Australian Government
Commonwealth Environmental Water Office

UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

COMMONWEALTH ENVIRONMENTAL WATER OFFICE LONG TERM INTERVENTION MONITORING PROJECT: LOWER LACHLAN RIVER SYSTEM 2015-16 TECHNICAL REPORTS

25 November 2016

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Commonwealth Environmental Water Office

Long Term Intervention Monitoring Project

Lower Lachlan river system 2016 Annual Report

Final February 2017

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This monitoring project was commissioned and funded by Commonwealth Environmental Water Office with additional in-kind support from the University of Canberra, NSW Office of Environment and Heritage, and Department of Primary Industries.

This report should be attributed as: Dyer, F., Broadhurst, B., Tschierschke, A., Thiem, J., Thompson, R., Driver, P., Bowen, S., Asmus, M., Wassens, S., Walcott, A., Lenehan, J. and van der Weyer, N. 2016. Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Lower Lachlan river system Selected Area 2015-16 Monitoring and Evaluation Synthesis Report. Commonwealth of Australia, 2016.

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Document history and status

Version	Date Issued	Issued to	Reviewed by	Approved by	Revision Type
Draft for review	10 Aug 2016	Jane Roberts	Project Team	Fiona Dyer	Nil
DRAFT	31 Aug 2016	CEWO	Jane Roberts	Fiona Dyer	Internal
PENULTIMATE	28 Oct 2016	CEWO	CEWO/MDFRC	Fiona Dyer	External
FINAL	9 Feb 2017	CEWO	CEWO	Fiona Dyer	External

Front cover photos: Top left Red gum Murrumbidgil Swamp; Top right Water quality sampling; Bottom left Golden Perch; Bottom right: Murrumbidgil Swamp. Photos by Fiona Dyer and Jason Thiem

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ACRONYMS AND ABBREVIATIONS

Accepted Acronym	Standard Term (capitalisation as specified)
ANAE	Australian National Aquatic Ecosystem
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CPUE	Catch per unit effort
GS	General Security
HS	High Security
IMEF	Integrated Monitoring of Environmental Flows
LLS	Local Land Services
LTIM Project	Long Term Intervention Monitoring Project
MDBA	Murray-Darling Basin Authority
M&E	Monitoring and Evaluation
MDMS	Monitoring Data Management System
SOP	Standard Operating Procedure
QA/QC	quality assurance / quality control

ACKNOWLEDGMENTS

The project team as well as the Commonwealth Environmental Water Office respectfully acknowledge the traditional owners, their Elders past and present, their Nations of the Murray-Darling Basin, and their cultural, social, environmental, spiritual and economic connection to their lands and waters. In particular in the Lower Lachlan river system Selected Area we acknowledge the Wiradjuri peoples, traditional owners of the land on which this publication is focused.

The project team also thank the team of people who contributed to the project delivery including: Rhian Clear, Ebony Coote, Erin Lenon, Elizabeth Symes, Paul Packard, Simon Votto, Ugyen Lhendup, Will Higgisson, Laura Caffrey, Foyez Shams, Emily Belton, Sally Hatton, Katie Ryan, Daniel Wright, Pat Ross-Magee, Hugh Allen, Mark Lintermans, Andy Lowes, Hannah Belnick.

The landholders who granted access to sites are thanked for their interest, cooperation and support.

The project was supported by a LTIM Reference Group for the Lower Lachlan river system consisting of Sam Davis (NSW DPI Fisheries), Paul Packard (NSW OEH), Patrick Driver (NSW DPI Water), Ebony Coote (CEWO), Damian McRae (CEWO), Bruce Campbell (CEWO) and Erin Lenon (CEWO).

Fish sampling was conducted under Fisheries NSW ACEC Research Authority Permit 14/10.

Larval fish sampling was conducted under NSW DPI permit No: P14/0022-1.0 and under approval from the University of Canberra Animal Ethics Committee (CEAE 14-12).

1 INTRODUCTION

Three environmental watering actions with a total of 48 029 ML of Commonwealth (36 020 ML) and NSW (12 007 ML) water were delivered to the Lower Lachlan river system in the 2015-16 water year. The Commonwealth environmental watering actions included:

1) 24 058 ML into the Lachlan River, targeting the Great Cumbung Swamp. This action was expected to consolidate the benefits of inundation that occurred in 2013 and support the survival and growth of wetland vegetation and habitat values for waterbirds and other water-dependent species.
2) 1087 ML to Merrimajeel Creek targeting Murrumbidgil Swamp and 1497 ML to Merrimajeel Creek to support waterbird habitat.
3) 9378 ML to the Lachlan River, targeting flow-cued native fish outcomes, specifically golden perch, but also to contribute to outcomes for non flow-cued native fish species such as Murray cod.

The Long-Term Intervention Monitoring Project (LTIM Project) is the primary means by which the Commonwealth Environmental Water Office (CEWO) undertakes monitoring and evaluation of the ecological outcomes of Commonwealth environmental watering. Monitoring activities implemented within the LTIM Project to evaluate the outcomes of Commonwealth environmental watering actions in the Lower Lachlan river system in 2015-16 included the monitoring of stream flows (hydrology), stream metabolism and water quality (dissolved oxygen, temperature, pH, electrical conductivity, turbidity and nutrients), fish (including larval fish), frogs and vegetation condition and diversity.

This document includes the technical reports for each of the monitoring activities. It is designed as a record of the supporting technical material for the synthesis report (Dyer et al. 2016). Each section is presented as a short scientific paper outlining the evaluation of each indicator. The technical reports are prefaced with an overview of the watering actions and the objectives (Section 1.1, Figure 1 and Table 1) and maps showing the location of the sampling sites (Figure 2 and Figure 3).

This is the second year of a five year monitoring program with 2015-16 watering actions almost an order of magnitude greater than those of 2014-15. The analysis and interpretation of indicator data draws on data from both years of monitoring as well as field observations.

1.1 WATERING ACTIONS AND THEIR OBJECTIVES

Three environmental watering actions were delivered to the Lower Lachlan river system between the 9th August and the 15th December 2015 (Figure 1). At the catchment scale the primary expected outcomes of the watering actions were to:

- Provide habitat to support survival, maintain condition of, and provide reproduction opportunities for native fish;
- Maintain the extent and diversity of aquatic and riparian vegetation;
- Support waterbird habitat, and breeding and recruitment opportunities; and
- Maintain hydrological connectivity including end of system flows.

The secondary expected outcomes were to:

- Contribute to ecosystem function; and
- Deliver landscape vegetation diversity and resilience.

Individually, the watering actions were expected to maintain hydrological connectivity, contribute to vegetation condition and diversity, provide habitat and access to habitat for frogs, fish and birds, trigger breeding and recruitment in frogs and generate movement and spawning of golden perch (Table 1).

1.2 OTHER ENVIRONMENTAL WATER IN THE LOWER LACHLAN RIVER SYSTEM: TRANSLUCENT RELEASES

Significant rainfall within the catchment in the first half of 2015 produced medium-large volumes of unregulated inflow to the Lachlan River, particularly from the Belubula and Boorowa Rivers. Inflows from 1 January to 26 August 2015 totalled 268 000 ML which triggered the delivery of translucent releases, as required under the Lachlan Regulated River Water Sharing Plan[1]. Dam levels were such that translucent releases were targeted at between 3500 ML/day and 5156 ML/day with a combination of passing flow and dam releases delivering the water to the Lower Lachlan river system (Figure 1). This translucent event contributed to approximately 72 000 ML of flow passing Lake Brewster weir in August-September 2015.

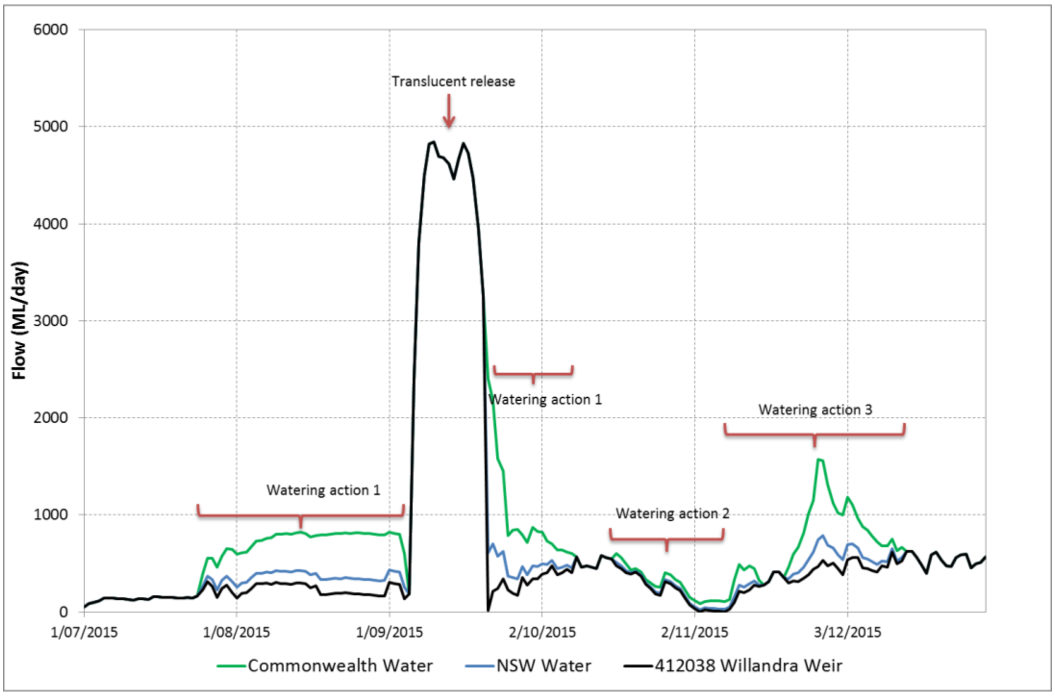


Figure 1. Flow at Willandra Weir (412038) showing Commonwealth (green) and NSW (blue) environmental water delivery.
Normal river flows (including licensed delivery of water) is shown in black. Watering actions are numbered according to the delivered watering actions (Table 1).

[1] More details about translucent flows can be found at http://www.water.nsw.gov.au/water-management/water-sharing/environmental-rules/rivers#flows

Table 1. The 2015-16 Commonwealth environmental watering actions.

DESCRIPTION	DETAILS			
Action	1	2		3
Target Asset	Great Cumbung Swamp	Booligal Wetlands – Merrimajeel and Muggabah Creek		Lachlan River, main channel
Reference	WUM10039	WUM10033		WUM10033
Accounting Location	Lachlan River at Booligal and at Willandra Weir	Merrimajeel/Muggabah offtake		Lachlan River at Willandra Weir
Flow component	Base flow; Fresh flow; Wetland inundation	Base flow; Fresh flow; Wetland inundation	Base flow; Fresh flow; Wetland inundation	Base flow; Fresh flow
Volume (CEW)	24 058.5	1087.5	1497	9378.5
Volume (NSW)	8019.5	362.5	499	3126.5
Total Volume (ML)	32 078	1450	1996	12 505
Primary Objective	To improve hydrological connectivity including end of system flows, contribute to ecosystem function, support vegetation condition (river red gum, lignum and aquatic macrophytes) and ecosystem resilience.	Contribute to hydrological connectivity in the Booligal Wetlands and 1) protect the extent and condition of native riparian and vegetation communities. 2) maintain base flows into Booligal Wetlands to support waterbird breeding to completion.	Should a colonial waterbird breeding event commence, meet critical water needs to maintain water levels for up to 100 days to support waterbird breeding, fledging and recruitment.	Contribute to supporting native riparian wetland and floodplain vegetation diversity and condition. Provide habitat to support, maintain condition of, and provide reproduction opportunities for native fish, waterbirds and other aquatic vertebrate species.
Secondary Objective	Support the ongoing recovery and resilience of the Great Cumbung Swamp if dry conditions continue by providing drought refuge.	Support the ongoing recovery and resilience of Murrumbidgil Swamp if dry conditions continue by providing drought refuge.	Contribute to ecosystem resilience and the quality of drought refuge for both water dependent and woodland bird species. Assist in the building of resilience of waterbird populations to endure future extended dry	Trial the augmentation of flow to generate a golden and/or silver perch movement and spawning response. Protect and maintain the health of existing extent of riparian floodplain and wetland native vegetation communities. Contribute to hydrological connectivity and improved water quality.

DESCRIPTION	DETAILS		
Action	1	2	3
		periods and capitalise on flooding periods.	
Basin Annual watering priorities 2015-16	*Basin-wide in-stream and riparian vegetation*: Maintain and where possible improve the condition of in-stream riparian vegetation, through in-channel freshes. *Basin-wide flow variability and longitudinal connectivity*: Provide flow variability and longitudinal connectivity within rivers to support refuge habitats.	*Basin-wide flow variability and longitudinal connectivity*: Provide flow variability and longitudinal connectivity within rivers to support refuge habitats. *Basin-wide waterbird habitat and future population recovery*: Improve the complexity and health of priority waterbird habitat to maintain species richness and aid future population recovery.	*Northern Basin fish refuges*: Protect native fish population and in-stream habitats, particularly drought refuges, in the northern Basin. *Basin-wide native fish habitat and movement*: Maintain native fish populations by protecting and improving the condition of fish habitat and providing opportunities for movement. *Basin-wide flow variability and longitudinal connectivity*: Provide flow variability and longitudinal connectivity within rivers to support refuge habitats.

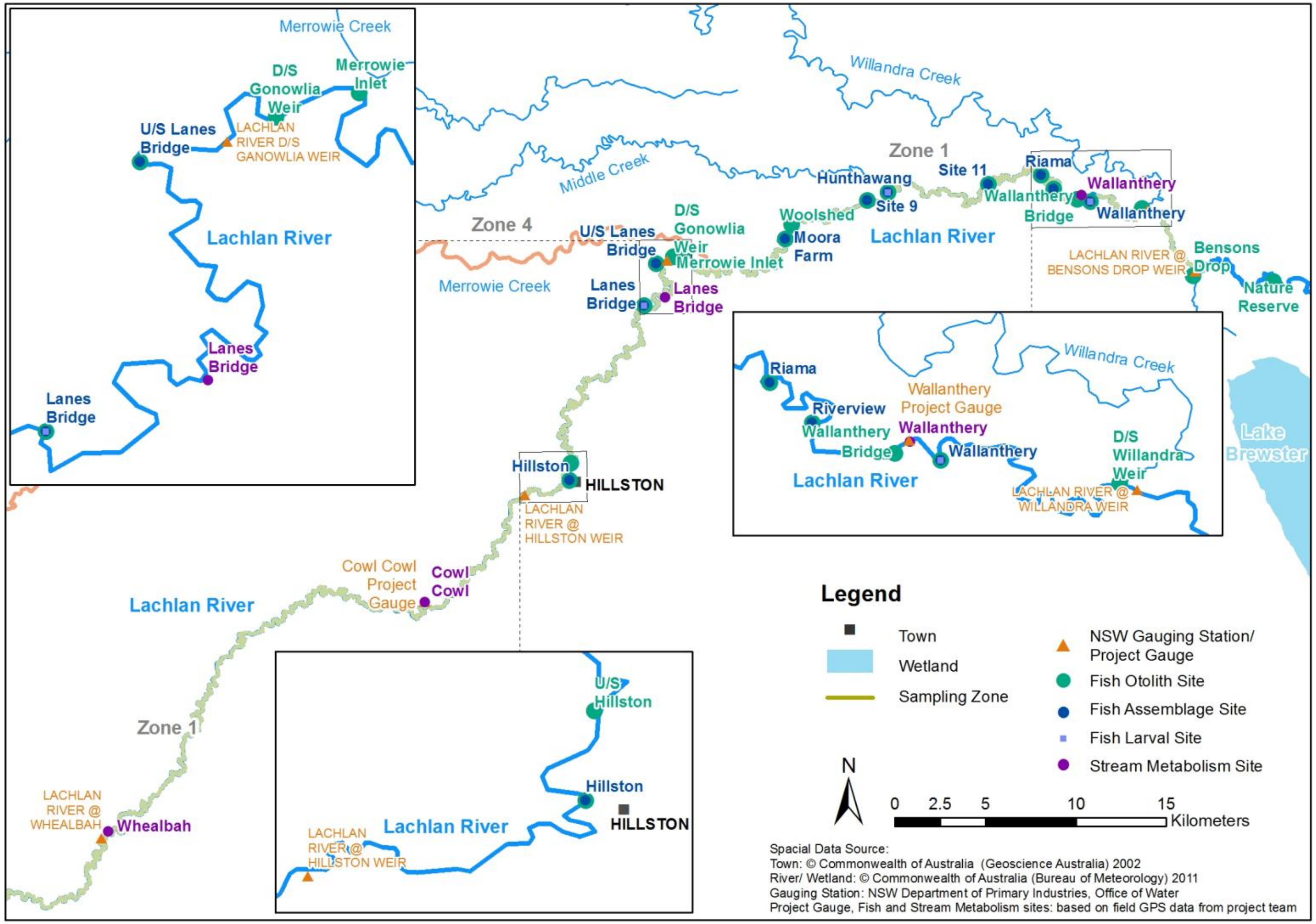


Figure 2. Map of monitoring sites for fish and stream metabolism in Zone 1.

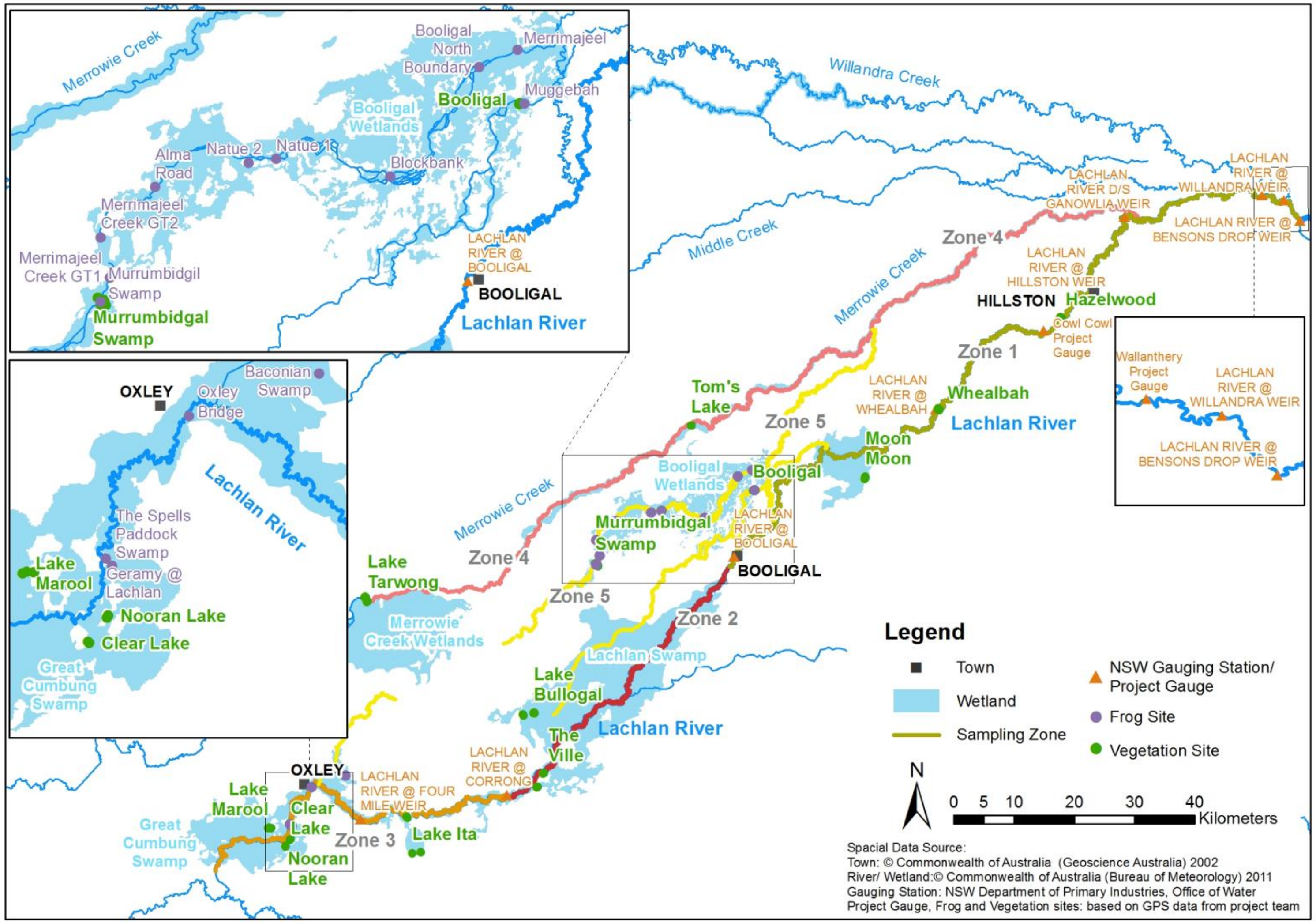


Figure 3. Map of monitoring sites for vegetation and frogs in the Selected Area.

2 HYDROLOGY

2.1 INTRODUCTION

The provision of water to maintain and restore riverine environments is based on the premise that the hydrological regime is one of the fundamental drivers of the structure and function of riverine and floodplain ecosystems (Nilsson and Berggren 2000, Bunn and Arthington 2002). Flow drives physical processes, providing longitudinal and lateral connectivity, moving sediments and nutrients and providing a diversity of hydraulic conditions for aquatic biota (Bunn and Arthington 2002). Altering flow regimes, through various water resource development activities, markedly affects the health of freshwater ecosystems (Walker and Thoms 1993, Gehrke et al. 1995, Kingsford 2000) and thus returning elements of the natural flow regime is an important part of managing and restoring river health.

In this chapter we evaluate the hydrological outcomes of providing Commonwealth environmental water to the Lower Lachlan river system. There are two components to the evaluation. The first is an evaluation of the hydrological outcomes in relation to the defined hydrological objectives of the watering actions and the second is an evaluation of the watering outcomes framed in the context of evaluation questions defined in the Long Term Intervention Monitoring and Evaluation Plan for the Lachlan river system (Dyer et al. 2014).

In 2015-16 three watering actions involving Commonwealth environmental water were delivered to the Lower Lachlan river system (Table 2). Two of these actions targeted wetland assets (Booligal Wetlands and the Great Cumbung Swamp) and the third targeted the main channel of the Lachlan River. The hydrological objectives were to improve the hydrological connectivity including end of system flows, maintain baseflows to Booligal Wetlands and provide habitat for native fish, waterbirds and other aquatic vertebrates (*Table* 2). The outcomes for both riverine and wetland hydrology are examined in this technical report and the following questions addressed:

2.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to maintaining hydrological connectivity including end of system flows?
2) What did Commonwealth environmental water contribute to hydrological connectivity at Murrumbidgil Swamp?
3) What did Commonwealth environmental water contribute to habitat for native fish, waterbirds, and other aquatic vertebrate species?

2.1.2 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

4) What did Commonwealth environmental water contribute to hydrological connectivity?

Table 2. The 2015-16 Commonwealth environmental watering actions in the Lower Lachlan river system and their hydrological objectives.

Action	Target	Flow components	Volumes delivered	Hydrology objectives
1	Great Cumbung Swamp	Base flow Fresh flow Wetland inundation	24 058 ML to the Lachlan River, targeting the Great Cumbung Swamp.	Improve hydrological connectivity including end of system flows.
2	Booligal Wetlands – Merrimajeel and Muggabah Creek	Base flow Fresh flow Wetland inundation	1087 ML to Merrimajeel Creek targeting Murrumbidgil Swamp. 1497 ML to Merrimajeel Creek to support waterbird habitat at the Blockbank.	Contribute to hydrological connectivity in the Booligal Wetlands.
3	Lower Lachlan River channel	Base flow Fresh flow	9378 ML to the Lachlan River, targeting flow cued native fish outcomes.	Provide habitat to support, maintain condition of, and provide reproduction opportunities for native fish, waterbirds and other aquatic vertebrate species. Contribute to hydrological connectivity.

2.2 METHODS

The evaluation of the hydrological outcomes used a combination of flow data, river height data, wetland inundation information and observations.

Mean daily discharge (ML/day) and daily mean ‘stage’ (as relative water level in metres) data were obtained from the NSW WaterInfo site (http://waterinfo.nsw.gov.au/) for gauging sites within the Selected Area (Figure 4). The selected gauging sites were those relevant to the locations at which monitoring activities were occurring as well as sites that could be used to evaluate the hydrological outcomes of Commonwealth environmental water. In addition to the NSW WaterInfo data, data were obtained from water level recorders installed at Wallanthery and Cowl Cowl to provide relative changes in water level at these sites.

The daily contribution of Commonwealth and NSW environmental water (ML/day) to the flow was provided by the Commonwealth Environmental Water Office and the NSW Office of Environment and Heritage. These contributions were subtracted from the flow at the relevant water accounting locations to produce hydrographs apportioning the relative contribution to the flow.

Gauging data was used to develop relationships between flow and water level for a number of sites. These relationships were used to estimate the relative contribution of the environmental water to the flow in the channel.

A combination of observations and analysis of flow in relation to published commence to flow data (Driver et al. 2004) was used to determine the contribution of environmental water to the inundation of wetlands. The wetlands that were assessed were those that were monitored for vegetation responses (see also Section 7) as well as those that were the targets of the environmental watering actions.

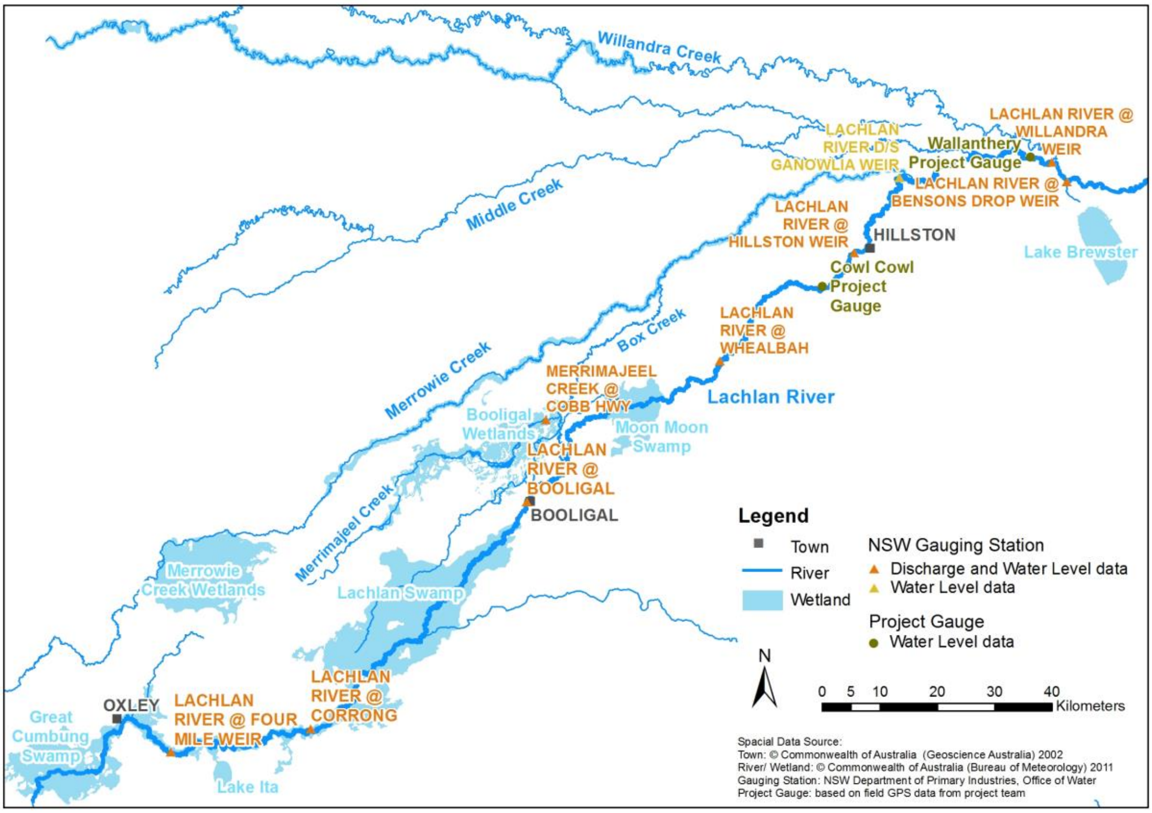


Figure 4. The location of relevant gauging stations in the Lower Lachlan river system.

2.3 RESULTS

The total environmental water delivery to the Lower Lachlan river system in 2015-2016 was 48 027 ML and was made up of 36 020 ML of Commonwealth environmental water and 12 007 ML of NSW water. A further 72 000 ML of translucent flows were delivered under the Lachlan Regulated River Water Sharing Plan making a total of 120 027 ML of environmental water delivered to the Lower Lachlan river system. Commonwealth environmental water contributed approximately 16% of the flow in the river in 2015-16 (based on the flow at Willandra Weir which was 226 445 ML for the period 1 July 2015 to 30 June 2016).

Significant rainfall across the catchment in the first half of 2015 produced medium-large volumes of unregulated inflow to the Lachlan River, particularly from the Belubula and

Boorowa Rivers. Inflows from 1st January to 26th August 2015 totalled 268 000 ML which triggered the delivery of translucent releases, as required under the Lachlan Regulated River Water Sharing Plan. Dam levels were such that translucent releases were targeted at between 3500 ML/day and 5156 ML/day with a combination of tributary inflow and dam releases delivering the water to the Lower Lachlan river system. This translucent event contributed to approximately 72 000 ML of flow passing Lake Brewster weir in September 2015.

The implementation of the translucent releases under the Lachlan Regulated River Water Sharing Plan meant that the three planned watering actions undertaken in 2015-16 were essentially delivered as four separate actions (Figure 5). Water targeting the end of system wetlands (Great Cumbung Swamp, Watering Action 1) was interrupted by the translucent flows, passing the gauge at Willandra Weir (412038) between 5th and 29th September 2015. Each of the watering actions were accounted to different gauges and the analysis is therefore presented in the following three sections.

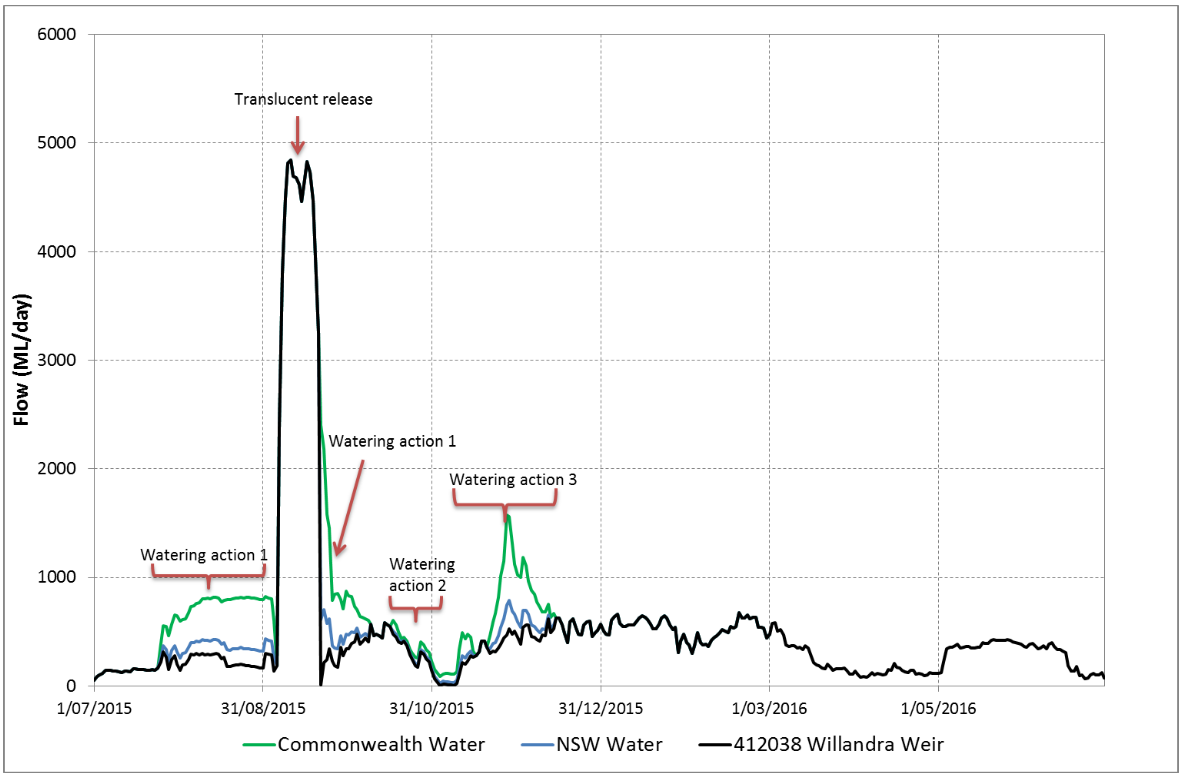


Figure 5. Flow at Willandra Weir (412038) illustrating the pattern of Commonwealth (green) and NSW (blue) environmental water delivery for the period 1 July 2015 to 30 June 2016. Normal river flows (including licensed delivery of water) is shown in black. Watering actions are numbered according to the descriptions in Table 2.

