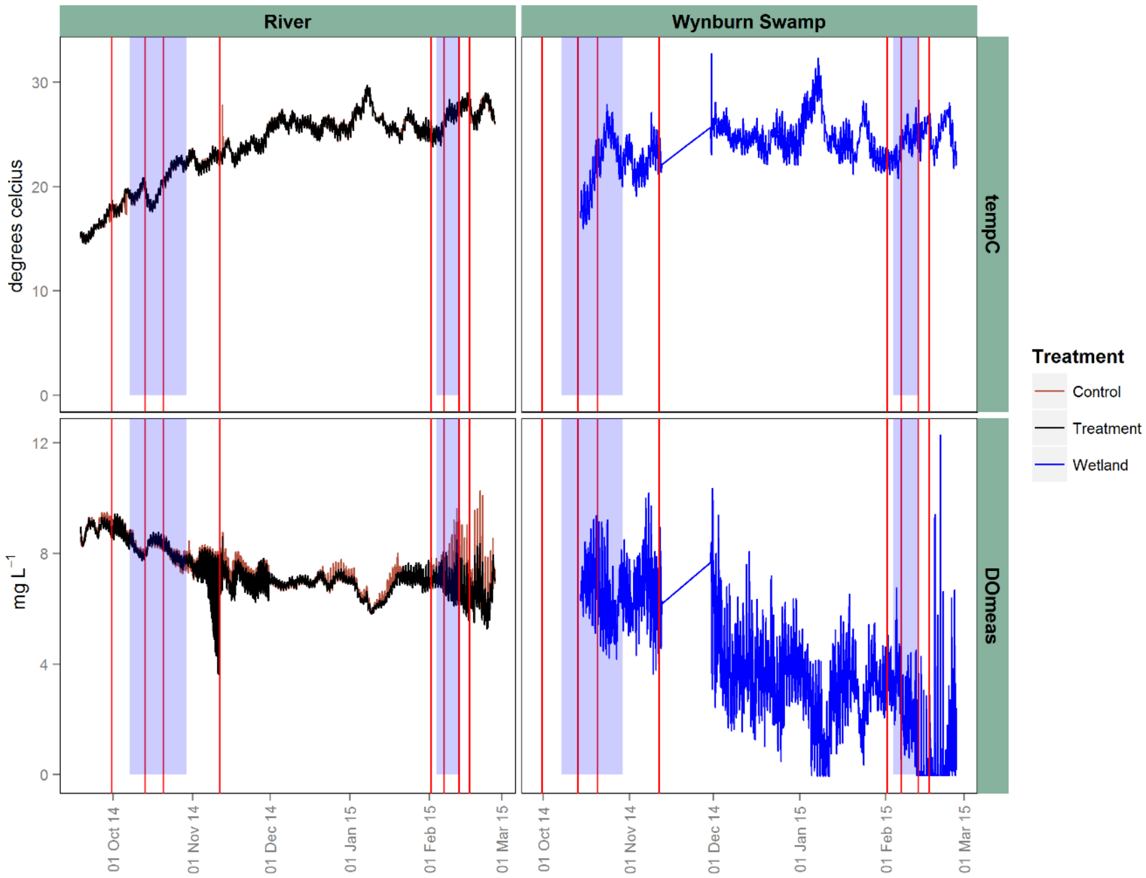


Figure 27 Water temperature and dissolved oxygen concentration at river (control and Treatment) and wetland sites during the October and February return flows. Data are recorded at 10 minute intervals, with fluctuations caused by daily cycles. Areas highlighted in blue indicate approximate beginning and end times of Release 1 (October 2014) and Release 2 (February 2015). Vertical lines show monitoring dates.

Nutrient and carbon concentrations

Overall, nutrient and chlorophyll-a concentrations were greater in the wetland than adjacent river habitats (without replicate wetland sites this cannot be tested; Figure 28). Wetland phosphate concentrations were highest in October 2014 but had declined by February 2015. DOC and chlorophyll-a concentrations both appeared higher in February than October.

On 14 October 2014 there was a spike in oxidised nitrogen (NO_x) concentration across all river sites, but not in the wetland. Peak NO_x has been observed at Murrumbidgee River sites during past monitoring (Wassens *et al.* 2014b).

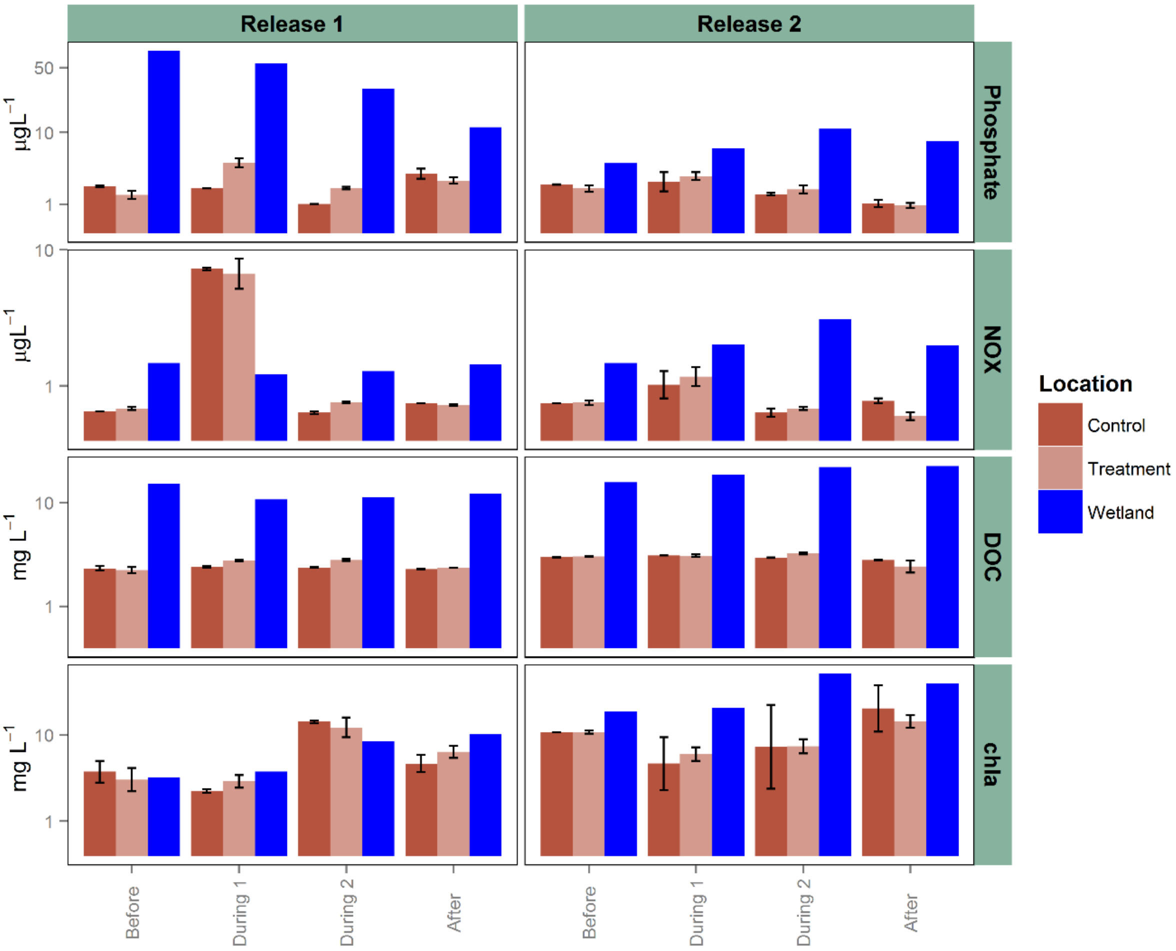


Figure 28 Average water column phosphate, oxidised nitrogen (NO_x), dissolved organic carbon (DOC) and chlorophyll-a concentrations from the Murrumbidgee River and the adjacent Wynburn Swamp. River sites are treatment and control locations. Bars on river data are standard error. Wynburn Swamp data are from a single site. Note that concentrations are shown on a Log10 scale.

Table 9 Pseudo-F results from PERMANOVA analyses performed on nutrient, metabolism and microinvertebrate data. Significance is indicated by *p-perm<0.05, p-perm<0.01, p-perm<0.001, significant results are shown in bold.

Release #	Return flow #1 October 2014			Return flow #2 February 2015		
Model Term	Treat.	Trip#	Treat. X Trip#	Treat.	Trip#	Treat. X Trip#
Phosphate	**5.910***	**12.581*****	**10.343****	0.235	**10.269****	0.568
NOx	N/A	**40.778*****	0.034	0.002	**7.939****	0.85
DOC	**11.062****	**7.5862****	**4.228***	0.007	**3.642***	1.333
Chlorophyll-a	0.049	**41.394*****	0.46	0.7	3.074	0.383
Microinvert. Community data	1.1222	**2.190****	0.543	0.693	**1.599***	0.59
Total Microinv. density	**3.285***	**3.762***	1.351	0.875	1.349	1.113
GPP	<0.001	2.458	0.027	0.464	0.636	0.074
ER	0.084	1.437	0.046	0.763	0.943	0.166
Prrat	0.704	**6.472****	0.225	0.120	**2.851***	0.360

Phosphate (PO_4) was significantly more concentrated at treatment compared with control sites on the two sample occasions during Release 1 (Table 9, pairwise P(MC)= 0.048 and 0.006 respectively; Figure 28). During Release 1 DOC was significantly more concentrated at treatment compared with control sites on occasions During 1, During 2 and After (Table 9, pairwise P(MC)= 0.015 , 0.016 and 0.031 respectively). Though significant, the magnitude of differences (approximately 0.4 mg L^{-1}) is relatively small. No other interactions among treatment and trip number were significant for either return flow (Table 9).

Benthic microinvertebrate communities

Community composition and densities of benthic microinvertebrates did not differ significantly between treatment (downstream escape) and control (upstream escape) sites across time during either release (Figure 29, Table 9). There appeared to be higher total densities of chydorids, copepods and ostracods at treatment compared with control sites during 1 and after release 2. However, these differences were not statistically significant. Conversely, during Release 1 there were significantly higher densities of microinvertebrates at control sites (Table 9, Figure 29).

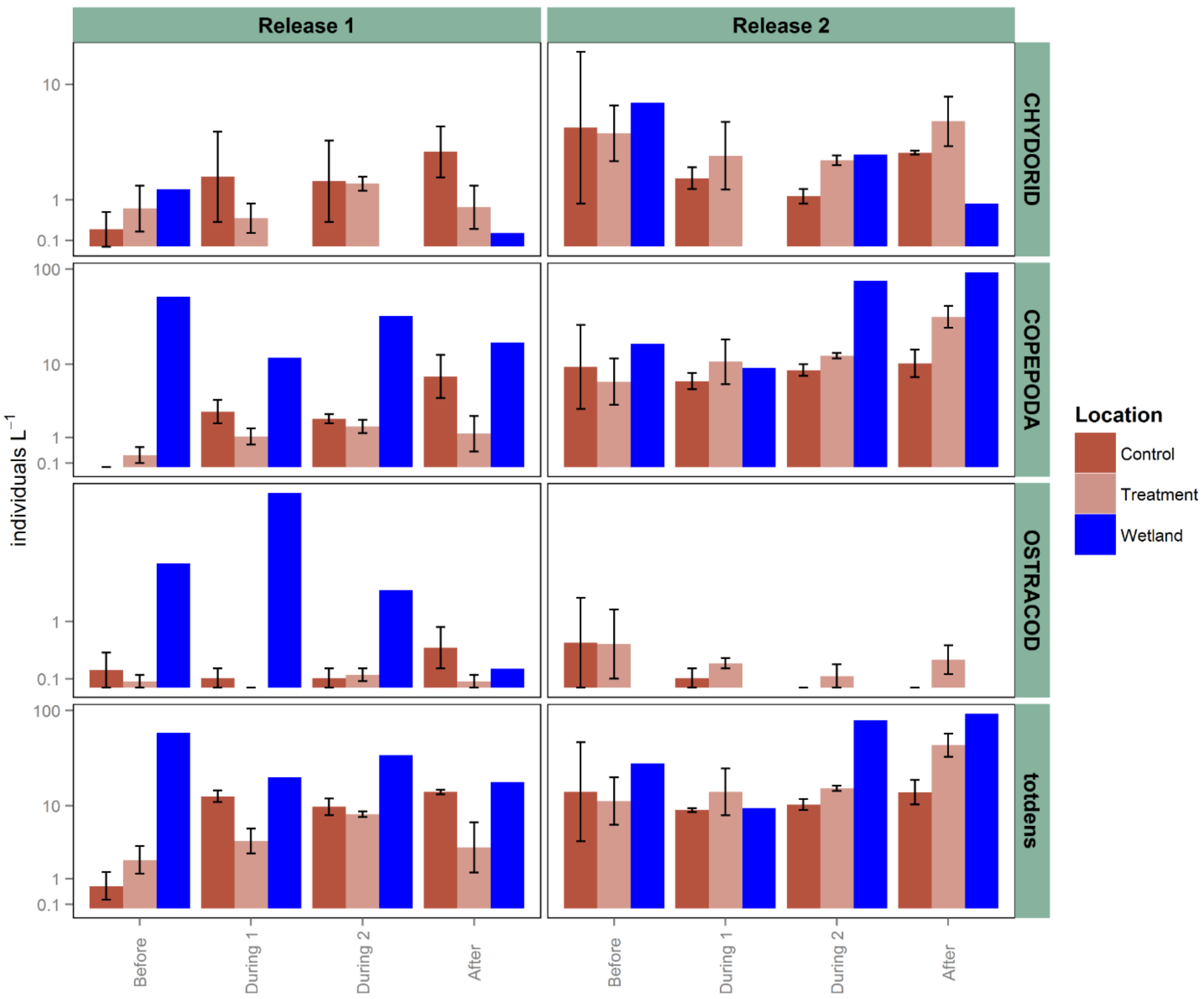


Figure 29 Densities of benthic (control and wetland) and pelagic (Escape) microinvertebrates collected during the October and February return flows monitoring. Control samples are the mean of two sites located in the Murrumbidgee River upstream of the Wynburn Escape. Error bars are standard error. Note that concentrations are shown on a Log10 scale.

Ecosystem metabolism

Overall, rates of gross primary production (GPP) and ecosystem respiration (ER) were higher during February 2015 than October 2014. The ratio of primary production and respiration differed significantly among sample occasions within each of the two releases (Prrat, Figure 30). The Prrat was significantly lower at During 1 than During 2 and after for the first release (P-perm = 0.039 and 0.004 respectively) and significantly than the Before sample for release 2. Lower. There was no significant difference in GPP between treatment and control sites were observed during either release (Table 9). Ecosystem respiration appeared to increase relative to GPP during the latter stages of the February return flow. Though this trend was not significant, this may be due to insufficient data.

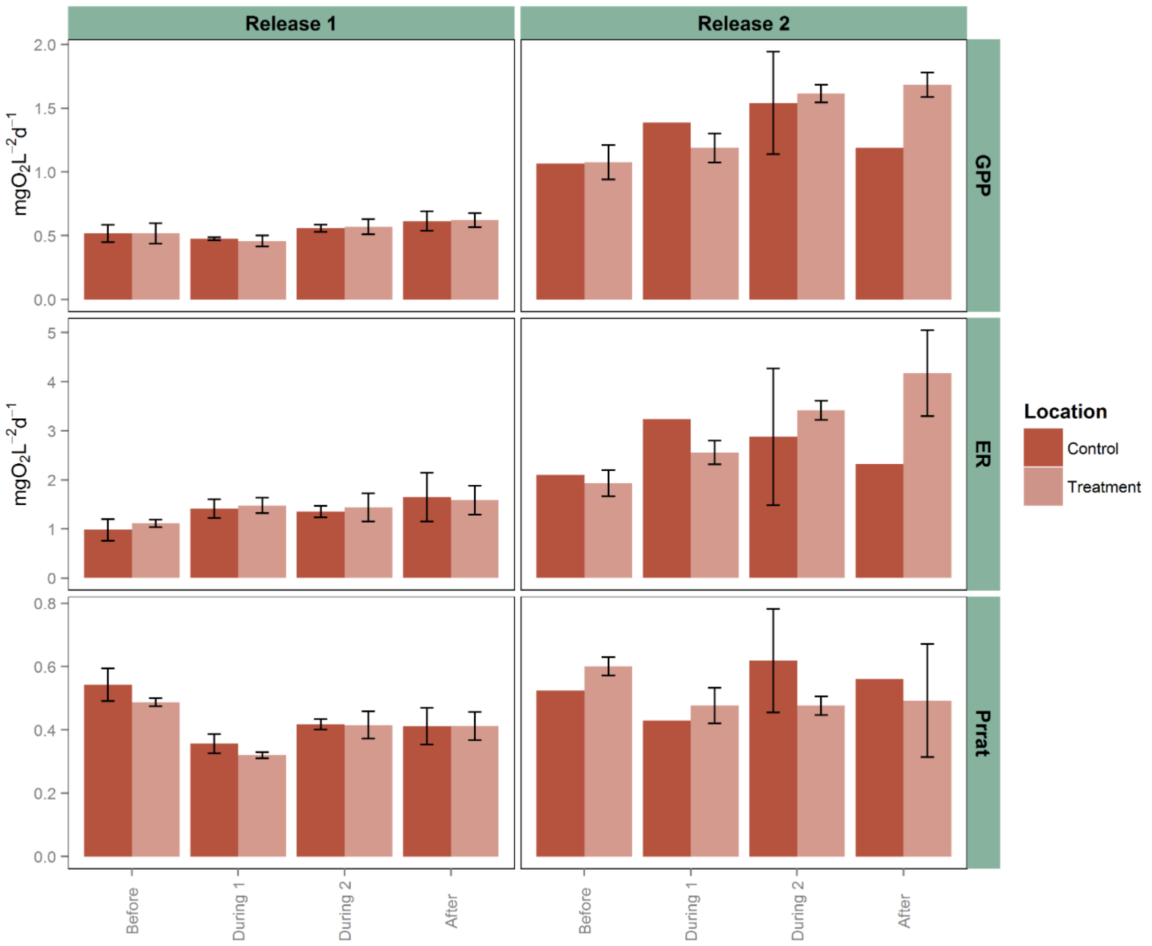


Figure 30 Average gross primary production (GPP), ecosystem respiration (ER) and the ratio of primary production to respiration (Prrat) for control (n=2) and treatment (n=3) sites in the Murrumbidgee River during the two return flow actions. Bars are standard error.

Discussion

Managed return flows from the North Redbank wetland complex in 2014-15 contributed to increased phosphate and DOC in the adjacent river which coincided with wetland water discharged during the October return flow. No differences were observed during the February return flow and this is largely due to much lower P concentration in the wetland following the extended period of inundation, and the proportionally small volumes of water released during the second return flow.

Downstream of the escape, the return flows contributed less than 7 per cent to total river discharge at any time during either release. Despite the small release volumes we detected an increase in riverine DOC and P. During October phosphate more than doubled at downstream treatment sites, with differences were detected as far as three kilometres downstream of the release point. There were no differences in riverine DOC and Phosphate during the February release largely because the concentrations in the wetlands were substantially reduced, possibly as a result of the first return flow in October.

Ecological responses to return flows in the Murrumbidgee River are likely to scale with the degree of nutrient enrichment. In this case the small volumes of water release relative to the total river volume, meant that while significant differences in DOC and Phosphate were achieved, the concentrations were not sufficient to drive a measurable increase in productivity downstream of the release. In the Murray River, Cook et al. (2014) reported a two-fold increase in GPP and a five-fold increase in ER after unmanaged flooding across large areas of floodplain in 2011 that was associated with an increase in river DOC concentrations from ~2 mg L^{-1} prior to the release up to 5-6 mg L^{-1}. During the present study, DOC concentration only increased by approximately 0.4 mg L^{-1}. There is a similar range of baseline carbon concentrations (~2-3 mg L^{-1} DOC) in the Murray and Murrumbidgee Rivers and their associated wetlands (10-15 mg L^{-1} DOC), suggesting an increase in DOC input, at the right time of year, will elicit a response in the Murrumbidgee River. The magnitude of this increase will depend on wetland DOC concentrations (which in the North Redbank system can be as high as 36 mg L^{-1}), discharge volumes (40-90 ML d^{-1}) and river volumes (as low as 450 Ml d^{-1}). We conclude that elevating riverine

DOC concentrations to the response range identified by Cook *et al.* (2015) (>5 mg L^{-1}) using small, managed releases is achievable in the Lower Murrumbidgee River.

Ecosystem responses to return flows (differences between treatment and control sites for metabolism, chlorophyll-a or microinvertebrates) were not significant during this study, although patterns indicate potential differences between control and treatment sites during the February return flow. During the second release both metabolism (GPP, ER) and microinvertebrate densities were higher in downstream treatment sites compared to controls. It is possible that a key nutrient was added via return flows, stimulating productivity even after the release had ended. However, during the return flow in February there was a considerable fall in discharge, coinciding with increased temperature that triggered an overall increase in productivity in the channel that was not attributed to return flows. Control and treatment reaches may have been responding differently to this change in flow height in response to an unmeasured covariate (i.e. water depth, shading).

Although microinvertebrate responses were not significant during this study, microinvertebrate densities, like nutrients, were recorded at lower densities than observed previously. During 2013-14, Wassens *et al.* (2014b) reported average benthic microinvertebrate densities in the North Redbank wetland complex of approximately 200 individuals per litre, ranging above 1000 individuals per litre. During 2014-15 densities in Wynburn Swamp were much lower, not exceeding 60 individuals per litre. Although the lower densities could reflect spatial variability within the wetland, it appears most likely that microinvertebrates had an overall decrease in the magnitude of response to flooding as the nutrient and carbon concentrations were similarly reduced. Higher densities of microinvertebrates in the wetland are more likely to see increased densities in the river associated with return flows.

Lessons learnt

The use of return flows to benefit riverine food webs hinges on better understanding the existing impacts and constraints acting on ecosystems in regulated floodplain rivers. There is evidence that productivity in the Murrumbidgee is relatively low (Vink *et al.* 2005) and that providing nutrients can improve rates of ecosystem production (Baldwin *et al.* 2014; Cook *et al.* 2015). However, the scale of intervention needed to reintroduce the necessary productivity to support river food webs is not yet known. In the Lower Murrumbidgee River system, return flows with a larger effect size could be implemented by timing releases to coincide with peak nutrient and microinvertebrate densities in wetlands, and with lower river volumes.

The 2014-15, return flows contributed to the removal of carbon and nutrients from the North Redbank wetlands. While small inputs of nutrients and carbon are beneficial, high levels of nutrient and carbon accumulation on the floodplain can result in adverse water quality conditions, including persistent daytime hypoxia (Wassens *et al.* 2014b). Our results suggest that successive years of watering has led to a reduction in the amount of dissolved and available nutrients in floodplain habitats culminating in an improvement in water quality conditions. The removal of nutrients and carbon during the 2014-15 return flows is likely to have further contributed to this improvement, lessening the magnitude of increased DOC and reduced dissolved oxygen observed during the onset of warmer weather in February 2015.

3.8 Fish reproduction and larval fish

Outcomes summary

Flow plays a critical role in the early life-cycle of native fish, and aspects including the duration, magnitude and timing of flows strongly influence adult spawning and subsequent survival and growth of larvae. Six in-channel larval fish sampling events were undertaken fortnightly between 20 October 2014 until 1 January 2015 at three sites in each of two hydrological zones (Narrandera and Carrathool) in the Murrumbidgee River. There were no direct in-channel environmental watering actions targeting fish reproduction or recruitment undertaken in 2014-15. However, environmental water deliveries to the Lowbidgee floodplain (Actions 6 and 9) contributed to patterns of hydrological variability in the Murrumbidgee River, providing baseline information to inform how environmental flows can be delivered to support food webs and maintain water quality in the river.

Key findings

- At least seven native fish species (Australian smelt *Retropinna semoni*, carp gudgeon *Hypseleotris* spp., golden perch *Macquaria ambigua*, Murray cod *Maccullochella peelii*, silver perch *Bidyanus bidyanus*, trout cod *Maccullochella macquariensis* and un-specked hardyhead *Craterocephalus stercusmuscarum fulvus*) and two alien species (common carp *Cyprinus carpio* and redfin perch *Perca fluviatilis*) spawned in the Murrumbidgee River in 2014-15.
- Larval fish catches were dominated by cod (*Maccullochella* spp.; November peak) and Australian smelt (November peak).
- Based on egg captures, multiple spawning events occurred for both golden (November and December) and silver perch (December only). Golden perch larvae were also captured.

Introduction

The larval 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 *et al.* 2013), dispersal (Gilligan *et al.* 2003), microinvertebrate abundance for first feed (King 2004) and increased nest site inundation (Baumgartner *et al.* 2014). Commonwealth environmental water allocations targeted to maintain hydrological conditions to support native fish species have the capacity to positively influence reproductive opportunities for fish, resulting in greater larval survival, and hence, increased 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 different species in a given water year (Devries *et al.* 1998; Baumgartner *et al.* 2014). For example, increased flows may inundate river or wetland habitat needed by small-bodied generalist species or large-bodied nesting species for reproduction, while also releasing nutrients and increasing productivity of microinvertebrates, a key prey item for the first feed of all species of native fish (Devries *et al.* 1998). Alternatively flow peaks may be used to trigger reproduction directly in flow-dependant species such as golden (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (King *et al.* 2009b). This study aimed to determine the seasonal timing of reproduction of native fish species within the Murrumbidgee Catchment, and the biotic and abiotic factors associated with early survival of fish larvae. The results represent the first year of a five year monitoring program, although previous monitoring using similar methods and sites has occurred over the preceding two years (Wassens *et al.* 2013a; Wassens *et al.* 2014b).

Methods

Larval fish were collected using methods described by Wassens et al. (2014). Larval fish sampling was undertaken at six riverine sites, with three sites selected within each of two hydrological zones (Figure 31). Eight larval drift nets and ten quatrefoil light traps were set overnight at each riverine site. Equipment and methods were consistent with those described by (Hale *et al.* 2014) with the exception 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 20 October 2014 until 1 January 2015, resulting in six sampling events at each of the six sites. 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 so that larvae could subsequently be 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 per cent ethanol for later laboratory identification using keys described in (Serafini *et al.* 2004).

A sub-sample of 50 larvae hatched from live-picked eggs (comprising both golden and silver perch) representing all possible combinations of sites and sampling events, were submitted to the Australian Genome Research Facility (AGRF). Nucleic acid extraction and subsequent verification of species assignment was based on dual-direction sequencing following polymerase chain reaction (PCR) amplification. Genetic assignment of golden 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. A sub-sample of ten 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. All samples were confirmed to be 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.* 2013a; Wassens *et al.* 2014b).

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 (NSW DPI Water gauge 410005) and Carrathool (gauge 410078) was used to represent daily water level changes in respective hydrological zones. Water temperature was only available from the Narrandera gauge and this was also used to represent water temperature in the Carrathool zone. Point measurements of water quality (including water temperature) were also recorded at the time of sampling and these are reported when presenting individual site results. To determine differences in larval fish, CPUE between zones and over time data were analysed using a two-way fixed factor (with zone and sampling event as factors) Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$.

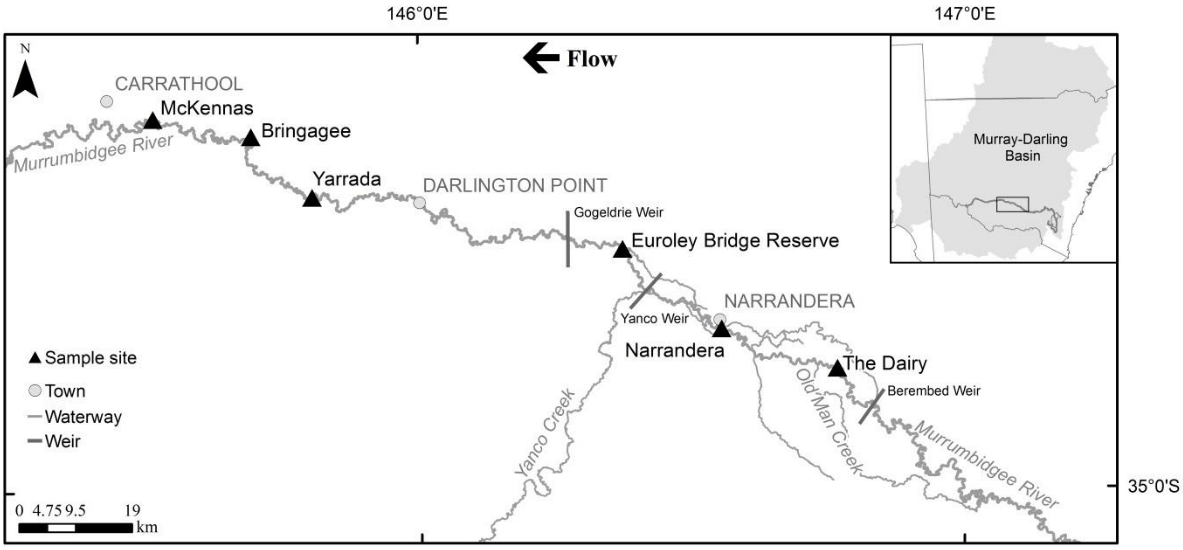


Figure 31 Locations of larval fish in-channel sampling sites on the Murrumbidgee River, encompassing Narrandera (The Dairy (DAI), Narrandera (NRD) and Euroley Bridge (EUB)) and Carrathool (Yarradda (YRR), Bringagee (BRI) and McKennas (MKR)) hydrological zones.

Results

A combined total of 3,028 eggs, larvae, juvenile and adult fish were collected during the 2014-15 sampling. Catches comprised at least seven native fish species (Australian smelt *Retropinna semoni*, carp gudgeon *Hypseleotris* spp., golden perch, Murray cod, silver perch, trout cod and un-specked hardyhead *Craterocephalus stercusmuscarum fulvus*) and two alien species (common carp *Cyprinus carpio* and redfin perch *Perca fluviatilis*) (Table 10). Additionally, early stage juvenile Murray River crayfish and freshwater yabby were captured in drift nets. Cod species were captured in the greatest abundance (*n*=809), and occurred at all combinations of sites and using both methods. Australian smelt larvae were also abundant (*n*=506) and were captured at all sites, although in light traps only. 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*=619) than golden perch eggs (*n*=397) which were captured at three sites. Golden perch larvae (post-flexion stage estimated at ~10–20 days post-hatch) were captured at The Dairy (*n*=1) and Narrandera (*n*=41) sites in the Narrandera zone only.

Catch per unit effort of larvae and eggs differed significantly between hydrological zones ($Pseudo\text{-}F_{1,24}$ = 9.568, P <0.001), among sampling events ($Pseudo\text{-}F_{5,24}$ = 10.409, P <0.001), and between sampling events within zones ($Pseudo\text{-}F_{5,24}$ = 4.077, P <0.001). Distinct peaks were evident in the timing of collection of larvae and eggs of most fish species in 2014-15. Carp gudgeon larvae were only sampled in the Carrathool zone, and captures peaked in mid-late December when water temperatures exceeded 21 °C (Figure 32 and Figure 33). Conversely, cod species larvae captures peaked on 19–21 November 2014 in the Narrandera zone (water temperature range 20.8–21.3 °C) and 3–5 November 2014 in the Carrathool zone (20.6–21.5 °C) (Figure 32 and Figure 33). Australian smelt captures exhibited multiple peaks in both hydrological zones (Figure 33). Redfin perch larvae were only captured in the Carrathool zone, once at Yarradda and once at Bringagee (Figure 33). Common carp larvae were captured in both hydrological zones, although only at the beginning of the study (Figure 33).

Silver perch eggs were collected from all sites in the Narrandera zone, and captures peaked on 3 December 2014 (water temperature 23.1–23.5 °C; Figure 32). In the Carrathool zone, silver perch eggs were also collected from all three sites, peaking on the 1–2 December 2014 (25.1–25.8 °C; Figure 32). No silver perch larvae were captured. Golden perch eggs were collected from one site (The Dairy) in the Narrandera zone on the 20 November 2014 (20.8 °C), 4 December 2014 (23.3 °C) and 18 December 2014 (24.4 °C) (Figure 32). Additionally, larvae in the post-flexion stage were collected using light traps from two sites on the 19–20 November 2014 (Figure 33). In the Carrathool zone, golden perch eggs were collect from two sites (Bringagee and McKennas) on the 17 November 2014 (21.5 °C; Figure 32). Golden perch larvae were not captured in the Carrathool zone.

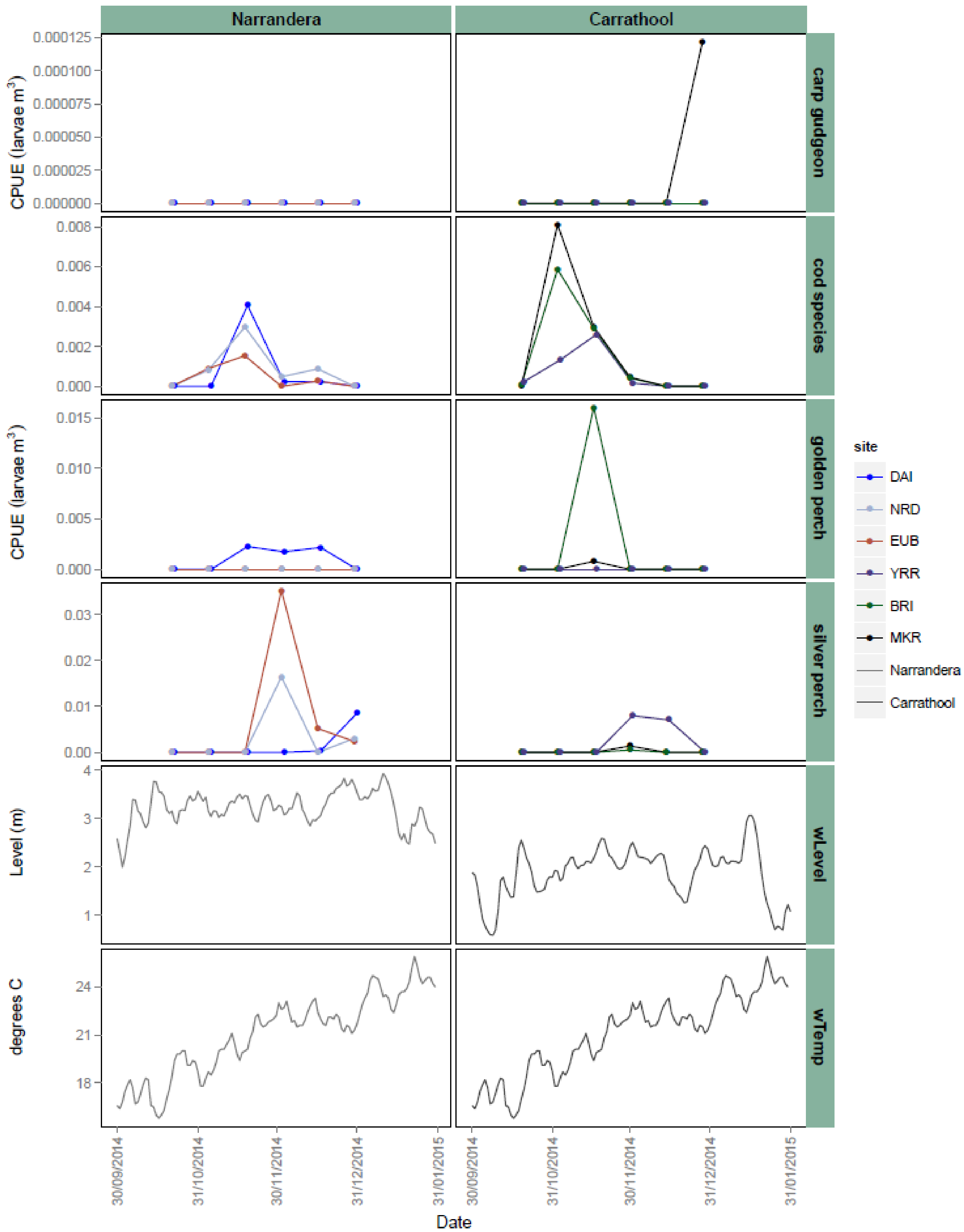


Figure 32 Larval drift net catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones. Captures of carp gudgeon and cod species are represented by larvae, and golden and silver perch by eggs.

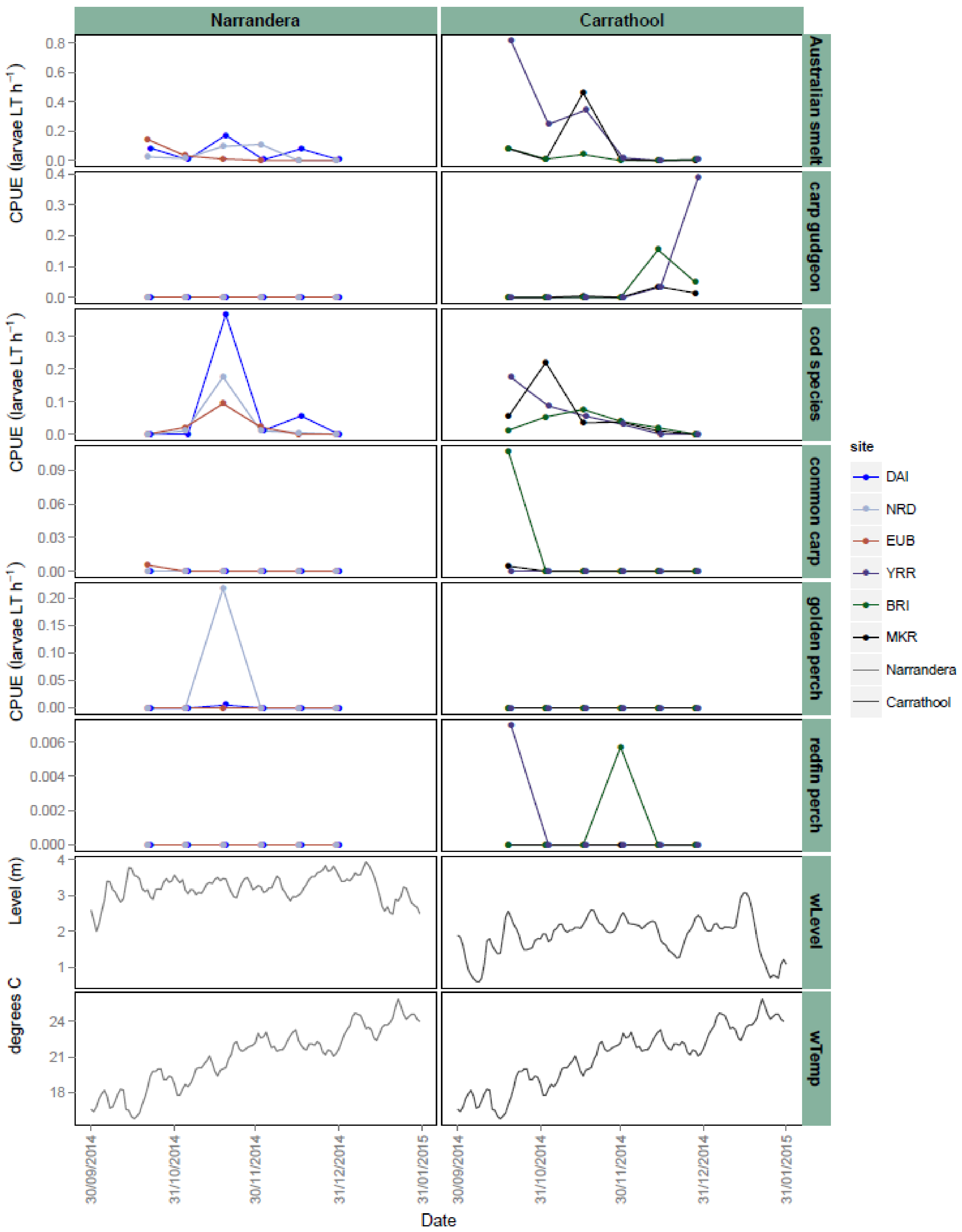


Figure 33 Larval light trap catch per unit effort (CPUE) across three sampling sites within each hydrological zone (Narrandera and Carrathool) and six sampling events, and the associated water level and water temperatures for these zones. Only captures of larvae are represented.

Table 10 Raw (unstandardised) total captures from larval drift nets (LDN) and light traps (LT) separated by life history (LH) stage and sampling site pooled across all sampling events.

		Hydrological zone											
		Narrandera						Carrathool					
		The Dairy		Narrandera		Euroley Bridge		Yarradda		Bringagee		McKennas	
Species	LH stage	LDN	LT	LDN	LT	LDN	LT	LDN	LT	LDN	LT	LDN	LT
Fish													
native species													
Australian smelt	larvae		63		47		35		225		23		113
	juveniles/adults		55		40		13		73		28		27
carp gudgeon	larvae							1	71		31	1	11
	juveniles/adults		14		1		1	1	4	2	60	2	9
cod species	larvae	34	78	36	38	18	25	42	53	141	35	237	72
	juveniles		1										
golden perch	eggs	48								330		19	
	larvae		1		41								
silver perch	eggs	84		172		264		75		6		18	
trout cod	juveniles	1											
un-specked hardyhead	juveniles/adults								1				
unidentified	eggs	5		16		10		7		18		6	
	larvae				83		20						2
alien species													
common carp	larvae						1				16		1
	juveniles		1			2		1		9	1	6	
redfin perch	larvae										1		
	juveniles								1				
Other													
Murray River crayfish	juveniles	2		3		2							
freshwater yabby	juveniles			1		1		3		1		5	

Discussion

No targeted in-channel environmental watering occurred in the Murrumbidgee River in 2014-15. Nevertheless, positive identification of spawning through the capture of eggs, larvae and juveniles of at least seven native species of fish in 2014-15, encompassing both the Narrandera and Carrathool hydrological zones, represented an increase in the number of native species in comparison to previous in-channel monitoring during short-term intervention projects. For example, in 2013-14 Australian smelt, carp gudgeon and cod (*Maccullochella* spp.) larvae were captured at in-channel sites, but no silver or golden perch were recorded (Wassens *et al.* 2014b). Flat-headed gudgeon (*Philypnodon grandiceps*) larvae were collected from wetland habitats in 2013-14, although sampling of these habitats did not occur in 2014-15. In 2012-13 during targeted in channel environmental water deliveries, Australian smelt, carp gudgeon and cod (*Maccullochella* spp.) larvae were captured at in-channel sites (Wassens *et al.* 2013a). River blackfish (*Gadopsis marmoratus*) larvae were also captured in 2012-13, although capture occurred at a site (Berry Jerry) upstream of the current sampling range (Wassens *et al.* 2013a).

The timing of larval capture in 2014-15 was generally consistent with data from previous short-term intervention monitoring projects, with respect to the collection of cod species, Australian smelt and carp gudgeon (Wassens *et al.* 2013a; Wassens *et al.* 2014b). Larval cod species have been the most abundant species captured over the past three years of sampling in the Murrumbidgee River, demonstrating consistent peaks in captures from early-mid November in all years (Wassens *et al.* 2013a; Wassens *et al.* 2014b). This synchronisation is an indication of consistent spawning responses to broad stimuli such as temperature or day length, and is characteristic of equilibrium species (King *et al.* 2013). The majority of larval cod captured, both in this and the previous two short-term intervention monitoring projects in the Murrumbidgee River, have been at either the post-flexion (~12 days post-hatch) or more commonly metalarva (~16 days post-hatch) developmental stage, at which point yolk-sac absorption has generally occurred and exogenous feeding has commenced (Rowland 1983). Subsequently, while spawning may be occurring independently of hydrological conditions, survival and growth from this point forward relies on adequate densities of appropriate food resources. In 2014-15 microinvertebrate densities peaked in early December (up to almost 5000 per litre), but there were densities above 100–200 per litre in the Narrandera zone in early November when the catch of Murray cod larvae peaked (see Section 3.6).

Spawning of golden and silver perch occurred in both hydrological zones during 2014-15. While the collection of unidentified fish eggs occurred in both 2013-14 and 2012-13, spawning of these species has not been identified during previous monitoring (Wassens *et al.* 2013a; Wassens *et al.* 2014b). Given the short hatch times of both species (~ 36 hrs; Rowland (1983) ,Rowland (1984)) and generally discrete spawning events, we would assume that fortnightly sampling underrepresents the level of spawning intensity that occurred in 2014-15 in the Murrumbidgee River. A high density of suitable prey was available to golden perch in the Carrathool zone in December 2014 (see Section 3.6), as early stage larvae generally feed on small cladocerans (Arumugam *et al.* 1992). However, silver perch larvae generally feed on rotifers at first feed, and while rotifers were likely captured in the current study, their abundance in samples was not quantified.

Both golden and silver perch have been observed to spawn and recruit during within channel flows, and across a broader range of water temperatures than originally thought (Humphries *et al.* 1999; Mallen-Cooper *et al.* 2003; Balcombe *et al.* 2006; Roberts *et al.* 2008; Ebner *et al.* 2009). However, the triggers that stimulate within channel spawning remain contentious. For example, spawning of 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 *et al.* (2003); King *et al.* (2005); Koster *et al.* (2014)). Interestingly, Zampatti *et al.* (2015) reported spawning of golden perch from October-December 2013 in the Goulburn, mid and lower Murray and lower Darling rivers coinciding with both the rising and descending limbs of the hydrograph. Although, recruitment occurred only from the lower Murray and Darling spawning events, and the fate of fish spawned in the remaining locations remains unresolved (Zampatti *et al.* 2015). Recent evidence suggests long-distance movements of juveniles may support extant populations where free-passage occurs, or where barriers to passage are drowned out on high flow events e.g. (Zampatti *et al.* 2015). This mechanism of dispersal is unlikely in the Murrumbidgee River given that the large number of weirs without fishways limit passage and population mixing. 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.

3.9 Fish communities

Outcomes summary

Two key Commonwealth environmental watering actions relating to fish communities in the Murrumbidgee Catchment in 2014-15 were Actions 2 (mid-Murrumbidgee wetlands) and Action 6 (watering wetlands in the Lowbidgee system). Fish communities in three wetland zones (Nimmie-Caira, Redbank and mid-Murrumbidgee) were sampled on four occasions in 2014-15 (September, November, January and March). In-channel fish communities were sampled once in March 2015 across three river zones (Narrandera, Carrathool and Balranald).

Key findings

- Ten native species and four alien species were captured across three hydrological zones in the Murrumbidgee River and in the three wetlands zones in 2014-15. Zone differences were evident in species richness, and species-specific abundance, biomass and size structure, although not for all pairwise zone comparisons.
- Recruitment was evident in a number of native species. In the Murrumbidgee River, Murray cod recruits were more abundant in the Carrathool zone, and this potentially corresponds to the higher food resources available to larvae at first feed in this zone compared with Narrandera. Despite spawning of golden and silver perch in both the Narrandera and Carrathool zones, only one silver perch recruit was captured (Carrathool zone) and no golden perch recruits were captured.

Introduction

Native fish communities in the Murrumbidgee Catchment are severely degraded, exhibiting declines in abundance, distribution and species richness (Gilligan 2005). Further, alien species (specifically common carp *Cyprinus carpio*) have been reported as occupying up to 90 per cent of the total biomass in some areas (Gilligan 2005). In addition, small-bodied floodplain species such as the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis agassizii*) were historically abundant from Murrumbidgee River wetland habitats (Anderson 1915; Cadwallader 1977) but are now considered to be 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 *et al.* 2003). Loss of connectivity has reduced permanent off channel habitats and prevented dispersal between river and floodplain habitats, also resulting in a loss of natural flow cues for in-channel species. The use of Commonwealth environmental water to restore more natural flow characteristics can benefit native fish by proving cues that stimulate reproductive behaviour, or by providing access to suitable breeding habitats and nursery areas and maintaining off channel habitats e.g. (King *et al.* 2009a; Beesley *et al.* 2014). Appropriate delivery of environmental water can also result in increased riverine productivity, food resources (i.e. microinvertebrates) and water quality, as well as facilitate longitudinal and lateral connectivity and dispersal (Koehn *et al.* 2014). Positive changes in native fish species richness, abundance and biomass are then predicted to occur.

The key Commonwealth environmental watering actions that relate to fish communities in the Murrumbidgee Catchment in 2014-15 were Actions 6 (watering wetlands in the Lowbidgee system). Specifically, the objective of Action 6 was to *provide wetland habitat to support the survival, and maintain condition, of native fish, waterbirds, and other aquatic vertebrates*. Environmental water was not specifically targeted for riverine fish communities in 2014-15, although the delivery of environmental water to the Lowbidgee floodplain (Action 6) contributed to an increase in water levels downstream of Darlington point (Carrathool Zone). We predicted that the changes in the river water levels produced during the delivery of environmental water to floodplain wetlands in the Lowbidgee floodplain would support native fish communities through the provision of appropriate water quality and access to suitable habitats. In wetlands, we predicted that Action 6 would provide reproduction and recruitment opportunities for native fish.

This monitoring program focused on benchmarking the fish community composition (species richness, abundance and biomass) across river and wetland LTIM monitoring sites and, where relevant, elucidates specific responses to Commonwealth environmental water delivery.

Methods

Riverine fish

Fish community sampling was undertaken in February and March 2015. Data was collected from 17 Murrumbidgee River sites spanning three hydrological zones (Narrandera, Carrathool and Balranald; Figure 1). Sampling sites and methods followed those in the Murrumbidgee Monitoring and Evaluation Plan for LTIM Category 3 (Wassens *et al.* 2014a). Additionally, data collected from four sites (Mckennas, Bringagee, Birdcage and Yarradda) as part of the Basin-Scale evaluation (Hale *et al.* 2014) was subsampled for the first 12 electrofishing operations (comparable effort to Category 3 methods), and bait trap captures were also included.