2.3.1 WATERING ACTION 1: GREAT CUMBUNG SWAMP

The first watering action was recorded around the 25th July 2015 at the gauge Willandra Weir, reaching Booligal on the 9th August (Figure 6). This event was interrupted by the translucent flows which were recorded at the gauge Willandra Weir on the 5th September and reached Booligal around the 12th September. Accounting of this watering action was complicated; the first part of the watering action was accounted at Booligal and the second (water provided to modify the recession of the hydrograph) accounted at the gauge Willandra Weir. The first part of Watering Action 1 reached Four Mile Weir on the 22nd August (Figure 6) thus reaching the Great Cumbung Swamp around the 26th August.

Watering Action 1 was designed to contribute to hydrological connectivity and end of system flows. The photo series in Figure 7 shows an outcome at Nooran Lake (in the Great Cumbung Swamp) with the passage of the first part of Watering Action 1 and the translucent flows.

The magnitude of the translucent flows meant that they dominated the watering in the Lower Lachlan river system during the 2015-16 watering season by providing flows of sufficient magnitude to inundate wetlands between Hillston and the Great Cumbung Swamp. However, the translucent flows were provided for a short duration and the first part of Watering Action 1 extended the connectivity and end-of-system flows for around 35 days. It is not possible to determine the contribution of the second part of Watering Action 1 to the duration of connectivity and end-of-system flows because the attenuation of flow through the system means that it becomes impossible to disentangle from the translucent flow.

The second part of Watering Action 1 was designed to attenuate a rapid reduction in flow in the river caused by the cessation of the translucent flows. In a low gradient lowland river such at the Lachlan, rapid changes in water level do not commonly occur and can have adverse effects on the river banks and potentially result in stranding of biota as off channel habitats become disconnected. The use of Commonwealth environmental water to modify the tail of the translucent flow in 2015-16 moderated the flow recession over approximately 5 days at Willandra Weir. A brief analysis of the hydrograph from 1940-1970 suggests that the recession was typically around 14 days for similarly sized flow events. Specific ecological implications of a 5 day recession compared with 14 days are not obvious and it is doubtful that the current monitoring program is able to provide much further information about this.

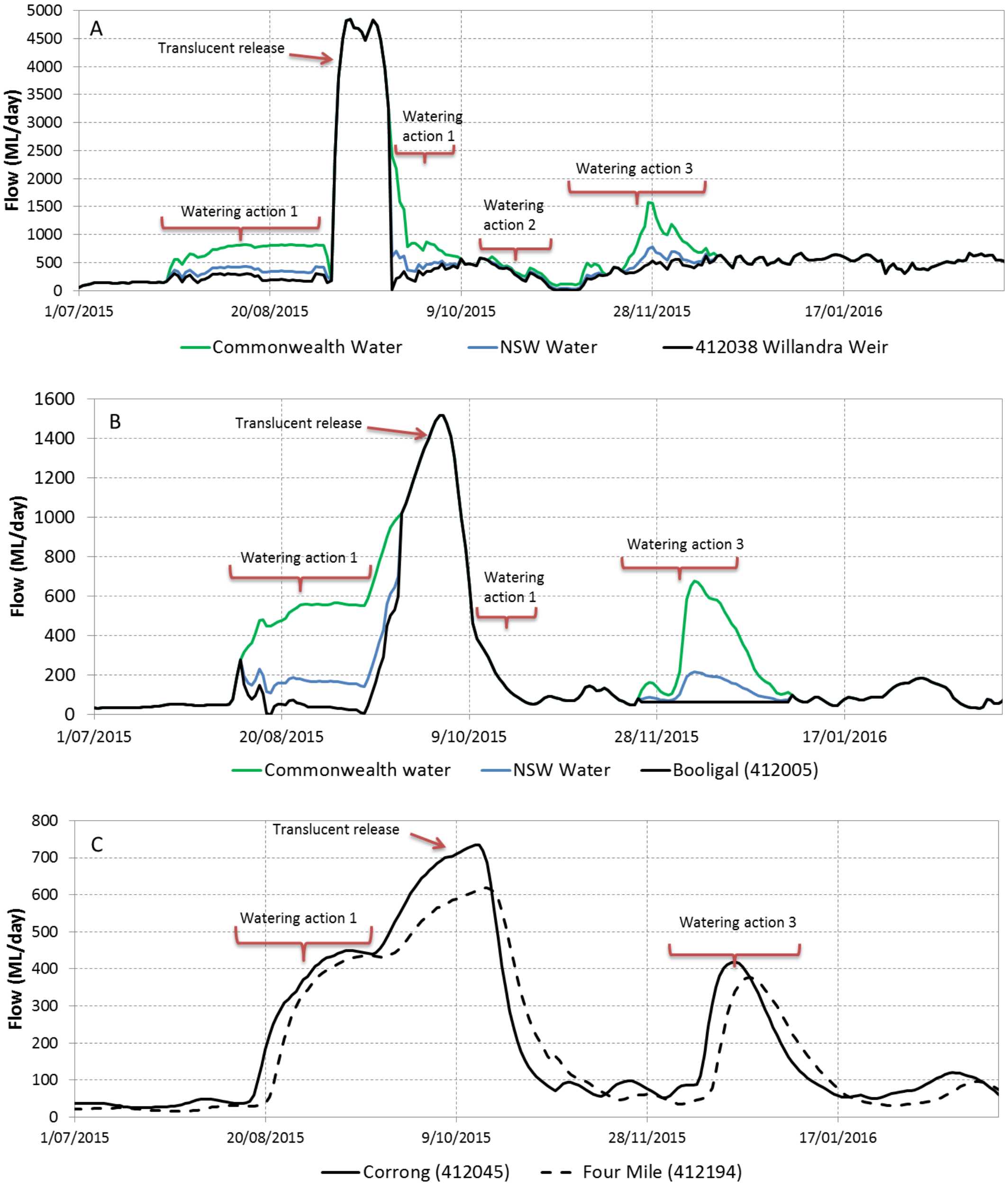


Figure 6. Passage of Watering Action 1 through the Lower Lachlan River System from the gauge at Willandra Weir to Four Mile Weir for the period 1 July 2015 to the 30 June 2016. Commonwealth (green) and NSW (blue) environmental water are shown along with estimates of normal creek flow (including the licensed delivery of water) in black. A) Data from the gauge at Willandra Weir (412038); B) data from the gauge at Booligal (412005); C) data from the gauges at Corrong (412045) and Four Mile Weir (412194). The second part of Watering Action 1 is not shown at the Corrong and Four mile gauges because the attenuation of flow makes it impossible to disentangle it from the translucent flow. Watering Action 2 is not shown beyond the Willandra Weir gauge because they are delivered to the Merrimajeel/Muggabah Creek system and do not pass subsequent gauges on the Lachlan River. Refer to Figure 4 for gauge locations.

A)

B)

C)

Figure 7. Water level fluctuations at Nooran Lake in the Great Cumbung Swamp. A) prior to the arrival of environmental water; B) the peak of Watering Action 1; C) the peak of the translucent flows.

2.3.2 WATERING ACTION 2: MURRUMBIDGIL SWAMP AND BOOLIGAL WETLANDS

Watering Action 2 was delivered in 3 parts, two of which were to Merrimajeel Creek (Figure 8) targeting Murrumbidgil Swamp, the third was to Muggabah Creek (not shown). The first part of the watering action in Merrimajeel Creek (early September) followed the delivery of replenishment flows making use of the wetted channel to minimise losses. The watering action was suspended as translucent flows passed between 16 September and 8th October. The second part of the Merrimajeel watering was delivered between the 21st October and the 17th November 2015 (Figure 8). Environmental water contributed all of the water in the creek between 21st October and 17th November thus extending the duration of flow in Merrimajeel Creek by approximately 28 days.

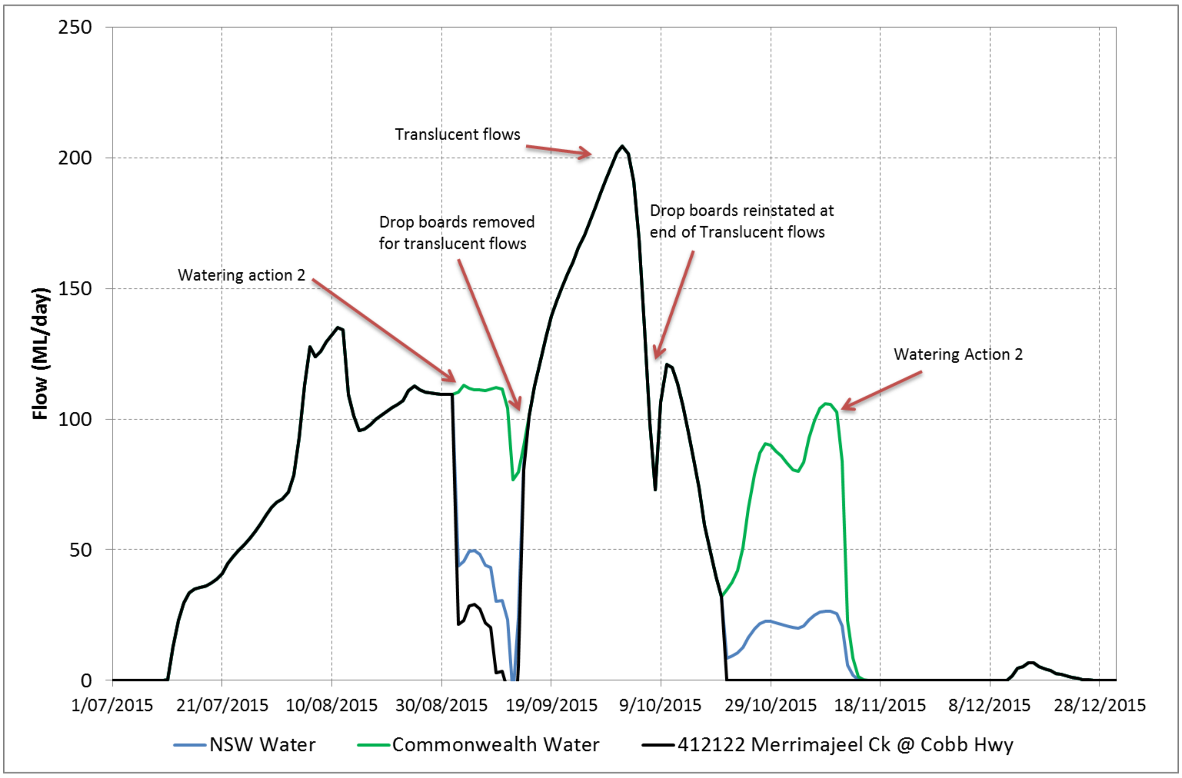


Figure 8. Flow at gauge Merrimajeel Creek (412122) showing the delivery of Commonwealth (green) and NSW (blue) environmental water.
Normal creek flow (including the licensed delivery of water) is shown in black. Operational notes are also provided.

Watering Action 2 provided water to Murrumbidgil Swamp, with water filling a number of the channels within the swamp. Observations from field work in late October (29/10/2015) were that the lower lying channels contained water to a maximum depth of 40 cm (Figure 9).

Figure 9. Environmental water in Murrumbidgil Swamp. October 29th 2015. Photos: Fiona Dyer.

2.3.3 WATERING ACTION 3: LACHLAN MAIN CHANNEL

Watering action 3 commenced at the gauge Willandra Weir on the 9th November 2015 and finished on the 15th December with two small fresh flows delivered in conjunction with normal licensed water delivery. The hydrograph created from this watering action displays two freshes the first peaking at 487 ML/day on 11th November and the second peaking at 1571 ML/day on the 27th November (Figure 10).

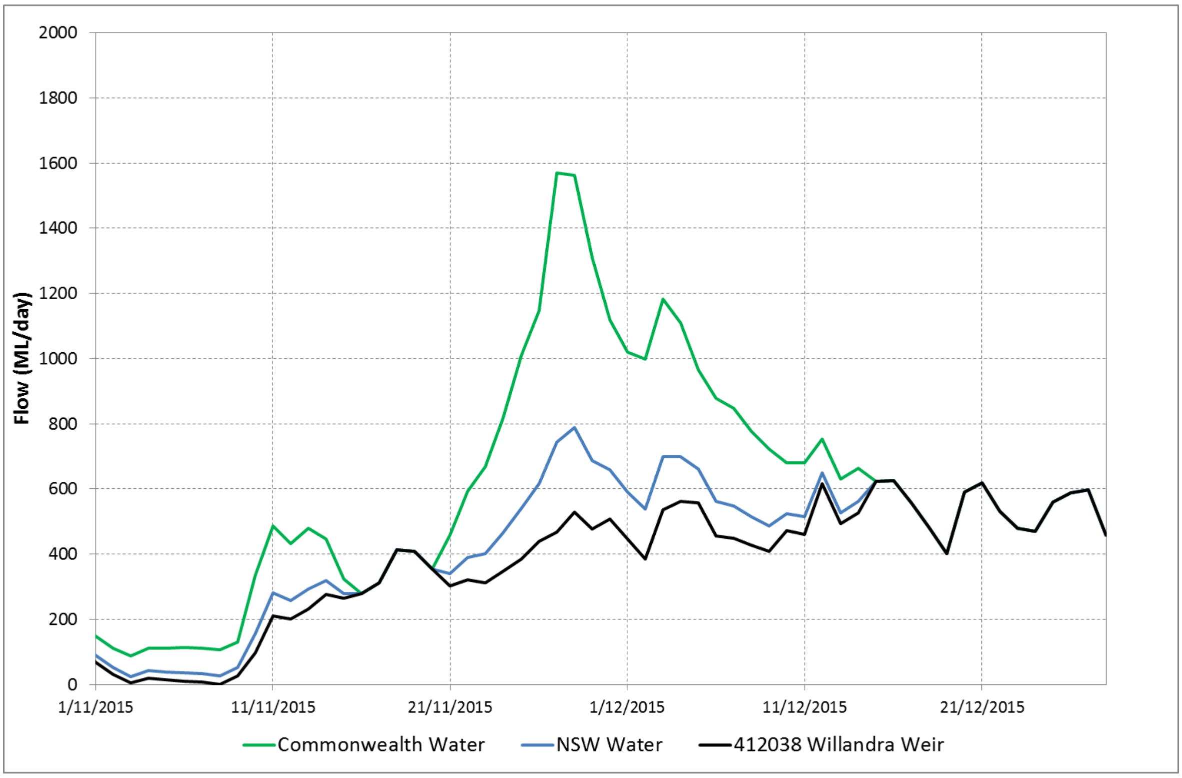


Figure 10. Flow at Willandra Weir (412038) during Watering Action 3.
Commonwealth (green) and NSW (blue) environmental water is shows as well as normal river flow (including licensed delivery of water) in black.

The relative in-channel water level changes associated with the delivery of Watering Action 3 were determined for Lane's Bridge, a site which is representative of the free flowing river (not sections of the river influenced by weirs). At Lane's Bridge (Ganowlia Weir) the river rose approximately 0.75 m for the first fresh and a further 1.0 m for the second fresh (Figure 11). These rises were significantly attenuated within the weir pools of the river. Watering Action 3 not only increased the available habitat within the main channel of the river, it also provided water to the Great Cumbung Swamp (Figure 12).

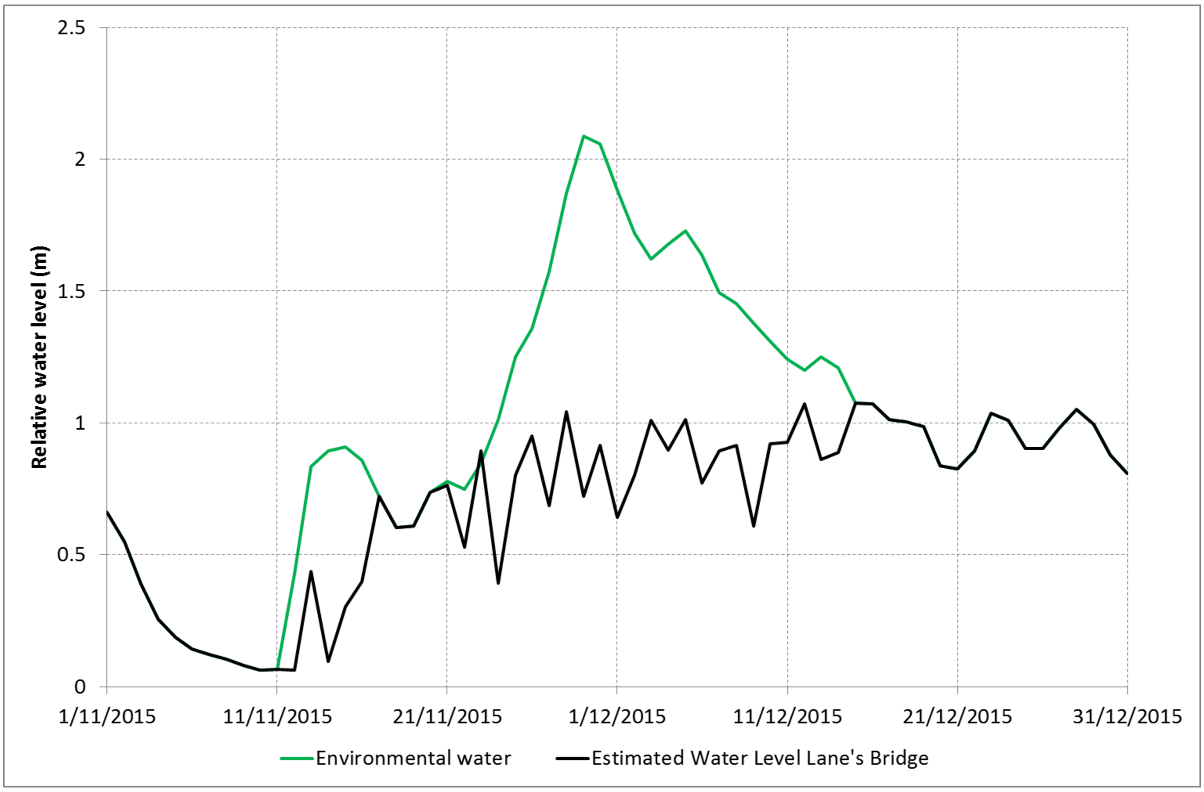


Figure 11. Relative water level changes associated with the delivery of Watering Action 3 at the Ganowlia Weir (412196) (Lane's Bridge).
The water level including environmental water is shown in green and an estimate of the water level without environmental water is shown in black.

A)

B)

Figure 12. Wetland inundation at Clear Lake in the Great Cumbung Swamp caused by Watering Action 3.
A) prior to the arrival of Watering Action 3; B) the peak of Watering Action 3.

2.3.4 END OF SYSTEM WATERING

The extent of the end of system watering that occurred in 2015-16 is shown in Figure 13 and field observations of inundation from the different watering actions included in Table 3.

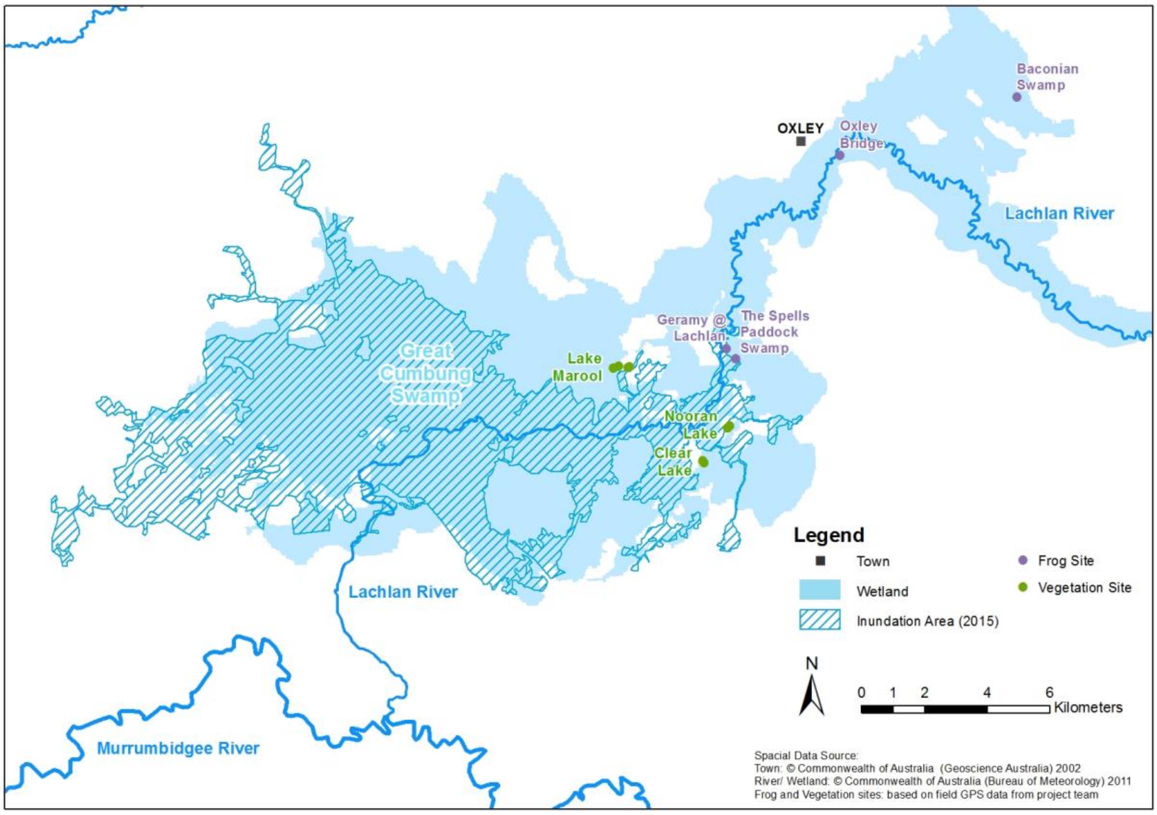


Figure 13. Inundation of the Great Cumbung Swamp caused by the combined watering actions in 2015-16. Data courtesy Paul Packard, NSW OEH.

Table 3. Observations of wetland watering in 2015-16 from the watering actions.

	COMMONWEALTH WATER			NSW WATER
SITE (CODE)	WATERING ACTION 1	WATERING ACTION 2	WATERING ACTION 3	TRANSLUCENT FLOWS
ZONE 1				
Hazelwood (HW)	N	N	N	Y
Whealbah (WB)	N	N	N	Y
Moon Moon (MM)	Y (extending duration)	N	N	Y
ZONE 2				
Lake Bullogal (LBU)	N	N	N	N
The Ville (TV)	N	N	N	Y
ZONE 3				
Clear Lake (CL)	Y	N	Y	Y
Nooran Lake (NL)	Y	N	Y	Y
Lake Marrool (LM)	N	Unknown	Unknown	Y
Reed beds	Y	N	Y	Y
ZONE 4				
Tom's Lake (TL)	N	N	N	Unknown
Lake Tarwong (LT)	N	N	N	N
ZONE 5				
Booligal (BO)	Y	N	N	Y
Murrumbidgil Swamp (MB)	Y	N	N	Y

2.4 EVALUATION

The three environmental watering actions delivered during 2015-16 were an order of magnitude greater than the watering action that was delivered in 2014-15 (Dyer et al. 2015). The 2015-16 actions connected wetlands and provided water to the end of the Lower Lachlan river system. In relation to the effects of Commonwealth environmental water, the evaluation questions are addressed as follows:

1) What did Commonwealth environmental water contribute to maintaining hydrological connectivity including end of system flows?

Watering Actions 1 and 3 delivered water to the end of the Lower Lachlan river system, extending the magnitude and duration of flows to the Great Cumbung Swamp. Watering Action 1 connected the main channels and central reed beds of the Swamp as well as providing water to some of the lakes that make up the wetland complex (such as Clear Lake and Nooran Lake). Watering Action 1 extended the duration of watering of the lakes for almost 30 days prior to the arrival of the translucent flow in mid-September. Watering from the translucent flows continued for another 45 days. Watering Action 3 also provided water to the main channels, central reed beds and lakes of the Swamp for a further 25 days from mid-December 2015 through to mid-January 2016. In combination the Commonwealth environmental watering events doubled the duration of hydrological connectivity and wetland inundation in the Great Cumbung Swamp.

The second part of Watering Action 1 was used to attenuate a rapid drop in flow in the river caused by the cessation of the translucent releases from the upstream storage. In a low gradient lowland river such at the Lachlan, rapid changes in water level do not commonly occur and can have adverse effects on the river banks and potentially result in stranding of biota. The use of Commonwealth environmental water to modify the tail of the translucent flow in 2015-16 moderated the flow recession over approximately 5 days at Willandra Weir. While this was shorter than the historically observed recession rate for similarly sized events and the effects were not directly monitored there were no reported adverse consequences.

2) What was the effect of Commonwealth environmental water on hydrological connectivity to Murrumbidgil Swamp?

Watering Action 2 delivered water through Merrimajeel Creek to Murrumbidgil Swamp. It extended the duration of flow in Merrimajeel Creek by 34 days. The pattern of delivery, following replenishment and translucent flow, prevented the the creek from drying between watering events. This is expected to have significantly reduced channel losses and likely resulted in water progressing further into the channels within Murrumbidgil Swamp than any of the events on their own. Without the environmental water Murrumbidgil Swamp would have remained dry and disconnected from the rest of the river system. As a consequence, any benefit from watering Murrumbidgil Swamp in 2015-16 may be solely attributed to environmental watering actions in which Commonwealth environmental water was a significant contribution.

3) What was the effect of Commonwealth environmental water on providing access to habitat for fish?

Watering Action 3 provided two freshes to the main channel of the Lower Lachlan River. The first fresh raised the water level by around 0.75 m and the second peak raised the water level in the main channel of the Lower Lachlan River by slightly more than 1 m. This connected in-channel habitats, providing access to additional habitat for fish as well as providing the water level rise of at least 0.5 m thought to be optimal for golden perch spawning.

4) What did Commonwealth environmental water contribute to hydrological connectivity?

The three watering actions delivered in 2015-16 connected in channel habitats and wetlands, and provided flow to the end of the river system. Commonwealth environmental water achieved hydrological connectivity in channel, longitudinally and laterally. But spatially the dominant watering event in the river system was the provision of 72 000 ML of translucent flow, delivered as part of the Lachlan Regulated River Water Sharing Plan rules. The translucent flow was of sufficient magnitude to inundate wetlands between Hillston and the Great Cumbung Swamp, however, the translucent flow was only short in duration.

Commonwealth environmental watering actions built on the watering provided by the translucent flow to significantly extend the duration of hydrological connectivity. This was particularly notable in the Great Cumbung Swamp where the combined Commonwealth watering actions doubled the duration of the wetland inundation and hydrological connectivity.

2.5 FINAL COMMENTS AND RECOMMENDATIONS

The hydrological analysis presented provides the context for the ecological responses. The watering actions delivered were designed for specific ecological outcomes and the responses observed are used to inform the design of future watering actions. As such recommendations specific to hydrology are limited and relate to our understanding of historical flow patterns and how these might inform future watering actions.

- The design of hydrographs for the delivery of water into Merrimajeel Creek and Muggabah Creek is constrained by flow records starting in 2003. To improve the design of the hydrographs and potentially achieve stronger outcomes for frogs and vegetation, some thought should be given to developing flow models that would enhance our understanding of natural flow patterns in these creeks.

3 STREAM METABOLISM AND WATER QUALITY

3.1 INTRODUCTION

The energetic base of food chains in freshwater systems is provided either by primary production (the energy fixed by photosynthesis occurring in plants and algae) or by breakdown of organic matter which enters the water from terrestrial sources (such as leaves, wood and organic carbon dissolved in the water). Those processes are both influenced by the availability of key nutrients, particularly nitrogen and phosphorus, and a range of physico-chemical variables, particularly water temperature and light. Primary production and organic matter breakdown can be measured through continuous monitoring of changes in the concentration of oxygen in the water (described as measurements of open channel stream metabolism).

Stream metabolism uses measurements of the concentrations of oxygen in the water over a day-night cycle to estimate the amount of carbon being fixed via photosynthesis (gross primary productivity [GPP]), and the amount of carbon being respired due to breakdown of organic material (ecosystem respiration [ER]). In heterotrophic ecosystems, GPP:ER is <1 which means the ecosystem is using more energy than it is creating *in situ*, relying largely on organic inputs from upstream or terrestrial sources. These systems will consume large amounts of oxygen as organic matter decomposes or is fed on by invertebrates (see Figure 14). In autotrophic ecosystems GPP:ER is >1, which means the ecosystem is creating more energy *in situ* than it is using, and is based on local photosynthesis. Highly autotrophic systems with rapid growth of algae (algal 'blooms') will produce large amounts of oxygen during the day. By combining measurements of oxygen concentration during the day and the night with estimates of aeration (the diffusion of oxygen into the water at the water surface) it is possible to determine the dominant energy source for the aquatic food web. Oxygen measurements can also provide measures of stress to aquatic organisms. Where large amounts of organic carbon enter the channel (e.g. 'blackwater' events) or when algal blooms die off, the demand for oxygen can be sufficiently high that there is insufficient oxygen remaining for fish, resulting in fish kills.

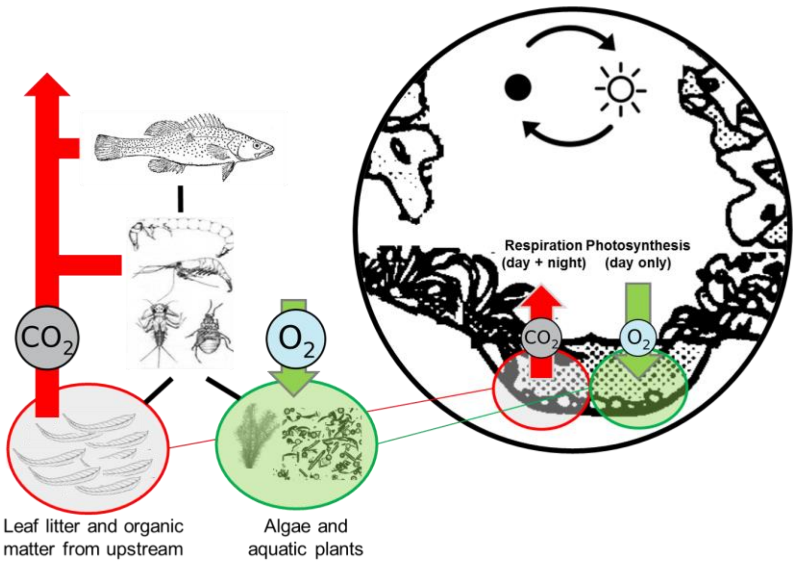


Figure 14. Conceptual model of oxygen fluxes in a stream channel (Ross Thompson).

Stream metabolism can be influenced by a number of drivers which respond to environmental flows (Figure 15), and which interact with channel characteristics and availability of light (Boulton and Lake 1992, Baldwin and Mitchell 2000, Bunn et al. 2006, Stewardson et al. 2013). In-channel features which accumulate organic matter, such as perched benches would need to be inundated during an environmental flow event in order to provide organic matter and nutrient inputs. Similarly, short term turbid environmental flows may decrease primary production where productive surfaces end up in deeper water beyond the photic depth, or where flows scour aquatic biofilms. Primary production responses due to inundation of additional suitable substrates are likely to lag behind watering events, as algal colonisation and proliferation of new substrates takes time, particularly in cooler conditions.

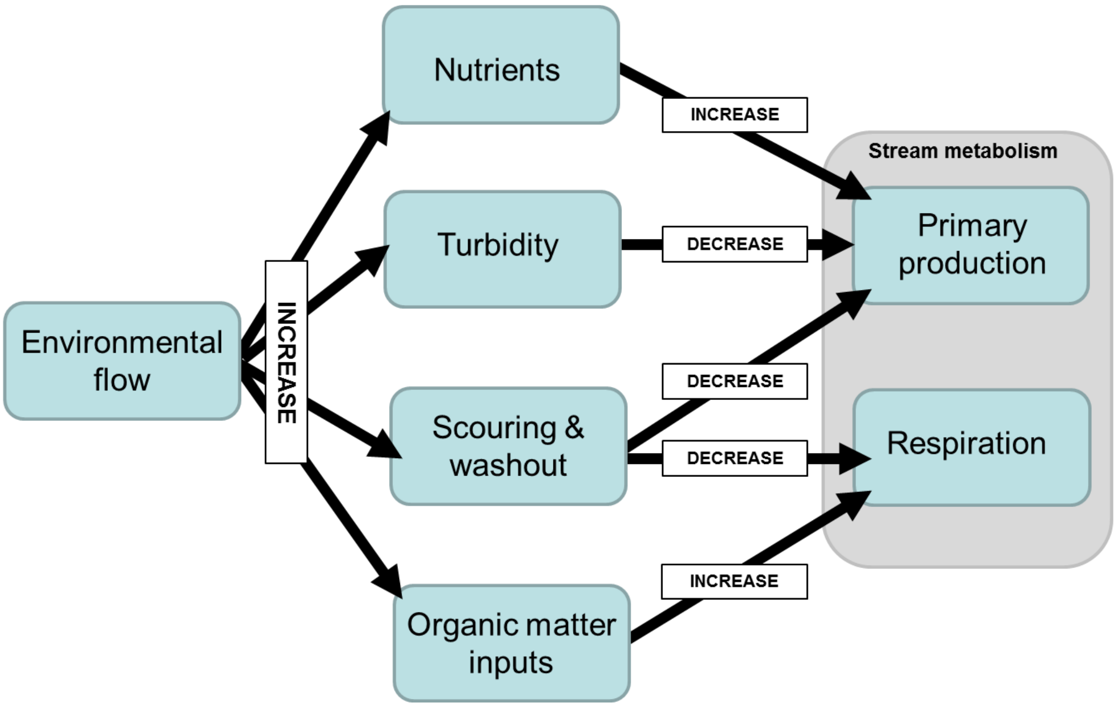


Figure 15. Conceptual model of the influence of environmental watering on drivers of stream metabolism (Ross Thompson).

In 2014 a single environmental flow was delivered to the system (peaking on 8th September 2014). Interpreting the effect of this flow on water quality and on the evaluation questions above was hindered by the single event (i.e. no replication). There was evidence based on the single environmental flow event in 2014 for a decrease in both gross primary production (GPP) and ecosystem respiration (ER) after the flow. This was likely to primarily be a consequence of dilution of phytoplankton and organic matter by the higher flows, together with reductions in light reaching the photosynthetically active surfaces in the channel. The relatively rapid increase in both GPP and ER after the flow suggested that disruption of biofilms and removal of organic matter were not likely mechanisms underpinning this response. However, the flow-independent major increase in both GPP and ER over this period meant that data on more flow events was required to address the effects of environmental flows on these parameters in any definitive way.

This report addresses the following evaluation questions:

1) What did Commonwealth environmental water contribute to patterns and rates of decomposition?
2) What did Commonwealth environmental contribute to patterns and rates of primary productivity?

3.2 METHODS

Sampling locations were established at four sites in the target reach: Wallanthery, Whealbah, Cowl Cowl and Lane's Bridge (Figure 2). These sites were sampled from June 2014.

Stream metabolism was measured applying the standard methods for the LTIM project (Dyer et al. 2014). An oxygen logger was installed at four of the sites (Wallanthery, Whealbah, Cowl Cowl and Lane's Bridge) in the middle of the water column at base flow. The depth of the probe varied as the water depth varied, but as the water column was well mixed, this has no effect on the data. Continuous sampling took place from 25th June 2015 until 25th March 2016. Dissolved oxygen (DO) and water temperature were logged at 10-min intervals using D-Opto dissolved oxygen sensors (Zebra-Tech, Nelson, New Zealand). Prior to and after deployment, the loggers were calibrated. If required, linear corrections were applied prior to metabolism calculations. Photosynthetic active radiation (PAR) was measured in adjacent unshaded locations at 10-min intervals using photosynthetic irradiance loggers (Odyssey, Christchurch, New Zealand). Barometric pressure was logged with a Silva Atmospheric Data Centre Pro (Silva, Sollentuna, Sweden).

Curve fitting was applied using the BASE model (Grace et al. 2015) to estimate primary production and respiration on a daily basis. Curve fits were examined by eye for the influence of any outliers (Figure 16). Where a single outlier was resulting in poor curve fit, that data point was removed and replaced by the average of the two adjoining data points. After this process estimates derived from curve fits with $R^2 < 0.90$ and/or CV for GPP of > 50% were discarded.

For water quality parameters, duplicate water samples were taken 2 metres from the water's edge at 1 metre depth at between 2 and 6 weekly intervals, before, during and after releases at three locations within each of the four sites. These were placed on ice and returned to University of Canberra for analysis for total nitrogen, nitrate/nitrite, total phosphorus, dissolved reactive phosphorus and ammonia. Conductivity and pH were recorded using a handheld water quality meter. There are incomplete data for some sites and times because of issues with access to sites (e.g. lack of access during high flows).

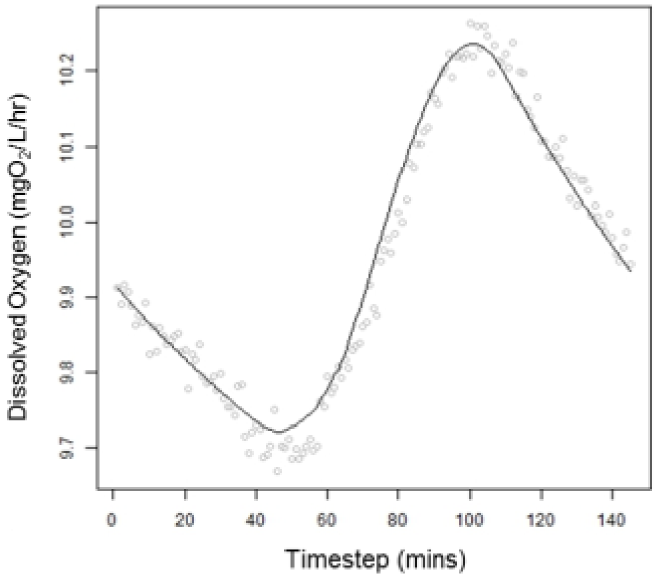


Figure 16. Example of excellent curve fit to measured dissolved oxygen (DO) generated by the program BASE (data are for 10th September 2014, R^2 = 0.98).

3.3 RESULTS

3.3.1 WATER LEVEL

There is a significant difference in the water level changes associated with the free flowing sections of the river (Lane's Bridge and Whealbah) and the weir pools (Willandra Weir and Hillston Weir) (Figure 17). The translucent flows resulted in changes in water level of around 3.0 m in the free flowing sections of the river and not quite 1.0 m in the weir pools. In contrast, Watering Action 1 and 3 resulted in a change in river level of 1.0 to 1.5 m in the free flowing section of the river and was barely noticeable in the weir pools. Rises in water-level inundate in-channel features (such as benches, vegetation and woody debris), and wet previously dry soils, potentially mobilising nutrients, transporting organic matter and stimulating production in the river. The significance of the observed changes will be discussed in subsequent sections.

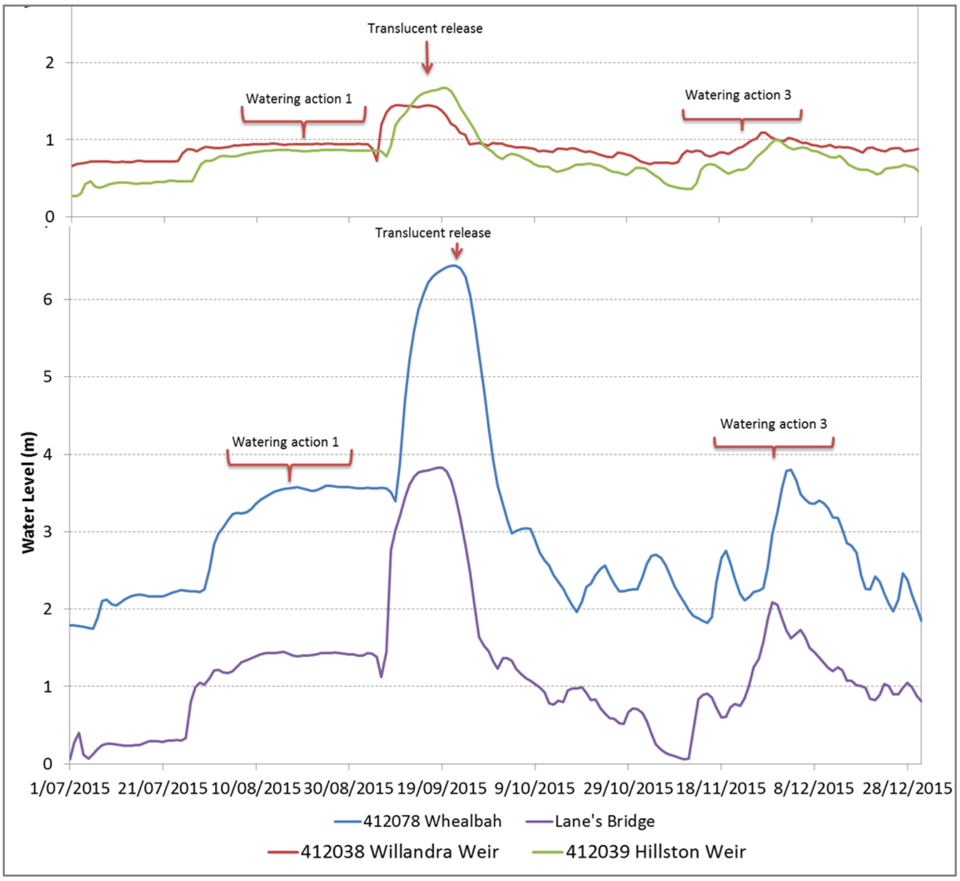


Figure 17. Relative changes in water level for representative gauging stations within Zone 1. Whealbah and Lane's bridge represent the free-flowing channel sections of the river; Hillston Weir and Willandra Weir are representative of the weir pools.

3.3.2 STREAM METABOLISM AND WATER QUALITY

Stream metabolism data was collected for the four sites referred to in Section 3.2 (Figure 18). For the 2015/2016 year, 44.5% of days across all sites were discarded because they failed to meet the criteria for curve fit. These poor fits were associated with very high estimates of values for both GPP and ER (Figure 18), and in particular with the translucent flow in August 2015. High standard deviations were associated with the highest estimated values, with high scatter in oxygen readings through the diel cycle evident over and above the expected diel variability when ER values, in particular, were high.

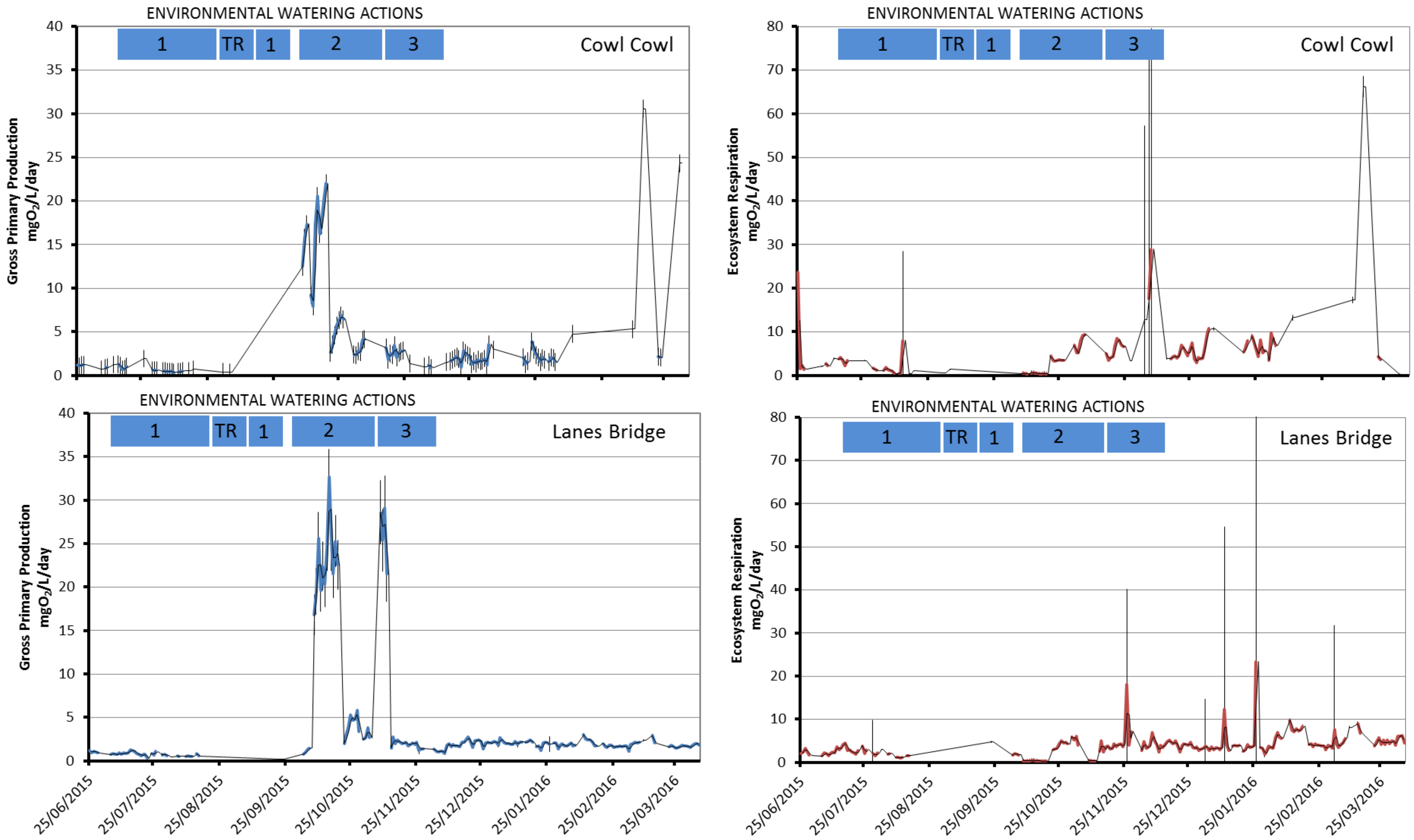
There were major differences between the four sites, with the Wallanthery site having relatively low GPP and ER relative to other sites. All sites were mildly to extremely heterotrophic (GPP:ER <1), with periodic autotrophic pulses (GPP:ER > 1).

There was no consistent response to environmental flows (Figure 18), although all sites showed elevated levels of GPP and ER after the translucent flow and subsequent environmental flow in August 2015, and were autotrophic at this time. This was associated with high nutrient availability over the same period. These patterns were much more muted at the Wallanthery site. There were a series of high values for GPP at Whealbah in December 2015/January 2016 that did not appear to be explained by flows or water chemistry. At Cowl Cowl and Lane's Bridge small peaks in ER were evident potentially associated with Water Action 3 in December 2015.

Water quality results are shown in Figure 19 and Figure 20. Average daily water temperatures ranged from 11 °C (winter) to 27 °C (mid-summer) and were broadly consistent across the four sites. Conductivity was generally low and relatively constant and pH was generally slightly alkaline. There were no significant episodes of low pH. Turbidity was generally highly variable across time and between sites. The ANZECC Water Quality Guidelines (2000) indicate that turbidity in lowland rivers can be extremely variable. Values at the high end of the range ~50, would be found in rivers draining slightly disturbed catchments and in many rivers at high flows.

Macronutrient concentrations were generally low, for both nitrogen and phosphorus relative to the ANZECC guideline for lowland aquatic ecosystems (ANZECC and ARMCANZ 2000). Total N and total P values exceeded the ANZECC (2000) guidelines for lowland rivers. The ratio of TN:TP, which can indicate risk of harmful algal blooms (HABs), ranged from 6-16. Values of <15 indicate elevated risk of HABs (ANZECC and ARMCANZ 2000). Concentrations of dissolved organic carbon and chlorophyll did not vary consistently through time or between sites, and showed no clear association with flow events. There was also no clear effect of season.

There was no clear effect of the environmental flow deliveries on most water quality variables (Figure 19 and Figure 20). The exception to this was the large translucent flow in August 2015, which was associated with elevated levels of both nitrogen and phosphorus (Figure 20). There was no evidence that this effect may be seasonal, as there was no evidence of any similar peaks in the previous year, when a translucent flow was not present.


ENVIRONMENTAL WATERING ACTIONS
1
TR
1
2
3
Cowl Cowl
Gross Primary Production
mgO2/L/day
Ecosystem Respiration
mgO2/L/day
Lanes Bridge
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
25/06/2015
25/07/2015
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25/02/2016
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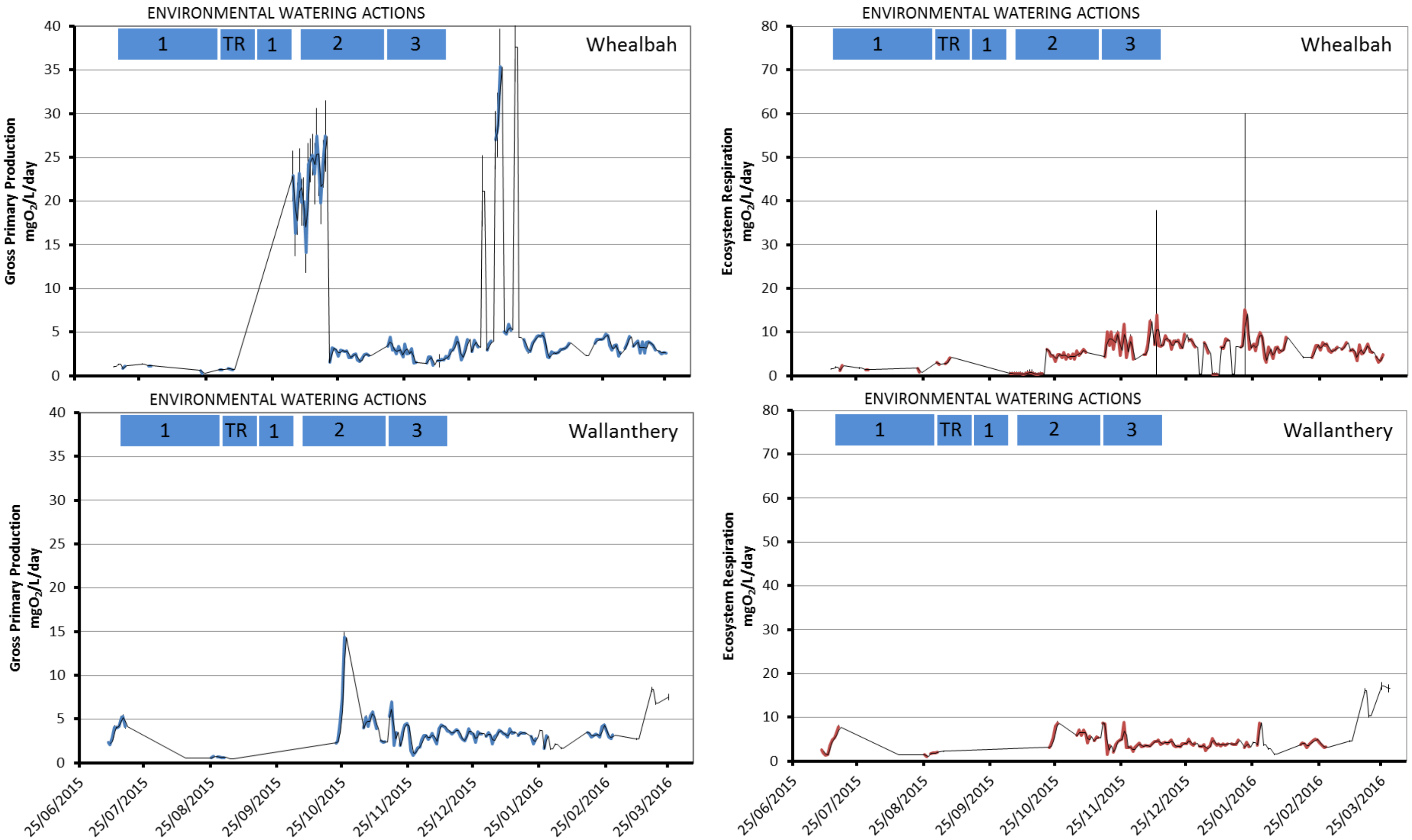


Figure 18. Gross Primary Production (left) and Ecosystem Respiration (right) at Cowl Cowl, Lane's Bridge, Whealbah and Wallanthery in 2015-16. The environmental watering actions shown as blue bars (Watering Action: TR = Translucent Flow, for numbering codes see Table 1).Results are modelled averages with standard deviations. Bold lines indicated modelled values based on measured data, the fine black lines indicate a moving average trend line. Missing data are largely as a consequence of modelled outcomes failing to meet the criteria for model convergence.

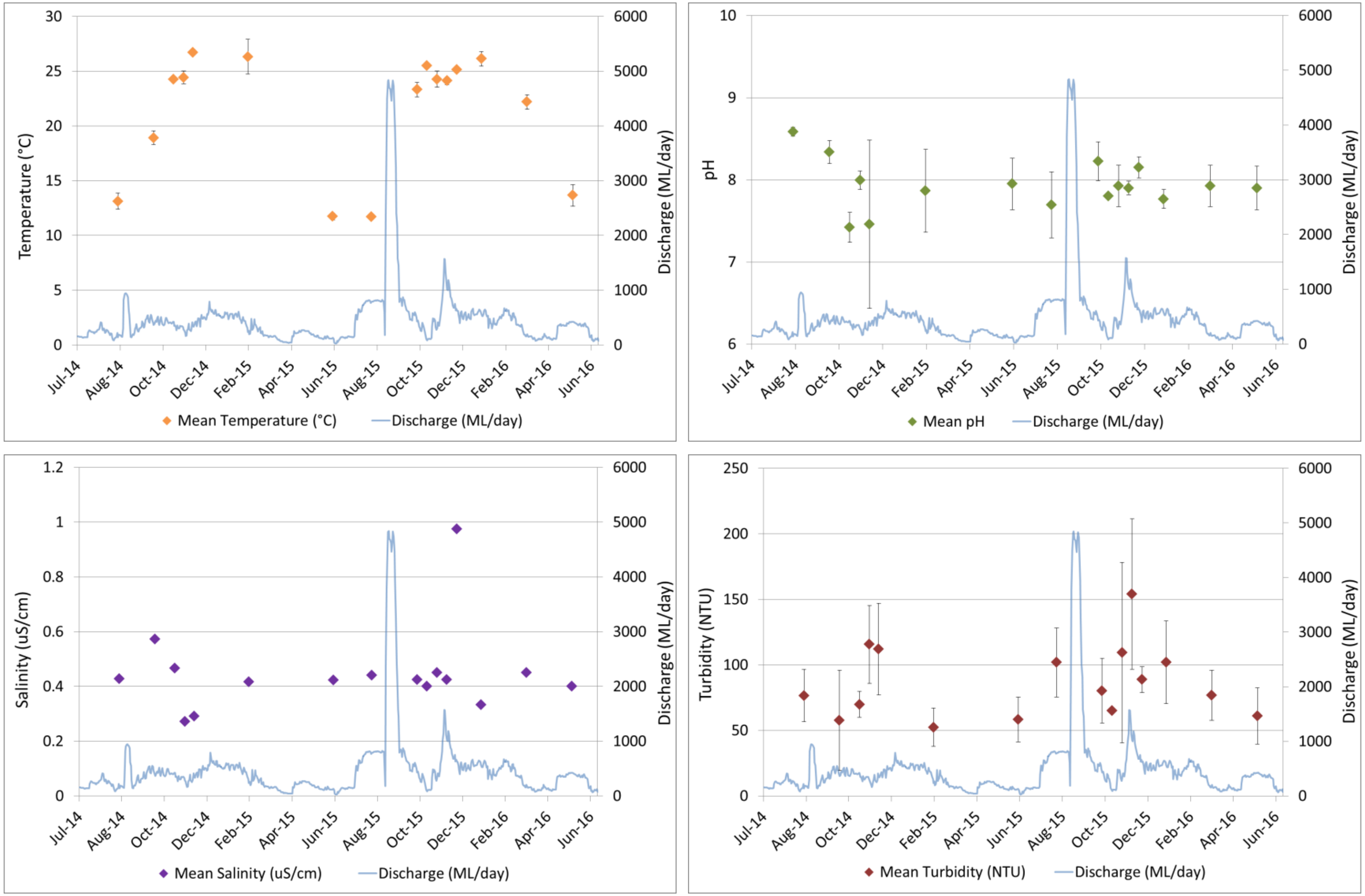


Figure 19. Mean water quality measurements (± standard error. Note: standard error for salinity plot is smaller than symbol size) for four sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period: physico chemical attributes.

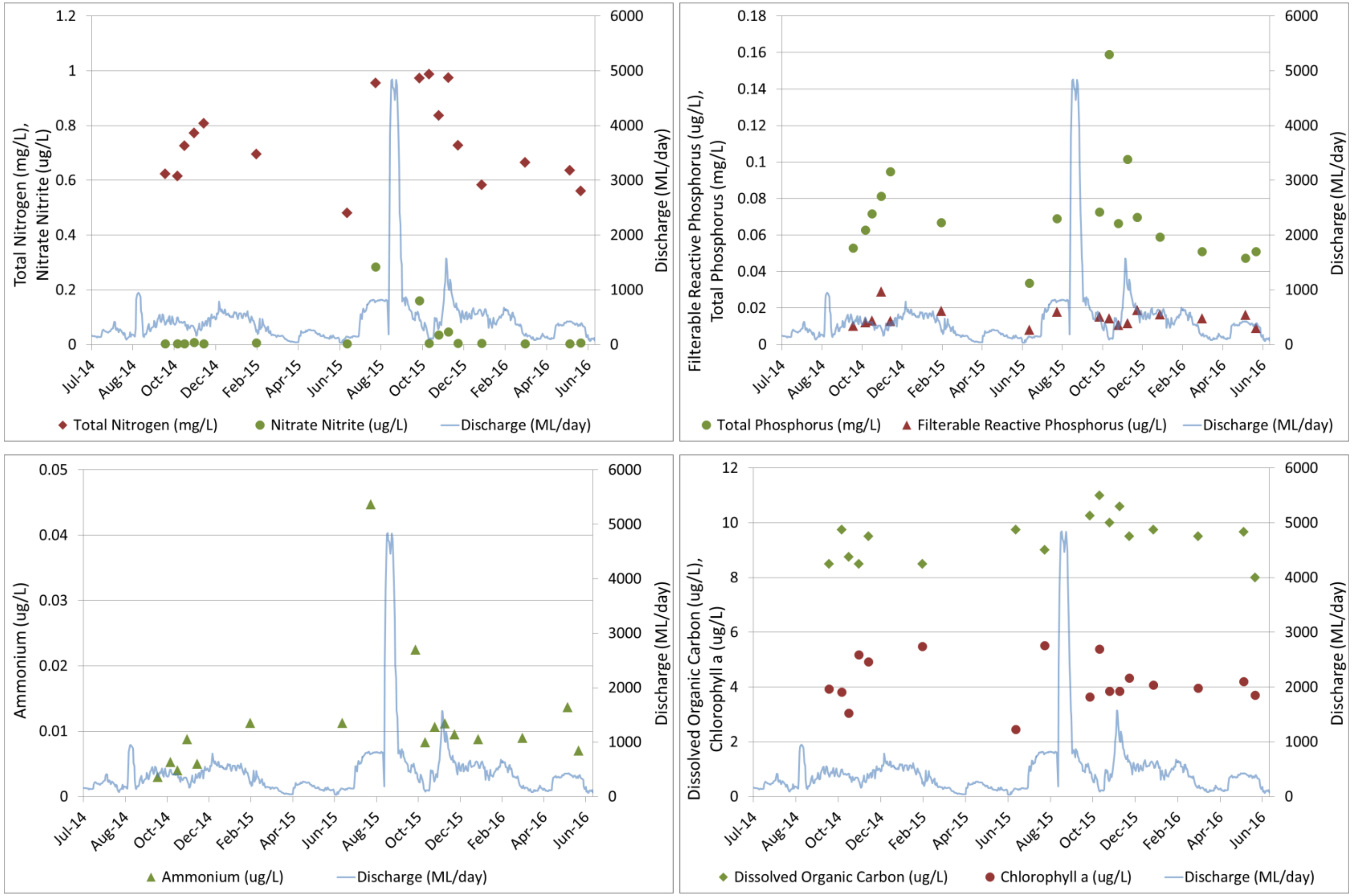


Figure 20. Mean water quality measurements for four sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period: nutrients and chlorophyll a.

3.4 DISCUSSION

The period for which data are available includes a series of environmental flows and a large translucent flow. The intention of this section was to assess the effects of Commonwealth environmental watering on rates of ecosystem functioning in the Lachlan River. Specifically it was sought to determine:

1) What did Commonwealth environmental water contribute to patterns and rates of decomposition?
2) What did Commonwealth environmental water contribute to patterns and rates of primary productivity.

There was no evidence that the environmental flows were associated with consistent responses in either GPP or ER. In contrast the large translucent flow was associated with increases in available nutrients and substantive peaks in GPP and in some sites in ER. This indicates an algal response to nutrient availability, and potentially to increased availability of light or increased substrate availability. The relatively rapid increase in both GPP and ER after the flow suggests that disruption of biofilms and removal of organic matter are not likely mechanisms underpinning this response.

There were no clear patterns in water chemistry associated with delivery of environmental flows. This may indicate that sites of accumulation of nutrients and organic matter were not inundated by these relatively small flow events. In contrast the translucent flow was associated with substantively elevated levels of nutrients, consistent with nutrient release from inundated sediments and organic matter. There was no evidence of consistent increases in either dissolved organic carbon or reductions in pH associated with any flow event that would be indicative of black water generation.

Rates of GPP and ER in this part of the Lower Lachlan river system were similar to those observed in similar lowland river ecosystems such as the Goulburn River (Stewardson et al. 2013) and the Edward-Wakool system (Watts et al. 2013), and consistent with findings reported in 2014/15. There was considerable variability in rates, even in the absence of major flow variability and a general trend towards higher values for GPP and ER moving into summer. Importantly the results were a likely consequence of the observed marked increase in water temperatures.

Results suggest that the GPP and ER responses to environmental flows are strongly affected by in-stream temperatures, and that spring environmental flows are likely to have smaller effects on GPP and ER than those in summer. Energetic responses (energy flowing from GPP into the food web and on to target consumers such as fish and birds) are likely to be larger and more rapid when environmental flows are provided in summer. However, it is also clear that the mobilisation of nutrients and subsequent increase in algal productivity does not appear to be being triggered by the relatively small environmental flows, compared to the much larger translucent flows. There is some evidence however that the second part of Commonwealth environmental Watering Action 1, which ‘piggy-backed’ on to the translucent flow, may have acted to prolong or potentially provide a second flush of GPP in the river. This is suggested by a prolonged GPP and ER response after the flow event, although observations and analysis of future, similar flow events are required.

3.5 FINAL COMMENTS AND RECOMMENDATIONS

The Commonwealth environmental watering actions provided in 2015-16 were in-channel rises of up to 1.5 m (Figure 11 and Figure 17). This is in contrast to rises of up to 3.0 m associated with the translucent flow. The rises associated with the watering actions were either not large enough to engage with in-channel features and mobilise nutrients and stimulate algal production, or there are not in-channel features (e.g. dry snags, perched benches with accumulated organic matter) in the target reach that would contribute nutrients. While the dynamics of this are complex, the lack of accumulated organic matter which is accessible to this flow may have been reduced by the translucent flow exporting material out of the reach. It is noted that there are constraints to the water level rises that can be achieved with Commonwealth environmental water with flows of 2000 ML/day at Willandra Weir considered the maximum that can be provided as an environmental watering action. Watering Action 3 peaked at 1500 ML/day at Willandra Weir (Figure 10).

- Recent high resolution habitat mapping in the target reach by NSW DPI Fisheries provides an opportunity to examine the possible water level rises in relation to the inundation of channel features, and may inform future flows targeting ecosystem responses through inundation of these features.

4 FISH COMMUNITY

4.1 INTRODUCTION

Fish are an integral component of aquatic ecosystems and have been used as an indicator of aquatic ecosystem health in several large river health monitoring programs in south-east Australia (Davies et al. 2010, Muschal et al. 2010). The advantages of using fish as indicators of aquatic ecosystem condition include: i) fish can be relatively long-lived compared with other potential indicators and are mobile, so reflect both short and longer-term and local to catchment scale processes, ii) they occupy higher trophic levels within aquatic ecosystems and, in turn, directly impact lower trophic level organisms, iii) they are relatively easily and rapidly collected and can be sampled non-destructively, iv) they are typically present in most waterbodies, and v) biological integrity of fish assemblages can be assessed easily and interpretation of indicators is relatively intuitive (Harris 1995). Further, as fish have a high public profile, with significant recreational, economic and social values, they foster substantial public interest (MDBC 2004).

Historically, 14 species of native fish are believed to have occurred in the Lower Lachlan river system (Dean Gilligan, NSW DPI, *unpublished data*). Recent monitoring indicates that 10 of these species are still present, leaving four species either locally extinct of extremely rare (NSW DPI, *unpublished data*). These four species include the flat headed galaxias (*Galaxias rostratus*), southern pygmy perch (*Nannoperca australis*), southern purple spotted gudgeon (*Mogurnda adspersa*) and the Murray-Darling rainbowfish (*Melanotaenia fluviatilis*). Of the 10 extant species, olive perchlet (*Ambassis agassizii*), silver perch (*Bidyanus bidyanus*) and freshwater catfish (*Tandanus tandanus*) are at very low abundance and/or have a very restricted distribution. Only two species: carp gudgeons (*Hypseleotris* spp.) and bony herring (*Nematalosa erebi*) could be considered widespread and abundant.