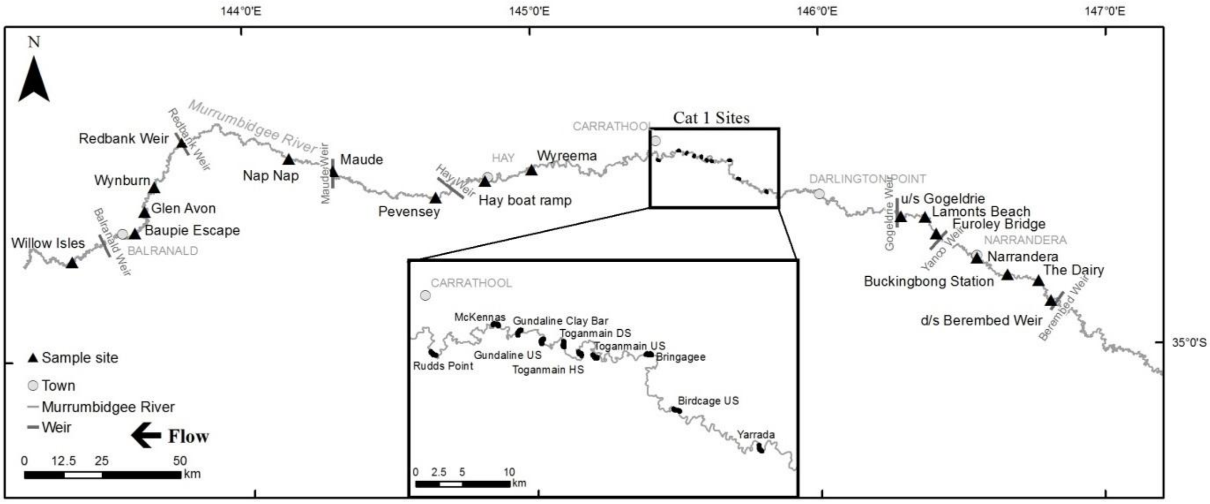


Figure 34 Location of fish community sites sampled in 2015 on the Murrumbidgee River. Data from four Cat 1 sites (McKennas, Bringagee, Birdcage and Yarradda) were used for this selected area evaluation.

Data analysis

Three Sustainable Rivers Audit (SRA) fish community indicators (Nativeness, Expectedness, Recruitment) and an overall Fish Condition Index were calculated for each hydrological zone to quantify overall condition of the fish community assemblage. Data were first portioned into recruits and non-recruits. Large-bodied and generally longer lived species (max. age >three years) were considered recruits when length was less than that of a one-year-old.

Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or expert opinion when literature was not available (Table 11).

Calculation of Sustainable Rivers Audit (SRA) fish indices.

Eight fish metrics were calculated using the methods described by (Robinson 2012). These metrics were subsequently aggregated to produce three indicators (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition index. Metric and indicator aggregation used Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) using the rule sets developed by (Davies *et al.* 2010). Expectedness represents the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition. This value is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). Nativeness represents the proportion of native compared to alien fishes, and is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robinson 2012). Recruitment represents the recent reproductive activity of the native fish community within each hydrological zone, and is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). Aggregation of individual metrics into relevant indicators was undertaken using the expert rule sets (Carter 2012). The three indicators were subsequently aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition can be partitioned into five equal categorical bands to rate the condition of the fish community as; "Good" (80–100), "Moderate" (60–79), "Poor" (40–59), "Very Poor" (20–39), or "Extremely Poor" (0–19).

To determine differences in fish communities among hydrological zones, abundance and biomass data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA Anderson *et al.* (2008)). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which zones differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between zones.

To determine differences in the length-frequency distributions (size-structure) among hydrological zones, species-specific length distributions were analysed using two-sample Kolmogorov-Smirnoff tests. These tests were only performed on the six most abundant species when catches within a hydrological zone consisted of >20 individuals. The significance level for each comparison was set by dividing *P* = 0.05 by the number of comparisons for that species (i.e. 0.05 / 3 zones = 0.017 for all species except bony herring as these were only captured in two hydrological zones) (Neumann *et al.* 2007).

Table 11 Size limits used to distinguish new recruits for each species. Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

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

Results

Riverine fish

A total of 1,041 fish comprising ten native and three exotic species were captured across 21 river sampling sites. This included three species listed as threatened (trout cod (*Maccullochella macquariensis*) (endangered; Fisheries Management Act, EPBC Act), silver perch (*Bidyanus bidyanus*) (vulnerable; Fisheries Management Act, critically endangered; EPBC Act), Murray cod (*Maccullochella peelii*) (vulnerable; EPBC Act)). Bony herring (*Nematolosa erebi)*, common carp, Australian smelt (*Retropinna semoni*) and carp gudgeon (*Hypseleotris* spp.) were the most abundant species in the river sites (Figure 35). Less commonly recorded species with <10 individuals recorded during surveys included un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), trout cod, silver perch and river blackfish (*Gadopsis marmoratus*). Un-specked hardyhead were captured at one site in each hydrological zone. Trout cod were captured in the Narrandera zone only, at

Berembed and Dairy sites. Silver perch were captured at one site within each zone. River blackfish were captured only at Berembed in the Narrandera zone.

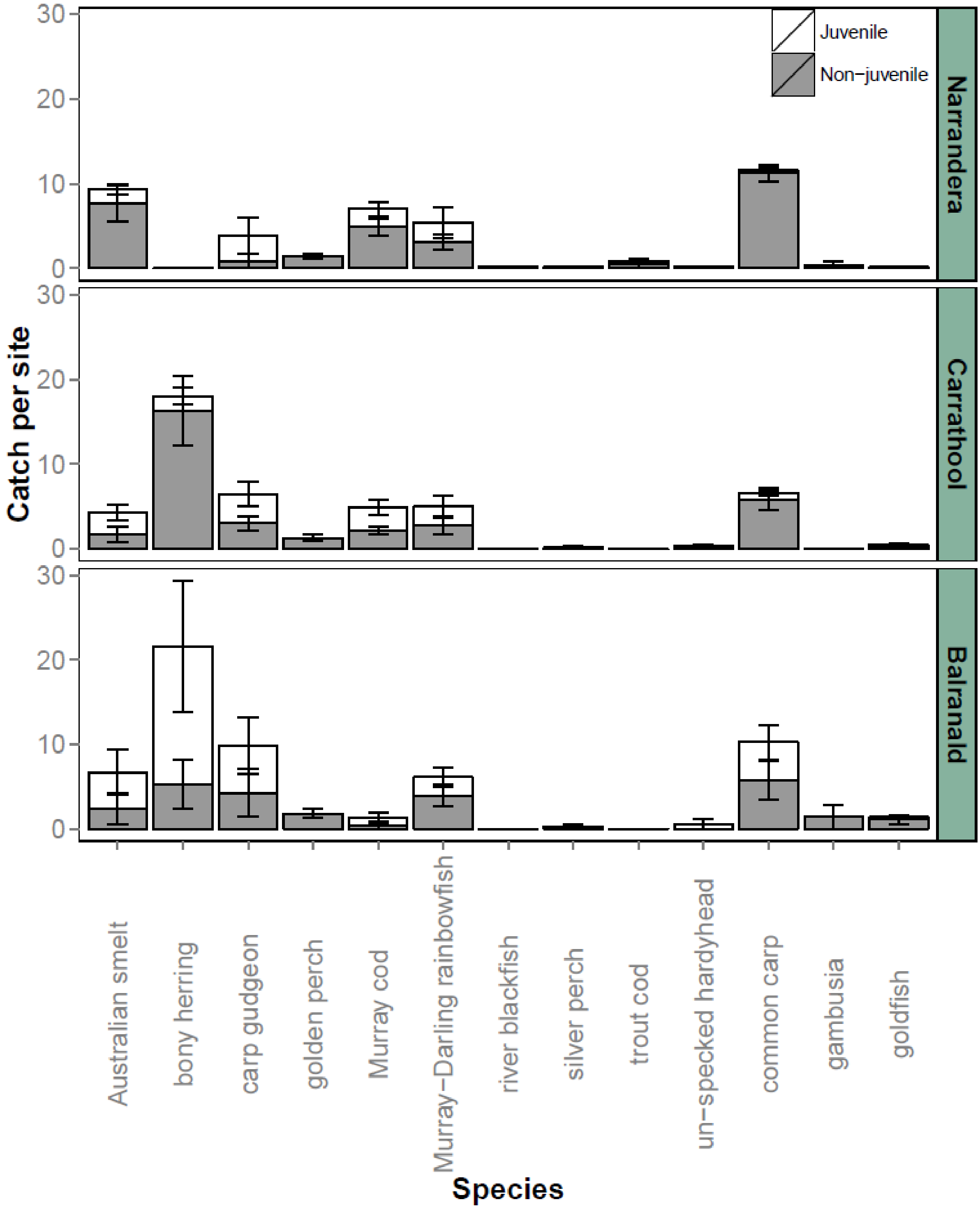


Figure 35 Average catch per unit effort (CPUE) per site (+SE) of each fish species within three zones of the Murrumbidgee River sampled in 2015. The white portion of the bar for each species represents CPUE of young-of-year recruits, or CPUE of non-mature individuals for short-lived species that reach sexual maturity within their first year of life (Table 11). The grey portion of the bar represents CPUE of all other individuals.

The fish community assemblage differed significantly in abundance among hydrological zones (*Pseudo*-$F_{2,18}$ = 4.722, P <0.001; Figure 35). SIMPER analysis indicated that the observed differences among zones were primarily driven by variability in the abundance of bony herring, Australian smelt, carp gudgeon, Murray cod and Murray-Darling rainbowfish, and contributions to differences were zone-specific (Table 12). Pair-wise tests indicated that the abundance of the assemblage was significantly different between Narrandera and Carrathool (t=2.559, P=0.001) and Narrandera and Balranald (t=2.572, P<0.001), although not between Carrathool and Balranald zones (t=1.221, P=0.194).

Common carp, Murray cod, golden perch (*Macquaria ambigua*) and bony herring contributed the greatest overall biomass in 2015, with an average biomass per site (and average percentage contribution) of 10,933 ± 1,644 g (64 ± 4%), 4,518 ± 1,645 g (16 ± 4%), 1,465 ± 276 g (11 ± 2%) and 595 ± 267 g (7 ± 3%), respectively (Figure 36). Biomass of the assemblage was significantly different among hydrological zones (*Pseudo*-$F_{2,18}$ = 8.217, P < 0.001). SIMPER analysis indicated that the observed differences among zones were primarily driven by variability in the biomass of Murray cod, bony herring, golden perch and common carp, and contributions to differences were zone-specific (Table 12). Pair-wise tests indicated that the biomass at sites was significantly different between all zone combinations (Narrandera-Carrathool: t=2.561, P<0.001; Narrandera-Balranald: t=3.689, P<0.001; Carrathool-Balranald: t=1.989, P=0.006).

Table 12 Contributions of fish species abundance and biomass to variability among zones in the Murrumbidgee River, determined through SIMPER analysis. Note that only species contributing ≥10% to changes in community composition are included.

Indicator	Zone comparison	Species	Contribution to difference (%)	Zone with greater value
Abundance	Narrandera-Carrathool	bony herring	29	Carrathool
		carp gudgeon	13	Carrathool
	Narrandera-Balranald	bony herring	22	Balranald
		Murray cod	15	Narrandera
		Australian smelt	13	Narrandera
	Carrathool-Balranald	Murray cod	18	Carrathool
		Australian smelt	14	Carrathool
		carp gudgeon	12	Carrathool
		Murray-Darling rainbowfish	12	Carrathool
Biomass	Narrandera-Carrathool	bony herring	26	Carrathool
		Murray cod	16	Narrandera
		golden perch	15	Narrandera
		common carp	11	Narrandera
	Narrandera-Balranald	Murray cod	31	Narrandera
		bony herring	18	Balranald
		common carp	12	Narrandera
		golden perch	10	Narrandera
	Carrathool-Balranald	Murray cod	32	Carrathool
		golden perch	17	Balranald

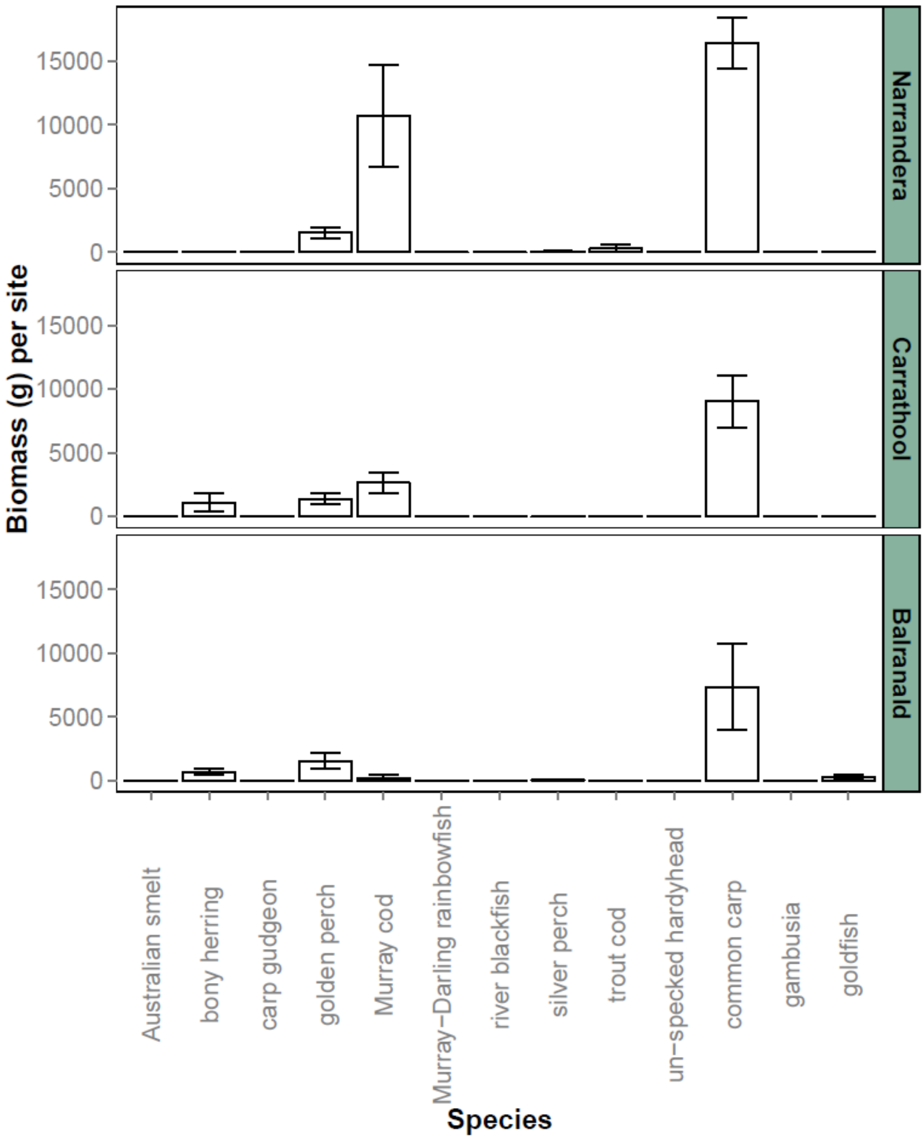


Figure 36 Average biomass per site (+SE) of each fish species within three zones of the Murrumbidgee River sampled in 2015.

Overall Condition of the fish community was higher in the Carrathool zone compared with Narrandera and Balranald zones, with Carrathool and Narrandera rated as "Poor" and Balranald as "Very Poor" (Table 13). Recruitment and Nativeness were highest in the Carrathool zone, although expectedness was highest in the Narrandera zone (Table 13).

Table 13 Sustainable Rivers Audit (SRA) fish indices (mean ± SE) for each of the three hydrological zones monitored in the Murrumbidgee River in 2015.

	Metric			
Hydrological zone	Recruitment	Nativeness	Expectedness	Overall condition
Narrandera	46.8 ± 0.0 (Poor)	70.0 ± 2.4 (Moderate)	49.2 ± 1.2 (Poor)	43.5 ± 0.7 (Poor)
Carrathool	61.3 ± 0.0 (Moderate)	75.2 ± 4.3 Moderate)	46.4 ± 2.4 (Poor)	49.5 ± 2.5 (Poor)
Balranald	46.9 ± 0.0 (Poor)	68.1 ± 3.7 (Moderate)	39.4 ± 3.3 (Very Poor)	36.8 ± 2.6 (Very Poor)

Differences in species-specific size-structure between hydrological zones were evident for five of the six species examined, although not for all hydrological zone comparisons (Table 14). Bony herring were not captured in the Narrandera zone, and were proportionately smaller in the Balranald (mean (range) of 70 mm (30–272 mm)) compared with the Carrathool zone (117 mm (32–302 mm)) (Figure 37). Murray cod were significantly smaller in the Carrathool (248 mm (54–604 mm)) compared to the Narrandera zone (372 mm (50–1097 mm)), and comparisons with the Balranald zone could not be made due to insufficient sample sizes. No differences in the length-frequency of common carp existed between Narrandera and Carrathool zones, although length-frequencies were significantly smaller in the Balranald zone (271 mm (50–505 mm)) compared with both Narrandera (412 mm (90–610 mm)) and Carrathool zones (403 mm (82–608 mm)) (Table 14, Figure 37). Murray-Darling rainbowfish sizes did not differ among any hydrological zones (Table 14, Figure 38). Carp gudgeon differed significantly between Narrandera (29 mm (20–45 mm)) and Carrathool (33 mm (20–45 mm)), and between Narrandera and Balranald zones (33 mm (19–46 mm)), although there were no differences between Carrathool and Balranald zones (Table 14, Figure 38). Similarly, Australian smelt differed significantly between Narrandera (48 mm (25–73 mm)) and Carrathool (41 mm (30–59 mm)), and between Narrandera and Balranald zones (41 mm (32–61 mm)), although there were no differences between Carrathool and Balranald zones (Table 14, Figure 38).

Table 14 Length-frequency distribution pair-wise comparisons between hydrological zones for the six most abundant fish species captured in the Murrumbidgee River in 2015. Significant differences are indicated in bold.

Species	Zone comparison					
	Narrandera - Carrathool		Narrandera - Balranald		Carrathool - Balranald	
	Z	*P*	*Z*	*P*	*Z*	*P*
Australian smelt	**3.041**	**<0.001**	**3.465**	**<0.001**	0.424	0.994
bony herring	-	-	-	-	**4.950**	**<0.001**
carp gudgeon	**2.051**	**<0.001**	**2.475**	**<0.001**	0.424	0.994
common carp	0.990	0.281	**3.182**	**<0.001**	**2.475**	**<0.001**
Murray cod	**2.263**	**<0.001**	-	-	-	-
Murray-Darling rainbowfish	0.849	0.468	0.707	0.699	0.354	1.000

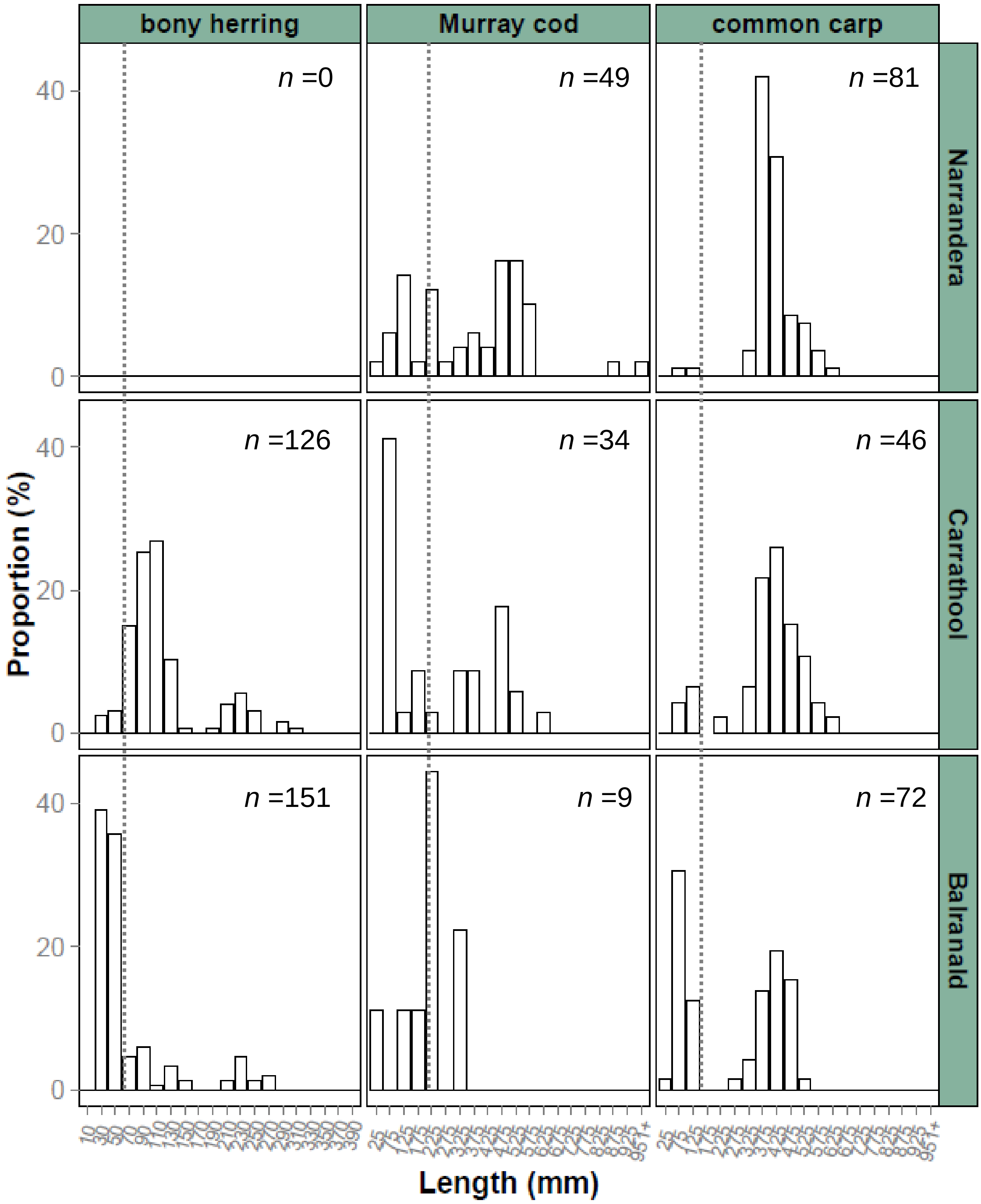


Figure 37 Length-frequency distributions of the most commonly encountered large bodied species captured in the Murrumbidgee River in 2015. The dashed line represents length to denote new recruits (see Table 11).

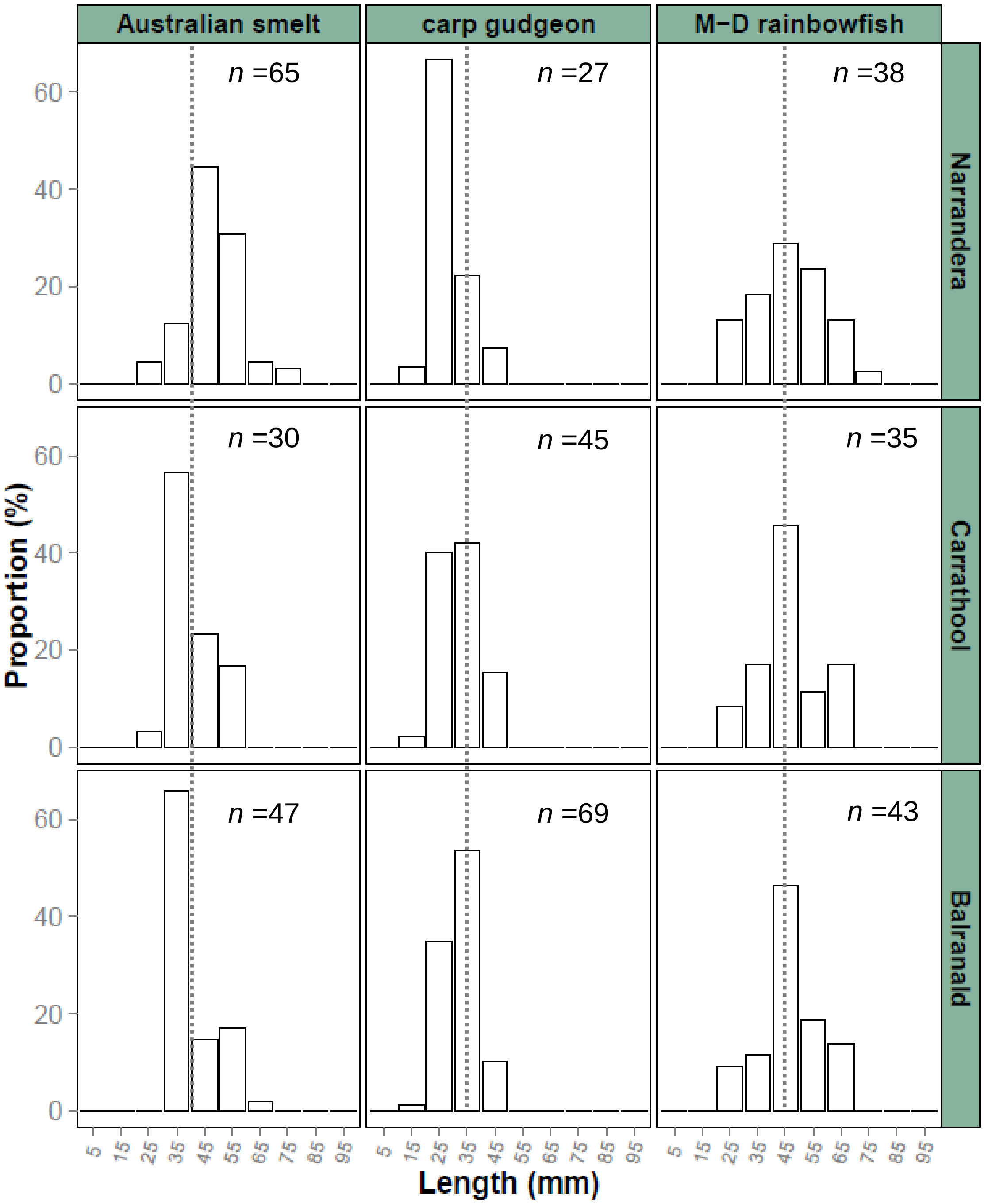


Figure 38 Length-frequency distributions of the most commonly encountered small bodied species captured in the Murrumbidgee River in 2015. The dashed line represents length to denote new recruits (see Table 11).