Flow plays an important role in the life-cycle of native fishes from larval through to adult life stages (Ellis et al. 2016). Water may inundate habitat needed for reproduction, triggering a spawning response, create a boost in primary production that improves recruitment success, improve habitat condition through maintaining natural geomorphic processes or stimulate in-stream migration. River channel dependent species require flow triggers to initiate spawning (i.e. golden perch (*Macquaria ambigua*), and silver perch), and recruitment success may be heavily dependent on nutrient inputs to the river channel following overbank flows. The seasonality of these flow triggers is critically important. Further, sediment transport and scouring during high flow events is essential for the maintenance of deep pools and the input of large wood habitat. Freshes also provide movement triggers and facilitate longitudinal connectivity within the system. Persistence of these species is dependent on the provision of natural spawning triggers and subsequent boosts in primary production to facilitate successful recruitment as well as longitudinal connectivity within the river channel network. For all fish species, access to high quality refugia during drought is critically important for ecosystem resilience, as unlike vegetation, many species of invertebrates, waterbirds and turtles, fish have no mechanisms to cope with the loss of water for even very brief periods of time.

In 2014-15 the CEWH instigated a Long Term Intervention Monitoring (LTIM) Project across the Lower Lachlan river system to quantify changes in ecosystem health in response to

Commonwealth environmental water delivery. This included monitoring the fish community.

One of the watering actions delivered in 2015-16 targeted flow cued native fish outcomes. Watering Action 3 (Table 1) aimed to:

1) Provide habitat to support, maintain condition of, and provide reproduction opportunities for native fish,
2) Trial the augmentation of flow to generate a golden and/or silver perch movement and spawning response.

To assess the contribution of Commonwealth environmental water to the fish community, the relevant short term and long term questions to be evaluated are:

4.1.1 SHORT-TERM (ONE-YEAR) EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to native fish community resilience?
2) What did Commonwealth environmental water contribute to native fish survival?

4.1.2 LONG-TERM (FIVE-YEAR) EVALUATION QUESTIONS:

3) What did Commonwealth environmental water contribute to native fish populations?
4) What did Commonwealth environmental water contribute to native fish diversity?

In 2015-16, the aim of this component of the Lachlan LTIM Project was to assess changes in the fish community in terms of its abundance, biomass and community health in the Lower Lachlan river system Selected Area, and provide a basis for determining changes in relation to environmental water. There was an additional focus on golden perch this year, given watering actions were specifically designed to encourage spawning (see Chapter 5). This chapter of the report evaluates the second year of the five-year Long Term Intervention Monitoring Project.

4.2 METHODS

Fish community data was collected from 10 in-channel sites in Zone 1 of the Lower Lachlan river system Selected Area, from Wallanthery to Hillston (Figure 21). All sites were randomly selected for this study, or had previously been randomly selected as part of another study (i.e. SRA; Davies et al. 2008, 2010). Sampling was undertaken in March and April 2016, and each site was sampled once using a suite of passive and active gears including boat-electrofishing (*n*=32 operations, each consisting of 90 seconds 'on-time'), unbaited bait traps (n=10; median total trap hours soak time 50 hrs, range 16-72 hrs) and small fyke nets (n=10; median total trap hours soak time 197 hrs, range 150-207 hrs) (Hale et al. 2014). Additionally, large fyke nets were used at each site to target freshwater catfish (n=4; median total trap hours soak time 79 hrs, range 59-82 hrs). Decapods (such as shrimp and yabbies) were also surveyed and these were sampled using baited opera house traps (n=5; median total trap hours soak time 25 hrs, range 8-35 hrs).

All captures (fish and other non-target taxa) were identified to species level and released onsite, with the exception of the periodic species bony herring which were retained for annual ageing (n=100) (Hale et al. 2014). Individuals were measured to the nearest mm and weighed to the nearest gram. Where large catches of particular species occurred, a sub-sample of individuals was measured and examined for each gear type. The sub-sampling procedure consisted of firstly measuring all individuals in each operation until at least 50 individuals had been measured in total. The remainder of individuals in that operation were also measured, although any individuals of that species from subsequent operations of that gear type were only counted. Fish that escaped capture, but could be positively identified were also counted and recorded as “observed”.

One week of additional targeted sampling was undertaken in April 2016 to examine the possible presence and subsequent age of juvenile golden perch within the focal zone. Sampling was undertaken using a backpack electrofishing unit and comprised unstandardized sampling effort targeting complex and/or fast flowing habitats, particularly around regulatory structures, that have in the past resulted in higher captures of juvenile golden perch. All golden perch captured that were <150 mm total length were retained for determination of annual age. Briefly, golden perch were euthanased using a benzocaine overdose (≥ 100 mg L^{-1}), measured and weighed, and both sagittal otoliths were removed. A minimum of one sagittal otolith from each fish was prepared as multiple transverse sections (Morison et al. 1998). Otoliths were ground to about 300 µm to check for the presence of opaque zones. If no opaque zones were present, individuals were assigned an annual age of 0+. Annuli were determined from each sectioned otolith using a Leica M80 microscope at 16 times magnification. Age was assigned based on a combination of annulus count and edge type in relation to capture date, and assigned a nominal birth date of October 1st. Any golden perch (or Murray cod) stocked into the Lachlan River in 2015 or 2016 (nominal birth years 2014 and 2015, respectively) are required to be marked with the chemical calcein to enable retrospective determination of hatchery origin. Subsequently, all otoliths were checked for the presence of calcein marks using a fluorescence compound microscope (Leitz-Leica DIAPLAN fitted with a 3-λ PLOEMOPAK incident light fluorescence illuminator) and a Leica 13 block filter set (450–470 nm band pass excitation filter with a RKP510 reflection short pass dichromatic mirror and a LP520 long pass suppression filter).

Total catch was pooled for all sites and methods, with the exception of calculation of SRA metrics where the first 12 electrofishing shots and bait trap data were used (Davies et al. 2010). To determine differences between years (2015 and 2016) 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 $P < 0.05$.

Sustainable Rivers Audit (SRA) fish community condition indices (Expectedness, Nativeness, Recruitment) were calculated to quantify overall condition of the fish community assemblage. Data were first portioned into new recruits and non-recruits. Large-bodied and generally longer lived species (maximum age >3 years) were considered new recruits when length was less than that of a one year old. Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 4). 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) (Davies et al. 2010, Carter 2012).

Table 4. Size limits used to distinguish new recruits for each species.
Values represent the length at one year of age for longer-lived species or the age at sexual maturity for species that reach maturity within one 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)
flat headed gudgeon	58 mm (Pusey et al. 2004; (Llewellyn 2007)
freshwater catfish	83 mm (Davies 1977)
golden perch	75 mm (Mallen-Cooper 1996)
Murray cod	222 mm (Gavin Butler, Unpublished data)
un-specked hardyhead	38 mm (Pusey et al. 2004)
Alien species	
common carp	155 mm (Vilizzi and Walker 1999)
eastern gambusia	20 mm (McDowall 1996)
goldfish	127 mm (Lorenzoni et al. 2007)

The Expectedness index is the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition. The index value is derived from two input metrics: the observed native species richness relative to 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). The Nativeness index is the proportion of native compared to alien fishes, and is derived from three input metrics: proportion of total biomass that is native, proportion of total abundance that is native and proportion of total species richness that is native (Robinson 2012). The Recruitment index represents the recent reproductive activity of the native fish community, and is derived from three input metrics: the proportion of native species showing evidence of recruitment, the average proportion of sites at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled; Table 5), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three indicators are aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition is then 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).

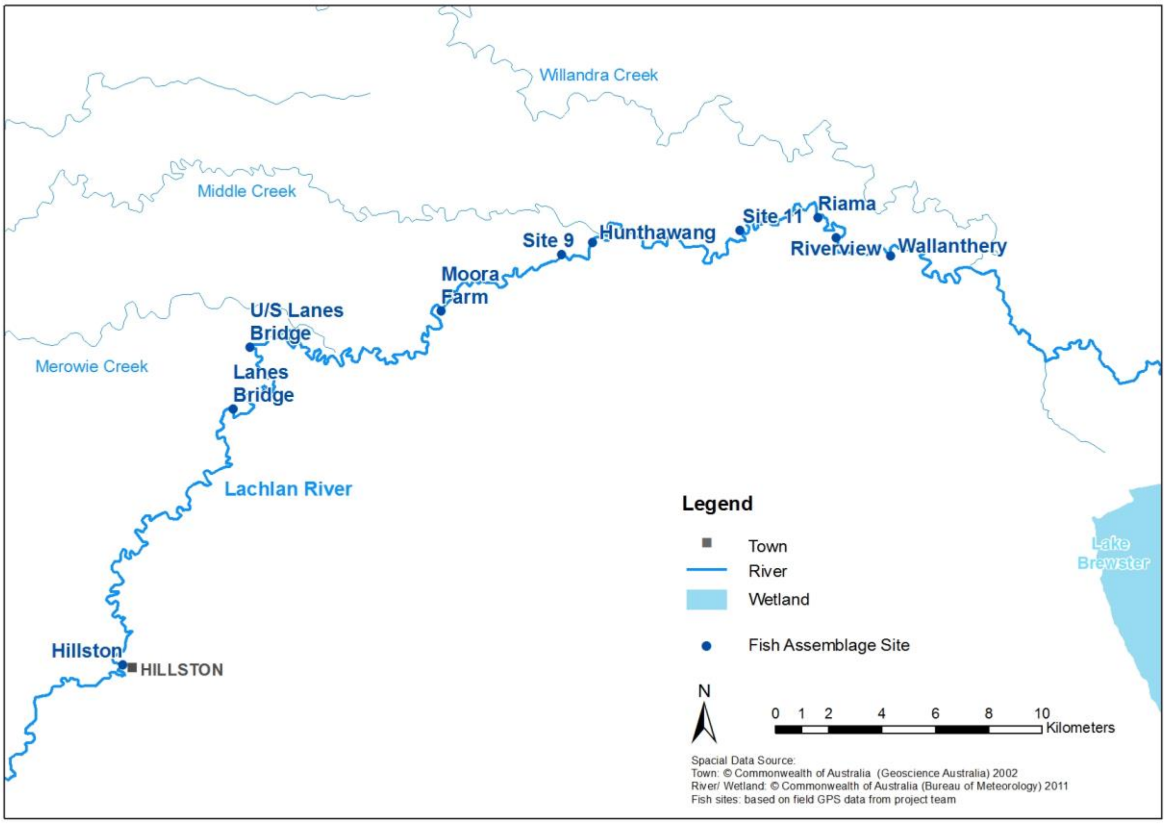


Figure 21. Riverine fish sampling sites on the Lachlan River.

4.3 RESULTS

A total of 4,917 fish comprising seven native and three alien species were captured across 10 in-channel sampling sites in 2016 (Table 5). In order, bony herring (*Nematalosa erebi*), eastern gambusia (*Gambusia holbrooki*), carp gudgeon (*Hypseleotris* spp.), common carp (*Cyprinus carpio*), golden perch (*Macquaria ambigua*) and Murray cod (*Maccullochella peelii*) were the most abundant species, respectively (Table 5; Figure 22). In order, Murray cod, common carp, golden perch and bony herring contributed the greatest overall biomass in 2016, respectively (Figure 23).

New recruits (juveniles) were detected in two native longer-lived species at multiple sites: bony herring (at 10 of 10 sites) and Murray cod (3 of 10 sites); see Figure 22 and Figure 24, and four native short-lived species: Australian smelt (*Retropinna semoni*) (2 of 4 sites), carp gudgeon (8 of 8 sites), flat headed gudgeon (*Philypnodon grandiceps*) (5 of 5 sites) and un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*) (3 of 5 sites); see Figure 22 and Figure 24. No golden perch new recruits were captured (Figure 22 and Figure 24). New recruits of all alien species were captured: common carp (9 of 10 sites), goldfish (*Carassius auratus*) (3 of 3 sites) and eastern gambusia (2 of 10 sites) (Figure 22 and Figure 24).

Sustainable Rivers Audit indices varied substantially in the target reach. Nativeness rated “Good” (mean ± SE score: 87.13 ± 3.3), Expectedness was “Poor” (41.0 ± 1.4) and Recruitment was “Very Poor” (33; zone metric). The Overall Condition of the fish community is rated “Very Poor” (32.6 ± 0.9).

There were no significant differences in the abundance (*Pseudo-*$F_{1,18}$ = 1.731, *P* =0.133) or biomass (*Pseudo-*$F_{1,18}$ = 1.529, *P* =0.204) of the fish community between years.

The additional targeted sampling for juvenile golden perch resulted in the capture of five individuals <150 mm in length (range 102–128 mm). All individuals were aged as 1+ (i.e. spawned in 2014) and all had visible calcein marks at ~90 days post-spawning indicating hatchery origin (Figure 25).

Table 5. Total (non-standardised) catch from the Lower Lachlan river system target reach. Sampling was undertaken in Autumn 2016 using a combination of five sampling gear types.

	SAMPLING METHOD					
COMMON NAME	BOAT ELECTRO-FISHING	SMALL FYKE NET	LARGE FYKE NET	BAIT TRAP	OPERA HOUSE TRAP	**TOTAL**
Fish						
native species						
Australian smelt	8					**8**
bony herring	3652	17	16			**3685**
carp gudgeon complex		206				**206**
flat headed gudgeon	1	10		1		**12**
golden perch	118		10			**128**
Murray cod	93		3			**96**
un-specked hardyhead	17	2				**19**
alien species						
common carp	136	2	5			**143**
eastern gambusia	7	591				**598**
goldfish	22					**22**
Turtles						
long-necked turtle			1			**1**
Murray River turtle			3			**3**
Decapods						
freshwater prawn		4090	32	229	147	**4498**
freshwater shrimp		863		139		**1002**
freshwater yabby	1	4				**5**

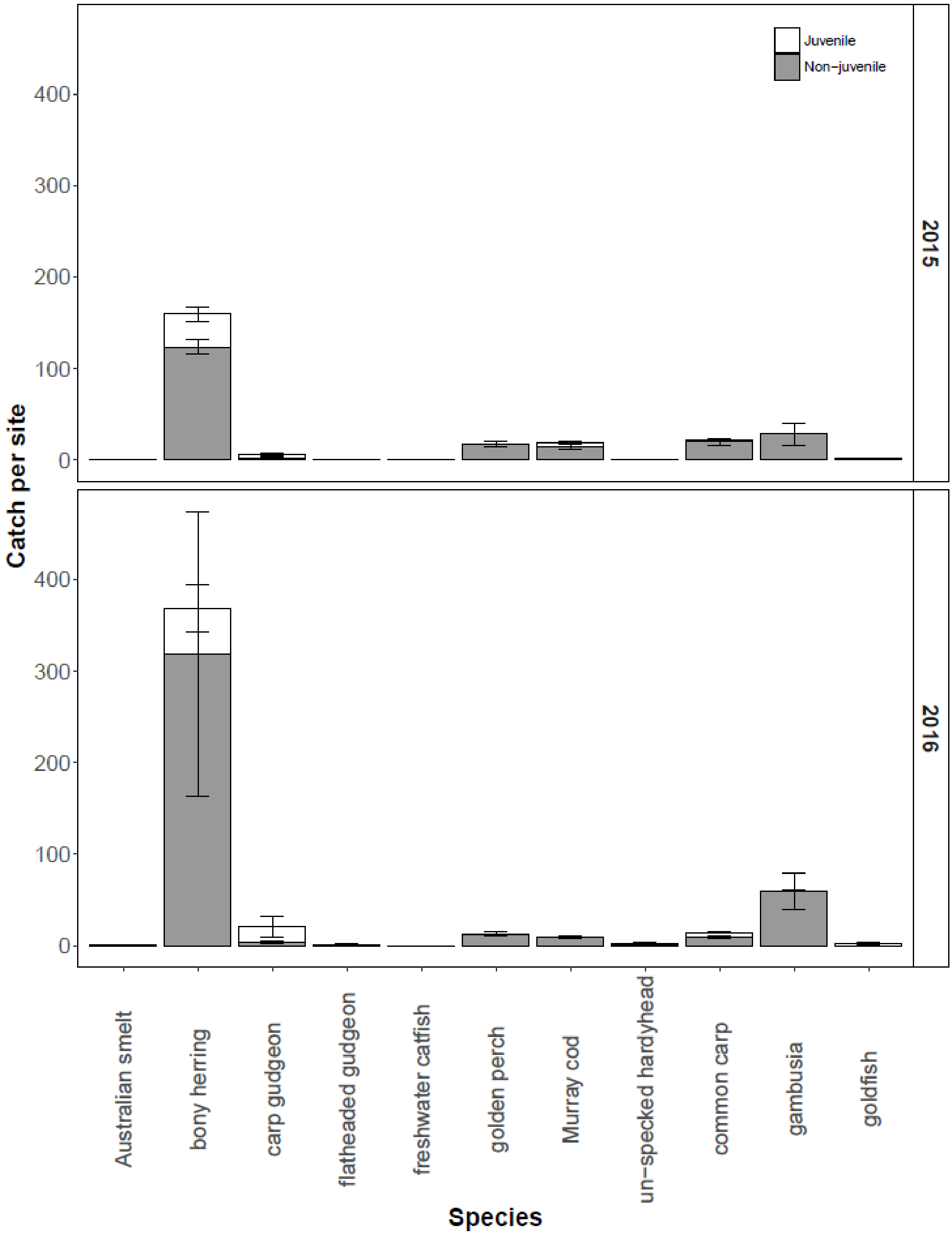


Figure 22. Catch per site (number of fish; mean ± SE) of each fish species within the Lower Lachlan river system target reach sampled in 2015 and 2016.

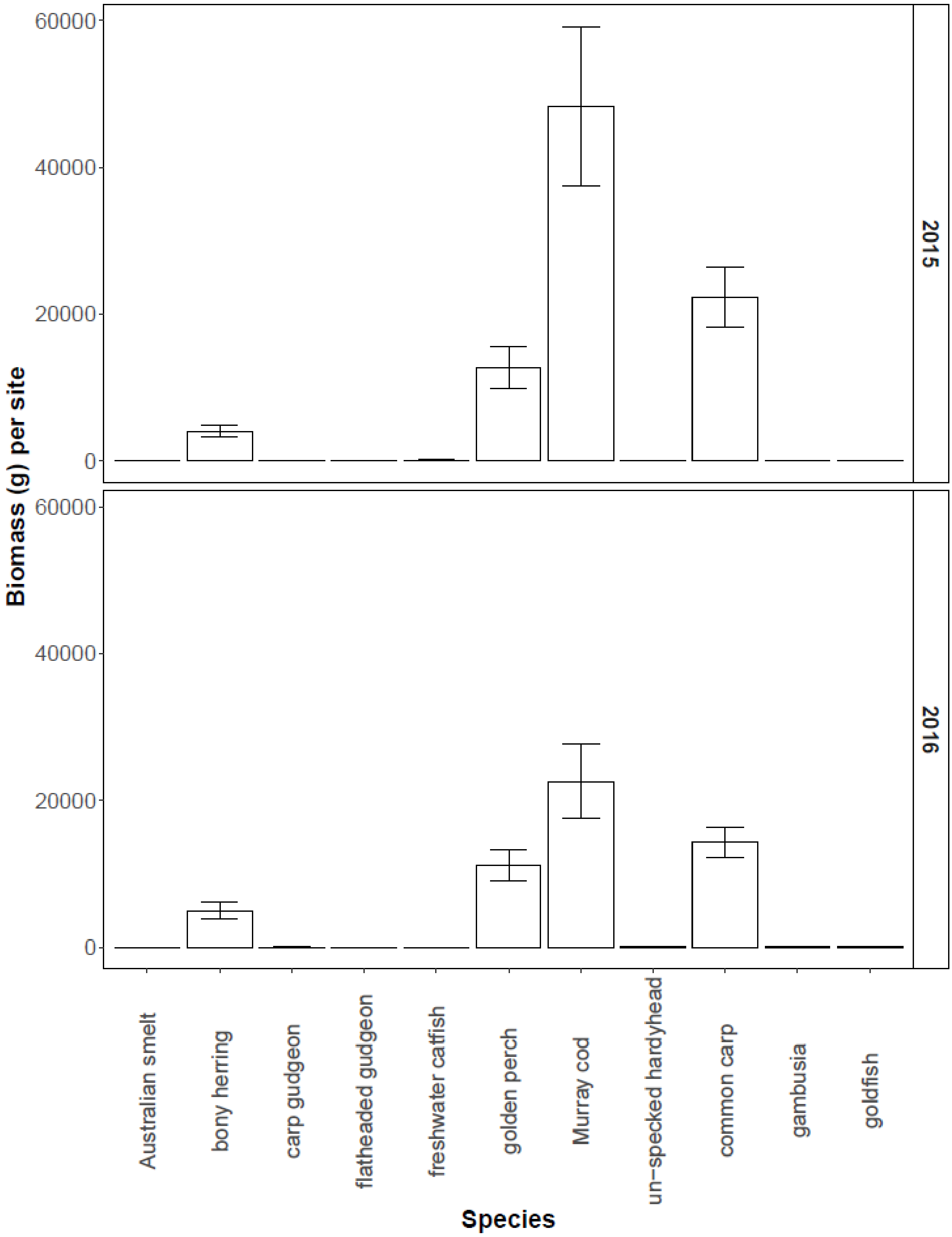


Figure 23. Biomass per site (g; mean ± SE) of each fish species within the Lower Lachlan river system target reach sampled in 2015 and 2016.

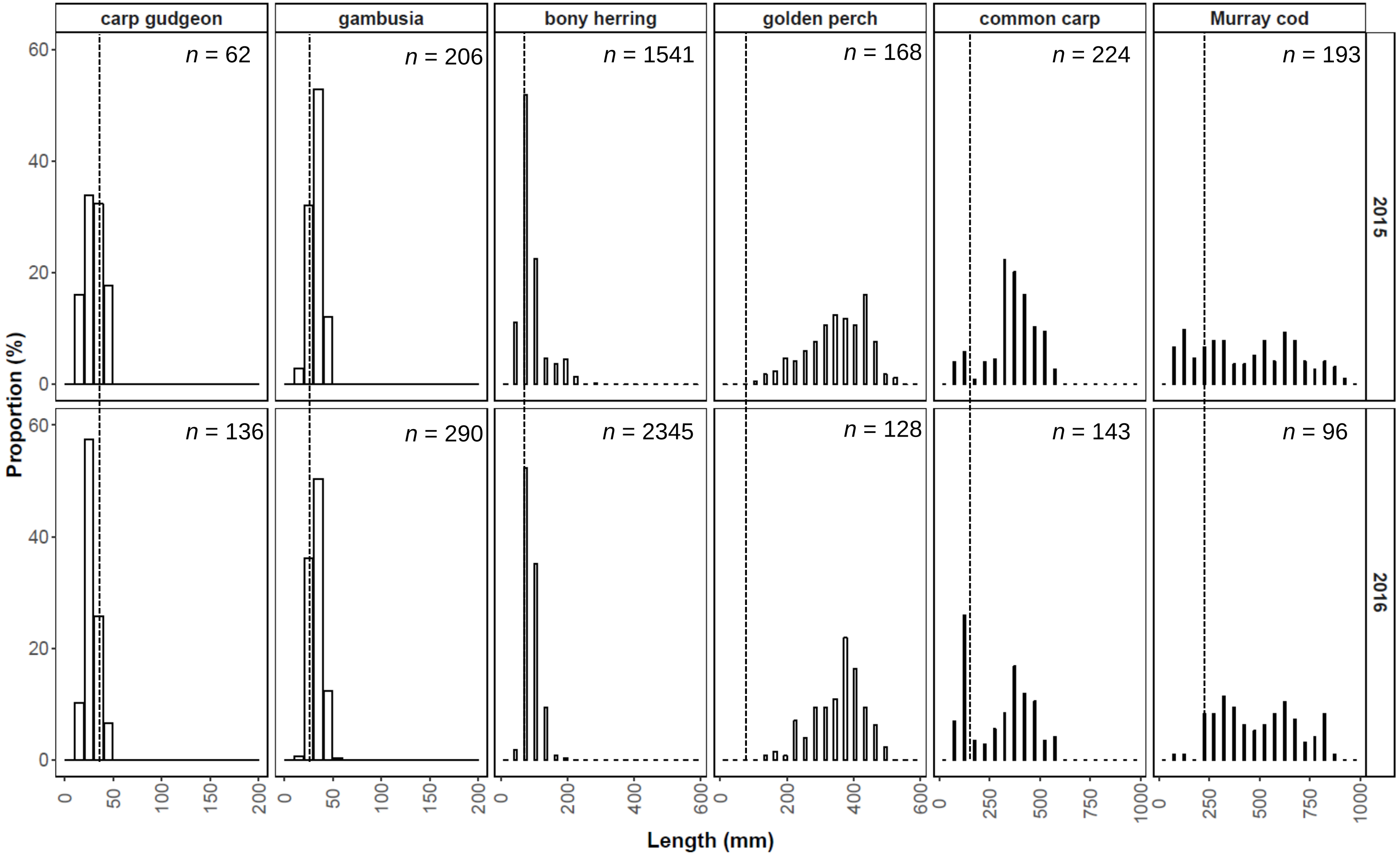


Figure 24. Proportionate length-frequencies of the six most abundant species captured in the Lower Lachlan River in 2015 and 2016. The dashed line indicates approximate size limits used to distinguish new recruits for each species (see Table 4).

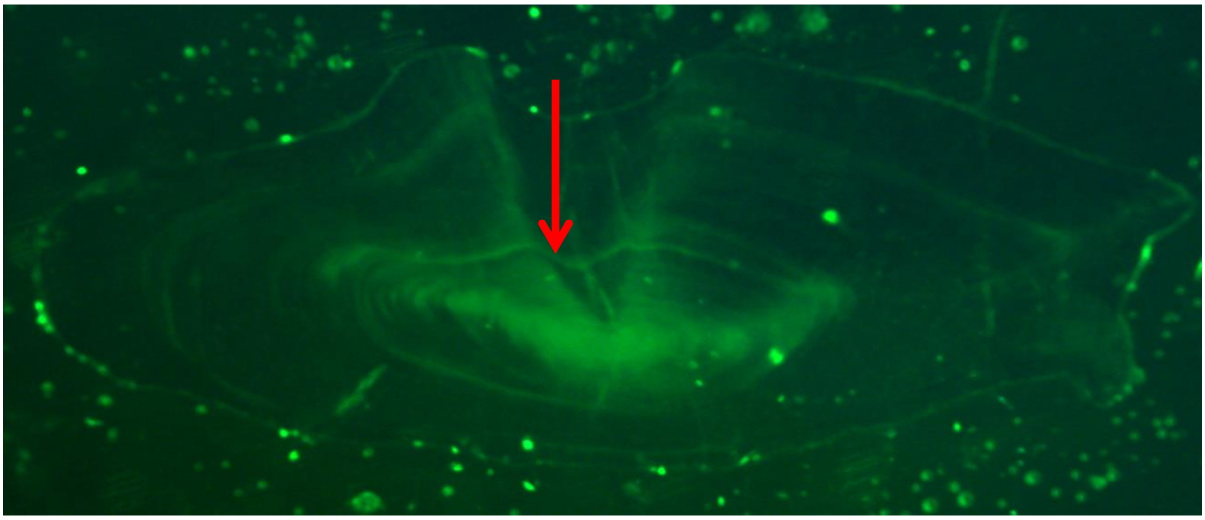


Figure 25. A calcein marked golden perch otolith (calcein mark indicated by the red arrow) collected from the Lachlan River in 2016, indicating hatchery origin.

4.3.1 BY-CATCH

A total of four turtles were captured during fish community monitoring, one long-necked turtle and three Murray River turtles (Table 5). Freshwater shrimp and prawns were the most abundant taxa in small mesh fyke nets and bait traps (Table 5). Only a small number of Yabbies were captured across the 10 monitoring sites (Table 5).

4.4 DISCUSSION

The current study resulted in the capture of seven native species of freshwater fish in the Lachlan Selected Area in 2016. Flat headed gudgeon were an additional species that were not captured in 2015 during fish community sampling, although were captured as larvae (Dyer et al. 2015). Freshwater catfish were not captured in 2016 despite additional targeted sampling for this species using large fyke nets. Two native species, Murray-Darling rainbowfish and silver perch, although presumed to have been historically common in lowland sections of the Lachlan Basin are now rarely encountered within the target reach and were not detected in the current study. Consistent with previous results, four native fish species (flat head galaxias, olive perchlet, southern purple spotted gudgeon and southern pygmy perch) which were historically present, were not detected in 2016. Of these, olive perchlet is the only species to have been recently detected (NSW DPI Fisheries, unpublished data). Despite the absence of a number of native species, the native species richness in this zone of the Lower Lachlan river system Selected Area is generally higher than in other parts of the catchment. Recent habitat mapping undertaken by NSW DPI indicates that the focal reach has high densities of available instream wood habitat across a range of flow regimes and extensive low flow refugia (NSW DPI, unpublished data). While no comparison exists to compare instream wood densities with other parts of the Lachlan River, the current densities exceed the benchmark wood loadings identified for the Barwon-Darling by Boys et al. (2013), indicating high habitat quality in the focal reach.

Based on the use of SRA metrics, the native fish community composition improved in 2016 compared with the previous year, although only through improvement in the Expectedness and Recruitment indices. The Overall Condition of the fish community is still considered

“Very Poor”, although this Zone of the Selected Area maintained “Good” Nativeness. Recent recruits of the same native species (Australian smelt, bony herring, carp gudgeon, Murray cod and un-specked hardyhead) were captured in 2016 as in 2015, with the addition of new recruits of flat headed gudgeon in 2016. New recruits of all alien species were captured in both 2016 and 2015. While none of the species contributing recent recruits would be considered flow-cued spawners based on knowledge of their life-history requirements, they all require suitable flows for the provision of appropriate habitat and food resources to enable the survival and growth of larvae.

It is worth considering the objectives that are established for fish in the Lower Lachlan river system. It is suggested that objectives for the use of Commonwealth environmental water focus on maintaining native fish populations, especially during low resource years. For example, water delivery should focus on maintenance/protection rather than enhancement/improving of native fish populations within the target reach to maximise survival of existing populations. This would then provide a suitable platform for population enhancement during high water resource years.

Consistent with the results from 2015, golden perch new recruits were not captured in 2016. This result alone does not provide definitive evidence of a lack of spawning within the lowland Lachlan River as other Selected Areas e.g. the Murrumbidgee (Wassens et al. 2015) that have detected spawning in this species rarely encounter new recruits either as a result of 1) high larval mortality, 2) inappropriate sampling methods or locations, or a combination of both. Subsequently, additional targeted sampling was undertaken in 2016, although only a small number of 1+ individuals spawned in 2014 were captured and these were all of hatchery origin. Stocking of golden perch has been undertaken in the Lachlan River since the 1970’s, including on numerous occasions within the Selected Area in the past 10 years (DPI Fisheries, unpublished data). It remains unknown whether the current adult population of golden perch is a result of stocking, wild-spawning, or a combination of the two. This represents an important knowledge gap when developing expected outcomes for future watering events. Recent published evidence suggests substantial variability in the contribution of stocking to riverine populations of golden perch (Crook et al. 2016, Forbes et al. 2016) and declines in stocking effectiveness have been observed with increasing riverine connectedness (Hunt et al. 2010).

Unlike 2014-15, water delivery in 2015-16 was more suited to golden perch spawning in the Lachlan River. However, nil capture of eggs or larvae (see Section 5), nil capture of new recruits during standardised sampling and capture of only stocked juveniles during targeted monitoring indicates that it is unlikely that spawning of golden perch occurred in response to the 2015-16 water delivery.

4.5 FINAL COMMENTS AND RECOMMENDATIONS

- Investigate the source (stocked or wild) of the existing golden perch population to evaluate the recent hydrological events that may have led to wild-spawning and recruitment (if any). For example, the current sampling program has indicated a substantial population of golden perch within the focal reach. Results have indicated golden perch from the 1+ age category in 2016 were from stockings. However, it is currently unknown whether the remainder of the population is a result of natural spawning and recruitment. Further investigation of the origin of this population (stocked or wild), while not within the scope of the current program, would assist in retrospectively assigning hydrological conditions that previously promoted spawning or recruitment within this population and thus providing suitable delivery targets for future years of water delivery.

4.6 APPENDIX 1

Figure 26. Example of mapped boat electrofishing units used for Category 1 fish community sampling in the Lachlan River.

Table 6. Pre-European (PERCH) list of the expected native species present in the Lowland Lachlan Basin, their associated rarity and subsequent detection during the LTIM 2016 census.

COMMON NAME	SCIENTIFIC NAME	OCCURRENCE [1]	2015 LTIM CENSUS	2016 LTIM CENSUS
Australian smelt	*Retropinna semoni*	common	Y	Y
bony herring	*Nematalosa erebi*	common	Y	Y
carp gudgeon	*Hypseleotris spp*	common	Y	Y
freshwater catfish	*Tandanus tandanus*	common	Y	
golden perch	*Macquaria ambigua*	common	Y	Y
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	common		
silver perch	*Bidyanus bidyanus*	common		
Murray cod	*Maccullochella peelii*	occasional	Y	Y
un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*	occasional	Y	Y
flat head galaxias	*Galaxias rostratus*	rare		
flat headed gudgeon	*Philypnodon grandiceps*	rare		Y
olive perchlet	*Ambassis agassizii*	rare		
southern purple spotted gudgeon	*Mogurnda adspersa*	rare		
southern pygmy perch	*Nannoperca australis*	rare		

[1]Description of predominance (occurrence) correspond to reference condition categories for the Murray-Darling Basin Sustainable Rivers Audit program and are used to generate fish condition metrics.