Wetlands

A total of 38,979 fish comprising six native and four exotic species were captured across 10 LTIM wetland sites that contained water between September 2014 and May 2015. Carp gudgeon, bony herring and Australian smelt were the most abundant native species (Figure 39) while gambusia, common carp and oriental weatherloach (*Misgurnus anguillicaudatus*) were the most commonly recorded exotic species. Fish communities differed significantly between the three wetland zones (ANOSIM Global R 0.226, p =0.001).

Despite being filled via pump, fish were present in Yarradda lagoon with the community dominated by bony herring and gambusia (Table 15). Exotic species contributed the most to differences between the two Lowbidgee zones with common carp, weatherloach and gambusia contributing to 92 per cent of differences among sites in the Redbank Zone, while in the Nimmie-Caira zone Common carp, gambusia, goldfish and Australian smelt contributed to differences. The composition of fish communities did not change over the four sampling periods (ANOSIM Global R 0.029, p = 0.213).

Table 15 SIMPER species contributions to differences between the three zones

		Av.Abund	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Nimmie-Caira Average similarity: 30.34	Common Carp	1.52	20.71	1.00	68.26	68.26
	gambusia	0.41	3.24	0.65	10.68	78.94
	Goldfish	0.33	2.35	0.49	7.75	86.69
	Australian smelt	0.26	1.99	0.38	6.55	93.24
Group Redbank Average similarity: 28.39	Common Carp	1.18	8.99	0.80	31.65	31.65
	oriental weatherloach	1.24	8.97	0.71	31.60	63.25
	gambusia	1.66	8.18	0.70	28.82	92.07
Group mid-Murrumbidgee Average similarity: 6.41	bony herring	0.43	4.77	0.41	74.43	74.43
	gambusia	0.39	1.64	0.41	25.57	100.00

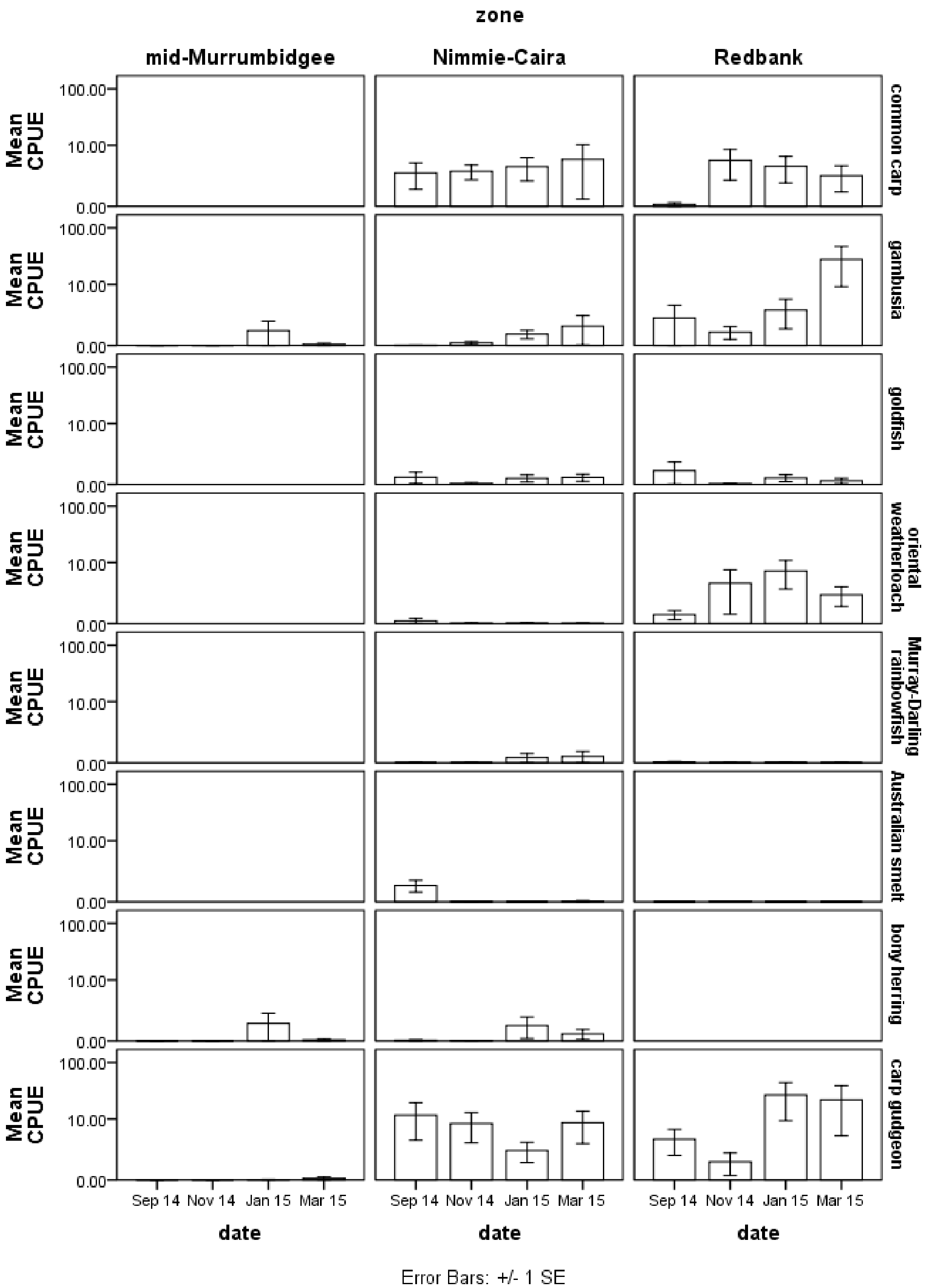


Figure 39 Mean catch per unit effort (CPUE) (±SE) of fish species over the four sample periods. Note that un-specked hardyhead and golden perch have been excluded from this figure as there were less than 3 cases. Note the log10 scale.

Size structure

As the composition of fish communities differed between zones, difference in size distributions in (September and November 2014) and (January and March 2015) were compared within each zone using the Kolmogorov-Smirnov test. In the mid-Murrumbidgee, bony herring were significantly smaller in January 2015 (four weeks after initial fill) compared to March 2015 reflecting a shift towards larger individuals with the March survey (Table 16, Figure 40). In the Lowbidgee, young-of-year carp gudgeon were recorded late in the season in both the Nimmie-Caira and Redbank zones indicated by a shift towards smaller individuals later in the season (Figure 41). There was evidence of a breeding event by common carp and gambusia in both the Redbank and Nimmie-Caira zones (Figure 42, Figure 43) as well as oriental weatherloach in the Redbank zone, which is indicated by a bimodal distribution in 2014, with an increase in the frequency of larger individuals later in the season (Figure 44).

Table 16 Length-frequency distribution pair-wise comparisons between the the September and November (pooled results) and the January-March (pooled sample results) for the six most abundant fish species captured in wetlands of the Murrumbidgee catchment in 2015. Bony herring were only recorded in sufficent numbers in 2015 in the mid-Mururmbidgee and Nimmie-Caira as a result comparisons are Jan 15 - March 15. Significant differences are indicated in bold.

	Mid-Murrubidgee		Redbank		Nimmie-Caira	
Species	*Z*	*P*	*Z*	*P*	*Z*	*P*
Australian smelt	-	-	-	-	**2.126**	**<0.001**
bony herring	**1.637**	**0.009**	-	-	**6.739**	**<0.001**
carp gudgeon	-	-	**7.544**	**<0.001**	**5.873**	**<0.001**
Murray-Darling rainbowfish	-	-	0.612	0.847	-	-
Golden perch	-	-	-	-	0.408	0.996
common carp	-	-	**0.315**	**<0.001**	**2.871**	**<0.001**
Orientail weatherloach	-	-	**5.117**	**<0.001**	0.935	0.346
Goldfish	-	-	**1.449**	**0.030**	**0.4573**	**<0.001**
Gambusia	1.237	0.094	**4.375**	**<0.001**	0.455	0.986

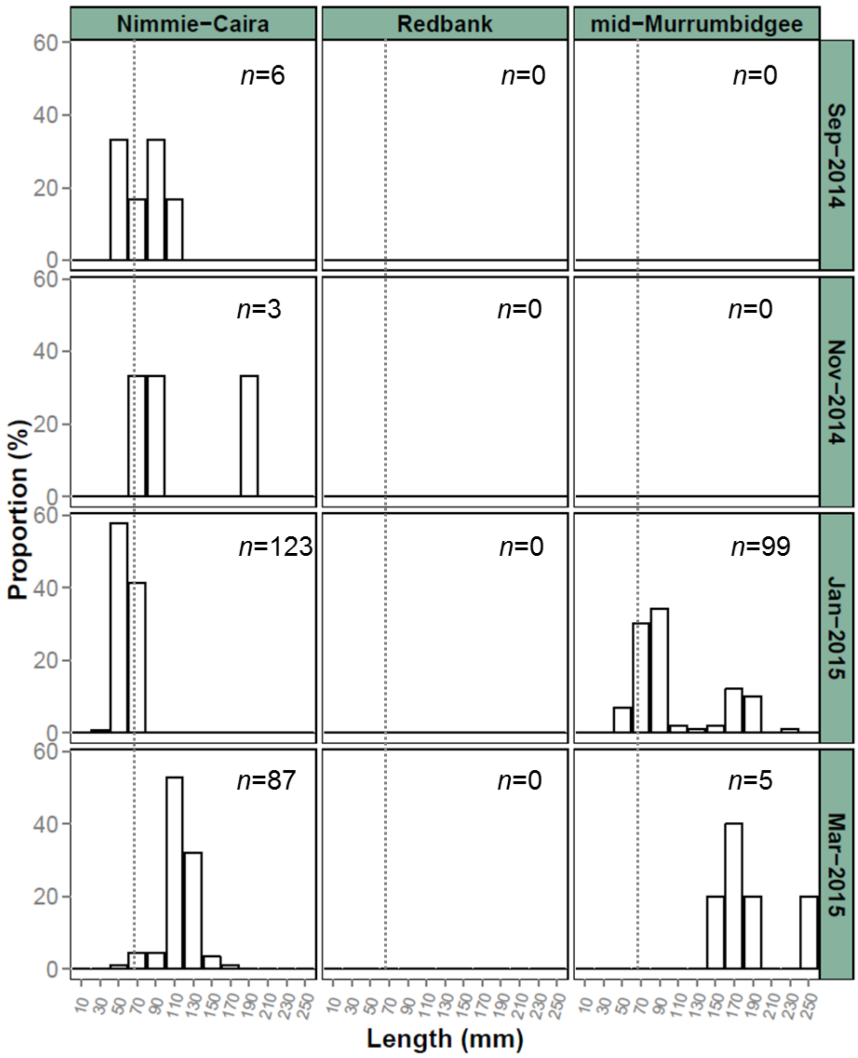


Figure 40 Length-frequency distributions bony herring. The dashed line represents length to denote new recruits (see Table 11).

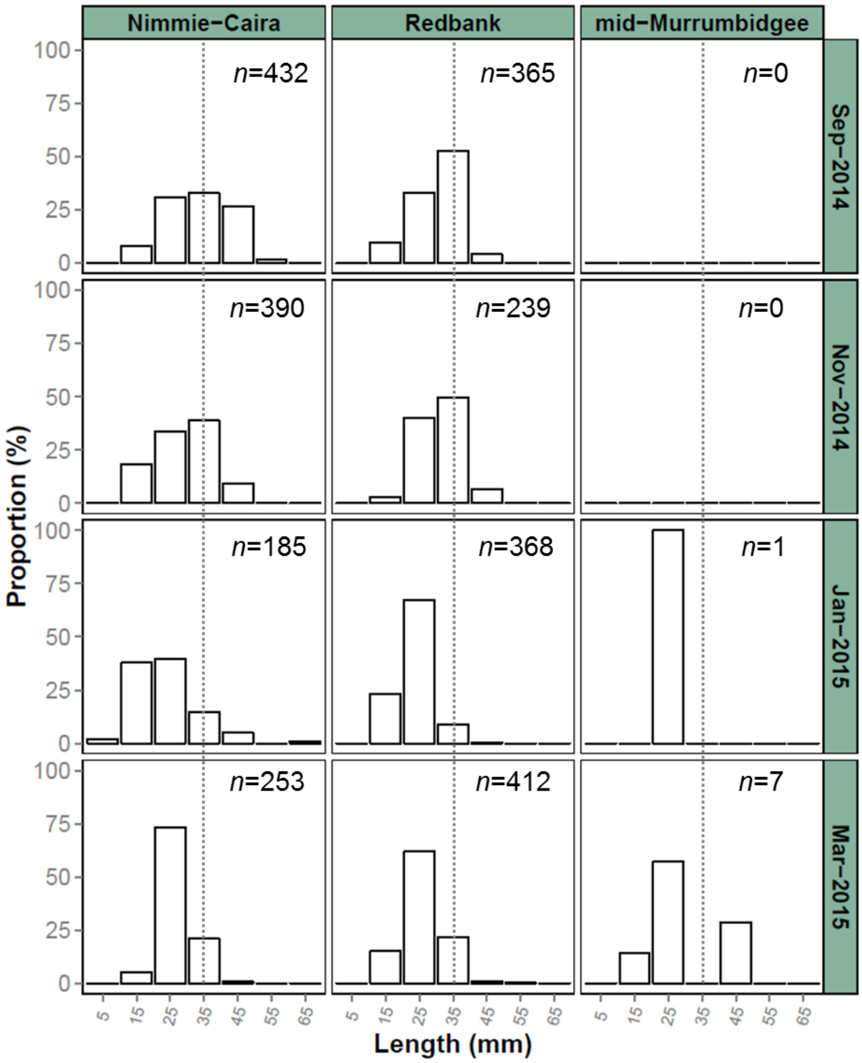


Figure 41 Length-frequency distributions carp gudgeon. The dashed line represents length to denote new recruits (see Table 11).

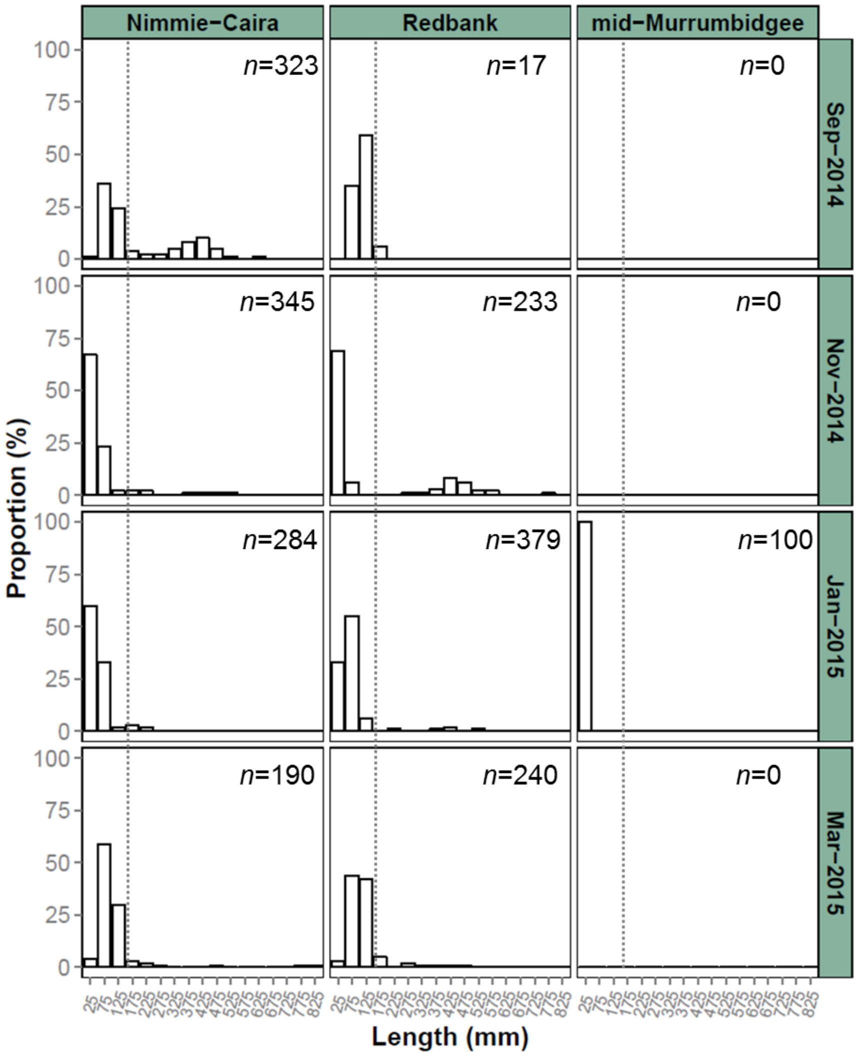


Figure 42 Length-frequency distributions common carp. The dashed line represents length to denote new recruits (see Table 11).

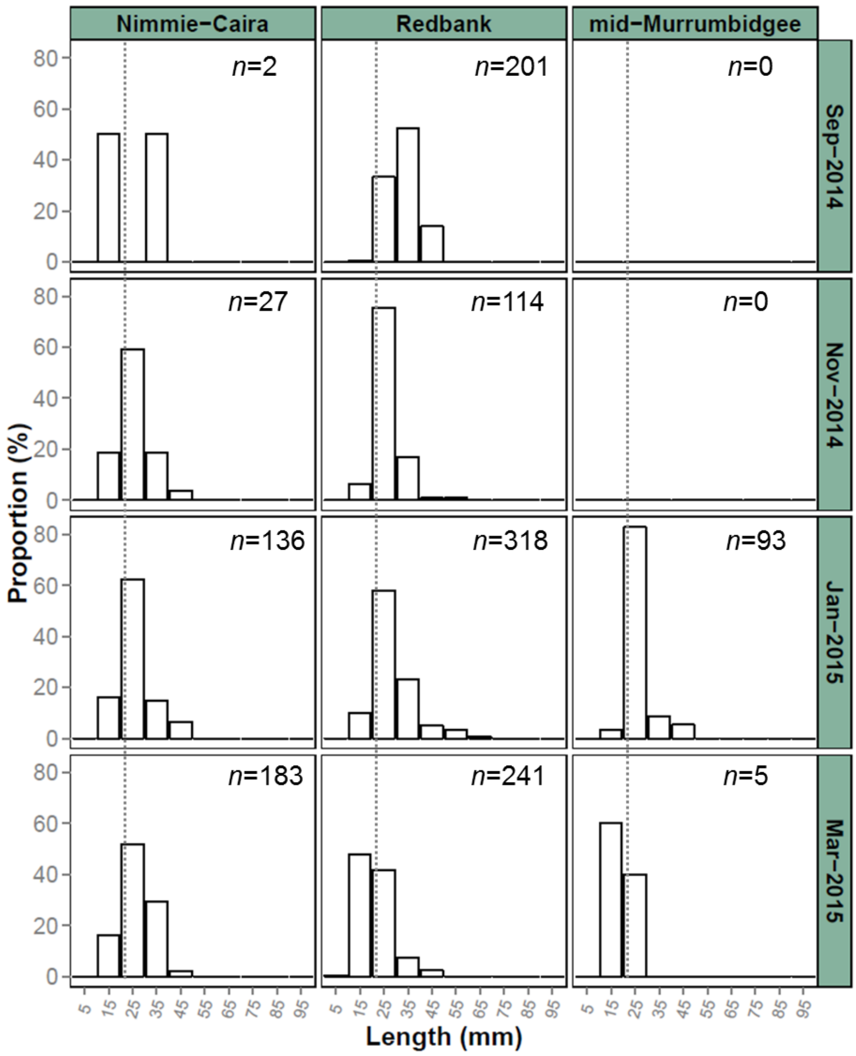


Figure 43 Length-frequency distributions gambusia. The dashed line represents length to denote new recruits (see Table 11).

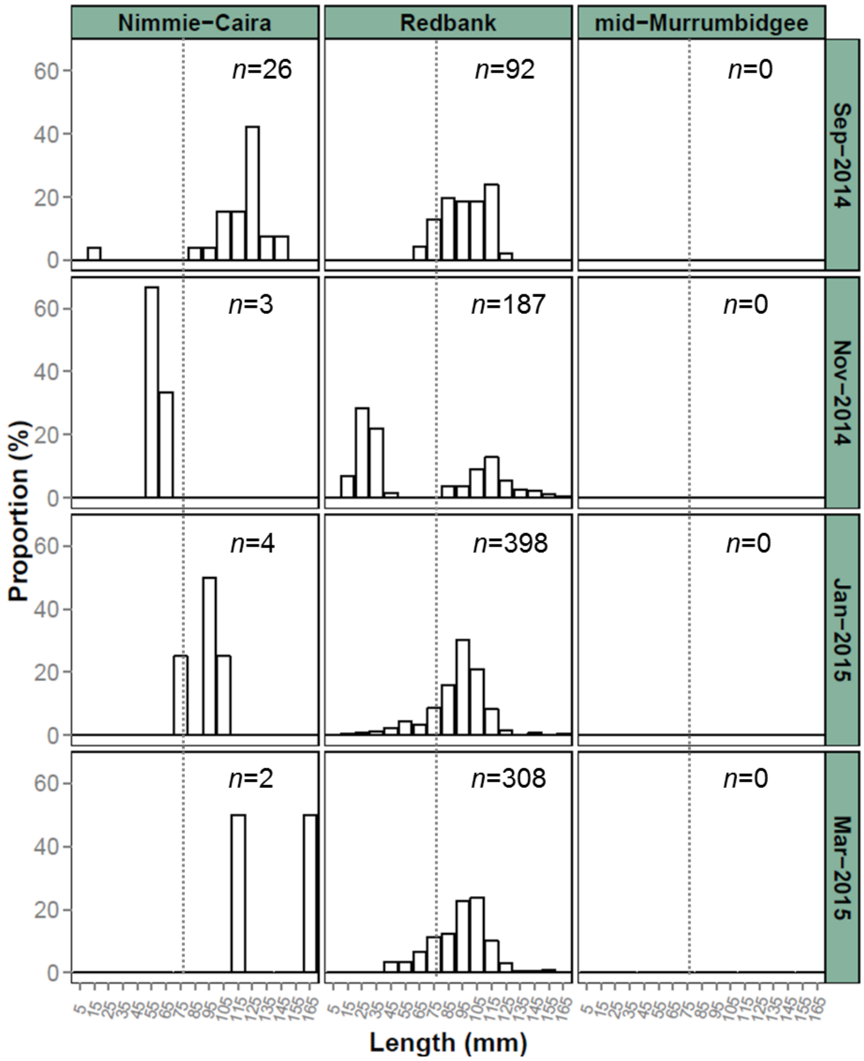


Figure 44 Length-frequency distributions oriental weatherloach. The dashed line represents length to denote new recruits (see Table 11).