5 SPAWNING AND LARVAL FISH

5.1 INTRODUCTION

Environmental flow regimes commonly aim to maintain and enhance native fish community populations (King et al. 2010). The premise being that aspects of the flow regime are linked to key components of the life history of fish, including pre-spawning condition and maturation, movement cues, spawning cues and behaviour, and larval and juvenile survival (Junk et al. 1989, Humphries et al. 1999, King et al. 2003, Balcombe et al. 2006). Since the strength of recruitment is largely driven by spawning success, and growth and survival of young, understanding how the flow regime influences the early life history of fishes is critical to managing fish populations (King et al. 2010).

There were three watering actions as part of the 2015-16 Commonwealth environmental watering program (Section 1.1). Of these, only Watering Action 3 had specific objectives concerning native fish with 9378 ML of Commonwealth environmental water delivered to:

1) Provide habitat to support, maintain condition of, and provide reproduction opportunities for native fish,
2) Trial the augmentation of flow to generate a golden and/or silver perch movement and spawning response.

To assess the contribution of Commonwealth environmental water to native fish spawning and recruitment, the relevant short term and long term questions to be evaluated are:

5.1.1 SHORT-TERM (ONE YEAR) EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to native fish reproduction in the Lower Lachlan river system?
2) What did Commonwealth environmental water contribute to native larval fish growth in the Lower Lachlan river system?

5.1.2 LONG-TERM (FIVE YEAR) EVALUATION QUESTIONS:

3) What did Commonwealth environmental water contribute to native fish populations in the Lower Lachlan river system?
4) What did Commonwealth environmental water contribute to native fish species diversity in the Lower Lachlan river system?

The larval fish monitoring implemented within the Lower Lachlan river system is directed at Basin scale evaluation and is confined to a single zone within the Lower Lachlan river system Selected Area. There are likely to be strong differences in the fish community and habitats between zones within the Selected Area resulting in the evaluation of outcomes for the Selected Area being confined to the target reach (i.e. Zone 1) (Dyer et al. 2014). There are two components to the evaluation provided in this report. The first evaluates the 2015-16 watering actions in relation to the specific objectives for fish, the second starts to address the short term evaluation questions.

5.2 METHODS

Larval fish were sampled at three sites (Dyer et al. 2014) on the Lower Lachlan river system Selected Area (Wallanthery, Hunthawang and Lane's Bridge, see Figure 2). Five sampling events were undertaken at fortnightly intervals between 19th October 2015 and 15th December 2015:

Sampling followed the delivery of Commonwealth environmental water and was timed to coincide with the known spawning windows of six target species:

- Equilibrium: Murray cod (*Maccullochella peeli*) and freshwater catfish (*Tandanus tandanus*)
- Periodic: Golden perch (*Macquaria ambigua*) and bony herring (*Nematalosa erebi*)
- Opportunistic: Carp gudgeons (*Hypseleotris spp*) and un-specked hardyhead (*Craterocephalus stercusmuscarum*).

To capture larval fish, three drift nets and 10 light traps were set overnight at each site (for more detail see Dyer et al. 2014). Catches of larval fish for drift nets was standardised as the number of individuals per cubic meter of water sampled. Set and retrieval times of light traps were recorded so that relative abundance can be expressed as catch-per-unit-effort (CPUE). Additional drift net sampling (3 drift nets per site) was undertaken in alternate weeks by NSW DPI between mid-November and mid-December to monitor for golden perch eggs and larvae.

5.3 RESULTS

A total of 1 141 larval fish were captured across the five sampling events of spring-summer 2015 comprising four native species (Murray cod, flat headed gudgeon, Australian smelt and carp gudgeon) and two alien fish species (eastern gambusia and common carp) (Table 7). Each of the two sampling techniques caught approximately the same number of larvae, although there were differences in the species captured (Table 7). Larval abundances peaked during the first sampling event (19/10/2015), when 64% of the total catch was captured and this was largely driven by the abundance of Murray cod (Figure 27). Murray cod were by far the most abundant species recorded at twice the numbers of the next most populous species: flat headed gudgeon (Table 7 and Figure 27). Flat headed gudgeon larvae were present at each site and sampling events, except sampling event 2 where they were not present at Lane's Bridge (Figure 27). Murray cod larvae were the next most frequently encountered species, but were only present in the first three sampling events (Figure 27). Australian smelt were only present in the first and second sampling events (Figure 27). Carp gudgeon were in low abundance and sporadically appeared in all sampling events except sampling event 2 (Figure 27).

Larval fish were captured for only two of the six target species in 2015: one Equilibrium species, Murray Cod, and one Opportunistic species, carp gudgeon. Murray cod larvae were captured from all three sites in three of the five sampling events, though the first sampling event (19 and 20th October 2015) had far higher abundances than other sampling events (Figure 27). The size distribution of Murray cod larvae indicates catches are likely to have been dominated by a single spawning event at each site. The spawning window for Murray cod in the Lower Lachlan river system Selected Area in 2015 extended from 9th of September to 5th of November 2015, and peak spawning occurring in the first half of October 2015 (section 5.6).

No Periodic representative species (golden perch or bony herring) were collected during larval sampling in 2015 (Table 7).

Table 7. Capture summary of larval fish from sampling conducted between mid-October to mid December 2015 in the Lower Lachlan river system Selected Area.

SPECIES	DRIFT NETS	LIGHT TRAPS	TOTAL
Murray cod	540	186	**726**
flat headed gudgeon	29	334	**363**
Australian smelt	0	29	**29**
carp gudgeon	5	7	**12**
freshwater catfish	0	0	**0**
golden perch	0	0	**0**
eastern gambusia	1	4	**5**
common carp	2	4	**6**
TOTAL	**577**	**564**	**1141**

Three opportunistic species were collected during larval sampling in 2015, these were carp gudgeons, flat headed gudgeons and Australian smelt. Flat headed gudgeon were captured at all three sites and during all five sampling events (Figure 27). The majority (39 / 42) of flat headed gudgeon were captured in light traps (Table 7 and Figure 27). Flat headed gudgeon ranged in length from 6.2 – 20.7 mm (Figure 28) with an estimated age of 18 – 112 days. This corresponds to an estimated spawning window from early August to late November, with an extended peak between mid-September and mid-October 2015 when water temperatures were 15 - 23 °C (see Figure 30, section 5.6). Mean length of flat headed gudgeons increased between sampling events 2 and 5 (Figure 28).

Australian smelt larvae were detected on the first and second sampling events (Table 7 and Figure 27). Australian smelt were captured at each site, and were most common at Lane's Bridge. Australian smelt captured ranged in size from 11.9 – 23.4 mm (Figure 28) and ranged in estimated age from 31 – 75 days. Length frequency distribution and associated back calculation of estimated spawning dates indicate that Australian smelt spawned late July to mid-September in 2015 with a peak in spawning activity in August, when water temperatures were around 11 – 13 °C (see Figure 30, section 5.6). The peak estimated spawning window coincided with the first commonwealth environmental flow release (see Figure 30, section 5.6). Length of Australian smelt increased between sampling events 1 and 2 (Figure 28).

A total of 10 larval carp gudgeon were captured in the 2015 larval fish sampling, most of which were captured from two sites (Hunthawang 3 / 10 and Lane's Bridge 6 / 10). Carp gudgeon were captured during one sampling event 1, 3, 4 and 5 in both drift and light traps (Table 7 and Figure 27). Carp gudgeon ranged in size from 9.348 – 15.698 mm (Figure 28) and had an estimated age range of 37 – 87 days. Estimated spawning dates in 2015 ranged from late-August to end of October, when water temperatures were 14 – 25 °C (see Figure 30, section 5.6).

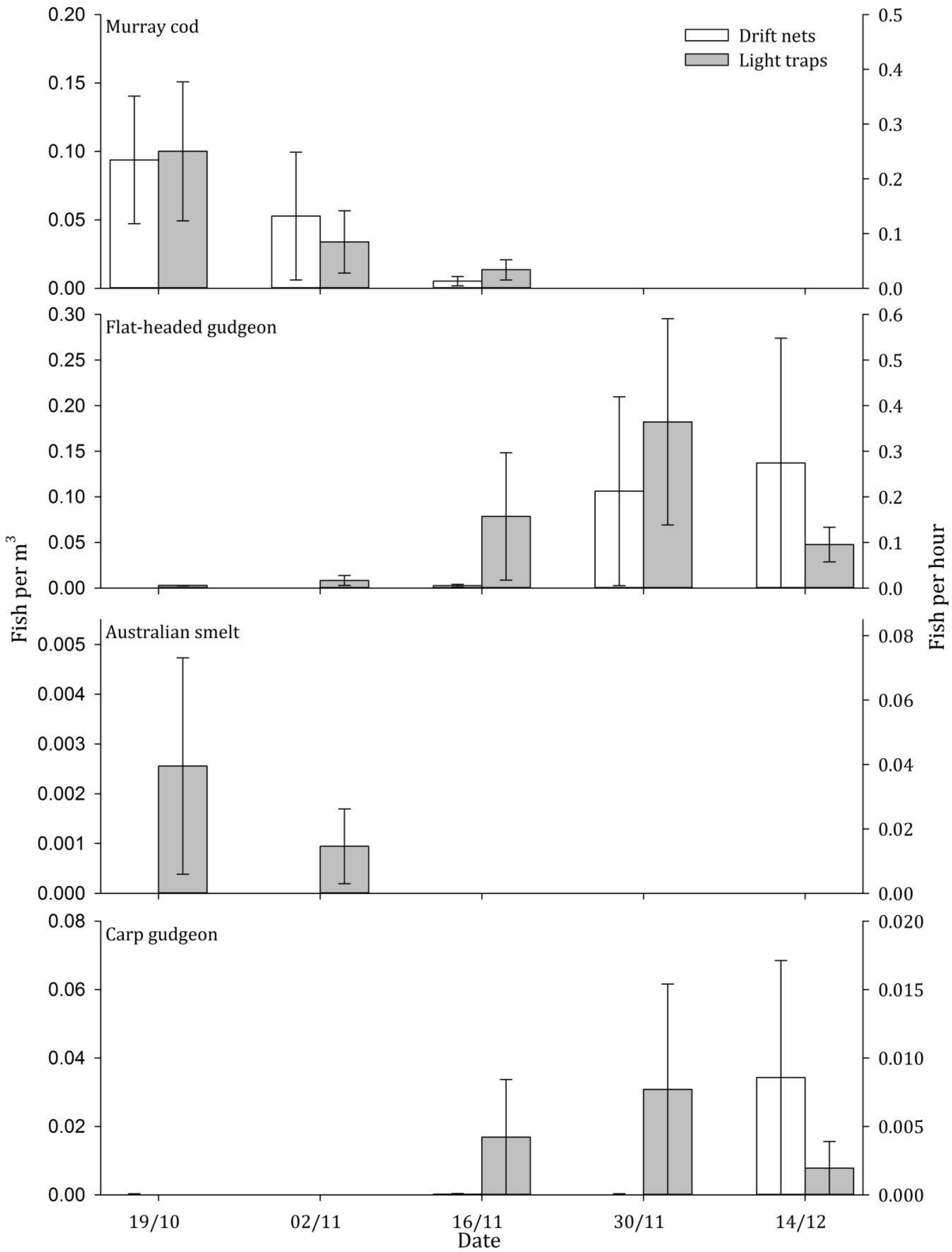


Figure 27. Mean catch per unit effort (± standard error) of the commonly caught larval native fish for drift nets (left axis, white bars) and light traps (right axis, grey bars) per sampling event in spring summer 2015.

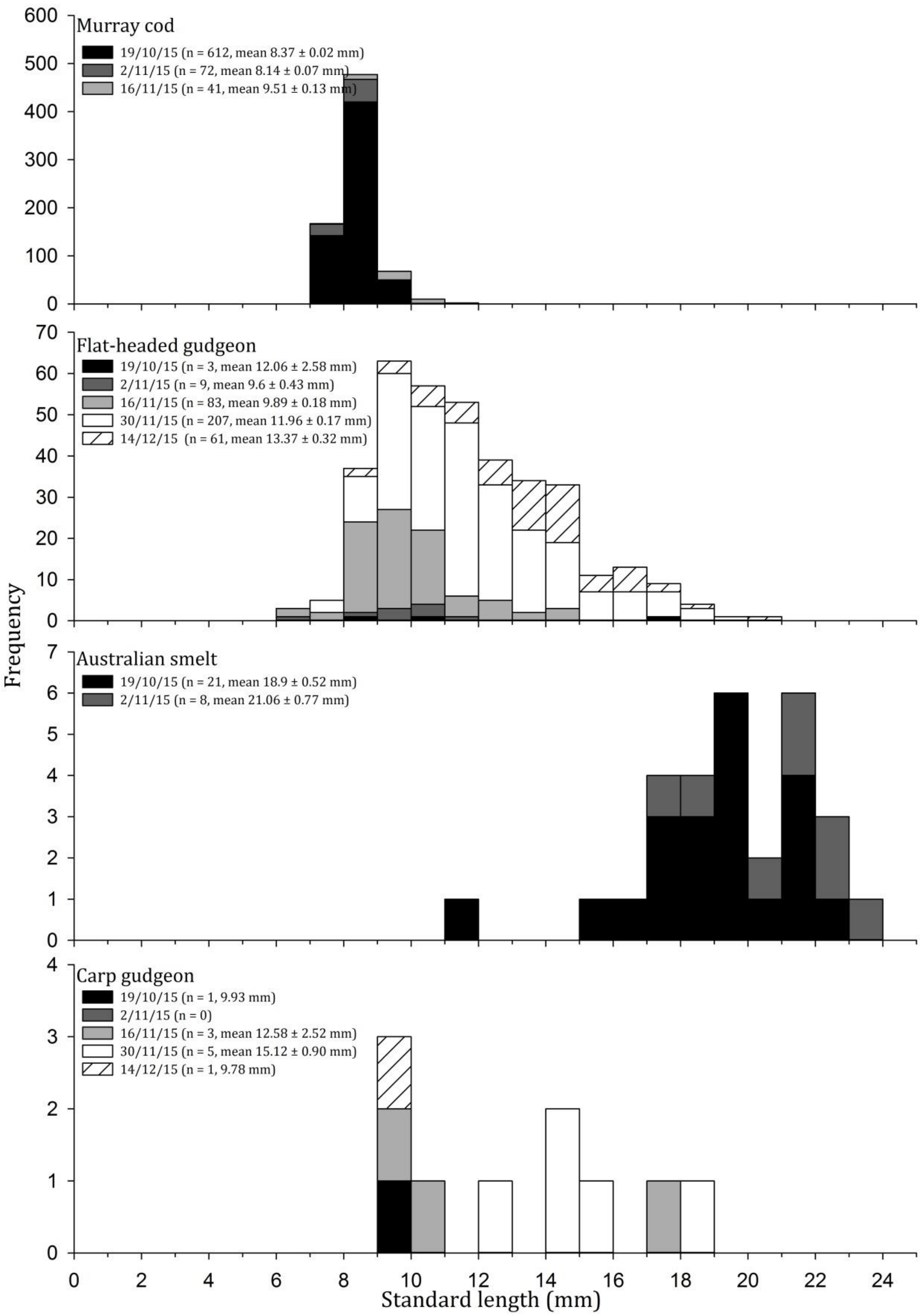


Figure 28. Length frequency histograms for each sampling event of commonly captured larval native fish species with site (n = 3) and sampling technique (n = 2) combined for 2015.

A total of 11 alien fish larvae were captured in 2015 comprising five eastern gambusia and six common carp (Table 7). The eastern gambusia were captured in trips 2 (n = 1), 3 (n = 4) and 5 (n = 1) in light traps and drift nets from two sites (Hunthawang and Lane's Bridge) and ranged in lengths from 7.2 – 23.5 mm. The common carp were all captured in trip 1 (four from Wallanthery and one each from Hunthawang and Lane's Bridge) and ranged in length from 9.5 – 17.6 mm.

5.3.1 COMPLEMENTARY MONITORING

Complementary monitoring undertaken by NSW DPI during the golden perch spawning flow release did not detect any evidence of golden perch spawning (Table 8). The complementary monitoring did detect two extra species, freshwater catfish and un-specked hardyhead, which were not found in the 2015 LTIM larval fish monitoring (Table 7 and Table 8).

Table 8. Capture summary of larval fish from complementary drift net sampling undertaken by NSW DPI conducted between mid-November to mid-December 2015 in the Lower Lachlan river system Selected Area

SPECIES	12th November	24-27th November	8-11th December	TOTAL
Murray cod	20	0	0	**20**
flat headed gudgeon	0	33	9	**42**
Australian smelt	0	0	0	**0**
carp gudgeon	0	9	4	**13**
freshwater catfish	5	4	4	**13**
golden perch	0	0	0	**0**
eastern gambusia	0	0	0	**0**
common carp	0	6	4	**10**
un-specked hardyhead	0	3	1	**4**
TOTAL	**25**	**55**	**22**	**102**

5.3.2 2014 VS 2015

The total number of fish captured in 2015 was more than double that of 2014. This was the result of an increase in the total numbers of Murray cod (increased by 70%) and flat headed gudgeon (increased by 860%). Catch-per-unit effort of each species was similar for most other species between 2014 and 2015, with the exception of flat headed gudgeon (Figure 29). Flat headed gudgeon increased in catch-per-unit-effort in 2015 by 900 and 10 000% for light traps and drift nets, respectively (Figure 29). Abundances of exotic eastern gambusia and common carp were low in both 2014 and 2015 compared to CPUE of native species (Figure 29).

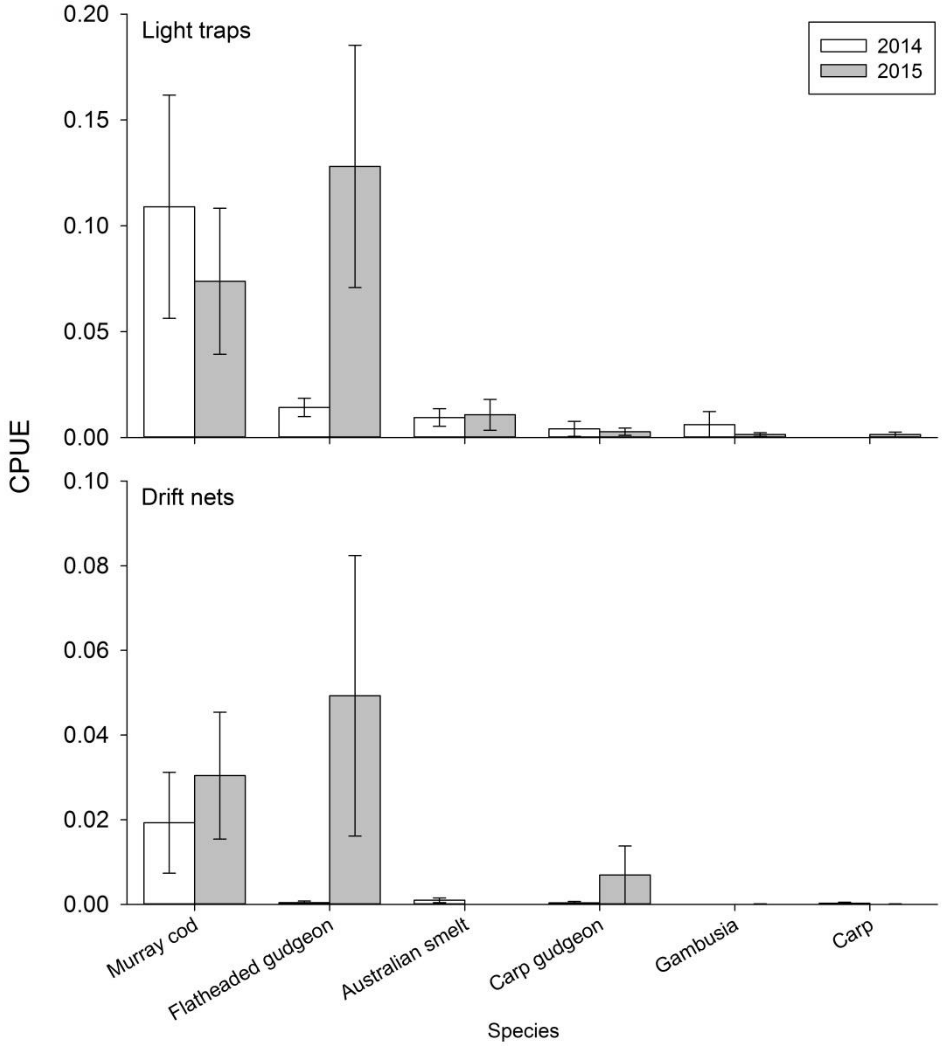


Figure 29. Mean catch per unit effort (± standard error) of larval fish species captured in light traps (CPUE = catch-per-hour, top) and drift nets (CPUE = individuals capture per m^3 of water sampled; bottom) from spring – summer 2014 and 2015.

5.4 DISCUSSION

5.4.1 GENERAL DISCUSSION

The results of the larval fish monitoring in 2015 indicate that expected outcomes for the flows, in terms of providing suitable cues and access to habitat for spawning as well as larval growth and survival, were partially met. Spawning was observed for non-flow dependent species; however, there was no evidence (eggs or larvae) of flow dependent species (golden perch) or bony herring spawning in September-December 2015 (young-of-year of the latter were captured in fish community sampling – see section 4).

Murray cod dominated the larval counts and were captured at each site from sampling event 1 – 3 in 2015, and were especially abundant during the first sampling event (mid October). In terms of timing, the presence of Murray cod larvae in this part of the Lower Lachlan river system was generally commensurate with other catchments (e.g. Humphries

2005, King et al. 2005, Koehn and Harrington 2006). The timing of the peak estimated spawning times were similar between 2015 and the first peak of 2014 (late September), when temperatures were around 17 °C. It is likely that this species is responding to factors such as photperiod and water temperature, rendering their direct spawning activity somewhat independent of large flows (Humphries 2005, Koehn and Harrington 2006). This appears to be consistent with what has been so far in the two years of monitoring in the Lower Lachlan in that 2014 and 2015 had very different flow regimes (small event in 2014, multiple large events in 2015), but the timing of spawning appeared to be similar between the years. Whilst it is evident that Murray cod are likely to spawn regardless of flow conditions, it is likely that flow can play a variety of roles in the success of spawning and recruitment. Firstly, increases in flow leading up to spawning increase stream productivity and potentially growth and can improve connectivity for migrating Murray cod. As Murray cod are a nesting species, stable flows during nesting are preferred as a sharp decrease in flow may leave eggs prone to drying and desiccation or a sharp increase in flow may displace eggs from the nest before hatching (Sharpe and Stuart 2013, Ellis et al. 2016). Once adrift, Murray cod larvae may benefit in increased flows as this would result in increased stream productivity and increase food resources, and allow for drift and dispersal (Humphries and King 2004, King et al. 2009).

Although the LTIM monitoring did not detect any freshwater catfish larva, they were detected in the complementary monitoring undertaken by NSW DPI at two sites and tends to suggest that conditions were suitable for spawning for this species. No individuals of this species were captured in the community monitoring in 2016 so an assessment of survival to recruitment is not possible (see Fish community, section 4, above). Although counts of larval freshwater catfish were low, this is a positive result, as the western population of this species is endangered and this population appears to be breeding each year of the monitoring program thus far.

The relative abundance of flat headed gudgeon was much greater in 2015 than 2014. Timing of spawning was similar between years, though in 2015 the window appeared to be slightly more protracted. The large difference in relative abundance between 2015 and 2014 appears to be driven by a localised spawning event, with exceptionally high numbers of individuals captured in light traps at Hunthawang in mid – late November. The increase in mean lengths of flat headed gudgeon across sampling events 2 - 5 indicates that in-channel conditions were suitable for growth and development. These results are somewhat expected as flat headed gudgeon and Australian smelt are capable of spawning multiple times over an extended period and are likely to have extended beyond the duration of the sampling events undertaken in 2014 (Humphries et al. 2008a, Humphries et al. 2013).

Golden perch spawning was a specific objective of the watering action delivered between mid-November and mid-December 2015 (Watering Action 3). There was no evidence of golden perch spawning in the monitored reach in either of the larval fish monitoring efforts (LTIM monitoring and the complementary NSW DPI monitoring). Additionally no young-of-year recruits were detected in the fish community sampling (see Section 4). This means that it is unlikely that spawning of golden perch occurred in response to the 2015-16 water delivery via the translucent flows of Commonwealth environmental water. This was in spite of observations by researchers from the University of Canberra that golden perch captured at Wallanthery on the 19th of October (with water temperatures of ~25 °C) were running ripe and expressed milt, indicating that these individuals were primed for spawning.

The reasons for the lack of detection of egg or larvae of this golden perch in 2015 is not clear at this stage and may be related to a number of factors. The two most likely factors at this stage of investigation are flow conditions and water temperatures.

Record high temperatures in the catchment in October 2015 resulted in rapid increase of water temperatures during this month. Water temperatures in the river were below 19 °C until the start of October, then increased rapidly over 10 days to 23 °C. This increase in stream temperatures coincided with declining flows in the river. The watering action was delivered when water temperatures had exceeded 25 °C and were fluctuating between 23 °C and 30 °C. It is possible that the translucent release (early to late September) triggered a movement and aggregation cue for golden perch in the Lachlan River. The recession at the end of the translucent release was followed by low flows for 35-40 days, and this may have caused the fish to cease spawning activities and begin to resorb their eggs (Mackay 1973).

Golden perch are noted for the ability to display opportunistic spawning behaviour (Ebner et al. 2009), but the literature suggests that they require water temperatures of greater than 19 °C (King et al. 2005, Stuart and Jones 2006) in the southern Murray-Darling Basin and temperatures of 23 °C are often quoted as optimal for spawning (Lake 1967, Roberts et al. 2008). It is also thought that water level changes of 0.5 m would be sufficient to trigger migration prior to spawning, though golden perch were also found to have spawned in the Murray River without a rise in water level (King et al. 2005) and in the Murray River without floodplain inundation (Mallen-Cooper and Stuart 2003, Zampatti and Leigh 2013) (in channel flow rise in Spring was still present in the later example). In isolation, the golden perch flow released in 2015 satisfied many of the hypothesised criteria of a golden perch spawning flow (rise in water level whilst water temperature reached 23 °C). When flow is considered in the context of antecedent conditions (previous high flows and sharp water temperature rise) the flow releases in terms of inducing a spawning event from golden perch was potentially less ideal. An alternative approach could be tested in future watering actions under similar conditions (i.e. with the presence of translucent releases being made in spring). This could include implementing the hydrograph developed for perch so that it follows immediately after the period of translucent releases if temperature cues are suitable.

Another probable factor contributing to the lack of golden perch spawning may be related to suitable hydraulic conditions for golden perch spawning not being attained. There is a growing belief that hydraulics, and in particular flow velocity, is important in native fish spawning and recruitment. However, relationships are at this stage are not well established. Currently a degree of uncertainty exists regarding the lack of spawning response of golden perch in the Lachlan River.

Bony Herring were again not detected during larval monitoring in 2015, which is somewhat surprising given that recruits were detected at the majority of sites in the fish community monitoring in early 2016 (see Section 4). This species was found to spawn in December and January when water temperatures reached 21-23 °C in the lower Murray River (Puckeridge and Walker 1990). The last sampling event was in early December, which may have preceded the onset of spawning (even though temperatures had reached ~28 °C). Certainly the detection of young-of-year in the fish community sampling component of the monitoring program (see Section 4) suggests that spawning of bony herring occurred outside the temporal or spatial range of the sampling program. This was also the case in 2014.

Small bodied native fish species tend to receive less attention than the more iconic larger species such as Murray cod and golden perch. Fish such as bony herring play a role in dryland river food webs and are an important dietary item for larger fish species as well as water birds. With the proposed future release of carp herpes virus there is likely to be a major impact on the food web: European carp are the most common prey item in the diet of Murray cod in the Murray River, occurring in more than a third of cod stomachs (Ebner 2006). This is likely to be related to availability of carp (contributing up to 90% of the fish biomass at sites in the MDB (Harris and Gehrke 1997). Bony herring are also an important dietary item of Murray cod (Ebner 2006). With the release of the European carp herpes virus, its potential effects on the foodwebs in lowland systems, particularly in shifting the load of predation from carp to potentially native fish species like bony herring, requires consideration. Considering this, and the learnings of the current LTIM program, understanding bony herring responses to flow delivery in terms of maximising the resilience of this species when carp numbers decline and Murray cod have to prey switch may be important once carp numbers decrease following the release of the virus.

Low numbers of common carp detected during larval fish monitoring indicate that the fish flows delivered in 2015 did not provide suitable conditions for a significant spawning event for this species at the three larval fish monitoring sites. There was a small increase in the proportion of young-of-year carp detected in the community fish monitoring in early 2016 compared to early 2015 (see Section 4). This is to be expected as there was significant inundation and connectivity of wetland and channel areas during the translucent flow, and these areas are suspected carp recruitment hotspots (Crook and Gillanders 2006, Driver et al. 2006, MacDonald et al. 2010). The lack of increase in larval carp detected in the larval monitoring combined with the results of the community monitoring that there was a small increase in the proportion of young-of-year carp detected in the fish community monitoring suggests is likely to be related to one or both of the following:

1) increased spawning activity of carp in 2015, though this occurred outside the larval monitoring sites
2) an artefact of sampling variability and there was no real difference in the level of carp spawning and recruitment

These results must be interpreted in the context that the zone in which monitoring is undertaken has been found to have a lower proportion of common carp compared to other zones within the Lower Lachlan river system Selected Area (particularly those at the end of the system – *NSW DPI unpublished data*). It is acknowledged that there is a risk of the potential to promote a common carp spawning event in response to environmental flows in warmer months, especially as there is extended connection between wetlands and the main channel (Conallin et al. 2012). Restricting connectivity between wetlands and the main channel during the warmer months is likely to continue to contribute to the low level of spawning response of common carp, especially in view of the spring / summer 2014 observations.

5.4.2 EVALUATION

Watering action 3 had two specific objectives relating to native fish:

1. Provide habitat to support, maintain condition of, and provide reproduction opportunities for native fish,
2. Trial the augmentation of flow to generate a golden and/or silver perch movement and spawning response.

Based on catches from larval fish monitoring, the specific objectives for watering action 3 were partially met. In terms of delivery, the augmented flow release was a success, with the smaller pulse then large pulse (achieving targeted river height changes) achieved (see hydrology technical report). In terms of ecological responses, the monitoring results suggest that objectives were largely not met. Firstly there was no detectable spawning response from golden perch in relation to the flow release, despite augmented larval fish and egg monitoring (see discussion below for interpretation). Estimated spawning dates of other non-flow cued native fish species indicate that no additional spawning took place as a result of watering action 3 (see Appendix 1).

To assess the contribution of Commonwealth environmental water to native fish spawning and recruitment, the relevant short term and long term questions to be evaluated are:

Short-term (one year) evaluation questions:

1) What did Commonwealth environmental water contribute to native fish reproduction in the Lower Lachlan river system?

The 2015 – 2016 watering year provided suitable conditions for six native fish to reproduce in the targeted reach (five non-flow cued species and one flow-cued species). Four of these species (Murray cod, flat headed gudgeon, Australian smelt and carp gudgeon) were detected via LTIM larval fish monitoring (see below), two species (freshwater catfish and un-specked hardyhead) were detected using complimentary monitoring by NSW DPI during watering action 3 and the last species (bony herring) whilst not detected in larval stage was detected as new recruits in the fish community monitoring (See Section 4).

2) What did Commonwealth environmental water contribute to native larval fish growth in the Lower Lachlan river system?

Without knowledge of age (independent of estimates based on size) it is impossible to accurately determine growth of larval fish in response to Commonwealth environmental flow releases in the targeted area. The increase of size of larvae between sampling events (Figure 28), along with the presence of larger again 0+ individuals in the fish community monitoring (see Section 4) provides an indication that growth is occurring.

Long-term (five year) evaluation questions:

3) What did Commonwealth environmental water contribute to native fish populations in the Lower Lachlan river system?
4) What did Commonwealth environmental water contribute to native fish species diversity in the Lower Lachlan river system?

This is the second year of a five year program and without baseline data, addressing long-term evaluation questions is not appropriate at this stage.

5.5 FINAL COMMENTS AND RECOMMENDATIONS

- Spawning of non-flow cued species was observed in 2015-16, but the only flow cued species observed to spawn was bony herring. The evidence for bony herring spawning was from the detection of young-of-year in the adult fish monitoring and the suggestion is that they spawned in January/February. Yet the role of flow in the spawning of bony herring remains unclear.
- Golden perch spawning was not observed in 2015-16 in spite of providing an environmental watering action that was expected to produce a response. The lack of golden perch spawning may be a result of the timing of the watering action in relation to water temperatures. It is recommended that the delivery of flows targeting golden perch spawning:
    - Make use of Translucent releases to prime the fish to move and spawn (based on observations of ripe golden perch at the end of the 2015 translucent flows)
    - Future water delivery should utilise natural triggers such as tributary inflows. Rather than focus solely on temperature triggers for water delivery, future watering could use a combination of tributary inflow triggers and temperature triggers. These inflow triggers may include unregulated flow events from tributaries further upstream in the catchment (i.e. upstream of Forbes) and may more accurately reflect local climatic conditions reflective of a natural regime.
- Increased monitoring intensity may be required to monitor a golden perch spawning response as the current methods may be temporally too coarse.
- There is a need to develop a greater understanding of the golden perch populations that exist in the Lachlan. The source (stocked or wild) of the existing population and demographic details (male: female ratios as well as age) should be investigated to evaluate the hydrological events that may contribute to spawning of this species in the Lower Lachlan river system.
- There is an opportunity to further interrogate historical flow conditions and recruitment patterns of golden perch in the Lower Lachlan catchment using age/frequency information.
- Increased monitoring intensity may also be required to monitor spawning response of golden perch as the current methods are potentially too temporally coarse.