Discussion

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

River populations

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

Recruitment

A number of longer-lived native species appear to be recruiting within the lowland sections of the Murrumbidgee River and in wetlands. For example, bony herring recruits were captured in both the Carrathool and Balranald zones, and in the mid-Murrumbidgee wetlands although proportionately more recruits were present in the Balranald zone. Despite being filled via an irrigation pump, bony herring were relatively abundant in Yarradda Lagoon, with individuals >100mm present in the wetland after it filled in mid-December. Bony herring spawn independently of flooding, generally at water temperatures of 21–23 °C (Puckridge *et al.* 1990) and are often abundant in both river and wetland habitats (Wassens *et al.* 2013a; Wassens *et al.* 2014b, this study). Both the abundance and the proportion of bony herring recruits appear to be higher in slower flowing, and less regulated locations (Gehrke 1997; Pusey *et al.* 2004), a result consistent with this study. In the Murrumbidgee River the abundance of Murray cod recruits was higher in the Carrathool zone, compared with both the Narrandera and Balranald zones. Spawning occurred in both Narrandera and Carrathool zones (See Section 3.8), although the density of key prey items such as cladocerans and copepods (Kaminskas *et al.* 2009) at first feed was substantially higher in the Carrathool zone (see Section 3.6). We hypothesise that this contributed to higher survival and subsequently a stronger recruitment event in this zone. Indeed Rowland (1992) demonstrated lower survival of Murray cod larvae following initial delays in available food and subsequent lower densities of microinvertebrates. Given that the species spawns in response to day length and temperature cues, rather than flow, elucidating the mechanisms driving prey availability for larvae and juveniles and their links to flow represent an important component of the current LTIM program.

While spawning of golden perch and silver perch occurred during 2014-15, only one silver perch recent recruit was captured in the Carrathool zone, and none were captured in the Narrandera zone. Further, no golden perch recent recruits were captured in the Murrumbidgee River, but small numbers of recruits were collected at Telephone Creek, which is a permanent channel within the Nimmie-Caira zone. Interestingly, a high density of appropriate first-feed food resources (generally small cladocerans; (Arumugam *et al.* 1992) were available to golden perch in the Carrathool zone and in the Nimmie-Caira wetlands (see Section 3.6). Previous studies have reported spawning by golden perch in multiple river systems within a single season, although limited recruitment in these same systems (Zampatti *et al.* 2015). Others have identified that strong year-classes of both species occurs in non-flood years e.g. (Mallen-Cooper *et al.* 2003), although the mechanisms contributing to these stronger recruitment events remains unknown and represents an important knowledge gap.

There was relatively high level of recruitment by exotic species in the Redbank and Nimmie-Caira zones, Notably a cohort of oriental weatherloach at less than 20mm were recorded in the Redbank zone, indicating that spawning may have occurred either in the wetland, or in the river channel prior to reconnection of the wetlands in October 2014.

3.10 Vegetation

Outcomes summary

The response of understorey vegetation communities to two environmental watering actions was assessed in the mid-Murrumbidgee, Redbank and Nimmie-Caira zones on four occasions (September 2014, November 2014, January 2015 and March-May 2015). Firstly, Action 2, environmental watering of mid-Murrumbidgee wetlands via infrastructure (with the objective of "*continue the recent improvements in wetland vegetation condition*". The second (Action 6) was a Lowbidgee watering event targeting wetlands in South Redbank (Yanga), North Redbank, Nimmie-Caira and Fiddlers-Uara Creek system with the objective of "*maintain, improve and in some cases promote the recovery of wetland vegetation diversity and condition (including lignum, black box and river red gums and associated understory communities such as reeds, sedges and rushes)*". Monitoring of Objective 6 was undertaken in the Redbank and Nimmie-Caira zones only. Dominant vegetation communities surveyed within the mid-Murrumbidgee zone were open ox-bow lagoons with fringing river red gum, with lignum swamps and lignum-black box complexes in the Nimmie-Caira zone and river red gum forest and woodlands and open, seasonally inundated spike rush wetlands in the Redbank zone.

Key findings

- The three wetland zones each support a distinct and diverse vegetation community, demonstrating the importance of delivering environmental water to a variety of wetland types across the Murrumbidgee Catchment.
- A key mid-Murrumbidgee species, Spiny mudgrass was recorded in Yarradda Lagoon following environmental watering in 2014-15. This is the first record of spiny mudgrass at Yarradda Lagoon since monitoring commenced in 2010.

Introduction

Plants growing in rivers, wetlands and floodplains are influenced by a range of factors including climate, geomorphology and inundation history (Brock *et al.* 2003). At a flow event scale the water regime controls hydrological conditions specific to a site (depth, timing, duration, turbulence) interacting with the local climate conditions such as temperature and light to influence the growth of plants (Brock *et al.* 1997; Brock *et al.* 1999; Casanova *et al.* 2000; Capon *et al.* 2006). For these reasons the vegetation communities of rivers, wetlands and floodplain are often characterised by a great diversity of plant species and life-histories ranging from entirely aquatic species, through to terrestrial colonising species which can colonise wetlands and floodplains during dry periods.

The mid-Murrumbidgee wetland system contains a series of anabranches, prior stream channels, and ox-bow lagoons which historically reconnected to the Murrumbidgee River during winter and spring as a result of rainfall and snow melt higher in the catchment (Frazier *et al.* 2005; Frazier *et al.* 2006; Murray 2008). The construction of headwater dams and management of water for irrigation reduced the frequency of these reconnections, particularly for wetlands higher on the floodplain, (Frazier *et al.* 2006). The four wetlands included in this monitoring program were historically either permanent, or annually inundated with infrequent periods of complete drying (Murray 2008).

More recently, in the mid-Murrumbidgee the 2000-2010 drought combined with increased water demand meant there were no flow periods high enough to inundate the majority of wetlands in this system. Two of the sites monitored in this zone Yarradda and Sunshower Lagoons received partial fills in 2005. A further site Gooragool Lagoon is used as an off river storage for irrigation and so would have received some inundation during the drought. Prior to 2001 Mckennas Lagoon was inundated annually, but remained dry from 2001 until 2010. Following the drought all four sites contained water from late 2010 until early 2013 (Wassens *et al.*). The rate of recovery of aquatic vegetation communities was far slower than expected based on seed bank assessments (Nielsen *et al.* 2012), with key species including spiny mud-grass absent between 2010 and 2014 e.g. (Wassens *et al.* 2011; Wassens *et al.* 2012b).

Likewise river red gum has declined over a large-scale in wetlands, forest and woodlands across the large flat, delta system comprising the Lowbidgee floodplain (Wen *et al.* 2009). Areas of functional wetland have reduced over the past 50 years as a result of upstream diversion for irrigation, and the construction of levees and clearing of native vegetation (Kingsford *et al.* 2004b). Despite significant hydrological alteration the Lowbidgee floodplain remains one of Australia's most significant wetland complexes (Kingsford, Brandis et al. 2004, Kingsford and Thomas 2004)(Kingsford *et al.* 2004a). Some wetland areas in both the Redbank and Nimmie-Caira were maintained in relatively good condition through the 2000-2010 drought as a result of environmental water deliveries and the use of Lowbidgee supplementary access licences for irrigation.

Methods

Surveys to assess the understory vegetation assemblage, diversity and cover were conducted at 12 LTIM wetland sites across three wetland zones (Mid-Murrumbidgee wetlands, Redbank and Nimmie- Caira) (Table 17). Understory vegetation at the above sites was monitored every two months starting September 2014 and following onto November 2014, January 2015 and March 2015 (note that the final Nimmie-Caira sampling date was delayed until May 2015 due to access and safety issues). Vegetation monitoring follows the methods described in (Wassens *et al.* 2014a). Vegetation surveys are undertaken along permanent transects that start at the highest point of the wetland and run towards the lowest (deepest point). Transects are between 90 and 250 m long, with understorey and over story vegetation assessed from 1m quadrats, spaced either 3 or 5 m apart along the transect. The length of transects and distance between quadrats is determined by the bathymetry and area of each wetland.

Commonwealth environment water was utilised at one of the four LTIM sites in the mid-Murrumbidgee (Yarradda Lagoon). To test the assumption that environmental watering contributed to achieving the watering objective "*continue the recent improvements in wetland vegetation condition*" we compared data collected in 2014-15 (this study) data collected annually from 2010 (Wassens *et al.* 2011; Wassens *et al.* 2012a; Wassens *et al.* 2013a; Wassens *et al.* 2014b). The period between 2010 and 2015 covered the first fill of the wetlands for five years (Yarradda Lagoon received a partial fill in 2005) and includes two years where the wetland was dry (2012-13 and 2013-2014).

To determine differences in plant communities between the three wetland zones and over time, percent cover data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA Anderson *et al.* (2008)). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which zones differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between zones.

Table 17 Summary of dominant vegetation communities and watering regimes across the 12 LTIM monitoring locations.

Zone	Description	Sites	Status 2004-15
Mid-Murrumbidgee (Action 2)	Open oxbow lagoons, fringing River Red Gum woodland. Highly altered inundation regime.	Mckennas	Dry
		Sunshower	Dry
		Goorgogool	Irrigation drainage
		Yarradda	Environmental water (infrastructure assisted)
Nimmie-Caira (Action 6)	Lignum, lignum-black box, some River red gum fringing permanent creek lines	Eulimbah	Environmental water
		Avalon	Environmental water
		Nap Nap	Environmental water
		Telephone creek	Environmental water (main creek is permanent)
Redbank (Action 6)	River red gum forest, open spike rush dominated wetlands with fringing river red gum	Mercedes	Environmental water
		Two Bridges	Environmental water
		Piggery lake	Environmental water
		Wagorah lagoon	Environmental water (main lagoon is permanent)

Results

Across all surveys a total of 169 predominantly understory plants were recorded, including 122 native species and 47 exotic species. As expected composition of vegetation communities differed significantly between each of the three monitoring zones (mid-Murrumbidgee, Nimmie-Caira and Redbank) ANOSIM (Global R): 0.579, $p < 0.0001$).

Species diversity (d) also differed significantly between zones (GLM, $f = 8.382$, $p < 0.001$), and over time (GLM, $f = 3.187$, $p = 0.036$), but there was no significant interaction between zone and time (GLM, $f = 1.800$, $p = 0.0128$)(Figure 45). Within each zone diversity (d) was significantly higher in September 2014 than in January 2015 surveys (Figure 45)(Sept-Jan Tukey HSD -1.989, $p = 0.011$), but diversity in September 2014 was similar to November 2014 and March 2015.

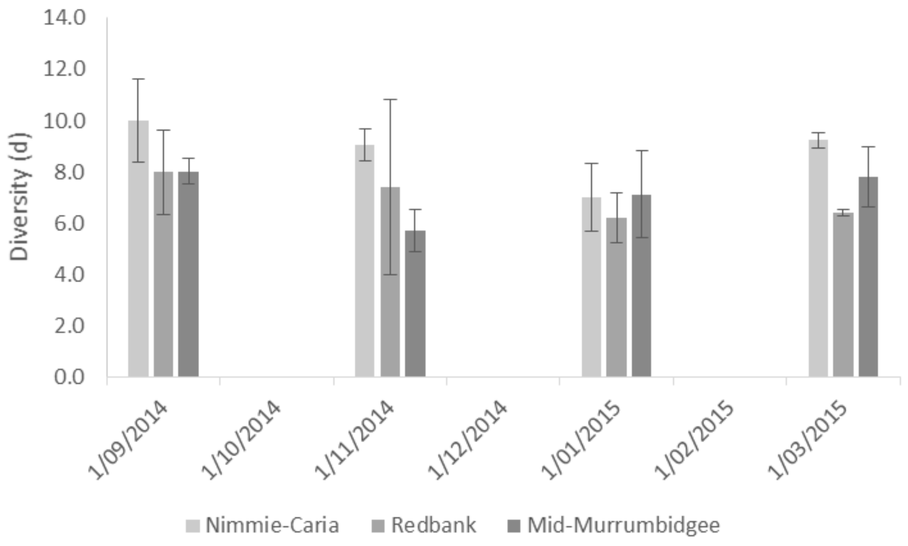


Figure 45 Mean species diversity (d)(±SE) within each zone over the four sampling periods

Mid-Murrumbidgee watering event (Action 2)

Overall there were significant differences in the vegetation community composition between the four mid-Murrumbidgee sites (ANOSIM Global r 0.573, p = 0.001) with two sites (Sunshower and Mckennas) remaining dry throughout the 2014-15 monitoring period while two others Gooragool Lagoon (contained irrigation drainage water) and Yarradda Lagoon (pumped environmental water) contained some water.

As expected community composition has changed significantly between water years reflecting wetting (2010-2012, 2014-2015) and drying (2013-14) patterns (ANOSIM Global R): 0.727, p < 0.001). Importantly the key amphibious species, spiny mud grass (*Pseudoraphis spinescens)* which was the dominant species at Yarradda Lagoon during IMEF monitoring (Chessman 2003) was recorded for the first time during these surveys (Figure 46).

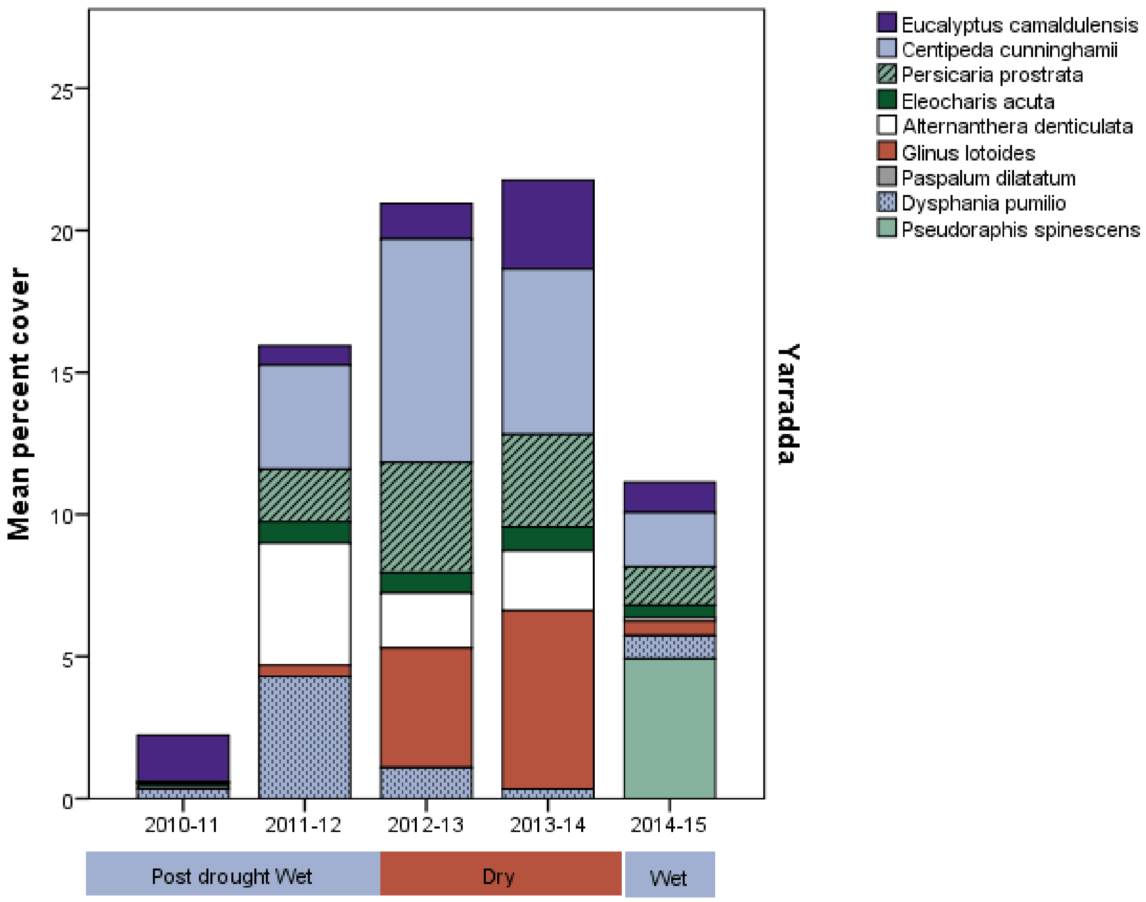


Figure 46 Change in the percent cover of dominant species between 2010 and 2015. Data is drawn from (Wassens *et al.* 2011; Wassens *et al.* 2012b; Wassens *et al.* 2013a; Wassens *et al.* 2014b)

SIMPER comparisons of wet and dry sites across the mid-Murrumbidgee in 2014-15 (Table 18) demonstrated clear differences between wet (Yarradda and Gooragool) and dry sites (Mckennas and Sunshower). Dry sites were dominated by exotic weed species including spear thistle (*Cirsium vulgare*), prickly lettuce (*Lactuca serriola*), exotic grasses, and were undergoing river red gum encroachment (Eucalyptus camaldulensis). Native terrestrial species including creeping saltbush (*Atriplex semibaccata*), burr daisy (*Calotis scapigera*) and Riverina bluebell (*Wahlenbergia fluminalis*) also occur. Wet sites were dominated by knotweed (*Persicaria decipiens*), spiny mudgrass (*Pseudoraphis spinescens*) and common spikerush

(*Eleocharis acuta*). The culturally significant species common sneeze weed (*Centipeda cunninghamii*) (Gukwonderuk, Budhaay) also made a significant contribution to the differences between wet and dry sites and was relatively common at wet sites Gooragool and Yarradda Lagoons.

Table 18 Simper comparisons between mid-Murrumbidgee sites containing water (wet) and dry sites

Species	**Group Wet Av.Abund**	**Group Dry Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Cirsium vulgare	0.6	1.78	3.96	0.97	5.16	5.16
Terrestrial grass	0.8	1.3	3.81	1.01	4.96	10.12
Persicaria decipiens	1.15	0.02	2.98	0.64	3.87	13.99
Pseudoraphis spinescens	0.96	0.1	2.79	0.73	3.64	17.63
Eleocharis acuta	1.32	0.45	2.75	1.08	3.58	21.2
Medicago polymorpha	0	1.17	2.45	0.58	3.19	24.39
Paspalum distichum	0.77	0.15	2.18	1.15	2.83	27.22
Eucalyptus camaldulensis	0.89	1.55	2.16	0.91	2.82	30.04
Cyperus eragrostis	0.88	0	2.16	0.9	2.81	32.85
Centipeda cunninghamii	0.79	0.42	2.1	1.11	2.74	35.59
Calotis scapigera	0.37	0.69	2.05	1.14	2.67	38.25
Panicum effusum	0.8	0	1.96	0.54	2.55	40.8
Chamaesyce drummondii	0.44	0.34	1.82	0.91	2.37	43.18
Alternanthera denticulata	0.75	0.12	1.65	0.97	2.15	45.33
Persicaria prostrata	0.4	0.3	1.54	0.85	2	47.33
Ludwigia peploides ssp. montevidensis	0.71	0	1.52	0.74	1.97	49.3
Juncus usitatus	0.66	0	1.48	1.04	1.92	51.22
Atriplex semibaccata	0.77	0.86	1.45	0.92	1.88	53.11
Polygonum aviculare	0.62	0.28	1.4	1.2	1.82	54.93
Senecio quadridentatus	0.08	0.47	1.38	0.85	1.8	56.73
Paspalidium jubiflorum	0.45	0.29	1.34	0.84	1.75	58.48
Lactuca serriola	0.2	0.63	1.33	1.13	1.73	60.22
Persicaria lapathifolia	0.5	0	1.22	0.57	1.59	61.81
Dysphania pumilio	0.43	0.18	1.19	0.81	1.55	63.36
Tragopogon porrifolius	0.5	0.18	1.15	1.29	1.5	64.86
Lythrum hyssopifolia	0.49	0	1.1	0.9	1.43	66.29
Senico runcinifolius	0.37	0.2	1.1	0.83	1.43	67.72
Sonchus oleraceus	0.1	0.41	0.99	1.01	1.29	69.01
Wahlenbergia fluminalis	0.07	0.4	0.98	1.25	1.28	70.29
Trifolium tomentosum	0.07	0.37	0.85	0.59	1.1	71.39
Trifolium arvense	0.08	0.36	0.83	0.59	1.08	72.48
Cynodon dactylon	0	0.32	0.82	0.5	1.07	73.55
Chenopodium curvispicatum	0.14	0.2	0.8	0.46	1.04	74.59
Conyza bonariensis	0.21	0.2	0.76	0.88	0.99	75.58
Bassia decurrens	0	0.25	0.76	0.62	0.99	76.56
Scleroblitum atriplicinun	0.03	0.26	0.73	0.76	0.95	77.51
Vittadinia cuneata	0	0.28	0.71	0.82	0.93	78.44
Forb	0.11	0.05	0.69	0.45	0.9	79.34

Two Bridges Swamp (transect 1) September 2014

Two Bridges Swamp (transect 1) November 2014

Plate 2 Rapid growth of common spikerush (E. acuta) at Two Bridges Swamp in the Redbank system from September 2014 (left) to November 2014 (right).

Lowbidgee and Nimmie-Caira watering

In the Nimmie-Caira zone the four most abundant species were lignum (*Muehlenbeckia florulenta*), water primrose (*Ludwigia peploides ssp. Montevidensis*), common sneeze weed and nardoo (*Marsilea drummondii*), while in the Redbank zone wetlands were dominated by tall spike rush (*Eleocharis sphacelata*), common spike rush (*Eleocharis acuta*), azolla (*Azolla filiculoides*), and nardoo (*Marsilea drummondii*). The composition of vegetation communities changed between the four sampling occasions, although the relationship was relatively weak (ANOSIM Global R 0.196, p =0.005). In the Redbank zone the majority of sites were dry in September and communities were dominated by opportunistic annual species and semi-aquatic species including common sneeze weed and swamp butter cup (*Ranunculus undosus*). There was a strong response to watering at the majority of Redbank sites (Plate 2), but the rate of change in the community was influenced by water depth, and increases in the cover of aquatic vegetation was slower at larger deeper sites such as Piggery Lake (Plate 3) compared to small shallow sites such as Two Bridges and Mercedes Swamps (Figure 47). With the exception of Avalon Swamp, the remaining Nimmie-Caira sites contained water in September and the percentage cover of amphibious species peaked in January before declining as the sites dried down.

Plate 3 Piggery Swamp, Redbank zone March 2015.

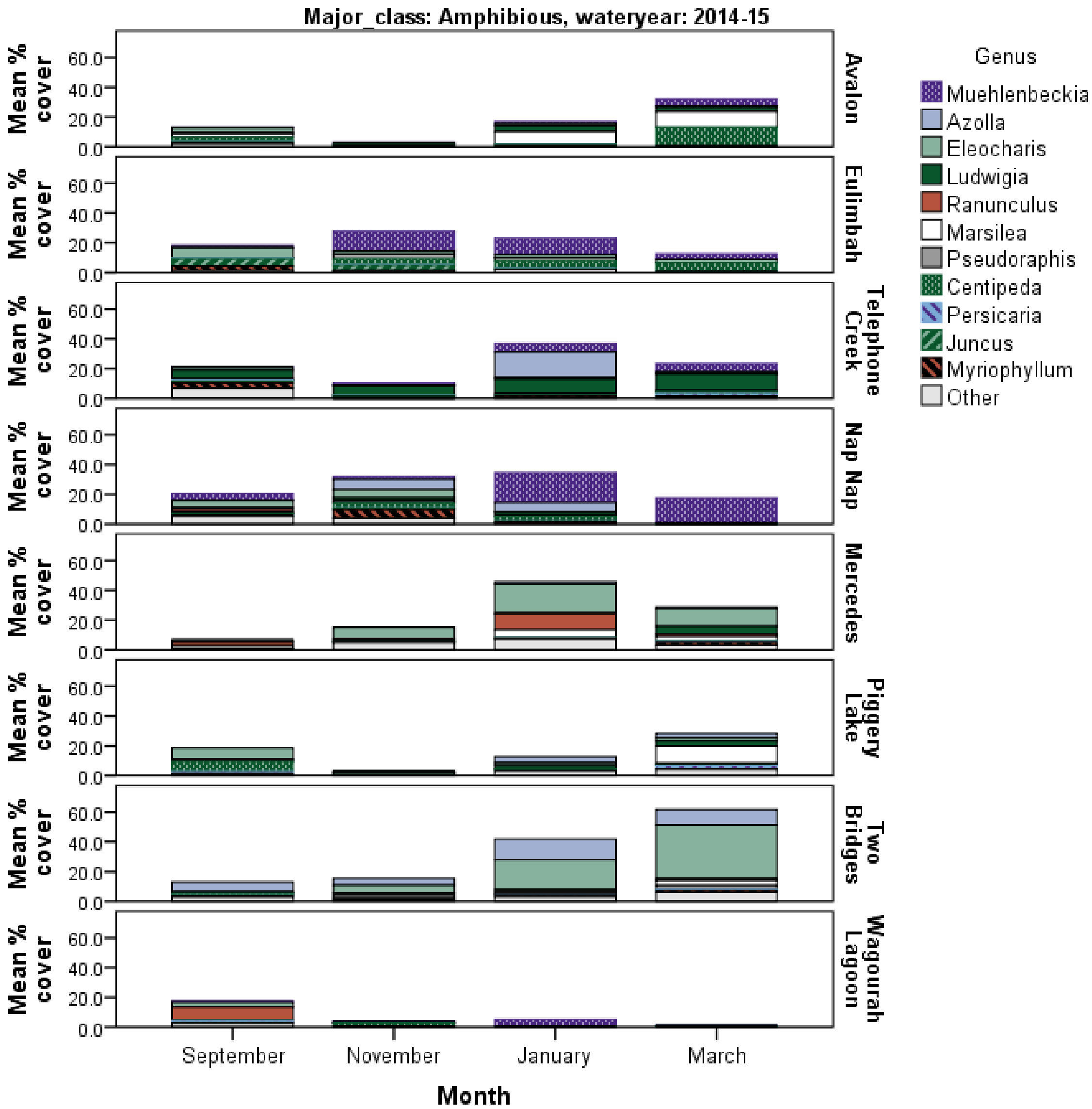


Figure 47 Changes in percentage cover of key amphibious (Casanova 2011) genera in the Lowbidgee sites from the Nimmie-Caira (Avalon, Eulimbah, Telephone Creek, Nap Nap)and Redbank (Mercedes, Piggery lake, Two bridges, Wagourah Lagoon).