- The short term connection between the wetlands and the main channel observed in 2015 as a consequence of the translucent releases only resulted in a low level of common carp spawning. Restricting connections between wetlands and the main channel in warmer months is likely to continue to contribute to a low level of carp spawning.
- It is not possible to confidently answer the second short-term evaluation question (What did Commonwealth environmental water contribute to native larval fish growth in the Lower Lachlan river system?). Daily aging of at least a sub set of species is strongly recommended to be able to calculate age: length ratios (to be able to determine and compare growth and survival between years) and to accurately estimate spawning date. Daily aging was initially excluded from the monitoring program due to resource limitations. Samples from the first two years of monitoring have been stored so that they can be used for aging should resources become available. The Lachlan project team also has complementary microinvertebrate abundance and diversity data that could value add to the fish growth data determined from otolith analysis.
- Small bodied native fish species tend to receive less attention than the more charismatic larger species such as Murray cod and golden perch. Fish such as bony herring play an important role in dryland river food webs and are an important dietary item for larger fish species as well as water birds. At present our understanding of bony herring responses to flow delivery is limited and as part of maintaining or enhancing fish populations in the system, it is worth some focus on improving our understanding and how water might be delivered to benefit them.

5.6 APPENDIX 1: ESTIMATING FISH SPAWNING DATES 2015

The most accurate and precise method of estimating larval fish age and hence of deriving spawning date is by direct daily aging using otoliths of larval fish (Anderson et al. 1992, Campana and Thorrold 2001b). Resource constraints meant direct aging was not currently feasible for this project (although larvae captured in 2014 and 2015 have been stored for potential otolith analysis should funds be available), and this forced the use of less accurate indirect methods of aging and spawning date estimation.

Ages of small bodied species (carp gudgeon, Australian smelt and flat headed gudgeon) ages were estimated from length-age equations for each species for a site on the Lower Murray floodplain (Lindsay Island), provided in Humphries *et al.* (2008b) and matched to capture month. Hatching times for small bodied species were taken from Lintermans (2007). Murray cod larval age were estimated by multiplying length by 1.372 (a factor to compensate for shrinkage in ethanol) matched against linear length age equation derived from length-age data in Serafini and Humphries (2004) (Age = 6.6302ln-48.104). This age along with estimated incubation period (= 20.67-0.667*[WaterTemp(°C)] taken from Ryan *et al.* (2003) – where water temperature was for the five days prior to the estimated spawning date was subtracted from the capture date to provide an estimate of spawning date.

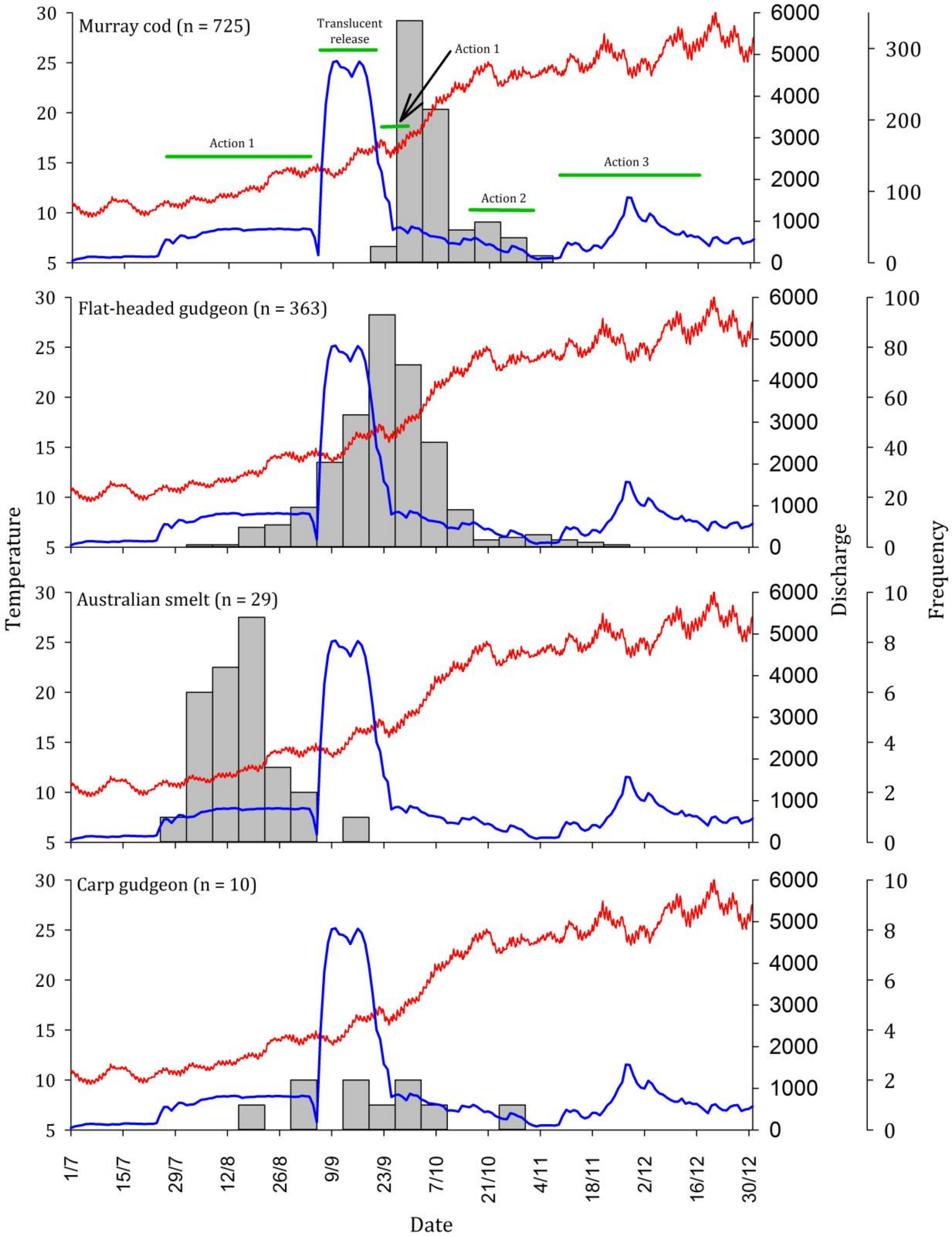


Figure 30. Estimated spawning date frequency (grey bars) and associated discharge and temperature for larval native fish species in 2015.
Discharge from Lachlan River at Willandra Weir (blue line) and temperature from Lachlan River at Willandra Weir (red line). Data are from all sites and methods combined. Green lines indicate durations of watering actions.

5.7 APPENDIX 2: DESIGN OF THE GOLDEN PERCH SPAWNING FLOW

To encourage a spawning response from the flow dependent golden perch, a flow was designed which aimed to meet the expected requirements of this species based on findings from other catchments. The following provides the detail around the design of the flow release.

Objectives: Provision of a designed or protected event to provide opportunities for medium-large bodied native fish that respond to significant changes in water height and flow velocity as cues for movement and spawning.

Target area for monitoring – Lachlan River below Wallanthery (d/s Willandra, u/s of Hillston).

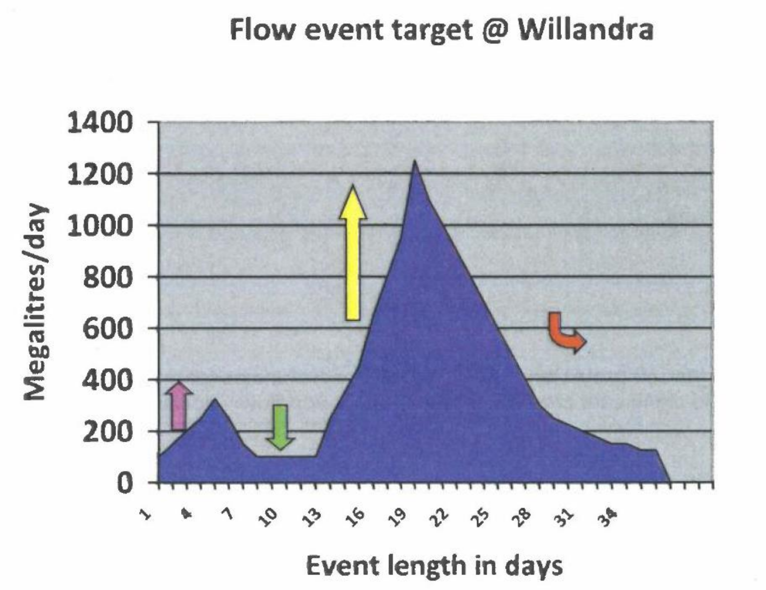
Environmental Triggers:

1. Compulsory - Water temperature must be >20 degrees - consistent post 20th October in the regulated Lachlan system.
2. Option - Unregulated tributary flows entering the system may contribute to the flow for both commencement date and volume (set window for dates).

Scenario 1:

Water Source:

CEWH: 13 826 ML



Action	Duration	Volume	Target river height change	Willandra gauge reading
(a) Small rise	Baseline flow to peak of **326 ML/day** over **7 days** (Day 1 to Day 7)	1426 ML	(Base + orders) + 0.25 m	0.83 m + (Base + orders)
(b) Recession	Baseline flow 0f 100 ML/day over 5 - 7 days (Day 8 to Day 12)	0 ML	Base + orders	
(c) Large rise	Peak of **1250 ML/day** over 8 days (Day 13 to Day 19)	4700 ML	(Base + orders) + 0.45m	1.03 m + (Base + orders)
(d) Ramp down	1250 – to baseline flow over 20 days (Day 20 to Day 36)	7700ML	Base + orders	

N.B: Recession = base flow + S&D, TWS, orders

Total volume at Willandra is 13 826 ML over 36 days

Environmental Triggers:

1. **Compulsory** - Water temperature must be >20 °C - consistent post October 20th.
2. **Option** - Unregulated tributary flows entering the system that would cause a peak range of 600 - 3512 ML/day @ Forbes between 03/10/2015 and 03/11/2015 may trigger the start of the event.

Tributary trigger thresholds:
Assuming 607 ML/day @ Forbes attenuates to 320 ML/day at Willandra, this will be the tributary trigger threshold for the small rise (action (a) in table above) portion of the event i.e. 0.25 m rise at Willandra gauge. In the event of a greater tributary contribution (assume that 3512 ML/day @ Forbes attenuates to 1250ML/day or 0.45 m @ Willandra), the magnitude and volume of the event will have to be considered. It may be that the planned event design could be abandoned in favour of shepherding a natural flow of a commensurate volume (and deducted from accounts) through the system as an alternative - this is a preferred option, particularly during the warmer months of the year. Any excess volume would be managed by Water NSW to fill orders or regulated into storage.

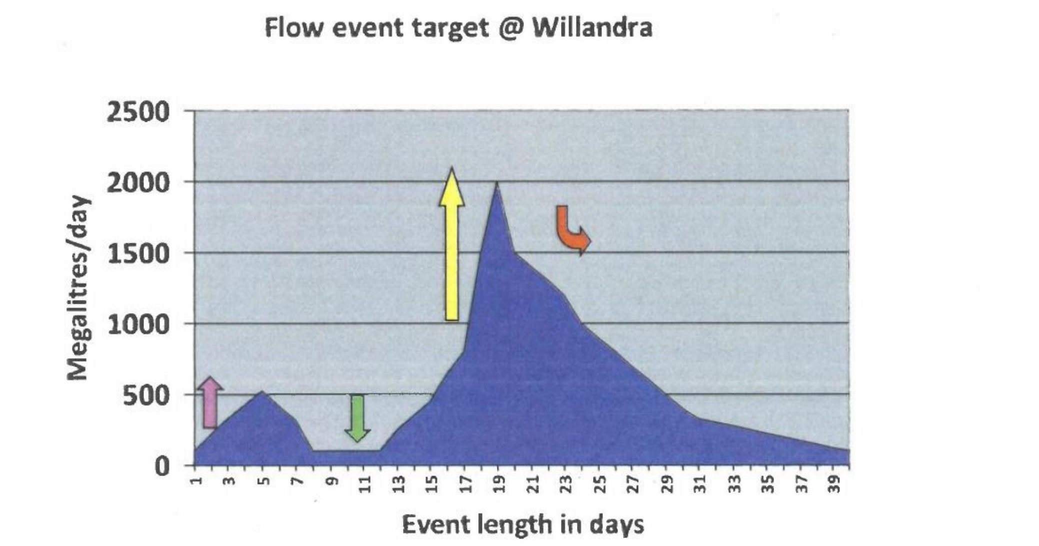
100% Managed Event - regulated sources of water:
If the unregulated flow trigger is not achieved during stipulated timeframe as outlined above, a release from storages shall commence from 20th October 2015 at the latest and conclude on the 25th November 2015 (operational details TBC - estimated travel time from Wyangala to Willandra is 22-24 days – the initial small rise also may be serviced from Brewster weir pool storage or Cargelligo - but operational details will be refined through discussion with LRWG & Water NSW.

Commencement date: If no natural trigger arrives in system, release from Wyangala should commence by 20/10/2015

Event Duration: 36 days

<u>Scenario 2:</u>
Water Source:

CEWH: 15 000 ML + State contribution + Brewster ECA = 20 759 ML



Action	Duration	Volume	Target river height change	Willandra gauge reading
(a) Small rise	Baseline flow to peak of **526 ML/day** over **7 days** (Day 1 to Day 7)	2334 ML	(Base + orders) + 0.30m	0.88 m + (Base + orders)
(b) Recession	Baseline flow 0f 100 ML/day over 5 -7 days (Day 8 to Day 12)	0 ML	Base + orders	
(c) Large rise	Peak of **2000 ML/day** over **8 days** (Day 13 to Day 19)	6000 ML	(Base + orders) + 0.55m	1.13 m + (Base + orders)
(d) Ramp down	2000 – to baseline flow over 20 days (Day 20 to Day 40)	12425 ML	Base + orders	

N.B: Recession (b) = base flow + S&D, TWS, orders

Total volume @ Willandra is 20 759 ML over 40 days.

6 FROG MONITORING

6.1 INTRODUCTION

Seven frog species have previously been recorded in the Lower Lachlan (downstream of Lake Cargelligo), this includes: spotted marsh frog (*Limnodynastes tasmaniensis*), barking marsh frog (*Limnodynastes fletcheri*), eastern sign-bearing froglet (*Crinia parinsignifera*), giant banjo frog (*Limnodynastes interioris*), Sudell's frog (*Neobatrachus sudelli*) and southern bell frog (*Litoria raniformis*) (at one site, Lake Bullogal) (Amos et al. 2014). Of these species, the southern bell frog is listed as vulnerable in the Environment Protection and Conservation Act, 1999 (EPBC Act). The status of these populations in terms of abundance and key breeding habitat remains relatively unknown.

Frog species respond to the inundation of dry wetlands with the majority of species known to breed in temporary aquatic habitats. Species require aquatic habitats to persist for the entire duration of their larval development phase with development times varying between species. For example, Crinia and Limnodynastes species tadpoles can metamorphose in as little as 2.5 to 3 months while the development of the southern bell frog is estimated to be 12-15 months (Anstis 2013). Wetland drying, prior to complete aquatic development will result in mortality due to desiccation with recurring recruitment failure events posing a significant risk to local population persistence (Wassens and Maher 2011, Wassens et al. 2013). The seasonal timing and frequency of inundation is critical to frog breeding outcomes as frog species respond to distinct cues (e.g. seasonal temperature, rainfall, hydrology) (Anstis 2013), and they have limited tolerances to prolonged drying periods (Wassens et al. 2010). Dry phases play an important role in excluding/ reducing colonisation by introduced fish which are significant predators of tadpoles. Though prone to fish colonisation, persistent aquatic habitats provide important refuge habitat during dry periods, particularly in spring and summer when the majority of species breed. Such habitat also fosters breeding by species with extended development times.

Breeding activity is an important measure of frog responses to environmental watering as male frogs call to attract their female counterparts for breeding and therefore, frog calling is commonly used as a proxy for breeding attempts with distinct species calls used for species identification (Trenham et al. 2003). The presence of tadpoles and metamorphs indicates successful larval development and recruitment to the terrestrial life phase.

The focus of frog monitoring is to evaluate the outcomes of Commonwealth environmental water delivery to the Lower Lachlan Catchment with respect to persistence of resident frog populations and their breeding activity. The three watering actions delivered in 2015-16 delivered water to benefit frog populations (Table 2) in the Great Cumbung Swamp and the Booligal Wetlands (Merrimajeel Creek and Murrumbidgil Swamp). In addition to the Commonwealth environmental watering actions, translucent flows inundated wetlands between Hillston and the Great Cumbung Swamp in 2015-16.

To determine the contribution of Commonwealth environmental water to the provision of aquatic habitat for frogs and breeding and recruitment of frogs in the Lower Lachlan river system, the following questions were addressed:

Selected area questions:

1) What did Commonwealth environmental water contribute to frog diversity and populations?
2) What did Commonwealth environmental water contribute to breeding and recruitment of frog species?

Action specific question:

3) What was the effect of Commonwealth environmental water on refuge for frogs in the Great Cumbung Swamp and Booligal Wetlands?

6.2 METHODS

Methods followed the standard methods for frogs in (Dyer et al. 2014). Fourteen sites across zones three and five (see Figure 3 and Table 9) were surveyed three times, that is at peak water level, beginning of water level decrease and dry or receded water levels.

Table 9. Site codes and details over previous surveys for each of the 14 frog sites in Zones 3 and 5.

Site	Code	Previously surveyed for frogs?[1]
Zone 5: Commonwealth environmental water to the Merrimajeel Creek targeting Murrumbidgil Swamp		
Alma road	ALMA	-
Blockbank	BLOC	P
Booligal north boundary	BONB	P
Merrimajeel Cobb Highway	MCOB	-
Muggebah Cobb highway	MUGG	A
Murrumbidgil Swamp	MURR	P, A
Merrimajeel Creek GT1	MUS1	-
Merrimajeel Creek GT2	MUS2	-
Natue 1	NATB	-
Natue 2	NATL	-
Zone 3: Commonwealth environmental water into the Lachlan River, targeting the Great Cumbung Swamp		
Baconian Swamp	BACC	-
Geramy Lachlan	GERA	-
Oxley bridge	OXLE	A
The Spells Paddock Swamp	SPELL	A

[1] *P = Call recordings made by Paul Packard, NSW OEH; A = (Amos et al. 2013); - = no frog records*

6.2.1 FIELD METHODS

Assessment of frog communities was undertaken at fourteen sites. Adult frogs and metamorphs were surveyed within each wetland after dark using a 3x10 minute visual encounter (person minutes) and a 3x1 minute audio survey (Wassens et al. 2011, Wassens et al. 2012).

A 15-30 watt torch was used to search for frogs along the wetland edge and into the surrounding terrestrial habitats. All individuals observed were identified to species and the number recorded (it is possible to identify individuals without capture). Timed surveys are more appropriate compared with set transects as variable water levels over time make the use of fixed transects impractical. Audio surveys involved listening for the distinct calls of resident frog species and the number of calling individuals was determined using the methodology described by (Wassens et al. 2011).

6.2.2 BREEDING AND SIZE STRUCTURE

An estimate of breeding activity was obtained by measuring a subset of 20 individuals, as size structure can give an indication of the number of recently metamorphosed individuals. Metamorphs are identified based on physical features including the presence of a resorbing tail. However, important to note is that growth rates can vary between sites. While variability in growth rates is widely acknowledged to occur, formal analysis of this variability has not been conducted in the Lachlan. The spotted marsh frog (*L. tasmaniensis*) and barking marsh frog (*L. fletcheri),* two common species across the Lachlan Catchment (Amos et al. 2013), were measured (snout-to-vent length) to give an indication of demographic structure and the presence of recent metamorphs.

6.2.3 VEGETATION

Vegetation transects were used to account for aquatic and riparian vegetation present at each site. Each transect was spaced 20 metres apart with 3 transects assessed per site. Transects were two metres wide and cut directly across the water body, starting five metres from the shore line and extending to the other side of the wetland or creek line. For very large wetlands, when that distance was beyond sight, the closest point that vegetation could be identified within sight was used. In each transect, the most prevalent aquatic vegetation types (>10%), were identified to species and the percentage cover of each species recorded; less dominant species were classified into broad categories. Percent cover of litter, bare ground, coarse woody debris, and open water were also recorded. The number of dead standing trees were also recorded for each transect during the initial survey (see Appendix 3, section 6.8.).

6.2.4 WATER QUALITY

Water quality was measured at three different locations within each water body and on each survey occasion. Five water quality variables were measured: temperature (˚C), conductivity (mS/cm), dissolved oxygen (mg/L), pH and turbidity (NTU) (see Appendix: 2, section 6.7). Measurements were made using a hand held multi-parameter water quality meter (U-50 Series, HORIBA Ltd., Kyoto, Japan) within 2.0-3.0 m of each measure. The measurements were made at a depth of at least 30 cm, or wherever possible in shallow waters. The meter was calibrated according to manufacturer specifications.

6.3 RESULTS

6.3.1 FROG DIVERSITY AND POPULATIONS

Overall, four frog species were observed: spotted marsh frog (*L. tasmaniensis*), giant banjo frog (*L. interioris*), Peron's tree frog (*Litoria peronii*) and eastern sign-bearing froglet (*C. parinsignifera*). Of these species, the spotted marsh frog was the most widespread and abundant observed at all 14 sites (Figure 3 and Table 9). The eastern sign-bearing froglet and giant banjo frog occurred at seven of the sites and Peron's tree frog was detected at six sites (Figure 32). All four species were identified in both zones three and five via one of the employed survey techniques, but Peron's tree frog was more abundant in Zone 3 (Kruskal – Wallis 20.586, $p<0.001$).

6.3.2 BREEDING AND RECRUITMENT OF FROG SPECIES

Calling was consistently higher for all four species in October 2015 when water levels were at a maximum. The spotted marsh frog (*L. tasmaniensis*) called during all three surveys however the occurrence the number of individuals calling was far higher in October 2015 (occurring at all sites) than in December and January (only occurred at 3 and 2 sites) (K-W 28.952, $p <0.001$) (see Figure 32). There were also significant difference in the number of the giant banjo frog (*L. interioris*) (K-W 13.568, $p =0.001$) and the eastern sign-bearing froglet (*C. parinsignifera*) (K-W 16.223, $p <0.001$) with calling limited to the October 2015 surveys. Overall larger numbers of Peron's tree frog (*L. peronii*) were recorded calling in October 2015, but this relationship was not significant with calling continuing through December 2015 and January 2016 at wetlands that continued to retain water (K-W 1.987, $p =0.370$) (see Figure 32).

Calling activity was strongly related to the initial wetland inundation, with a significant correlation (Spearman's Rank) between calling activity and the percentage open water (a measure of inundation) for the eastern sign-bearing froglet ($r=0.377$, $p =0.014$), Peron's tree frog ($r=0.032$, $p = 0.004$), the spotted marsh frog ($r=0.540$, $p <0.001$) and the giant banjo frog ($r=0.403$, $p =0.008$).

Successful breeding attempts in response to the water delivery was evident for the Limnodynastes species (most likely: spotted marsh frog (*L. tasmaniensis*)) with tadpoles detected at 10 sites across (see Figure 32). Limnodynastes spp. tadpoles were most abundant in December (K-W 25.011, $p <0.001$). Giant banjo frog tadpoles (*L. interioris*) were also observed at one site (Blockbank) during December 2015.

The size of spotted marsh frog (*L. tasmaniensis*) metamorphs is known to be less than 23 mm (Anstis 2013), although intraspecific geographic variation is common. Across all sites, smaller individuals were recorded in December and compared to January (Mann-Whitney U test 1974, $p = 0.02$) (Figure 33). This shifting size structure from very small (recently metamorphosed individuals) in December to larger individuals in January is consistent with recruitment of metamorphs in December and increased size structure (associated with their growth) in January.

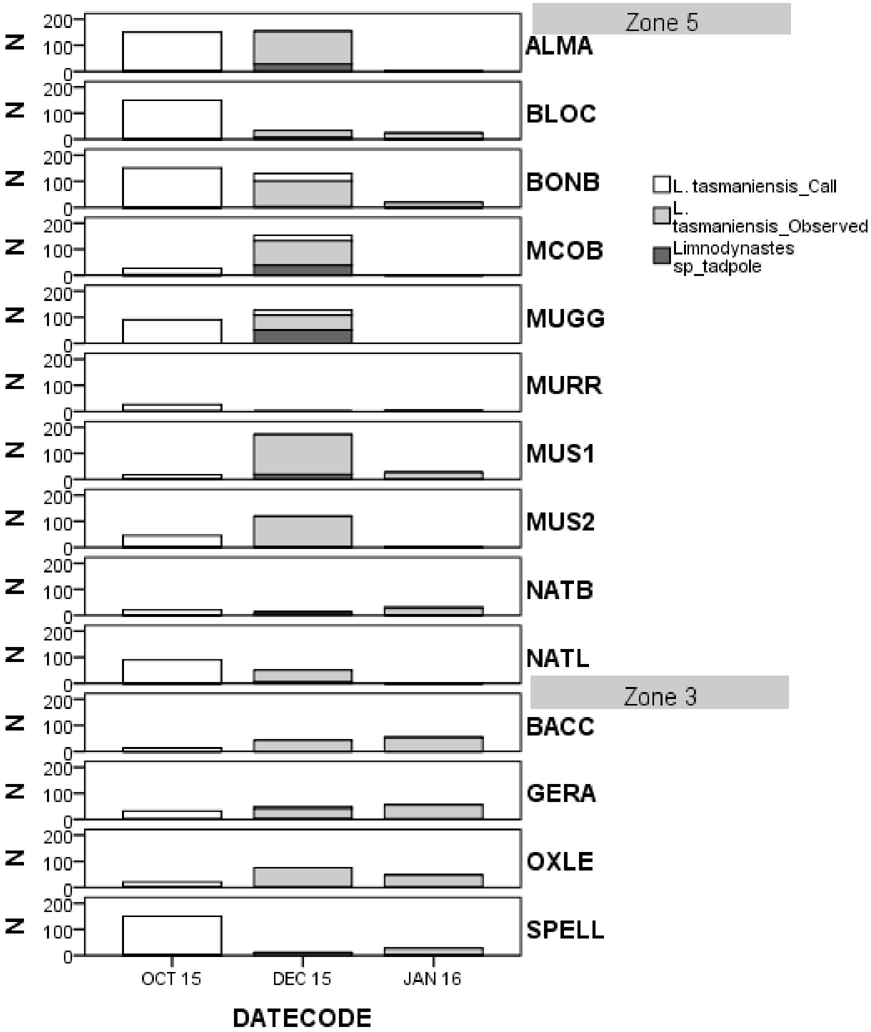


Figure 31. Spotted marsh frog (L. tasmaniensis) abundance at each of the 14 sites according to survey method (observed adult/metamorph, calling adult and tadpole).
Surveys were conducted during October 2015, December 2015 and January 2016 which corresponded with high, receding and low/dry water levels (respectively).
Site code: site name
ALMA: Alma road, BLOC: Blockbank, BONB: Booligal north boundary, MCOB: Merrimajeel Cobb Highway, MUGG: Muggebah Cobb Highway, MURR: Murrumbidgil Swamp, MUS1: Merrimajeel Creek GT1, MUS2: Merrimajeel Creek GT2, NATB: Natue 1, NATL: Natue 2, BACC: Bacconian swamp, GERA: Geramy Lachlan, OXLE: Oxley bridge, SPELL: the Spell's paddock swamp.

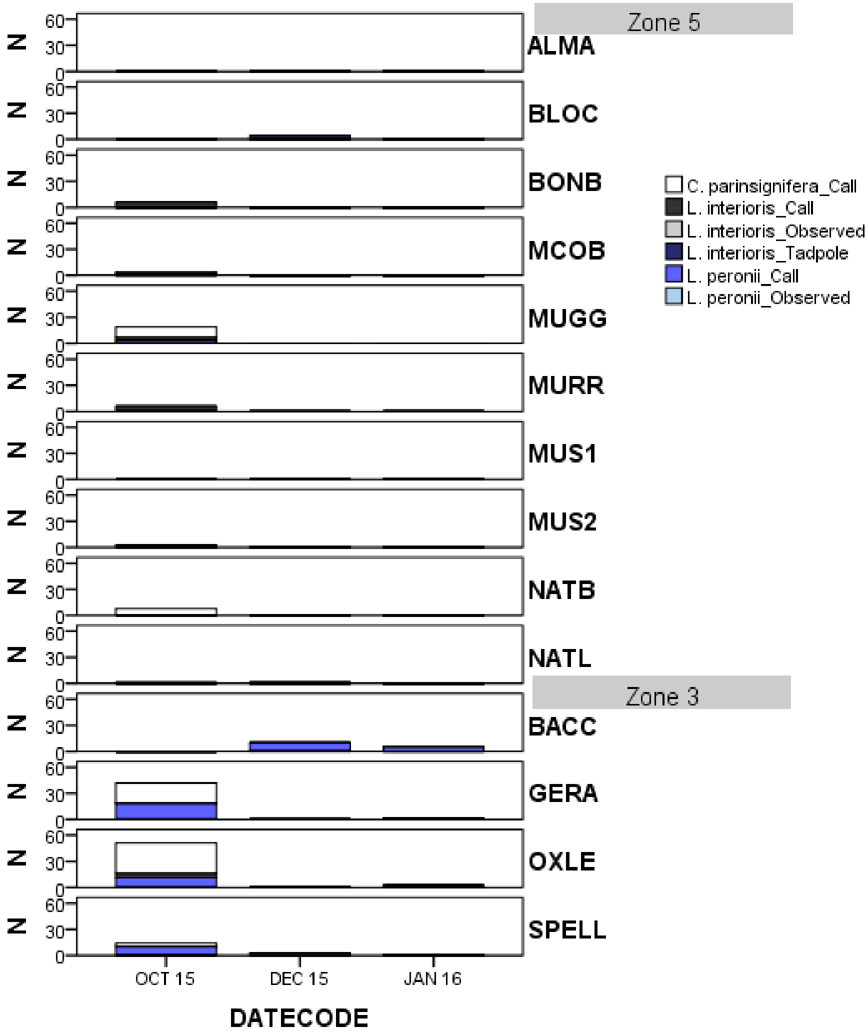


Figure 32. Spotted marsh frog (L. tasmaniensis), eastern sign-bearing froglet (C. parinsignifera) and Peron's tree frog (L. peronii) abundance at each of the 14 sites according to species and survey method (observed adult/metamorph, calling adult and tadpole).
Surveys were conducted during October 2015, December 2015 and January 2016 which corresponded with high, receding and low/dry water levels (respectively).
Site code: site name
ALMA: Alma road, BLOC: Blockbank, BONB: Booligal north boundary, MCOB: Merrimajeel Cobb Highway, MUGG: Muggebah Cobb Highway, MURR: Murrumbidgil Swamp, MUS1: Merrimajeel Creek GT1, MUS2: Merrimajeel Creek GT2, NATB: Natue 1, NATL: Natue 2, BACC: Bacconian swamp, GERA: Geramy Lachlan, OXLE: Oxley bridge, SPELL: the Spell's paddock swamp.