Table 19 Simper comparisons between Nimmie-Caira and Redbank zones in the Lowbidgee floodplain

Species	Nimmie-Caira Av.Abund	Redbank Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum.%
Eleocharis sphacelata	0	2.76	5.04	1.01	6.45	6.45
Muehlenbeckia florulenta	2.31	0.38	4.13	1.43	5.3	11.75
Azolla filiculoides	0.85	1.31	2.93	0.99	3.76	15.51
Eleocharis acuta	0.9	1.81	2.9	1.26	3.71	19.22
Ludwigia peploides ssp. montevidensis	1.59	0.84	2.63	1.13	3.37	22.59
Marsilea drummondii	1.35	1.3	2.52	1.09	3.23	25.82
Eleocharis pusilla	1.07	1.15	2.27	1.23	2.91	28.73
Centipeda cunninghamii	1.48	0.82	2.2	1.22	2.82	31.55
Alternanthera denticulata	0.68	0.78	1.63	1.07	2.09	33.64
Paspalidium jubiflorum	0.75	0.55	1.58	1.14	2.02	35.67
Juncus usitatus	0.78	0	1.51	1.06	1.93	37.6
Heliotropium europaeum	0.61	0.23	1.34	0.9	1.72	39.32
Ranunculus undosus	0	0.66	1.2	0.55	1.54	40.86
Dysphania pumilio	0.56	0.14	1.12	0.86	1.43	42.29
Chenopodium nitrariaceum	0.39	0.3	1.07	0.86	1.37	43.66
Persicaria decipiens	0.36	0.44	1.04	1.04	1.34	45
Myriophyllum papillosum	0.42	0.35	1.02	1.01	1.31	46.31
Myriophyllum verrucosum	0.55	0	1	0.66	1.28	47.59
Grass	0.53	0.11	0.97	0.98	1.24	48.83
Marrubium vulgare	0.13	0.46	0.91	0.89	1.17	50
Ranunculus pumilio	0.21	0.37	0.91	0.48	1.16	51.16
Pratia concolor	0.38	0.33	0.9	1.09	1.15	52.31
Paspalum distichum	0.05	0.44	0.9	0.88	1.15	53.46
Sclerolaena muricata	0.1	0.38	0.86	0.67	1.1	54.57
Damasonium minus	0.09	0.46	0.83	0.64	1.07	55.63
Chlarophyte	0.03	0.41	0.83	0.56	1.06	56.69
Eucalyptus camaldulensis	0.31	0.37	0.81	1.21	1.04	57.73
Atriplex semibaccata	0.24	0.29	0.81	0.79	1.04	58.77
Rorippa eustylis	0.42	0.08	0.81	0.67	1.04	59.8
Brachycome basaltica	0.06	0.43	0.78	1.19	1	60.81
Verbena supina	0.4	0.02	0.78	0.94	0.99	61.8
Myriophyllum crispatum	0.3	0.19	0.77	0.68	0.98	62.78
Senico runcinifolius	0.41	0.13	0.75	1.33	0.97	63.75
Pseudoraphis spinescens	0.06	0.37	0.75	0.66	0.96	64.71
Mentha australis	0.38	0	0.73	0.85	0.94	65.64
Ammannia multiflora var. multiflora	0.29	0.1	0.71	0.59	0.91	66.55
Lythrum hyssopifolia	0.34	0.05	0.68	0.76	0.87	67.42
Asperula geminifolia	0.35	0	0.63	0.97	0.81	68.23
Marsilea hirsuta	0.21	0.14	0.63	0.54	0.8	69.03
Crassula helmsii	0.26	0.14	0.62	0.72	0.79	69.82
Typha spp.	0.04	0.3	0.61	0.61	0.78	70.61
Mimulus graculis	0.3	0.06	0.6	0.56	0.77	71.38
Cyperus difformis	0.26	0.08	0.59	0.66	0.76	72.13
Potamogeton tricarinatus auct.	0.13	0.23	0.58	0.68	0.75	72.88
Chamaesyce drummondii	0.13	0.25	0.58	0.88	0.74	73.62
Conyza bonariensis	0.24	0.15	0.58	0.82	0.74	74.36
Polygonum aviculare	0.3	0.03	0.57	0.77	0.74	75.09
Persicaria prostrata	0.27	0.03	0.57	0.58	0.73	75.83
Cirsium vulgare	0.13	0.27	0.57	0.75	0.73	76.56
Rhagodia nutans	0.2	0.14	0.57	0.6	0.73	77.28
Chenopodium album	0.08	0.26	0.57	0.51	0.72	78.01
Juncus flavidus	0.28	0	0.56	0.57	0.72	78.73
Goodenia heteromera	0.26	0	0.56	0.56	0.71	79.44
Eleocharis pallens	0.29	0	0.55	0.37	0.71	80.15

Discussion

Relatively small scale infrastructure assisted water deliveries have aided this recovery at Yarradda Lagoon this year allowing for the reestablishment of spiny mudgrass. Indeed, as the seedbank viability of spiny mudgrass is relatively short, it is likely that the transfer of water to the lagoon via irrigation canals containing spiny mudgrass may have facilitated its reintroduction to the lagoon. The wetlands of the mid-Murrumbidgee have been subject to significant, long-term hydrological modification. Following the natural flooding in 2010, rate of recovery of vegetation communities has been extremely slow with a number of previously common amphibious species including tall spike rush, common spike rush and spiny mudgrass largely absent from the mid-Murrumbidgee wetlands between 2010 and 2014 (Wassens *et al.* 2011; Wassens *et al.* 2012a; Wassens *et al.* 2013a; Wassens *et al.* 2014b). Loss of perennial rhizomes and diminished seed banks are expected to have contributed to the poor rate of recovery in the mid-Murrumbidgee as has been recorded in other areas e.g. (Reid *et al.* 2011).

River red gum encroachment is a serious problem at dry sites in the mid-Murrumbidgee with both McKennas and Sunshower Lagoons containing dense stands of river red gum seedlings. Environmental watering is one of the principle mechanisms for controlling river red gum encroachment into wetlands and is a high priority for encroached sites in the mid-Murrumbidgee.

Compared to the mid-Murrumbidgee wetland systems, wetlands through the Lowbidgee floodplain are in relatively good condition and support diverse, native vegetation communities. The response to Commonwealth environmental watering is rapid, indicating that perennial rhizomes are in good condition and that seedbanks are viable. This is the first year of monitoring in the Lowbidgee systems and represents a benchmark against which to assess long-term changes in vegetation communities.

3.11 Other vertebrate diversity- Frogs and Turtles

Outcomes summary

Frogs and their tadpoles are important components of wetland ecosystems. The response of frogs to environmental watering is influenced by the timing and duration of the inundation, as well as wetland characteristics such as aquatic vegetation cover and flooding frequency. The Commonwealth environmental watering objectives for the Murrumbidgee River system in 2014-15 related to frogs were Action 2 – mid-Murrumbidgee reconnection (infrastructure assisted) and Action 6 – Lowbidgee – wetlands. Nine of the 12 LTIM monitoring wetlands received environmental water in 2014-15, while one, Gooragool Lagoon in the mid-Murrumbidgee received drainage water nearby from irrigation operations. The remaining two wetlands, McKenna's and Sunshower lagoons in the mid-Murrumbidgee zone remained dry.

The key watering objectives related to frogs were to "*Provide habitat to maintain condition of waterbirds, native fish, other aquatic vertebrates (turtles, frogs) and invertebrates*" and "*Provide habitat to support survival and maintain condition of native fish, waterbirds and other aquatic vertebrates (frogs).*" The maintenance of frog communities and population through the Murrumbidgee Catchment relate to longer term Basin Plan objectives of maintaining biodiversity. Overall, five frog species were recorded breeding across the ten LTIM monitoring sites.

Key findings

- Environmental watering, using NSW EWA, targeted known habitats of the southern bell frog (*Litoria raniformis*) in the Nimmie-Caira zone (Action 6). Calling and tadpoles of southern bell frogs and other frog species were recorded at all four LTIM monitoring wetlands in the Nimmie-Caira, indicating that these flows were successful in created breeding opportunities for this nationally vulnerable species, and other floodplain frog species.
- Commonwealth environmental watering targeted one wetland (Yarradda Lagoon) in the mid-Murrumbidgee wetland systems (Action 2). Inland banjo frog (*Limnodynastes interioris*) adults and tadpoles were recorded in this

wetland for the first time since monitoring commenced in 2010. Large numbers of Peron's tree frog (*Litoria peronii*) tadpoles were also recorded.

Introduction

Frogs are important components of floodplain wetlands. Both adults and tadpoles can comprise a significant proportion of aquatic biomass and therefore provide key energy resources for wetland predators including waterbirds, aquatic invertebrates and snakes (Gibbons *et al.* 2006; Chan *et al.* 2009; Connelly *et al.* 2011). Most frog species in the mid and lower Murrumbidgee catchment wetlands prefer still or slow moving water, particularly for breeding. Environmental watering actions targeting wetlands can provide benefits for frogs and their tadpoles and are important to the survival of flow-specialist species, such as the vulnerable southern bell frog (*Litoria raniformis*).

The Commonwealth watering objectives for the Murrumbidgee River system in 2014-15 relating to frogs were **Action 2** – mid-Murrumbidgee reconnection (infrastructure assisted) and **Action 6** – Lowbidgee – wetlands in Yanga, North Redbank, Nimmie-Caira and Fiddlers-Uara Creek system. Adult frogs and their tadpoles were monitored at 10 wetlands receiving Commonwealth environmental water in the mid-Murrumbidgee, Redbank and Nimmie-Caira zones. In both cases, the watering action aimed to: "*Provide habitat to maintain condition of waterbirds, native fish, other aquatic vertebrates (turtles, frogs) and invertebrates*." Specifically, we predicted that:

- environmental watering will support species richness in each zone,
- environmental watering will promote calling behaviour indicative of breeding activity followed by tadpole occurrence, and
- environmental water coinciding with the breeding window of southern bell frogs will trigger breeding activity, e.g. the presence of calling males and tadpoles.

Methods

Adult frogs were surveyed for presence and calling behaviour during timed nocturnal searches at 10 wetland sites (Nimmie-Caira, n = 4, Redbank, n = 4, and Mid-Murrumbidgee n = 2) on four occasions between September 2014 – May 2015.

Tadpoles were monitored alongside the wetland fish surveys (see Section 3.9) using a combination of small (n=2) and large fyke (n=2) nets set overnight. Adults frogs were surveyed along two timed 20 minute transects after dark, the number of calling individuals was recorded at 5 minute intervals during the transect survey as well as the average number recorded (for full details see (Wassens *et al.* 2014a). Monitoring for frogs and tadpoles was undertaken at the 10 LTIM monitoring sites that contained water during the study period. The two other LTIM monitoring sites (Sunshower and Mckennas, both mid-Murrumbidgee) were dry and consequently not surveyed for tadpoles or adult frogs.

One of the mid-Murrumbidgee sites (Gooragol Lagoon), received a small amount of water which had drained from surrounding irrigation area and was only deep enough to survey for tadpoles in November 2014. Yarradda Lagoon received Commonwealth environmental water in December 2014.

Results

Overall, 2,212 adult frogs (seen and heard) and 1,100 tadpoles of six species were recorded between September 2014 and May 2015 across 10 LTIM monitoring sites, with two sites remaining dry throughout 2014-15.

Adult barking marsh frogs (*Limnodynastes fletcheri*), spotted marsh frogs (*Limnodynastes tasmaniensis*), plains froglets (*Crinia parinsignifera*) were recorded in all three zones. Peron's tree frogs (*Litoria peronii*), inland banjo frogs (*Limnodynastes interioris*) were less widespread, while the vulnerable southern bell frog (*Litoria raniformis*) had the most restricted distribution, only occurring across the four Nimmie-Caira sites.

As expected the abundance of southern bell frog adults was significantly higher in the Nimmie-Caira zone, with no individuals recorded in either the Redbank or mid-Murrumbidgee zones (GLM 16.045, $p < 0.001$), abundance was highest in November coinciding with the start of the breeding period, contributing to slight, but not significant interaction between zone and time (GLM 11.429, $p = 0.076$)(Figure 48). Southern bell frog tadpoles were most abundant in January, with small numbers also recorded in November.

Peron's tree frog adults and tadpoles were most abundant in the mid-Murrumbidgee, with high numbers recorded in January following environmental watering of Yarradda Lagoon (Action 2). Inland banjo frog adults and tadpoles were recorded in Yarradda lagoon, the first record of this species at this site since monitoring commenced in 2010.

Spotted and barking marsh frogs were most abundant through the Redbank systems with comparatively high numbers of adults and tadpoles recorded (Figure 49). The barking marsh frog in particular was comparatively rare in the Nimmie-Caira and mid-Murrumbidgee contributing to significant differences between zones (GLM 33.160, $P < 0.00$), reflecting this species preference for frequently inundated waterbodies. Spotted and barking marsh frog tadpoles are indistinguishable and are therefore grouped as *Limnodynastes sp. Limnodynastes* tadpoles were most abundant in November and January through the Redbank zone with relatively small numbers recorded through the Nimmie-Caira and Redbank (see Figure 49).

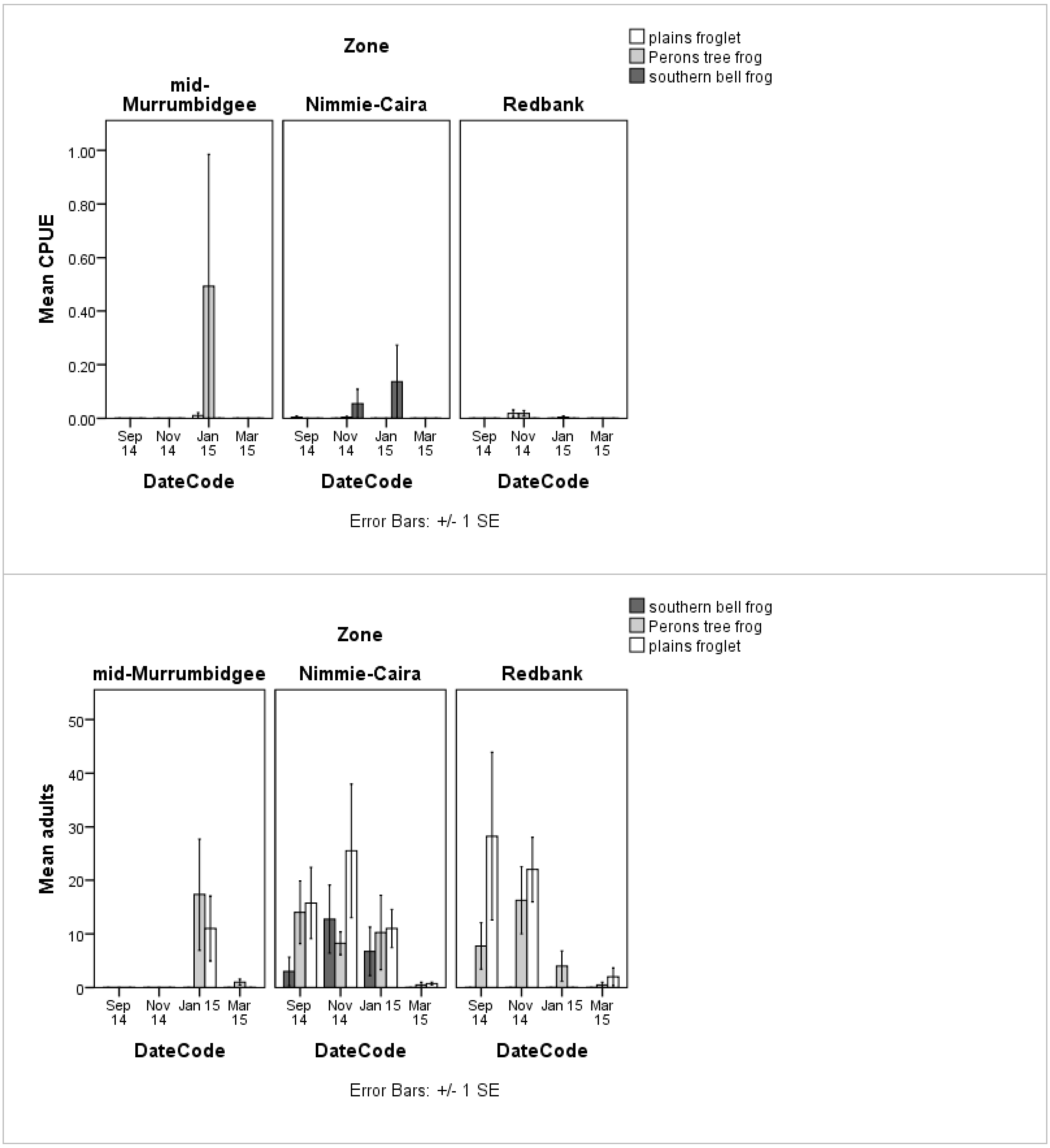


Figure 48 Mean (± SE) CPUE of tadpoles (top) and abundance of adult (bottom) southern bell frogs, Perons tree frog and plains froglet across the four sampling occasions.

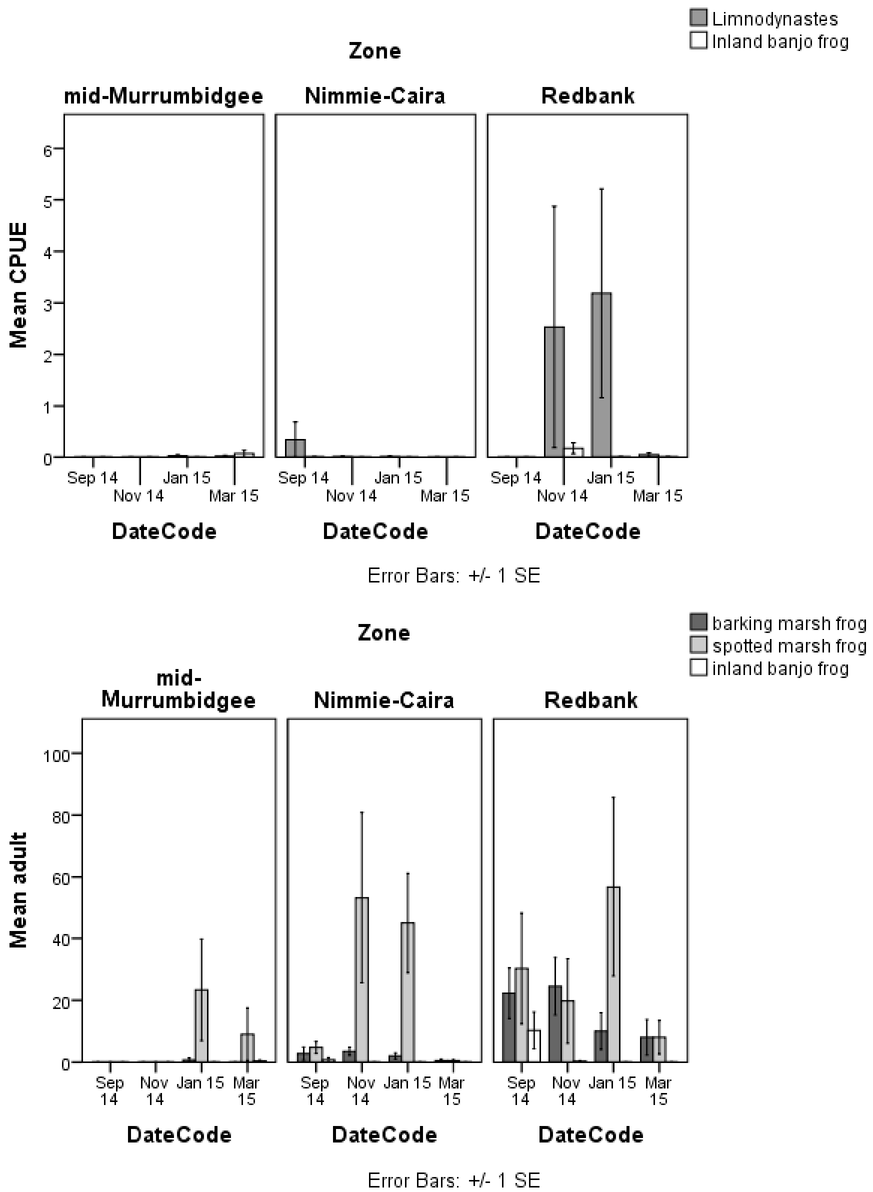


Figure 49 Mean (± SE) CPUE of tadpoles (top) and abundance of adult (bottom) barking marsh frogs, spotted marsh frog and inland banjo frog bell frogs.

Turtles

Two species of freshwater turtles were recorded in the LTIM wetland sites that held water in 2014-15. In total, 28 individuals were recorded, nearly all of which were the eastern long-necked turtles which were recorded at all 10 LTIM wetland sites (27 turtles). One broad shell turtle was recorded at one site only (Wagourah Lagoon, Redbank). No recent hatchlings were recorded, however, based on size at sexual maturity (160 mm in female and 145 mm in male eastern long-neck turtle (Kennett *et al.* 1990), carapace lengths indicated eight of the 28 individuals collected were not yet sexually mature. The smallest individuals were recorded at Nap Nap Swamp (84 mm, Nimmie-Caira) and Two Bridges swamp (90 mm, Redbank).

Discussion

Three frog species were recorded breeding in Yarradda Lagoon following infrastructure mediated delivery of environmental water (Action 2). Peron's tree frogs and inland banjo frogs with smaller numbers of spotted marsh frogs. This is the first record of inland banjo frogs in Yarradda Lagoon and the first record of this species in the mid-Murrumbidgee LTIM sites. The abundance of *Limnodynastes* tadpoles were slightly lower than in previous years (Wassens *et al.* 2012a; Wassens *et al.* 2013a; Wassens *et al.* 2014b), however large numbers of Peron's tree frog tadpoles were recorded in January 2015 and inland banjo frog tadpoles were recorded in March 2015.

Six species of frogs were recorded across the Nimmie-Caira and Redbank zones during the 2014-15 Commonwealth environmental watering action (Action 6) with evidence of breeding activity for all species (calling males heard and/or tadpoles caught). The composition of frog communities differed between the two zones, with southern bell frog recorded at all four sites in the Nimmie-Caira, but not in any Redbank wetlands during 2014-15. Environmental water was delivered to wetlands in the Nimmie-Caira and Redbank zones where the southern bell frog had been recorded in 2012-13 and 2013-14 water years (Wassens *et al.* 2014b). Southern bell frogs were recorded calling at environmental watering sites in September, November 2014 and January 2015 following environmental watering. There has been a gradual decline in southern bell frog abundances at Redbank sites relative to previous years e.g. (Wassens *et al.* 2010; Spencer *et al.* 2011b), and no southern bell frogs recorded at watering sites in the Redbank zone in 2014-15.

Environmental watering can promote amphibian calling behaviour indicated by breeding activity followed by tadpole occurrence and recently metamorphosed frogs at LTIM wetlands, though the species which are active will vary depending on the timing of the watering event e.g. (Wassens 2010a; Wassens 2010b; McGinness *et al.* 2014). The focus on late spring and summer watering in recent years has appeared to increase breeding outcomes for the vulnerable southern bell frog in the Nimmie-Caira, with numbers of southern bell frogs recorded higher than in 2013-14 (Wassens *et al.* 2014b). There has been a general positive recovery of this species following successive years of environmental watering in the Nimmie-Caira see (Spencer *et al.* 2011a; Wassens *et al.* 2013a; Wassens *et al.* 2013b).

Southern bell frogs have highly specialised habitat requirements, preferring seasonally inundated wetlands with areas of warm, shallow water (Wassens *et al.* 2008; Wassens *et al.* 2010). As in previous years tadpoles were recorded in November and January, which is characteristic of this summer breeding species. The Nimmie-Caira zone is an important area for the vulnerable southern bell frogs which have been consistently recorded calling at Telephone Creek, Eulimbah, Nap Nap and Avalon swamps, with tadpoles caught at Nap Nap swamp in 2014-15. Complementary nocturnal surveys for adult frogs by NSW OEH and CEWO staff, also identified calling by southern bell frogs at an additional three sites across the Nimmie-Caira which neighbour the LTIM wetlands. In contrast, no southern bell frogs were observed at wetlands in Redbank in 2014-15 which is consistent with a decline in this zone, previous 2013-14 only small numbers a few individuals were recorded at Mercedes Swamp and Paul Coates Swamp (North Redbank) during previous water years. In 2001 southern bell frogs were abundant through the Redbank system and the causes of the decline of this species is unclear. Current monitoring shows water quality parameters are broadly consistent between Redbank and Nimmie-Caira zones (see Section 3.4) although minimum DO was significantly lower in the Redbank zone. More research is needed to examine whether DO may be a driver of the decline in southern bell frogs. The establishment of oriental weatherloach populations in the Redbank zone since 2013 might also have contributed to southern bell frog declines these relationships have never been fully established. The barking marsh frog and spotted marsh frog continue to dominate the frog communities at the deeper, more persistent wetlands within the Redbank zone.

In the mid-Murrumbidgee (Action 2), infrastructure assisted delivery of environmental water had a strong positive effect on frog communities, with breeding by Peron's tree frog and inland banjo frog recorded at this wetland for the first time since monitoring commenced in 2011 (Wassens *et al.* 2012b; Wassens *et al.* 2013a; Wassens *et al.* 2014b). Tadpole abundances were higher in Yarradda then in Gooragool lagoons, possibly because the duration of inundation resulting from irrigation drainage water was not sufficient to sustain tadpole growth and development.

3.12 Waterbird Diversity

Outcomes summary

Wetlands in the Murrumbidgee Catchment are widely recognised for their importance for waterbirds, providing breeding habitat for colonially-nesting waterbirds and habitat for waterbird species listed as threatened under the Commonwealth *EPBC Act 1999* or under migratory bird agreements Australia has with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA). In 2014-15 the key objective of the Commonwealth environmental watering actions in the Murrumbidgee Catchment in relation to waterbirds was to "*provide habitat for waterbirds, native fish and other aquatic vertebrates*" across Actions 2 and 6 watering actions, where Action 2 involved the use of infrastructure to reconnect parts of the mid-Murrumbidgee wetlands and Action 6 aimed to inundate large parts of the Lowbidgee floodplain. We undertook quarterly ground surveys for waterbirds in the mid-Murrumbidgee, Nimmie-Caira and Redbank zones in 2014-15 alongside wetland fish, frog, microinvertebrate and nutrient monitoring the 12 Murrumbidgee LTIM wetland sites. The results of these surveys were used to assess waterbird species diversity, abundance and breeding activity, and their responses to the delivery of Commonwealth environmental water. These surveys followed on from quarterly monitoring of waterbirds across the Murrumbidgee Catchment since 2008. The 2014-15 surveys were complemented by coincident surveys by NSW OEH and CEWO staff during the same time period across a greater spread of sites in the three zones and the neighbouring Western Lakes. We expected local increases in the abundance and diversity of waterbird species, including species of conservation significance (i.e. threatened species, and JAMBA, CAMBA and ROKAMBA species), and some small scale colonial waterbird breeding in response to Commonwealth environmental watering in 2014-15.

Key findings

- 36 waterbird species were observed across the 12 Murrumbidgee LTIM wetland survey sites. This compares with at least 58 waterbird species recorded over the preceding 2008-14 monitoring period. Waterbird diversity and abundance peaked in the January 2015 surveys when the extent of flooding was greatest.

- Under **Action 2** Yarradda Lagoon received water in December 2014, with influxes of pink-eared ducks (*Malacorhynchus membranaceus)* recorded.
- In the Lowbidgee floodplain (**Action 6**) two species listed Eastern great egret sharp-tailed sandpiper on two or more international bilateral migratory bird agreements (JAMBA, CAMBA and ROKAMBA) were recorded in wetlands that received Commonwealth environmental water in 2014-15.
- Two species were recorded breeding at the LTIM monitoring sites in the Lowbidgee floodplain, the grey teal (*Anas gracilis*) and Pacific black duck (*Anas superciliosa*)

Introduction

Waterbirds are highly mobile and can feed on a wide range of flora and fauna, moving between wetlands in response to drying and flooding phases to maximise feeding and breeding opportunities (Roshier *et al.* 2001; Kingsford *et al.* 2002; Roshier *et al.* 2002). As a group, waterbirds are an important part of aquatic ecosystems and their diversity and abundance can be linked to multiple wetland components including aquatic vegetation cover, and microinvertebrate density and fish abundance. The mid-Murrumbidgee and Lowbidgee wetlands are recognised as nationally significant habitat for waterbirds, supporting nationally threatened species and species listed under international migratory bird agreements. During large floods the Lowbidgee wetlands can also support some of the largest colonies of nesting waterbirds in the Murray-Darling Basin (Bino *et al.* 2014).

Methods

Ground surveys to assess waterbird species diversity, maximum abundance and breeding activity were conducted at the 12 LTIM wetland survey sites spread across the mid-Murrumbidgee, Nimmie-Caira and Redbank zones. Methods followed those employed previously to survey waterbirds in the Murrumbidgee Catchment and are documented in (Wassens *et al.* 2014a).

Waterbird species were separated into eight functional groups as per (Hale *et al.* 2014) (see Appendices) 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 Section 3.3. Across the 12 wetland survey sites approximately 152 ha of wetlands were surveyed in Redbank zone, 198 ha in the Nimmie-Caira zone and 104 ha in the mid-Murrumbidgee zone. Multivariate analyses (PRIMER 2002) were used to investigate differences in waterbird species assemblages in the wetlands sites before and after Commonwealth environmental watering, and with sites that did not receive environmental water in 2014-15.

Results

Waterbird diversity

In total 5,703 waterbirds from 36 waterbird species were recorded during the 2014-15 surveys of the Murrumbidgee wetland sites. This included the national endangered Australasian bittern (*Botaurus poiciloptilus)* (EPBC Act), and Eastern great egret *(Ardea modesta)* and sharp-tailed sandpiper *(Calidris acuminata)* which are listed under two or more international migratory bird agreements (see Appendices).

Total waterbird diversity and abundance varied across the wetland zones in response to varying patterns of flooding. Sites in the Nimmie-Caira zone supported the most diverse waterbird assemblages (30 species) compared to the Redbank (25 species) and mid-Murrumbidgee (17 species) sites which received environmental watering later in the 2014-15 water year. As some sites dried down exposing shallower habitat and other sites received inflows over summer and autumn, the overall diversity of waterbirds increased (Figure 50).

Two of the mid-Murrumbidgee sites were dry for 2014-15 (Sunshower or McKennas lagoons) and therefore no waterbirds were observed. Inflows into the other two Mid-Murrumbidgee sites, Yarradda (Action 2) and Gooragool lagoons in summer provided habitat for filter-feeding ducks such as pink-eared ducks that often move to wetlands on re-flooding to exploit peaks in invertebrate prey.

The composition of waterbird communities, based on waterbird functional groups, differed between the three zones (ANOSIM R 0.2, $p < 0.01$). Overall, ‘dabbling and filter-feeding ducks’ were the most abundant group comprising more than 31 per cent of waterbird abundance followed by 'large wading birds' (25%), 'diving ducks, aquatic gallinules and swans' (22%), and 'fish-eating (Piscivores)' (13%) and the remaining four waterbird groups (9%) (Figure 51, see Appendices). 'Dabbling and filter-feeding ducks' (grey teal (*Anas gracilis)* and Pacific black duck (*Anas superciliosa)* predominately) and 'fish-eating (Piscivores) waterbirds' (little black cormorant (*Phalacrocorax sulcirostris)* and white-faced heron (*Egretta novaehollandiae)* predominately) were also the most widespread functional groups across the surveyed wetlands. Both groups were observed at 10 of the surveyed wetlands which held water over 2014-15.

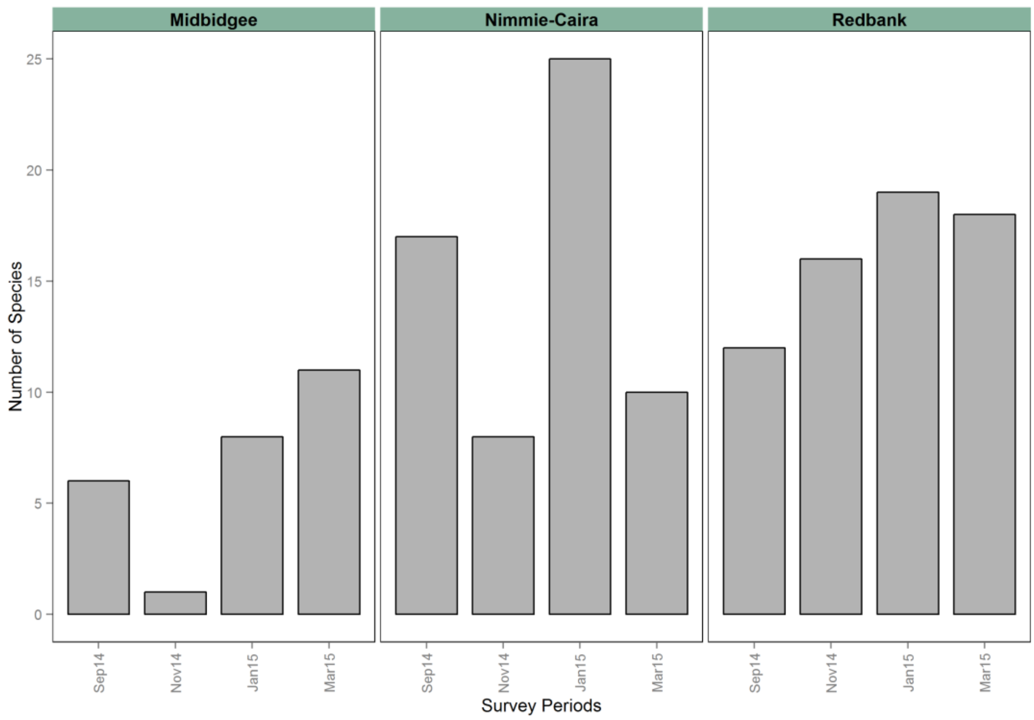


Figure 50 Maximum number of waterbird species recorded in each survey month in the three wetland zones in the Murrumbidgee Catchment. Note that much of the mid-Murrumbidgee zone was dry with only two sites receiving some inflows in summer 2015.

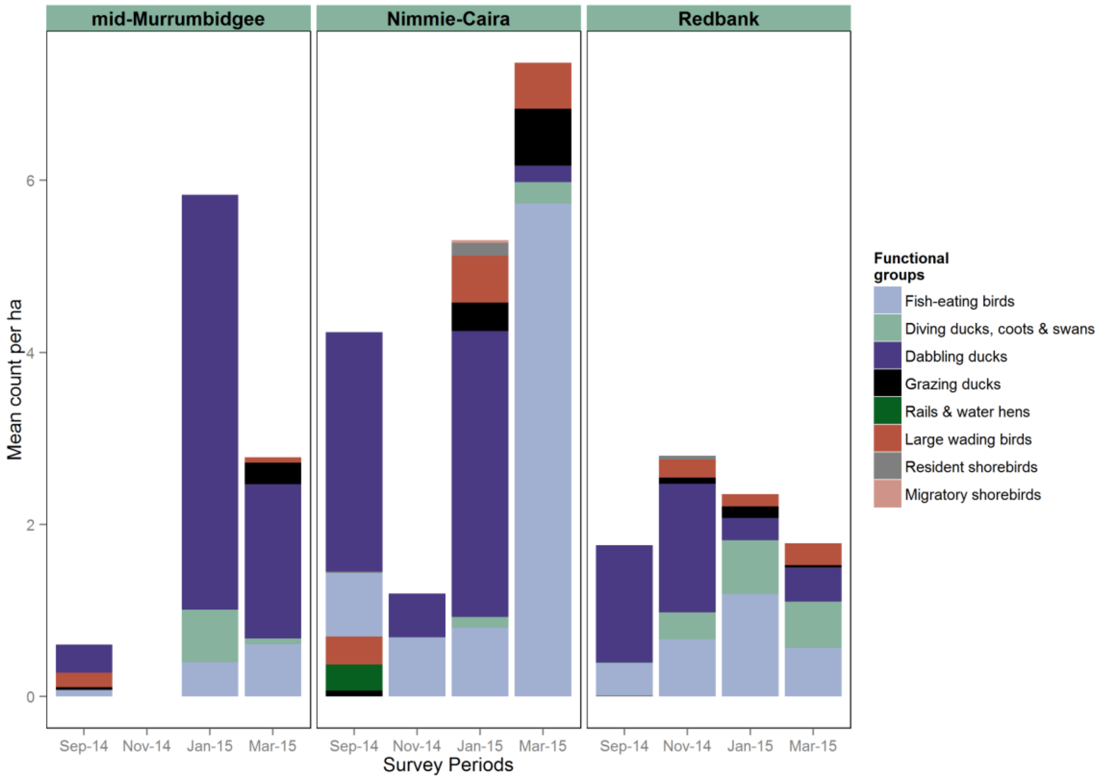


Figure 51 Mean count of each waterbird functional group (adjusted to birds/ha) in each survey month across the four wetland zones. Note that the mid-Murrumbidgee zone did not receive inflows until summer 2015 and this was limited to two sites only.

Across all zones the abundance of 'fish-eating birds', and 'dabbling and filter-feeding ducks' contributed most to the similarities among sites in all survey periods. The peaks in abundance in dabbling ducks and fish-eating birds over January and March 2015 across the mid-Murrumbidgee and Nimmie-Caira zones contributed to the most site differences. 'Large-wading birds' (ibis, egrets, for example) formed a larger proportion of the waterbird communities in the Nimmie-Caira and Redbank sites (Figure 51).

Waterbird breeding

Observed waterbird breeding was limited across the survey sites, with only observed grey teal and Pacific black duck observed with broods of young.

Discussion

Waterbird breeding was not monitored as part of the 2014-15 LTIM program. However small-scale egret, heron and cormorant breeding was reported following aerial and ground surveys by NSW OEH and CEWO staff at seven sites across the Lowbidgee floodplain, including Two Bridges Swamp, in the Redbank system and Telephone Creek in the Nimmie-Caira. Waterbird breeding, including the total number of nesting birds and number of active breeding sites is linked to the total flooded area, large-scale waterbird breeding does not occur in years when only small areas are inundated.

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. Overall waterbird diversity was lower than in previous years (Wassens *et al.* 2013a; Wassens *et al.* 2014b), reflecting the relatively small volumes of environmental water utilised in the Nimmie-Caira and Redbank zones. Using environmental flows to inundate large areas, covering a range of wetland types to varying depths can cater for the water requirements of a range of waterbird species and therefore maximise waterbird diversity outcomes (Bino *et al.* 2014). Creating a diversity of habitats including areas of shallow water and muddy wetland margins can also support species such as sharp-tailed sandpipers recognised on international migratory agreements (JAMBA, CAMBA and ROKAMBA) as observed over summer months in parts of the Nimmie-Caira.

Timing flows to inundate these types of shallow habitats in spring with a long draw-down phase over autumn has the potential to provide feeding habitat for migratory shorebirds during both their southward and northward migrations (Kingsford *et al.* 2005), as well as potentially stimulating high densities of microinvertebrates prey for filter feeding ducks. In all cases considering the historical wetting and drying regime is essential for each wetland type so that they can be watered to maximise the associated wetland vegetation and the food sources on which waterbirds depend.

In years of median water availability winter-spring watering can prime the system for potential breeding later in spring-summer months as seen in 2014-15. The use of contingency allowances to support waterbird breeding in the Redbank zone can be crucial for ensuring the colony sites and surrounding foraging habitats are flooded for long enough to allow birds to fledge their young successfully. This approach can also keep key breeding and feeding sites in 'event-ready' condition in intervening years between large-scale natural flooding, particularly in parts of the Nimmie-Caira floodways and associated feeding grounds which traditionally can support some of the largest ibis colonies in Australia. In these wetter years the benefits of watering in the previous intervening years and/or months can allow waterbirds to build condition so they can readily exploit breeding opportunities and ensure abundant food sources are available to support their successful breeding.

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5 Appendices

1. Wetland-dependent bird species recorded during surveys of the Murrumbidgee in 2014-15

Family	Common Name^	*Scientific Name*	Functional Group#	CAVS Code
Accipitridae	Whistling kite	*Haliastur sphenurus*	Raptors	CAVS: 0228
Accipitridae	White-bellied sea-eagle	*Haliaaetus leucogaster*	Raptors	CAVS: 0226
Acrocephalidae	Australian reed-warbler	*Acrocephalus australis*	Reed-inhabiting passerines	CAVS: 524
Alcedinidae	Azure kingfisher	*Ceyx azureus*	Piscivores	CAVS: 0319
Anatidae	Australasian shoveler	*Anas rhynchotis*	Dabbling and filter-feeding ducks	CAVS: 0212
Anatidae	Australian shelduck	*Tadorna tadornoides*	Grazing ducks	CAVS: 0207
Anatidae	Australian wood duck	*Chenonetta jubata*	Grazing ducks	CAVS: 0202
Anatidae	Black swan*	*Cygnus atratus*	Diving ducks, aquatic gallinules and swans	CAVS: 0203
Anatidae	Grey teal*	*Anas gracilis*	Dabbling and filter-feeding ducks	CAVS: 0211
Anatidae	Hardhead	*Aythya australis*	Dabbling and filter-feeding ducks	CAVS: 0215
Anatidae	Musk duck	*Biziura lobata*	Diving ducks, aquatic gallinules and swans	CAVS: 0217
Anatidae	Pacific black duck*	*Anas superciliosa*	Dabbling and filter-feeding ducks	CAVS: 0208
Anatidae	Pink-eared duck	*Malacorhynchus membranaceus*	Dabbling and filter-feeding ducks	CAVS: 0213
Anatidae	Plumed whistling-duck	*Dendrocygna eytoni*	Grazing ducks	CAVS: 0205
Anhingidae	Australasian darter*	*Anhinga novaehollandiae*	Piscivores	CAVS: 8731
Ardeidae	Australasian bittern	*Botaurus pociloptilus*	Piscivores	CAVS: 0197
Ardeidae	Eastern great egret*	*Ardea modesta*	Piscivores	CAVS: 8712
Ardeidae	intermediate egret*	*Ardea intermedia*	Piscivores	CAVS: 0186
Ardeidae	Little egret*	*Egretta garzetta*	Piscivores	CAVS: 0185
Ardeidae	Nankeen night-heron*	*Nycticorax caledonicus*	Piscivores	CAVS: 0192
Ardeidae	White-faced heron	*Egretta novaehollandiae*	Piscivores	CAVS: 0188
Ardeidae	White-necked heron	*Ardea pacifica*	Piscivores	CAVS: 0189
Charadriidae	Black-fronted dotterel	*Elseyornis melanops*	Australian-breeding Charadriiform shorebirds	CAVS: 0144
Charadriidae	Masked lapwing	*Vanellus miles*	Australian-breeding Charadriiform shorebirds	CAVS: 0133
Charadriidae	Red-capped plover	*Charadrius ruficapillus*	Australian-breeding Charadriiform shorebirds	CAVS: 0143
Charadriidae	Red-kneed dotterel	*Erythrogonys cinctus*	Australian-breeding Charadriiform shorebirds	CAVS: 0132

Pelecanidae	Australian pelican	*Pelecanus conspicillatus*	Piscivores	CAVS: 0106
Phalacrocoracidae	Great cormorant*	*Phalacrocorax carbo*	Piscivores	CAVS: 0096
Phalacrocoracidae	Little black cormorant*	*Phalacrocorax sulcirostris*	Piscivores	CAVS: 0097
Phalacrocoracidae	Little pied cormorant*	*Microcarbo melanoleucos*	Piscivores	CAVS: 0100
Podicipedidae	Australasian grebe	*Tachybaptus novaehollandiae*	Piscivores	CAVS: 0061
Podicipedidae	Hoary-headed grebe	*Poliocephalus poliocephalus*	Piscivores	CAVS: 0062
Rallidae	Black-tailed native-hen	*Tribonyx ventralis*	Rails and shoreline gallinules	CAVS: 0055
Rallidae	Eurasian coot	*Fulica atra*	Diving ducks, aquatic gallinules and swans	CAVS: 0059
Recurvirostridae	Black-winged stilt	*Himantopus himantopus*	Australian-breeding Charadriiform shorebirds	CAVS: 0146
Scolopacidae	Sharp-tailed sandpiper	*Calidris acuminata*	Migratory Charadriiform shorebirds	CAVS: 0163
Threskiornithidae	Australian white ibis*	*Threskiornis molucca*	Large wading birds	CAVS: 0179
Threskiornithidae	Royal spoonbill	*Platalea regia*	Large wading birds	CAVS: 0181
Threskiornithidae	Straw-necked ibis	*Threskiornis spinicollis*	Large wading birds	CAVS: 0180
Threskiornithidae	Yellow-billed spoonbill	*Platalea flavipes*	Large wading birds	CAVS: 0182

* Breeding activity: species recorded nesting and/or with young. ^ Status: J = JAMBA, C = CAMBA, R = ROKAMBA (International migratory bird agreements Australia has with Japan, China, and Republic of Korea, respectively), E = endangered under Commonwealth EPBC Act 1999. Nomenclature taken from Christidis and Boles (2008). # Functional groups as per Hale et al. (2014).

2. Classification and Regression Tree (CART) analysis

We undertook a Classification and Regression Tree (CART) approach to identify key thresholds that determine the occurrence of larvae and eggs of key fish species for both drift and light traps. We considered a range of factors including hydrology, water temperature, dissolved organic carbon (DOC), chlorophyll a, and microinvertebrates (see Table 3).

Cod species

Cod species were captured in the greatest abundance (*n*=809), and occurred at all sites. The CART model for combined total drift net and light traps of cod species showed a temperature threshold, with larval cod species more abundant once temperature was greater than or equal to 22 °C

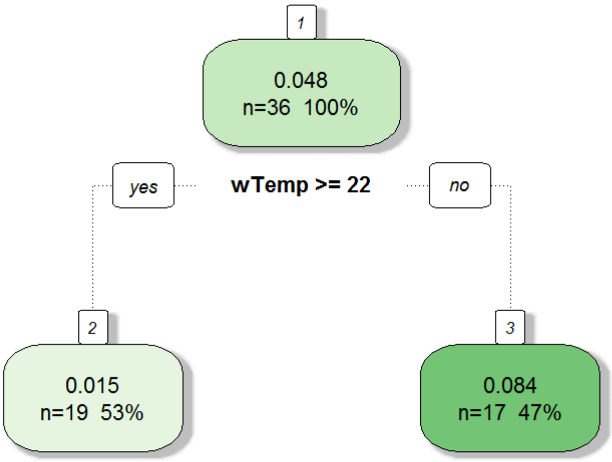

Figure 52 Classification and Regression Tree larval Cod species CPUE

Silver Perch

Silver perch eggs (*n*=619) were collected from all sites in the Narrandera zone, and captures peaked on 3 December 2014 In the Carrathool zone, silver perch eggs were also collected from all three sites, peaking on the 1–2 December 2014. No silver perch larvae were captured. The CART analysis confirmed water temperature as a key factor driving spawning by Silver perch, with the model identifying a single split when water temperature greater than 23℃ which had a likelihood of silver perch presence of 0.61 compared with sites with water temperatures lower than 23℃ which had no silver perch eggs (Figure 53). Despite the overall discharge being higher in the Narrandera compared to the Carrathool zone, the cumulative discharge was not a significant predictor of silver perch occurrence.

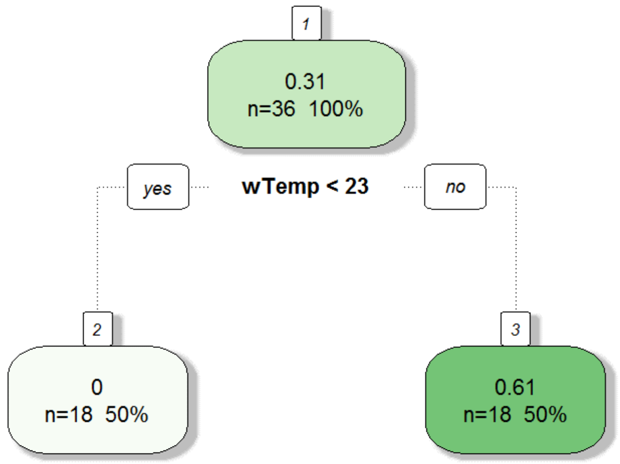

Figure 53 Classification and Regression Tree of silver perch eggs and larvae CPUE

Golden Perch

Golden perch eggs were collected from one site (The Dairy) in the Narrandera zone on three occasions; 20 November 2014, 4 December 2014 and 18 December 2014. Additionally, larvae in the post-flexion stage were collected using light traps from two sites on the 19–20 November 2014 in the Narrandera Zone. In the Carrathool zone, golden perch eggs were collect from two sites on the 17 November 2014. No golden perch larvae were captured in the Carrathool zone. The CART model for golden perch identified the highest likelihood of presence in sites when water temperature was between 21℃ and 23℃ (average of 0.44)(Figure 54). In sites when water temperature was greater than 23℃, the likelihood of golden perch was 0.062.