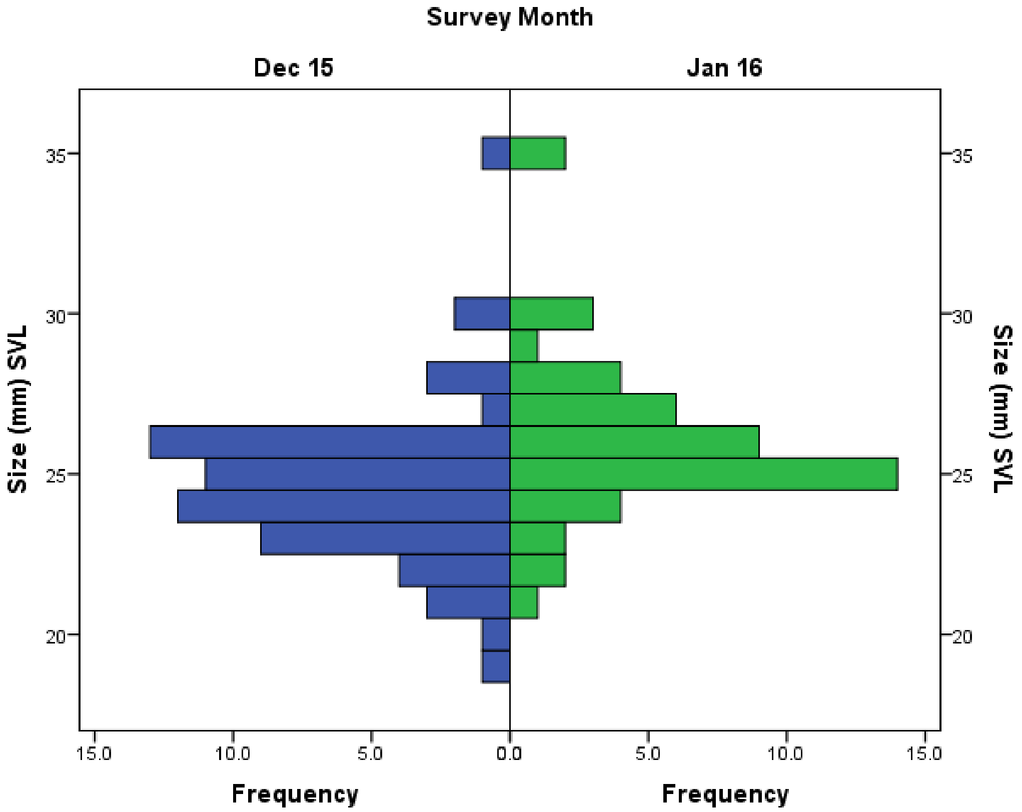


Figure 33. Summary of the snout to vent length distribution recorded for spotted marsh frog (L. tasmaniensis) individuals. Mann-Whitney U test, 1974.

6.3.3 MAINTENANCE OF REFUGE HABITATS FOR FROG SPECIES

Watering of the Merrimajeel Creek system targeted the ongoing recovery and resilience of Murrumbidgil Swamp and also the provision of drought refugia. Two species, spotted marsh frog (*L. tasmaniensis*), giant banjo frog (*L. interioris*), were recorded at Murrumbidgil, with calling by both species in October when part of the swamp contained low levels of water. Assessment across years is required to determine whether this wetland acted as a drought refuge for frogs, however, drying of several sites along the Merrimajeel Creek as well as the short hydroperiod of Murrumbidgil Swamp (dry by the December surveys) indicates that greater volumes of water would be required to create refuge for frog populations through summer.

6.4 DISCUSSION: EVALUATION OF THE SPECIFIC OBJECTIVES

6.4.1 FROG DIVERSITY AND POPULATIONS?

1) What did Commonwealth environmental water contribute to frog diversity and populations in the long term (5-year)?

The species observed in these surveys were similar to other surveys conducted in the Lower Lachlan including some of the same sites as Amos et al. (2013) and in close proximity (in the

Lake Bullogal region (Amos et al. 2014) suggesting that a similar diversity of frog populations has been maintained. High levels of occupancy were identified for all species with the spotted marsh frog (*L. tasmaniensis*) detected at 100% of the sites, the eastern sign-bearing froglet (*C. parinsignifera*) and the giant banjo frog (*L. interioris*) each detected at 50% of the sites and Peron's tree frog (*L. peronii*) at 43% of sites.

One noticeable difference was that barking marsh frog (*L. fletcheri*), was not detected (calling adult, observed metamorph nor tadpole) throughout the three surveys, whereas, this species was commonly detected in both previous studies. Surveys were conducted within the peak calling times known for this species (October, November and March) (Anstis 2013) and when high water levels caused by the combination of Commonwealth environmental water and the translucent flows were also available (in October). While barking marsh frog (*L. fletcheri*) and spotted marsh frog (*L. tasmaniensis*) tadpoles are indistinguishable, the lack of calling by this species and the high number of spotted marsh frog (*L. tasmaniensis*) metamorphs also indicates the absence, or rather than non-detection of this species.

Another species that has been observed within the Lower Lachlan but was not observed during these surveys was the Sudell's frog (*N. sudelli*). This burrowing species breeds in response to heavy rain in late winter through to early summer and early autumn (Anstis 2013) and so breeding was unlikely during these surveys due to the lack of heavy rainfall. The vulnerable southern bell frog (*L. raniformis*) was not detected during the surveys. However, this species was identified to be actively breeding at an irrigated rice crop close to Hay during the October surveys indicating that the survey timing was appropriate for detection of this species. It is likely that persistent dry conditions through the Lower Lachlan and relatively short duration of inundation that occurred following environmental watering would have limited breeding opportunities for this species (Anstis 2013).

6.4.2 BREEDING AND RECRUITMENT OF FROG SPECIES IN THE SHORT-TERM

2) What did commonwealth environmental water contribute to breeding and recruitment of frog species in the short-term?

The timing and duration of this water delivery (late winter/early spring) was well suited to successful breeding by the spotted marsh frog. Strong indicators of this breeding include the high occurrence of calling individuals (indicating attempted breeding) in October, as well as the high occurrence of tadpoles and metamorphs of this species detected at nearly all sites surveyed. The general trend of larger sized individuals identified during late January further suggests successful growth for this species. The high calling activity detected for Peron's tree frog (*L. peronei*), eastern sign-bearing froglet (*C. parinsignifera*) and giant banjo frog (*L. interioris*) during the October surveys when water levels were high; and subsequent cessation, or decline, in calling during the December and January surveys correlated with dropping water levels. Apart from spotted marsh frogs (*L. tasmaniensis*), few giant banjo frog (*L. interioris*) tadpoles and metamorphs were observed during the December surveys suggesting that this flow was also conducive to successful recruitment outcomes for this species.

The small, late winter-early spring flow was conducive to breeding attempts by the four species. However, most sites were drying during December and dry by late January and so the lack of standing water during summer did not cater to the breeding requirements of summer active species such as Peron's tree frog (*L. peronii*), barking marsh frog (*L. fletcheri*) and southern bell frog (*L. raniformis*). Calling by spotted marsh frogs (*L. tasmaniensis*) and Peron's tree frog (*L. peronii*) during the December and January surveys continued to occur at the few sites where water persisted.

6.4.3 MAINTENANCE OF REFUGE HABITATS FOR FROGS

3) What was the effect of Commonwealth environmental water on refuge for frogs in the Great Cumbung Swamp and Booligal Wetlands?

The inundation of the Great Cumbung Swamp from a combination of Commonwealth environmental water and translucent flows provided refuge and habitat for the four frog species detected during the monitoring. The duration of inundation and persistence of aquatic habitat into January allowed for continued breeding attempts (indicated by calling) by Peron's tree frog (*L. peronii*) and southern bell frog (*L. raniformis*).

In contrast, the inundation of the Merrimajeel Creek and Murrumbidgil Swamp in the Booligal Wetlands was of a much shorter duration. Two species, spotted marsh frogs (*L. tasmaniensis*) and giant banjo frog (*L. interioris*) were recorded at sites within Murrumbidgil Swamp, with calling by both species in October when part of the swamp contained low levels of water. Assessment across years is required to determine whether this wetland acted as a drought refuge for frogs, however, drying of several sites along the Merrimajeel Creek as well as the short hydroperiod of Murrumbidgil Swamp (dry by the December surveys) indicates that greater volumes of water would be required to create refuge for frog populations through summer.

6.5 FINAL COMMENTS AND RECOMMENDATIONS

- Calling by eastern sign-bearing froglet (*C. parinsignifera*), Peron's tree frog (*L. peronii*), spotted marsh frogs (*L. tasmaniensis*) and giant banjo frog (*L. interioris*) was correlated with wetland inundation. Maintaining large areas of shallow inundated habitat is import for successful frog breeding, recruitment outcomes for summer breeding species including southern bell frog (*L. raniformis*) will be improved if the inundation period is extended through summer with wetlands drying down in early autumn.

- The delivery of environmental water to the Merrimajeel Creek system (Zone 5) in late winter/early spring triggered a strong and positive breeding response by *L. tasmaniensis*. The volume of water delivered to the Merrimajeel Creek system was adequate for short-term breeding (October-December) for spotted marsh frogs (*L. tasmaniensis*) and to some extent giant banjo frog (*L. interioris*). However, within the wetland itself the short duration of inundation may limit the value of this site as a refuge habitat for frogs. A higher number of individuals and greater breeding success was observed upstream within the more persistent areas Merrimajeel Creek system, suggesting that this area may play a key role in supporting frog populations.

- The environmental water delivered to Zone 3, targeting the Great Cumbung Swamp provided as a refuge habitat for frogs for summer active species with Peron's tree frog (*L. peronii*) continuing to call in January in this zone. While the provision of aquatic habitat during summer presents the risk of being conducive to carp spawning, the majority of frog species actively breed during this time (late spring and summer) necessitating persistence during this time.

6.6 APPENDIX 1: PHOTOS

Figure 34. Murrumbidgil Swamp (above) and Spell's Paddock Swamp (below) in January 2016. Photograph comparison of the two target refuge sites, only Spell's Paddock Swamp provided aquatic habitat (potential refuge) through to January.

Figure 35. Spotted marsh frog (L. tasmaniensis) metamorphs December 2015.
Metamorphs indicate a breeding response of the species to the spring watering event.

Figure 36. Giant banjo frog (L. interiori) metamorphs.
Few L. interioris metemophs were observed indicating a small response to the watering actions.

Figure 37. Peron's tree frog (L. peronii) adult.
L. peronii adults called throughout each of the surveys in Zone 3 where water persisted suggesting additional water delivery is needed to allow for breeding of this summer active species.

6.7 APPENDIX 2: WATER QUALITY MEASURED WITH FROG MONITORING.

Table 10. Water quality measured in association with frog monitoring (October 2015 and December 2015). Gaps in the data occur when the wetland was dry.

		Temperature		pH		Conductivity		NTU		DO mg/L		DO%		Depth (m)	
Site Name	Survey Month	Mean	Standard Error of Mean	Mean	Standard Error of Mean	Mean	Standard Error of Mean	Mean	Standard Error of Mean	Mean	Standard Error of Mean	Mean	Standard Error of Mean	Mean	Standard Error of Mean
Alma crossing	OCT 15	26.33	0.33	7.74	0.09	0.65	0.01	86.47	45.82	7.51	0.80	93.27	8.88	0.30	0.00
	DEC 15													0.00	0.00
Bacconian Swamp	OCT 15	26.33	0.33	7.45	0.04	0.62	0.00	67.77	28.05	1.99	0.04	24.07	0.54	0.42	0.29
	DEC 15	33.83	0.48	7.72	0.14	0.97	0.07	503.00	99.81	6.29	0.60	88.00	8.64	0.10	0.03
Blockbank	OCT 15	20.67	0.33	7.20	0.03	0.49	0.01	28.17	11.58	7.19	0.87	79.33	7.89	0.15	0.03
	DEC 15	29.67	0.33	8.35	0.03	0.81	0.14	336.00	42.00	8.81	0.55	117.23	9.27	0.33	0.22
Booligal North Boundary	OCT 15	18.00	0.00	7.31	0.09	0.45	0.00	433.00	115.75	6.23	0.37	66.10	4.16	0.08	0.01
	DEC 15													0.50	0.50
Geramy Lachlan	OCT 15	23.00	0.00	7.54	0.03	0.42	0.00	126.67	24.18	5.46	1.05	62.47	9.99	0.20	0.00
	DEC 15	30.17	0.17	7.97	0.06	0.65	0.01	109.78	28.49	6.31	0.39	83.07	5.39	0.14	0.02
Merrimajeel Cobb Hwy	OCT 15	23.33	0.33	8.82	0.04	0.44	0.00	48.77	4.71	11.56	1.02	135.33	12.18	0.20	0.00
	DEC 15													1.00	1.00
Merrimajeel upstream 1	OCT 15	15.00	0.00	7.55	0.09	0.74	0.00	35.10	15.38	6.54	1.74	64.93	15.08	0.13	0.02
	DEC 15	29.33	0.42	8.57	0.07	1.05	0.07	414.67	58.32	13.17	0.59	182.40	11.25	0.13	0.01
Merrimajeel upstream 2	OCT 15	16.00	0.00	7.83	0.05	0.67	0.00	9.70	0.60	8.36	0.08	86.07	1.40	0.28	0.07
	DEC 15	27.33	0.33	7.52	0.06	0.66	0.01	73.57	38.33	5.91	0.38	75.83	4.67	0.13	0.04
Muggebah Cobb Hwy	OCT 15	19.00	0.00	7.59	0.06	0.44	0.00	226.00	63.91	6.38	0.37	68.58	4.25	0.27	0.09
	DEC 15													0.00	0.00
Murrumbidgil	OCT 15	25.00	0.00	7.32	0.02	0.83	0.00	160.13	71.95	3.28	0.31	38.37	2.92	0.08	0.01
	DEC 15													0.00	0.00
	OCT 15	29.33	0.33	9.42	0.04	0.64	0.00	356.67	104.25	13.60	1.21	109.53	45.55	0.06	0.01

		Temperature		pH		Conductivity		NTU		DO mg/L		DO%		Depth (m)	
Natue 1	DEC 15	24.67	0.67	7.07	0.11	0.85	0.08	316.00	100.94	3.78	0.13	44.67	1.27	0.13	0.04
Natue 2 (lignum)	OCT 15	21.33	0.33	7.87	0.08	0.53	0.00	25.97	17.32	9.68	0.21	113.97	0.47	0.32	0.04
	DEC 15	27.33	0.67	9.18	0.12	1.05	0.02	935.67	64.33	11.26	0.39	142.77	4.57	0.03	0.01
Oxley Bridge	OCT 15	23.67	0.33	7.35	0.11	0.44	0.00	84.30	5.14	6.09	0.42	71.27	5.32	0.47	0.03
	DEC 15	29.50	0.43	8.01	0.17	0.69	0.01	77.50	18.31	8.71	0.41	114.22	5.99	0.22	0.04
Spells Paddock	OCT 15	27.00	0.58	7.43	0.02	0.68	0.00	70.07	5.19	3.50	0.25	42.57	2.62	0.08	0.02
	DEC 15	34.33	0.33	8.99	0.18	1.29	0.03	200.00	39.40	15.18	1.96	212.43	28.09	0.03	0.00

6.8 APPENDIX 3: RAPID FROG HABITAT ASSESSMENT.

Table 11. Rapid frog habitat assessment in % (October 2015, December 2015 and January 2016). Percentages presented are averaged from three transects per survey while tree canopy and dead standing timber counts were only estimated during the initial survey.

Site Name	Survey Month	Dry?	Open water	Inundated terrestrial vegetation	Mud flat	Dry bare ground	Dry terrestrial vegetation	Free floating vegetation	Submerged aquatic vegetation	Low growing aquatic vegetation	Emergent aquatic vegetation <1m	Emergent aquatic vegetation >1m	Tree canopy	Dead standing trees (count)
Merrimajeel upstream 1	OCT 15	No	45	18	1	2	15	0	3	0	8	8	0	0
	DEC 15	Yes	0	0	0	5	80	0	0	0	10	5		
	JAN 16	Yes	0	0	0	7	90	0	0	0	0	3		
Merrimajeel upstream 2	OCT 15	No	38	18	0	0	22	0	5	0	10	7	0	0
	DEC 15	No	37	20	0	3	30	0	0	0	5	5		
	JAN 16	Yes	0	0	0	3	90	0	0	0	0	7		
Murrumbidgil	OCT 15	No	2	25	0	5	68	0	0	0	0	0	90	6
	DEC 15	Yes	0	0	0	5	95	0	0	0	0	0		
	JAN 16	Yes	0	0	0	3	97	0	0	0	0	0		
Blockbank	OCT 15	No	40	7	0	0	15	5	5	5	8	15	0	0
	DEC 15	No	8	2	10	5	46	0	5	4	5	15		
	JAN 16	Yes	0	0	0	10	75	0	0	0	0	15		
Merrimajeel Cobb Hwy	OCT 15	No	30	13	0	5	15	15	15	0	5	2	80	2
	DEC 15	No	25	0	0	30	35	0	4	0	3	3		
	JAN 16	Yes	0	0	0	22	70	0	0	0	3	5		
Muggebah Cobb Hwy	OCT 15	No	40	5	0	3	14	1	0	0	10	27	75	0
	DEC 15	Yes	0	0	0	5	60	0	0	0	10	25		
	JAN 16	Yes	0	0	0	10	60	0	0	0	5	25		
Booligal North Boundary	OCT 15	No	66	5	2	0	4	0	0	0	3	20	3	0
	DEC 15	No	15	2	2	15	44	0	0	0	0	22		
	JAN 16	Yes	0	0	0	19	60	0	0	0	1	20		
Alma crossing	OCT 15	No	40	5	0	4	10	0	6	5	25	5	0	1

Site Name	Survey Month	Dry?	Open water	Inundated terrestrial vegetation	Mud flat	Dry bare ground	Dry terrestrial vegetation	Free floating vegetation	Submerged aquatic vegetation	Low growing aquatic vegetation	Emergent aquatic vegetation <1m	Emergent aquatic vegetation >1m	Tree canopy	Dead standing trees (count)
	DEC 15	Yes	0	0	0	8	60	0	0	5	23	4		
	JAN 16	Yes	0	0	0	8	90	0	0	0	15	6		
Natue 1 (bridges)	OCT 15	No	45	5	3	1	16	2	8	4	6	10	0	0
	DEC 15	No	30	0	0	1	30	3	10	5	6	15		
	JAN 16	Yes	0	0	0	3	75	0	0	0	7	15		
Natue 2 (lignum)	OCT 15	No	60	5	0	4	10	4	0	2	0	15	90	5
	DEC 15	No	2	0	10	8	65	0	0	0	0	15		
	JAN 16	Yes	0	0	0	3	82	0	0	0	0	15		
Spells Paddock	OCT 15	No	68	10	0	0	10	5	3	0	3	1	13	0
	DEC 15	Yes	0	0	15	4	81	0	0	0	0	0		
	JAN 16	No	13	2	5	2	78	0	0	0	0	0		
Geramy Lachlan	OCT 15	No	70	0	0	4	10	3	0	1	2	10	60	4
	DEC 15	No	70	0	0	6	13	0	0	0	2	9		
	JAN 16	No	70	0	2	7	12	0	0	0	0	9		
Bacconian Swamp	OCT 15	No	65	0	4	5	11	15	0	0	0	0	80	1
	DEC 15	No	65	0	4	3	13	15	0	0	0	0		
	JAN 16	No	15	0	4	10	71	0	0	0	0	0		
Oxley Bridge	OCT 15	No	60	0	1	7	10	10	0	2	4	6	75	0
	DEC 15	No	73	0	1	10	5	0	0	1	5	5		
	JAN 16	No	80	0	1	9	7	0	0	0	0	3		

7 VEGETATION

7.1 INTRODUCTION

The Lower Lachlan river system contains many wetlands considered to be of national, regional and local importance. These are sites of high-value wetland plant communities including black box (*Eucalyptus largiflorens*), river cooba (*Acacia stenophylla*), extensive reed beds (*Phragmites australis*) and substantial areas of riparian fringing river red gum forest (*Eucalyptus camaldulensis*) and woodland. The Great Cumbung Swamp contains one of the largest stands of river red gum in NSW. These vegetation communities provide food and habitat for water birds, amphibians, fish, terrestrial vertebrates and a variety of other biota and support breeding events for tens of thousands of colonial nesting birds.

The condition, type and diversity of riparian and wetland vegetation communities are strongly influenced by the frequency and duration of inundation (Brock and Casanova 1997, Kingsford 2000). The floodplain and wetland vegetation communities of the Lower Lachlan river system display sequences of dry and wet phases depending on regional climatic conditions. During the Millenium drought (2001-2009), the health of the wetland vegetation declined rapidly (Armstrong et al. 2009). Observations and measurement made during the years immediately after the drought (2010-2012) suggested some degree of drought recovery was occurring within wetland vegetation communities, but by early 2012 aquatic vegetation, such as within the Great Cumbung Swamp, Lake Bullogal and Lake Merrimajeel was starting to show drought effects again (Driver et al. 2011, Driver et al. 2013a, Driver et al. 2013b).

In 2015-16, three Commonwealth environmental watering actions expected to deliver outcomes for riparian and wetland vegetation were delivered to the Lower Lachlan river system (Table 1). In addition translucent releases delivered a single large watering event to the Lower Lachlan river system providing flows of sufficient magnitude to inundate some of the wetlands between Hillston and the Great Cumbung Swamp.

This technical report evaluates the vegetation outcomes for vegetation and in doing so, the following questions are addressed:

What did Commonwealth environmental water contribute to:

1) vegetation species diversity?
2) vegetation community diversity?
3) the condition of floodplain and riparian trees?
4) populations of long-lived organisms?

We also evaluate the outcomes in relation to the objectives of the 2015-16 watering actions (Table 2). It should be noted that the objectives relating to the recovery and resilience of Murrumbidgil Swamp are unable to be addressed because landowner permission to monitor sites within the Swamp was withdrawn in early 2016.

7.2 METHODS

Vegetation surveys were conducted in both non-tree and tree communities during October/November 2015 and May/June 2016. Sites were selected to provide a sample from the different vegetation communities distributed across wetlands and riparian zones with different environmental watering probabilities (Figure 3 and Table 13).

The non-tree community survey was conducted along 2 replicate 100 m transects extending from the fringing woodland into the deeper section of the wetlands and billabongs at each of 10 sites (Table 13) using the methods of (Driver et al. 2003) described in (Dyer et al. 2014). Species abundance (and cover) was recorded in 1 m^2 quadrats placed at 10 m intervals along the 100 m transects (n=10 per transect).

Woodland tree communities were surveyed in a minimum of 2 replicate 0.1 ha plots at each of 12 sites (Table 13) using the methods of (Bowen 2013) described in (Dyer et al. 2014). An understory floristic survey was undertaken in a nested 0.04 ha plot inside the 0.1 ha plots. In each 0.1 ha plot, measures of stand and tree condition (basal area, canopy openness, canopy extent, live/dead limbs) were recorded as well as tree recruitment (trees >10 cm in diameter). In each 0.04 ha plot, the floristic survey recorded species abundance as cover.

All plants observed were identified to species either during field surveys or from field specimens which were preserved for later identification. The exception was grasses where individual species were not identified. Field observations indicate that fewer than 5 grass species were present at most sites.

Table 12. Observations of wetland watering in 2015-16 from the watering actions

	COMMONWEALTH WATER			NSW WATER
SITE (CODE)	WATERING ACTION 1	WATERING ACTION 2	WATERING ACTION 3	TRANSLUCENT FLOWS
Zone 1				
Hazelwood (HW)	N	N	N	Y
Whealbah (WB)	N	N	N	Y
Moon Moon (MM)	Y (extended duration)	N	N	Y
Zone 2				
Lake Bullogal (LBU)	N	N	N	N
The Ville (TV)	N	N	N	Y
Zone 3				
Lake Ita (LI)	N	N	N	N
Clear Lake (CL)	Y	N	Y	Y
Nooran Lake (NL)	Y	N	Y	Y
Lake Marrool (LM)	N	Unknown	Unknown	Y
Reed beds	Y	N	Y	Y
Zone 4				
Tom's Lake (TL)	N	N	N	Unknown
Lake Tarwong (LT)	N	N	N	N
Zone 5				
Booligal (BO)	Y	N	N	Y
Murrumbidgil Swamp (MB)	Y	N	N	Y

Table 13. Summary of vegetation monitoring sites.

The location of the sites within each Zone has been provided, however we do not consider the vegetation to be clearly separated according to zone.

SITE (CODE)	GEOMORPHIC DESCRIPTION	ANAE CLASSIFICATION	VEGETATION COMMUNITY	TREE COMMUNITY: RIPARIAN PLOTS	NON – TREE COMMUNITY: TRANSECTS
ZONE 1					
Hazelwood (HW)	Floodplain Billabong	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
Whealbah (WB)	Floodplain Billabong	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum/lignum	2	2
Moon Moon (MM)	Open lake fringed with red gum	Lt2.1: Temporary floodplain lakes Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
ZONE 2					
Lake Bullogal (LBU)	Channel mound wetland	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
The Ville (TV)	Floodplain Billabong	Pt1.2.1 Intermittent black box floodplain swamp Pt1.1.1: Intermittent River red gum floodplain swamp	Black box/river cooba/lignum River red gum	4	2
ZONE 3					
Lake Ita (LI)	Open Lake fringed with black box and red gums	Lt2.1: Temporary floodplain lakes	Black box/river cooba River red gum	4	0
Clear Lake (CL)	Lake (with reed beds) fringed with red gum	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	0
Nooran Lake (NL)	Lake (with reed beds) fringed with red gum	Lt2.1: Temporary floodplain lakes	River red gum	2	2
Lake Marrool (LM)	Open lake fringed with red gum	Lt2.1: Temporary floodplain lakes	River red gum	2	2

SITE (CODE)	GEOMORPHIC DESCRIPTION	ANAE CLASSIFICATION	VEGETATION COMMUNITY	TREE COMMUNITY: RIPARIAN PLOTS	NON – TREE COMMUNITY: TRANSECTS
ZONE 4					
Tom's Lake (TL)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	0
Lake Tarwong (LT)	Floodplain wetland Channel mound wetland	Pt1.2.1 Intermittent black box floodplain swamp/ Pt1.1.1: Intermittent River red gum floodplain swamp	Black box/river cooba/lignum River red gum	4	2
ZONE 5					
Booligal (BO)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	2
Murrumbidgil Swamp (MB)	Channel mound wetland	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	4	4

Table 14. Wetland watering observations 2015-16.

[1] *Watering categories were defined as follows: D= Dry, WN = watering of adjacent wetland, PW = partially wet/inundated, W = wet/inundated*

	OBSERVATION				NOTES		SOURCE OF WATER	WATERING CATEGORY[1]	
	Oct./Nov. 2015		May/June 2016						
SITE (CODE)	Transect	Plot	Transect	Plot	Transect	Plot		Transect	Plot
ZONE 1									
Hazelwood (HW)	15%	dry	dry	dry	Up to 20% of the transects had been under water		Translucent releases	PW	D
Whealbah (WB)	85%	dry	5%	dry	Maximum of 90% of the transects under water (2015)		Translucent releases	W	WN
Moon Moon (MM)	100%	100%	dry	dry			Translucent releases and Water: Action 1	W	W
ZONE 2									
Lake Bullogal (LBU)	dry	dry	dry	dry	No water reached the monitoring locations		N/A	D	D
The Ville (TV)	15%	dry	dry	dry	Up to 20% of the transect had been under water	Water had been onto two of the plots	Translucent releases	PW	D
ZONE 3									
Lake Ita (LI)		Not sampled		dry	No water reached the monitoring locations		N/A		D

	OBSERVATION				NOTES		SOURCE OF WATER	WATERING CATEGORY[1]	
	Oct./Nov. 2015		May/June 2016						
SITE (CODE)	Transect	Plot	Transect	Plot	Transect	Plot		Transect	Plot
Clear Lake (CL)		dry		dry		The area had been watered – but there was no evidence that the plots had received water	N/A		WN
Nooran Lake (NL)	55%	dry	dry	dry		Evidence of water over part of the plots	Commonwealth water (Actions 1 and 3) and Translucent releases	PW	WN
Lake Marrool (LM)	dry	dry	dry	dry	Evidence of water over approx. 30% of transects		Translucent releases	PW	WN
ZONE 4									
Tom's Lake (TL)		85%		dry		Evidence of water over 95% of one plot	Commonwealth water: Action 1		PW
Lake Tarwong (LT)	dry	dry	dry	dry				D	D
ZONE 5									
Booligal (BO)	5%	dry	20%	dry	up to 25% of the transects had been under water (2016)	Evidence of water over 20% of one plot	Commonwealth water: Action 1	PW	PW
Murrumbidgil Swamp (MB)	30%	3%	Not sampled	Not sampled	up to 45% of the transects had been under water (2015)	Evidence of water over 10% of one plot	Commonwealth water: Action 1	PW	WN

7.2.1 EVALUATION APPROACH

A combination of Commonwealth environmental water and translucent flow meant that 9 of the 13 monitored sites received water during the 2015-16 watering season (Table 14). Of these, 5 received a combination of Commonwealth water and translucent flow, and the remaining 4 received only translucent flow. Prior to the 2015-16 watering, the last watering of almost all of the sites occurred during the large scale watering action in 2012-13. At each site, transects and plots were assigned to a watering category based on the 2015-16 inundation and their recent watering history (Table 15) and these categories were used to structure the data analysis.

Table 15. Watering categories used to structure analysis of vegetation data

Watering category	Description
D (dry)	Not watered in 2015-16; Previous watering between 2011 and 2013
WN (watering of adjacent wetland)	2015-16 watering events did not inundate monitoring site, but water reached adjacent wetlands; Previous watering 2012 and 2013
PW (partially wet/inundated)	2015-16 watering events partially inundated the monitoring site; Previous watering 2013
W (wet/inundated)	2015-16 watering events inundated the monitoring site; previous watering 2013

The limited number of our sites that received Commonwealth environmental water during 2015-16 means that to determine the effects of watering, we have not differentiated between sites that were watered with Commonwealth environmental water and translucent flows. Where possible, we have used professional judgement to infer the effect of Commonwealth environmental water compared to translucent flows, but in many cases it is not possible to make a judgement around this. This is only the second year of monitoring vegetation responses to watering actions in the Lower Lachlan catchment and the first in which watering actions have inundated vegetation monitoring sites. It is expected that future watering actions will improve our understanding and ability to determine the effect of Commonwealth environmental water.

The analysis focussed on comparing the vegetation data from each season (i.e. spring 2014 with spring 2015 and autumn 2015 with autumn 2016) to remove potential seasonal effects. To evaluate vegetation outcomes the following approach was applied:

- Vegetation species diversity is defined as the number of groundcover species (excluding grasses) and the evenness of their abundance. For the evaluation, Simpson’s Diversity Index has been calculated for each sampling unit and compared across years for each watering treatment.
- Vegetation community diversity is taken to mean the composition of the community in terms of species composition, functional type and nativeness. For the evaluation species have been classified according to the plant functional types (Table 16) of Brock and Casanova (1997) and Casanova (2011). Species were also classified as native/non-native using information provided on PlantNET (http://plantnet.rbgsyd.nsw.gov.au/).

- The condition of floodplain and riparian trees is defined as the canopy cover of the floodplain trees (red gums and black box). For the evaluation condition metrics (Table 17) are derived from (Bowen 2013), Bowen and Simpson (2010) and Bowen et al (2012) and are adapted from Cunningham et al (2007).
- Long lived organisms refers to the floodplain and riparian trees (river red gum, black box and river cooba) and the contributions to populations of long-lived organisms means ensuring that there are new cohorts in the population. The evaluation was based on the number of eucalypt seedlings following watering and their persistence over time.

Table 16. Plant functional group classifications of Brock and Casnova (1997) and Casanova (2011)

FUNCTIONAL TYPE	DESCRIPTION
Amphibious responders (AmR)	Plants which change their growth form in response to flooding and drying cycles.
Amphibious tolerators (AmT)	Plants which tolerate flooding patterns without changing their growth form.
Terrestrial damp plants (Tda)	Plants which are terrestrial species but tend to grow close to the water margin on damp soils.
Terrestrial dry plants (Tdr)	Plants which are terrestrial species which don't normally grow in wetlands but may be encroaching into the area due to prolonged drying.

7.2.2 DATA ANALYSIS

For the analysis presented in this report the survey data have been treated in the following way:

- Species richness was calculated from the combined survey data from the two sampling dates and an average of the data from multiple plots or transects at each site.
- Simpson's Diversity Index (D) is calculated as:

  $$D = 1 - (\sum n(n-1)/N(N-1))$$

  where n = the total number of organisms of a particular species

  N = the total number of organisms of all species.
- Measures of stand and tree condition at each site were calculated as the average of the plot data from each vegetation community at each site. This means that for sites with more than one vegetation community, there are two measures of stand and tree condition provided (e.g. Lake Tarwong black box and Lake Tarwong river red gums).

Table 17. Plant condition classification derived from from (Bowen 2013), Bowen and Simpson (2010) and Bowen et al (2012) and are adapted from Cunningham et al (2007)

CONDITION	DESCRIPTION
Good	0-10% Dead Canopy
Intermediate	11-40% Dead Canopy
Intermediate/poor	41-80% Dead Canopy
Poor	> 81% Dead Canopy

The observations relating to landuse and other activities that may confound the interpretation of vegetation response to watering were recorded. The frequency and time since activity were recorded for grazing by livestock, firewood collection and site disturbance. The presence of feral animals was also noted.

7.3 RESULTS

7.3.1 VEGETATION SPECIES DIVERSITY

The numbers of species reported are conservative as grasses were excluded (individual species were not identified) as well as approximately 5% of species that could not be identified accurately. Field observations were that a small number of grasses were present at most sites during surveys and as such the overestimate is likely to be small.

7.3.1.1 Non-tree community

A total of 154 species were identified across the non-tree community sites during the 2015-16 watering season compared with 130 species identified during the 2014-15 watering season. In both 2015-16 and 2014-15, the plant community was dominated by chenopods (Chenopodiaceae spp.) which are terrestrial species adapted to dry conditions with asters (Asteraceae spp.) and grasses (Poaceae spp.) common at most sites.