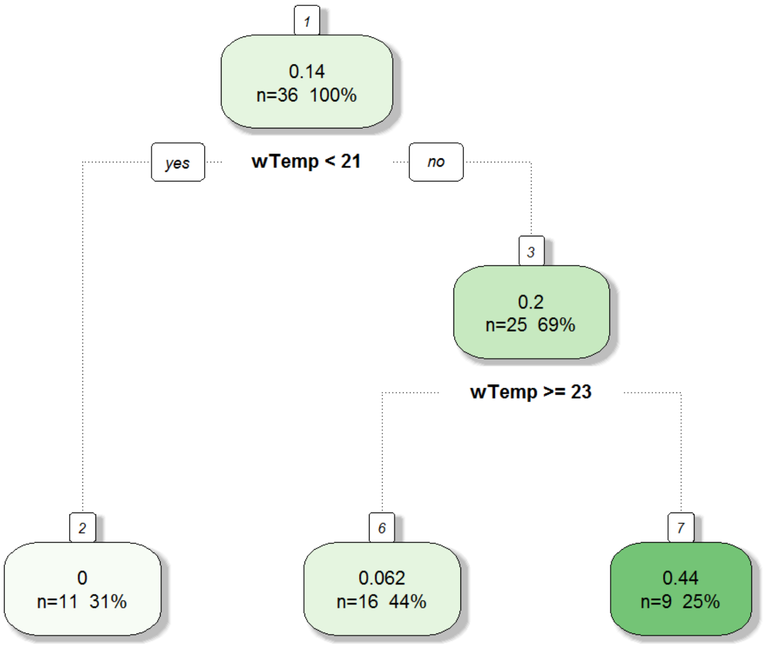

Figure 54 Classification and Regression Tree of Golden perch eggs and larvae CPUE

The occurrence and abundance of fish, frogs and waterbirds in wetlands targeted with environmental water is often driven by availability of key hydrological and biological resources including the area of wetland inundated, water depths and food resources. To determine if the environmental watering actions achieved critical thresholds required to support native fish, frog and waterbirds, we employed a Classification and Regression Tree (CART) approach.

Waterbirds

Overall, 36 waterbird species were observed across the 12 Murrumbidgee LTIM wetland survey sites. Waterbird diversity and abundance peaked in the January 2015 surveys when the extent of flooding was greatest. Under **Action 2** Yarradda Lagoon received water in December 2014, with large numbers of pink-eared ducks *Malacorhynchus membranaceus* recorded. In the Lowbidgee floodplain (**Action 6**) two species listed on two or more international bilateral migratory bird agreements (JAMBA, CAMBA and ROKAMBA), the Eastern great egret *(Ardea modesta)* and sharp-tailed sandpiper *(Calidris acuminate)* along with the nationally endangered

Australasian bittern (*Botaurus poiciloptilus)* (EPBC Act), were recorded. Overall fish eating waterbirds and dabbling ducks were the most abundant functional groups.

Water depth was a key parameter influencing the abundance of fish easting waterbirds through wetlands in the mid-Murrumbidgee and Lowbidgee floodplain, The CART analysis identified, wetlands with water depth greater than 0.51 m, had a far higher abundances of fish-eating waterbirds (average abundance of 17 birds) compared shallow, drying wetlands (average abundance 0.26 birds) (Figure 55). While water depth was the key driver determining the abundance of fish eating waterbirds, Food availability was also an important driver of waterbird abundance, with wetlands where total fish abundance (CPUE) greater than 13 fish supporting having a greater abundance of fish-eating birds (on average 29 fish-eating waterbirds) compared to sites where lower fish CPUE was recorded (on average 8 fish-eating waterbirds) (Figure 55).

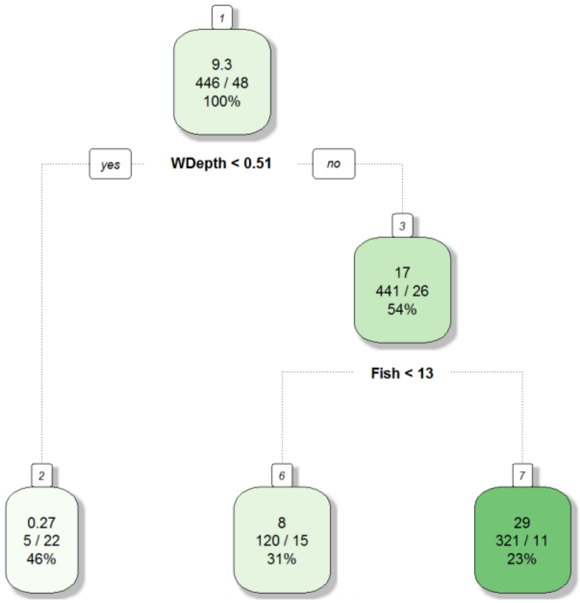

Figure 55 Classification and Regression Tree of fish eating waterbirds

In contrast, water depth was not a significant driver of the abundance of filter-feeding ducks species, such as pink-eared ducks and Australasian shovelers *Anas rhynchotis* but the availability of food resources mainly benthic microinvertebrates was the key driver for the number of this group of waterbirds. Based on the CART model, sites that had total benthic bio-volume over 40,000,000 had an average filter-feeding duck abundance of 40 (total 437) while in sites with lower benthic bio-volume, average duck abundance was 0.18 (Figure 56).

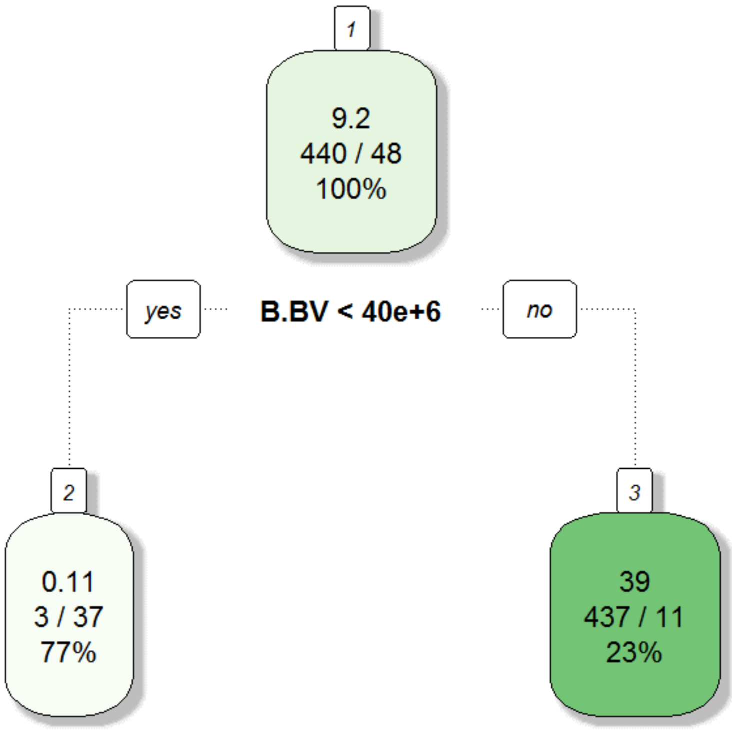

Figure 56 Classification and Regression Tree of filter-feeding ducks

Fish

In wetlands a total of 38,979 fish comprising six native and four exotic species were captured across 10 LTIM wetland sites that contained water between September 2014 and May 2015. Carp gudgeon, bony herring and Australian smelt were the most abundant native species, while gambusia, common carp and oriental weatherloach were the most commonly recorded exotic species (Figure 57). Despite being filled via pumping, fish were present in Yarradda lagoon (Action 2) with the community dominated by bony herring and gambusia. Fish communities differed significantly between the three wetland zones (ANOSIM Global R 0.226, p =0.001). In the Redbank zone, relatively high numbers of oriental weatherloach were observed in November and January, while the native Carp gudgeon were most abundant in January and March 2015. In Nimmie-Caira, fish numbers were dominated by Carp gudgeon and with smaller numbers of common carp.

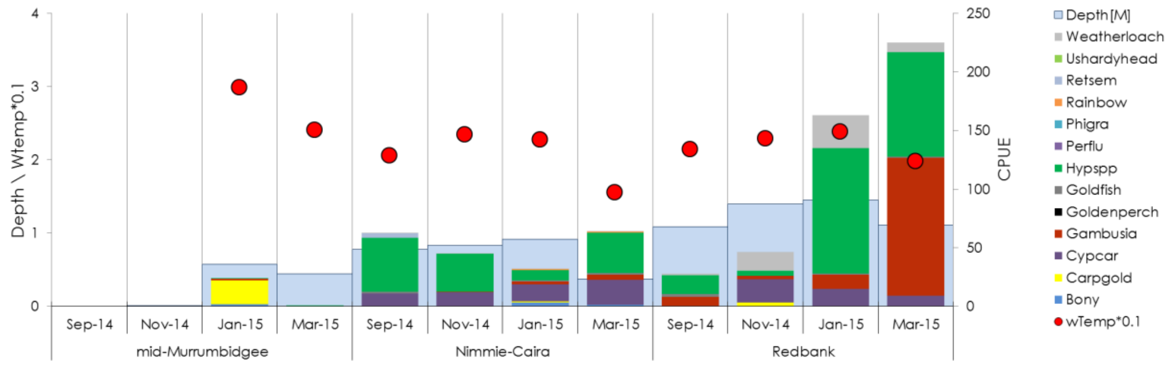

Figure 57 Total fish numbers in the three zones and four survey occasions

When both native and exotic species were considered together, the availability of water is the key predictor of fish CPUE, with no fish recorded when water depth were below the critical 0.24m (Figure 58. Once some level of inundation has been achieved, the abundance of fish in the wetlands increased markedly once environmental watering had inundated the wetland to more than 0.84 (84%) of its total area CPUE (46, n=7), while in wetlands where the proportion of inundation was less than 84%, fish CPUE was 15. Of those, sites with water temperature lower than 23°C had an average fish CPUE of 20 while sites with water temperature higher than 23°C had an average fish CPUE of 7.4.

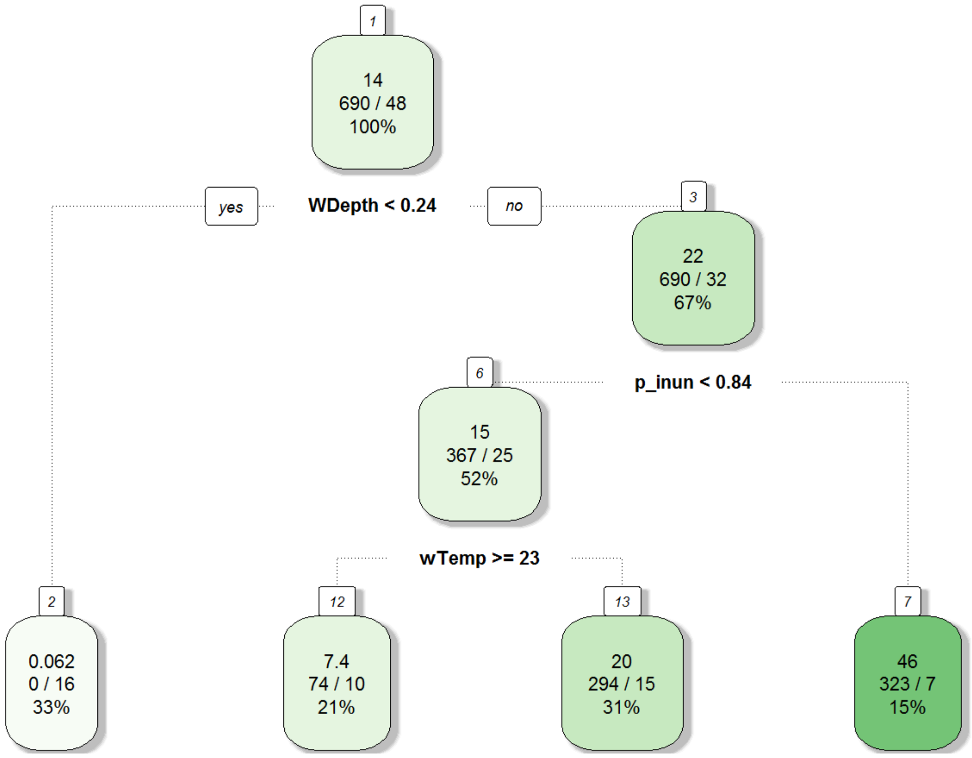

Figure 58 Classification and Regression Tree of all fish species CPUE

Native fish

When considered separately, the CART model for native fish indicate greater sensitivity to water depth, compared to the previous model where all species are combined. Native fish CPUE was highest water depth was greater than 0.91m (compared to 0.24m for all species model), within these wetlands water temperature lower than 24℃ (average 23 CPUE), (Figure 59). In sites with water temperatures lower than 24℃ average native CPUE was 6.2. In sites with water depth lower than 0.91m average CPUE was 2.3 and those between 0.91m and 0.26m had average CPUE of 5.9.

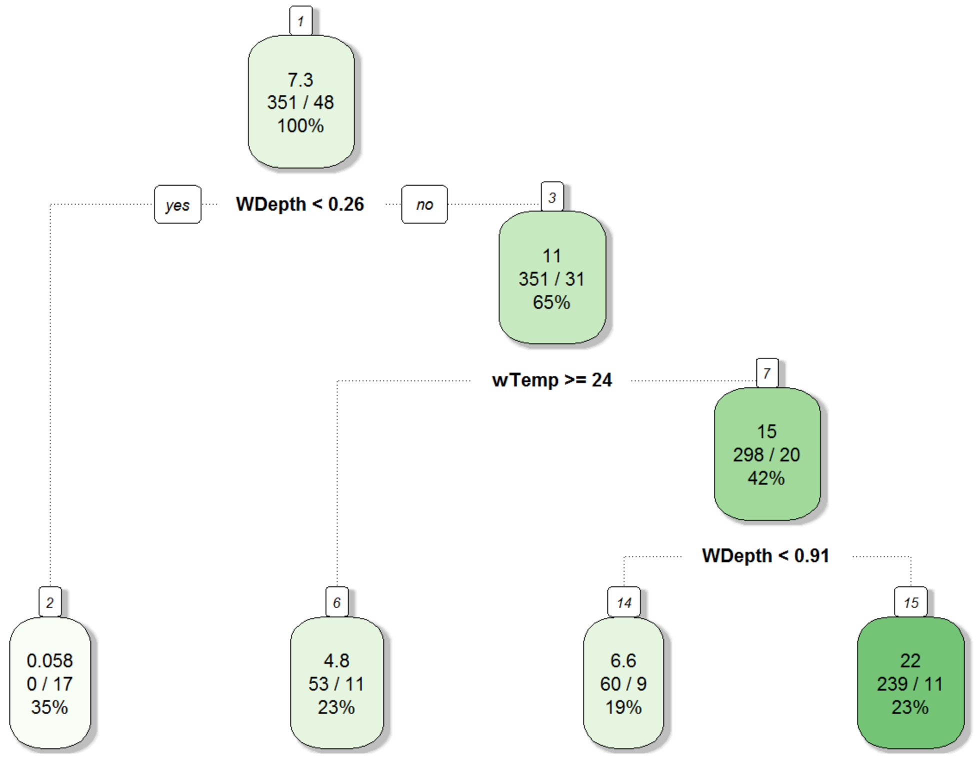

Figure 59 Classification and Regression Tree of native fish CPUE abundance

Exotic fish

The proportion of the wetland inundated had a significant effect on the abundance of exotic species, with exotic fish species more abundant in wetlands that were only partially inundated (less than 0.8) (Figure 60). Of these wetlands with higher exotic fish CPUE, deeper wetlands had higher CPUE than did wetlands less than 0.24m, broadly reflecting the response of all fish species to wetland inundation.

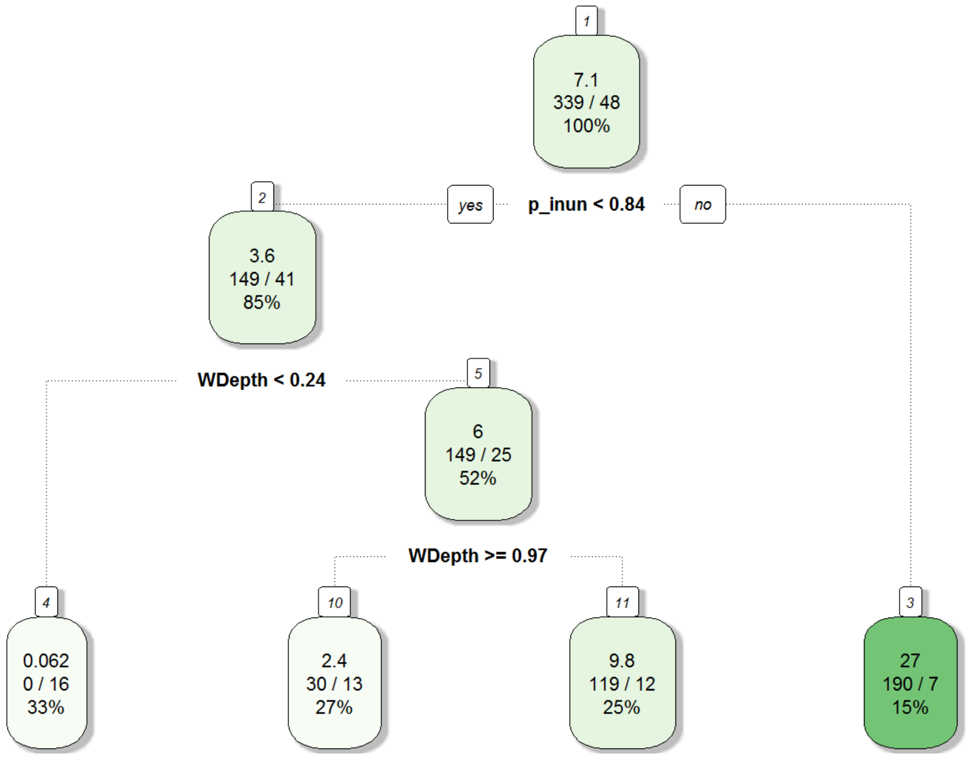

Figure 60 Classification and Regression Tree of exotic fish CPUE abundance

Frogs and tadpoles

Overall, 2,212 adult frogs (seen and heard) and 1,100 tadpoles of six species were recorded between September 2014 and May 2015 across 10 LTIM monitoring sites, with two sites remaining dry throughout 2014-15. Adult barking marsh frogs (*Limnodynastes fletcheri*), spotted marsh frogs (*Limnodynastes tasmaniensis*), plains froglets (*Crinia parinsignifera*) were recorded in all three zones. Peron's tree frogs (*Litoria peronii*), inland banjo frogs (*Limnodynastes interioris*) were less widespread, while the vulnerable southern bell frog (*Litoria raniformis*) had the most restricted distribution, only occurring across the four Nimmie-Caira sites.

Commonwealth environmental watering targeted known habitats of the southern bell frog (*Litoria raniformis*) in the Nimmie-Caira zone (**Action 6**). Calling and tadpoles of southern bell frogs and other frog species were recorded at all four LTIM monitoring wetlands in the Nimmie-Caira, indicating that these flows were successful in created breeding opportunities for this nationally vulnerable species, and other floodplain frog species. Commonwealth environmental watering targeted one wetland (Yarradda Lagoon) in the mid-Murrumbidgee wetland systems (**Action 2**).

Inland banjo frog (*Limnodynastes interioris*) adults and tadpoles were recorded in this wetland for the first time since monitoring commenced in 2010. Large numbers of Peron's tree frog (*Litoria peronii*) tadpoles were also recorded.

Frogs

Water temperate influenced the abundance of frogs, with just 36 of the 2,157 individuals recorded, occurring in wetlands with water temperate below 17°C. The majority of individuals were recorded in wetlands once water temperature exceeded 25°C (average abundance was 112 compared to water temperatures between 17°C and 25°C had frog abundance of 56 (n=24), (Figure 61). In those sites, a third split was identified when water PH was lower than 7.7, where frog abundance was 72 compared with 29.

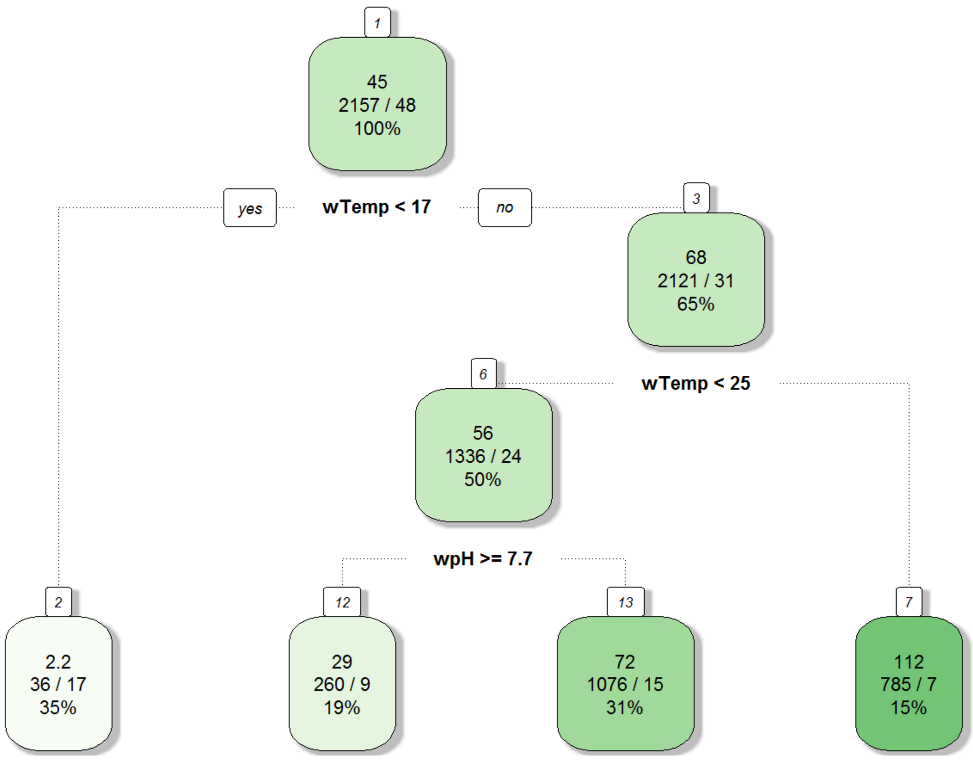

Figure 61 Classification and Regression Tree of frog abundance

Tadpoles

While the abundance of adult frogs were influenced by water temperature, frog breeding outcomes were most strongly linked to inundation area, with the average tadpole abundance highest once environmental watering of wetlands had achieved wetlands inundation above 0.65 (65% of the total wetland area) (Figure 62). Some breeding did occur at sites with lower levels of inundation, including Yarradda Lagoon in the mid-Murrumbidgee, and in these instances the abundance of tadpoles was higher when wetlands had higher when the pelagic bio-volume was greater than 11,000,000 where tadpole abundance was 0.41 compared with 0.034.

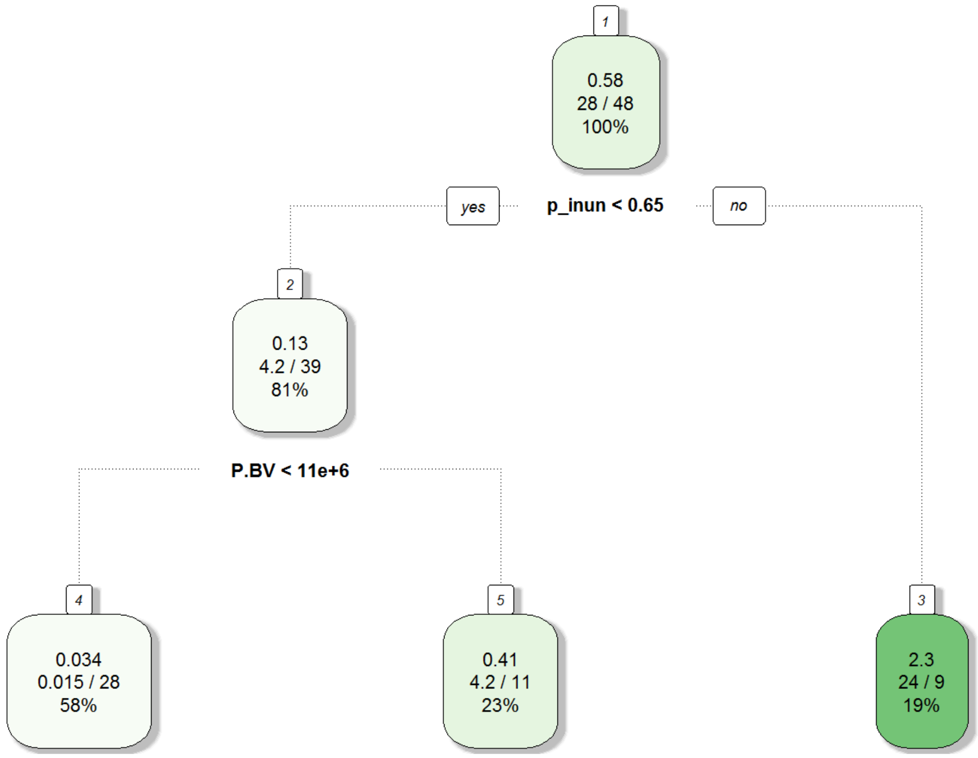

Figure 62 Classification and Regression Tree of tadpole abundance