The vegetation diversity (Simpson's diversity index) was seasonally variable with sites that were completely inundated in Spring 2015 displaying low diversity during 2015-16 in comparison to sites that were not inundated Figure 38. This was the result of the inundated sites becoming completely dominated by a few species during and after the watering. In spring sites that were inundated were dominated by duckweed (*Lemna minor*) and in autumn by Ward's weed, burr medic and crumb-weed (*Carichtera annua, Medicago polymorpha* and *Chenopodium pumilio* respectively).

The presence of Ward's weed at sites is of concern because of the highly invasive nature of this plant. At one of the monitoring sites (Whealbah), the adjacent paddock had become a mono-culture of Ward's weed. While this is a terrestrial species, it will be worth noting it is spread across the riparian zone as it may make affect the ability to achieve outcomes for future watering actions.

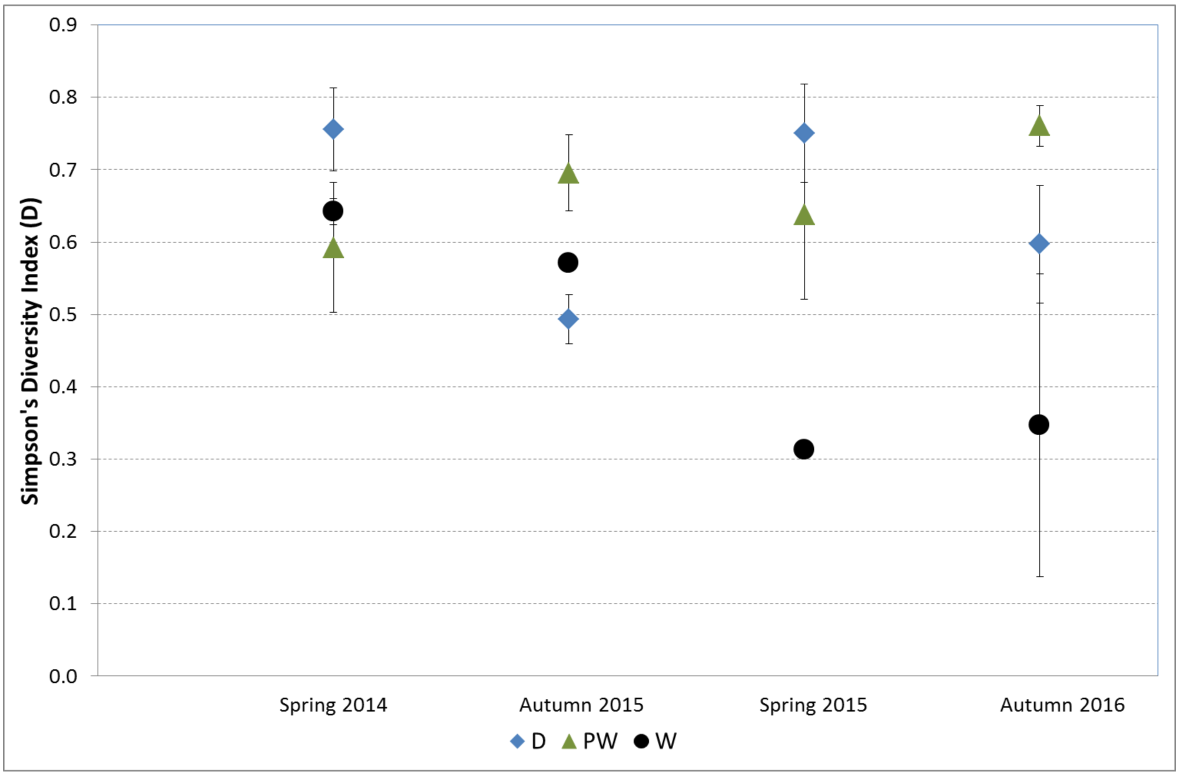


Figure 38. Comparison of groundcover vegetation diversity in the non-tree community between seasons and years using Simpson's diversity index.
The data points are the mean diversity index for each watering treatment (refer to Table 15). Error bars represent ± the standard error. The absence of error bars either means they are smaller than the symbol size or there is only one data point.

7.3.1.2 Tree community

A total of 162 species were identified across the tree community plots during the 2015-16 watering season compared with 137 species identified during the 2014-15 watering season. Chenopods (Chenopodiaceae spp.) and asters (Asteraceae spp.) dominated the plant community in both seasons, but in 2014-15 chenopods were the most common whereas in 2015-16 asters were more common.

The vegetation diversity was consistent across seasons and year (Figure 39) with a noticeable decrease in diversity in autumn 2016 which was caused by a high number of seedling (germinants) observed within the plots. There is a decrease in groundcover diversity in autumn 2016 at the site that was completely inundated in spring 2015 which was caused by a dominance of sneeze weed (*Centipeda cunninghamii*). This is consistent with observations from the non-tree community.

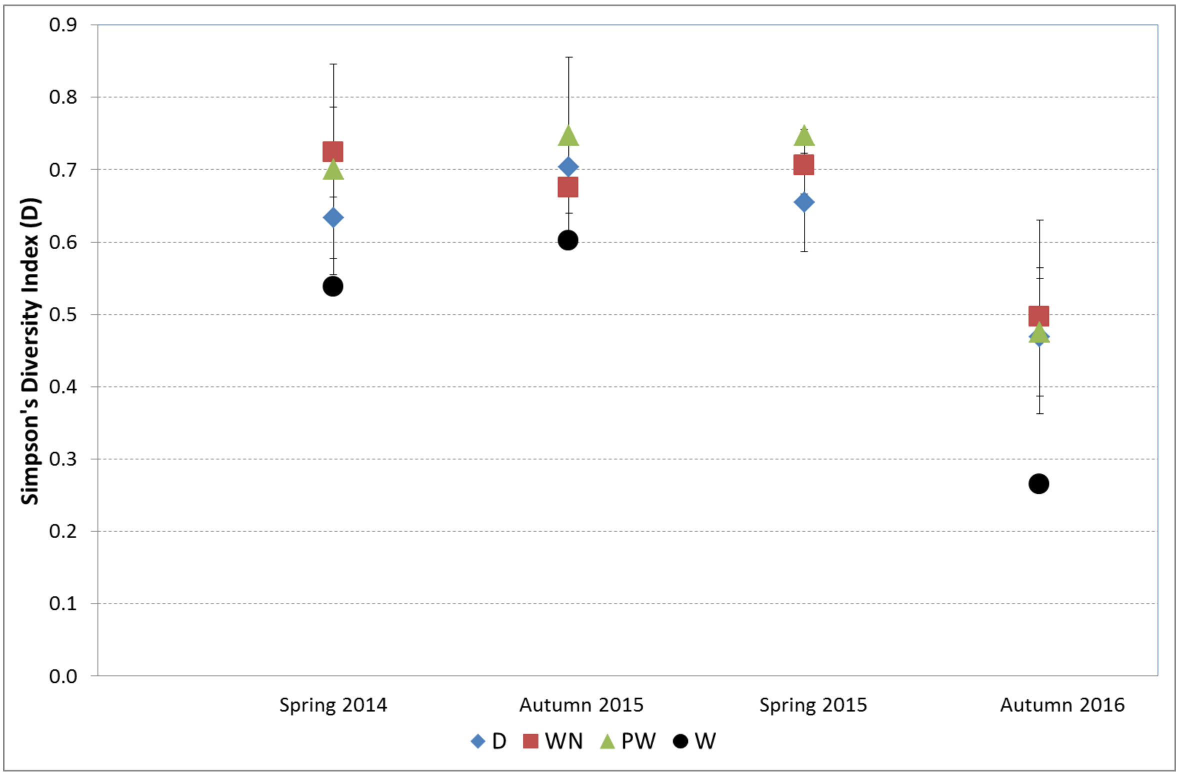


Figure 39. Comparison of groundcover diversity in the tree community between seasons and years using Simpson's diversity index.
The data points are the mean diversity index for each watering treatment (refer to Table 15). Error bars represent ± the standard error. No error bars are presented for treatment W (wet/inundated) as there is only 1 site in this category for the 2015-16 watering season. Spring 2015 data were not available for treatment W because the site was completely inundated at the time of sampling.

7.3.2 VEGETATION COMMUNITY DIVERSITY

7.3.2.1 Nativeness and functional types: non-tree community

Across almost all of the monitored sites, approximately 60% of the species identified in the 2014-15 monitoring were native. While the proportion of native species remained high (50-70 during the 2015-16 monitoring, some individual sites displayed a decrease in the proportion of native species and there was greater site variability in the proportion of native/exotic species (Figure 40). This does not appear to be confined to sites that were inundated and may be a response to above average spring rains in the catchment.

All of the sites were dominated by terrestrial vegetation (using the definition of Casanova, 2011) and very little amphibious vegetation was observed (Figure 41). Sites classified as Dry (did not receive water in 2015-16 and the last known watering was prior to 2013) had the lowest proportion of both amphibious and terrestrial-damp vegetation. Sites that were classified as PW (partially watered in 2015-16 and previously watered in 2013) and W (completely inundated in 2015-16 and previously watered in 2013) had higher proportions of both amphibious and terrestrial-damp vegetation. This suggests that there is some separation of the vegetation by site, based on a watering history and this will be further explored as data from subsequent monitoring becomes available. Sites that were inundated in 2015-16 (classified as W in Figure 41) showed an increase in amphibious vegetation in spring 2015 which is when the sites were either under water or had recently been under water (Figure 41).

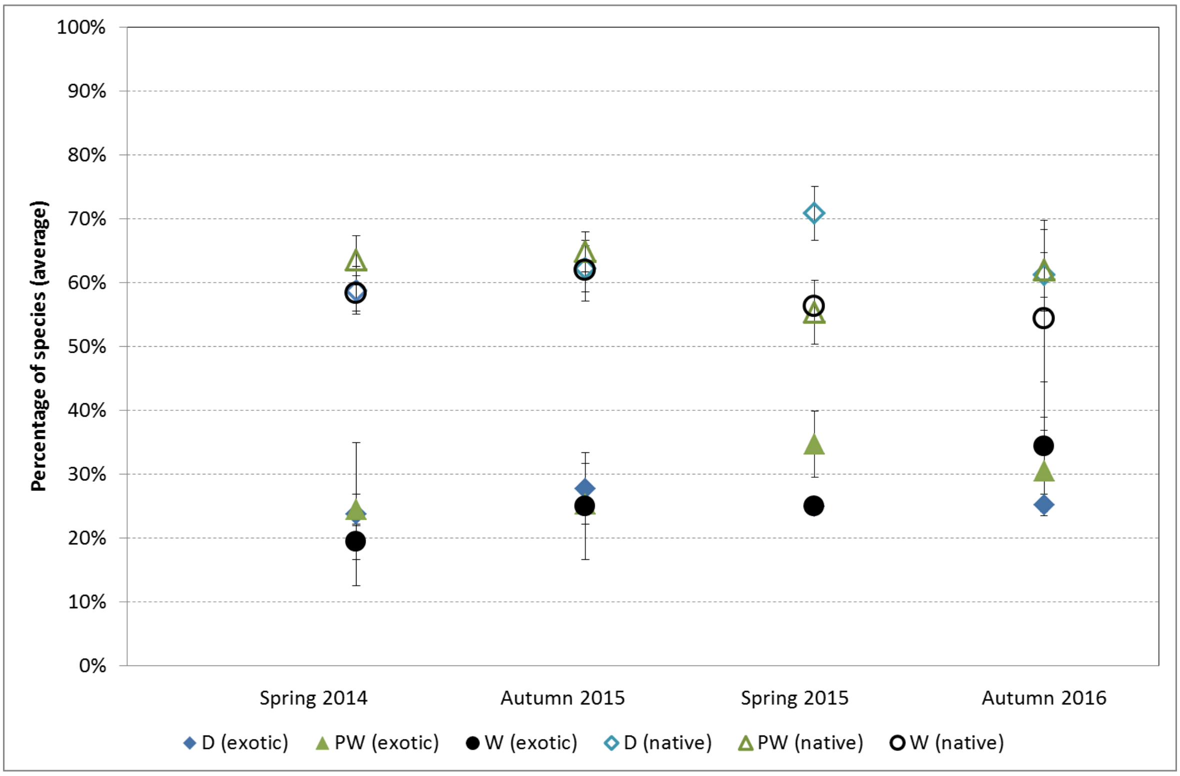


Figure 40. Average proportion of native and exotic species for the non-tree communities. The data points represent the mean for each watering treatment (refer to Table 15) and the error bars represent ± the standard error. The proportion of native species is shown by open symbols and the proportion of exotic species are shown by closed symbols.

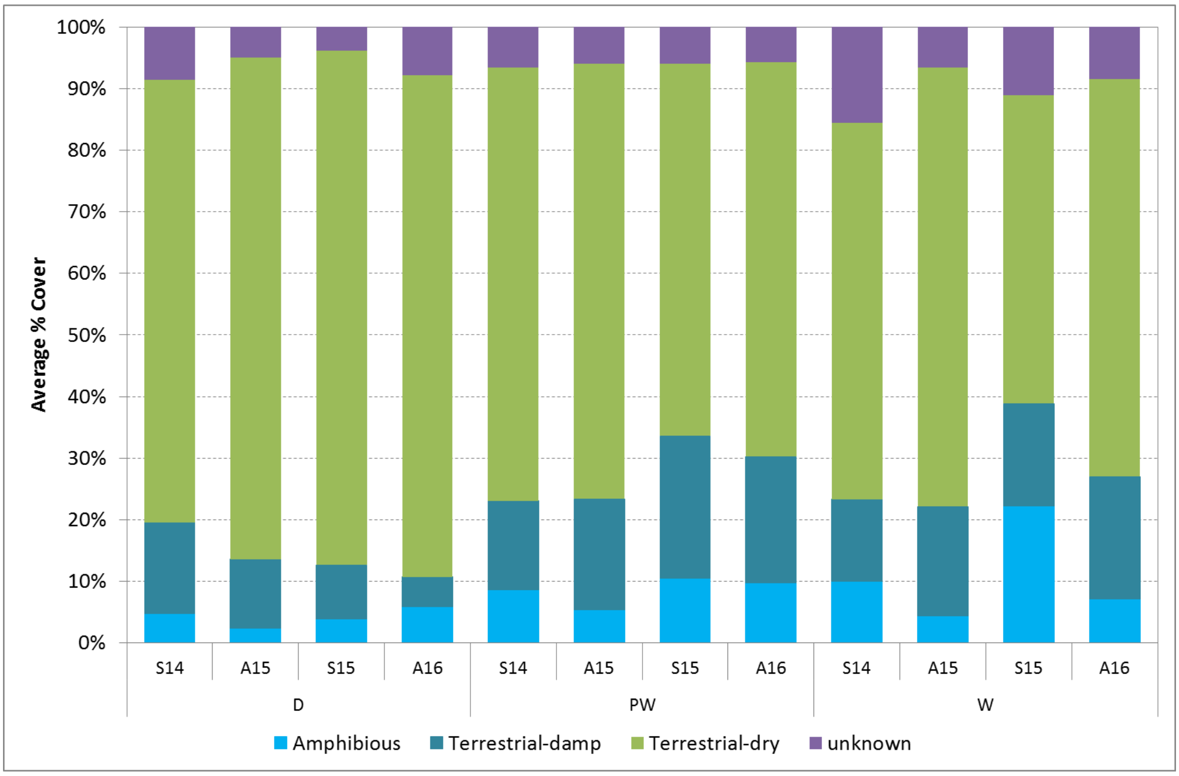


Figure 41. Average proportional cover of terrestrial and amphibious species within the non-tree community for sites from each watering treatment over the sampling period (S14: Spring 2014, A15: Autumn 2015, S15: Spring 15, A16: Autumn 16) (refer to Table 15 for watering categories). Unknown represents species that were unable to be identified to a level suitable for classification.

7.3.2.2 Nativeness and functional types: tree community

Across all of the monitored sites, more than 60% of species recorded in both spring 2014 and autumn 2015 were native species (Figure 42). While the proportion of native species remained high in 2015-16, the site that was completely inundated showed a substantial reduction in the proportion of native species (Figure 42). It should be noted that this is the response of a single site only (Moon Moon Swamp) which has had a lower proportion of native species throughout the monitoring program and was not reflected in the non-tree community data (see Section 7.3.2.1).

Most of the species identified are classified as terrestrial species and few amphibious species were observed (Figure 43). Sites classified as Dry (did not receive water in 2015-16 and the last known watering was prior to 2013) and Watered Nearby (the adjacent wetland received water in 2015-16 and previously watered in 2013) had the lowest proportion of both amphibious and terrestrial-damp vegetation and showed very little change over the two years of monitoring. Sites that were classified as PW (partially watered in 2015-16 and previously watered in 2013) had higher proportions of amphibious and terrestrial-damp vegetation and the proportions of these types of vegetation increased during the two years of monitoring suggesting that watering was producing a vegetation response at these sites. The one site that had been completely inundated in 2015-16 and previously watered in 2013 had little in the way of amphibious vegetation and a relatively consistent proportion of terrestrial-damp vegetation. As with the non-tree vegetation community, this suggests that there is some differences in the groundcover vegetation across the sites based on watering history and this will be further explored as data from subsequent monitoring becomes available.

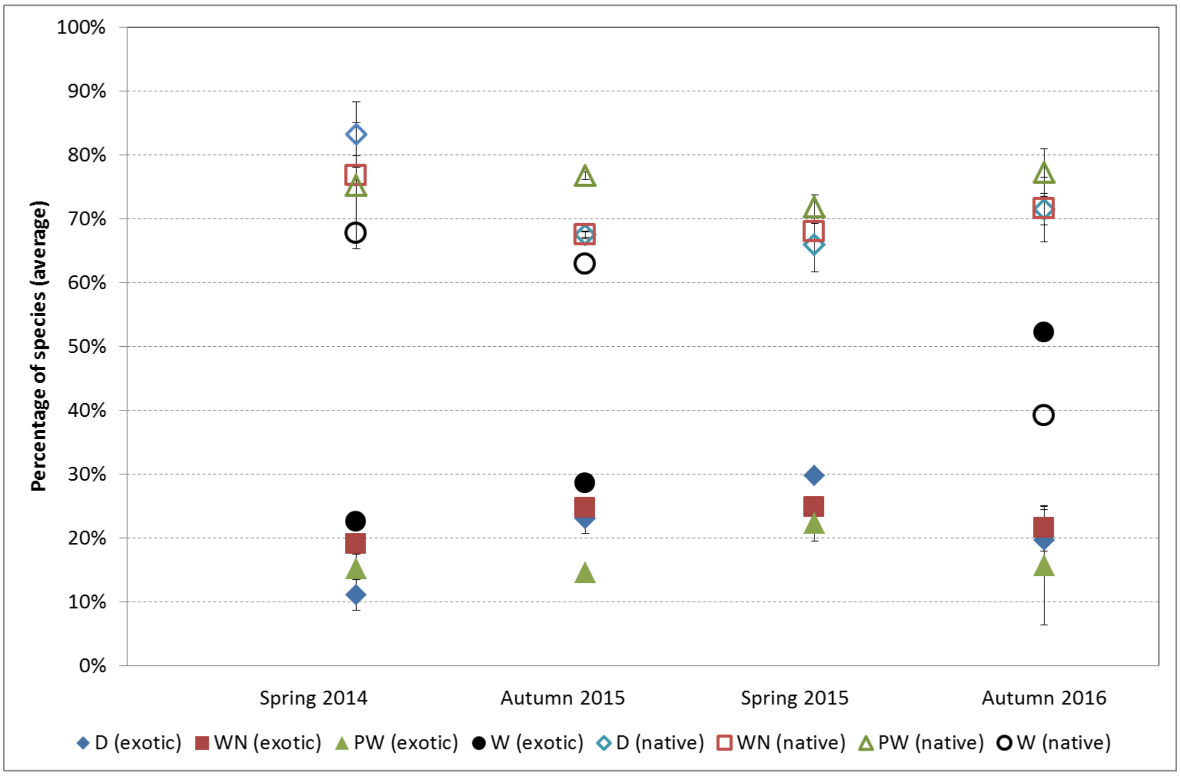


Figure 42. Average proportion of native and exotic species for the tree communities.
The data points are the mean (+/- standard error) for each watering treatment (refer to Table 15). The proportion of native species is shown by open symbols and the proportion of exotic species are shown by closed symbols.

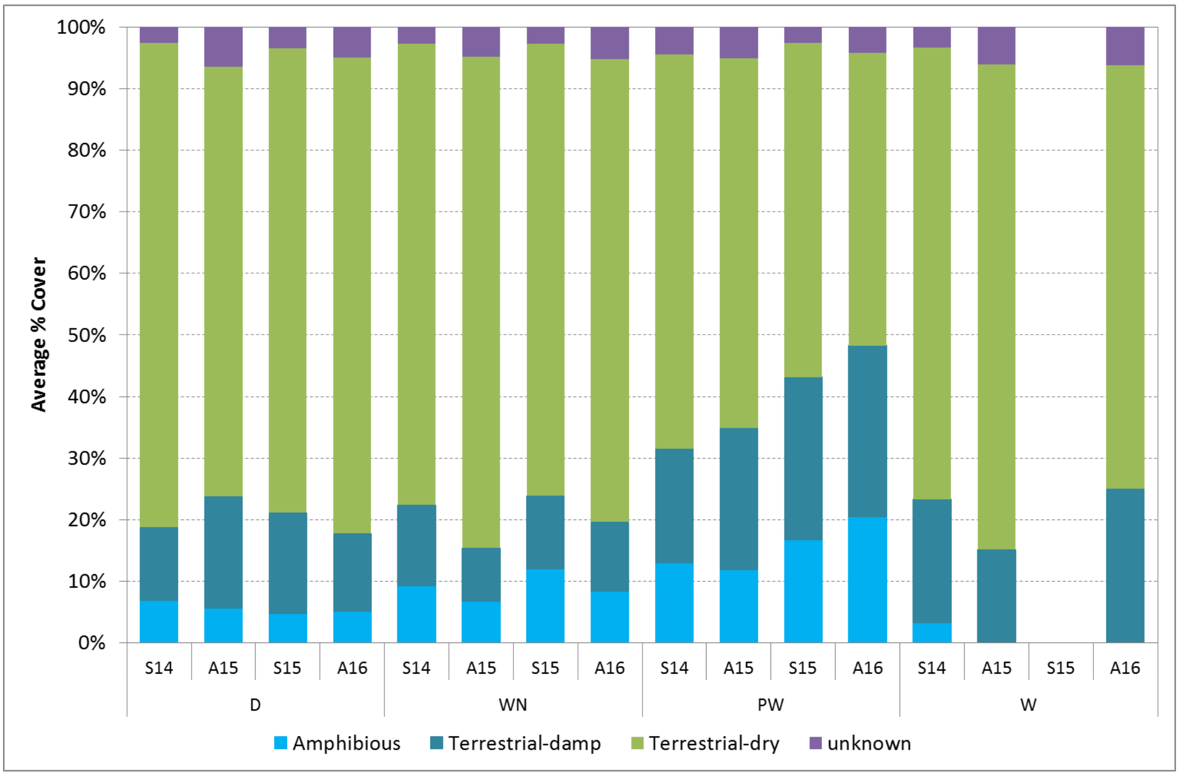


Figure 43. Average proportion of terrestrial and amphibious species within the tree community for sites from each watering treatment over the sampling period (S14: Spring 2014, A15: Autumn 2015, S15: Spring 15, A16: Autumn 16) (refer to Table 15 for watering categories). Unknown are species that were unable to be identified to a level suitable for classification.

7.3.3 CONDITION OF FLOODPLAIN AND RIPARIAN TREES

There was a general increase in the % foliage cover of the river red gum and black box in the catchment in 2015-16 and the increase was greater if the sites were completely inundated (watered) or partially inundated (Figure 44). While the sample size is small, the data suggests that environmental water has produced a small improvement in the condition of floodplain and riparian trees.

There was a very small improvement in the % dead canopy of the river red gum and black box in 2014-15 but the change was not sufficient to result in a change in the condition classification of any of the sites (Figure 45).

7.3.4 CONTRIBUTIONS TO LONG LIVED ORGANISMS

The numbers of seedlings and saplings present in all plots per site were aggregated to give a combined count per time of sampling, and to facilitate comparison between monitoring dates (Table 18). All sites had some seedlings or saplings present (Table 18) except for Lake Bullogal where stocking density of sheep was high. The most obvious response to environmental watering was at Moon Moon Swamp and Whealbah Billabong where the flooding in spring 2015 triggered the germination of a large number of seedlings within the monitoring plots. The response at the remaining sites was patchy, with a general decline in the number of seedlings and saplings recorded. Field observations suggest that grazing pressure is a factor in the number of seedlings and saplings persisting at a site, with seedlings and saplings obviously grazed. This is not reflected in the number of seedlings and saplings present at sites this year and future years of monitoring will determine the longer term effects of grazing pressure.

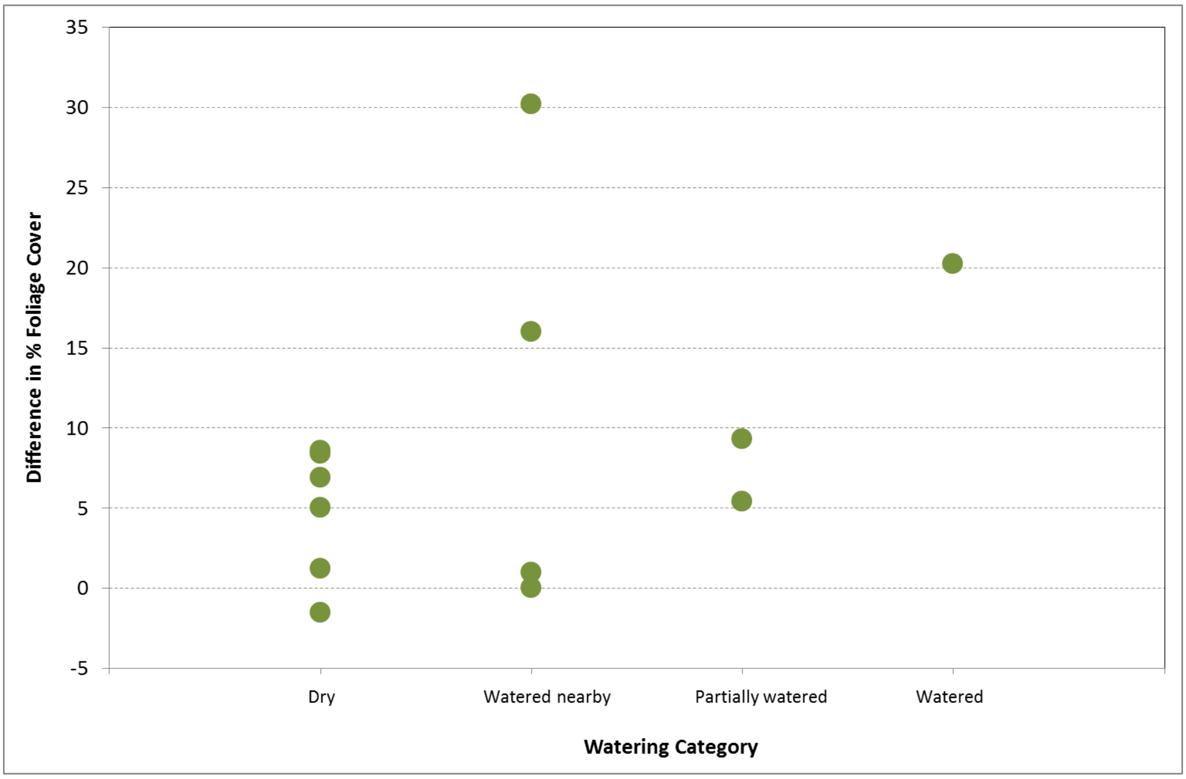


Figure 44. The difference in % Foliage cover between 2014-15 and 2015-16 for river red gum and black box with watering.

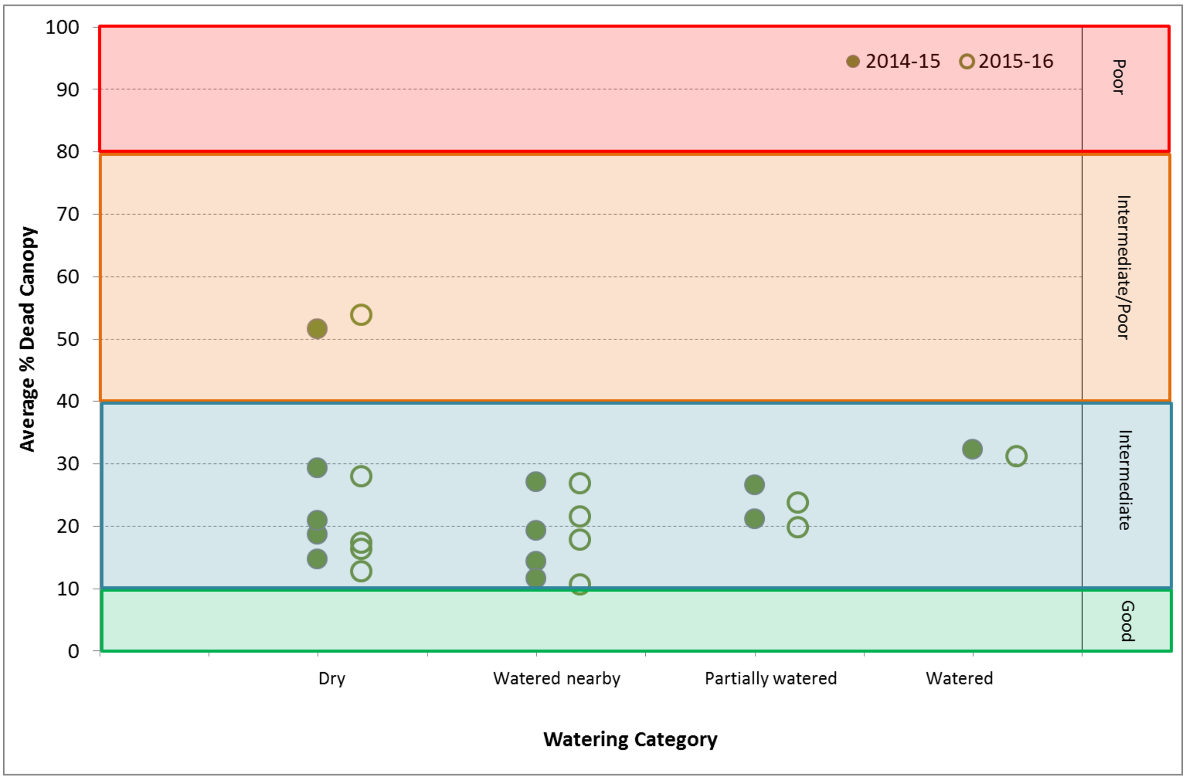


Figure 45. Change in the % dead canopy between 2014-15 and 2015-16 for the woodland vegetation community of the Lower Lachlan river system.
Sites are grouped according to watering category (see Table 15) and condition classification is shown in coloured bands (refer to Table 17)

Table 18. The average number of seedlings and saplings per site.

SITE	FLOODPLAIN/ WETLAND COMPLEX	LANDUSE	GRAZING INTENSITY	RECRUITMENT (<0.2 to >3.0 m)		
Trip				Autumn 2015	Spring 2015	Autumn 2016
Red gum community						
Hazelwood	Lachlan River Floodplain	Grazing (sheep)	Recent and frequent	35	35	41
Whealbah	Lachlan River Floodplain	Grazing (sheep)	Recent and occasional	740	315	926
Moon Moon Swamp	Booligal Wetlands	Grazing (cattle)	Recent and frequent	13	100% flooded	73
Nooran Lake	Great Cumbung Swamp	Grazing (cattle)	Recent and frequent	14	40	38
Lake Marrool	Great Cumbung Swamp	Grazing	Recent and occasional	2	3	1
Murrumbidgil Swamp	Booligal Wetlands	Grazing (sheep)	Recent and frequent	211	320	no visit
Lake Bullogal	Lachlan Swamp	Grazing (sheep – large numbers)	Recent and frequent	0	0	0
Lake Tarwong	Merrowie/Box Creek	Grazing (sheep)	Recent and frequent	237	136	91
Clear Lake	Cumbung Swamp	Grazing (cattle)	Recent and frequent	61	29	23
Black box community						
Booligal wetland	Booligal Wetlands	Nature conservation	Low	44	75	43
Tom's Lake	Booligal Wetlands	Grazing (cattle)	Recent and frequent	1	16	41
Lake Tarwong	Merrowie/Box Creek	Grazing (sheep)	Recent and frequent	0	6	1
Mixed Red Gum, River Cooba and Black Box						
The Ville	Lachlan Swamp	Nature conservation	Low	42	45	157
Lake Ita	Lachlan River Floodplain	Nature conservation	Low	no visit		3
Lake Ita (Inlet)	Lachlan River Floodplain	Nature conservation	Low			3

7.4 DISCUSSION: ADDRESSING EVALUATION QUESTIONS

All of the sites that received environmental water in 2015-16 received either a combination of Commonwealth water and translucent flows or only translucent flow. This means that the relative contribution of the different sources of environmental water (Commonwealth environmental watering actions or translucent flows) are generally unable to be disentangled. Learning from the combined watering actions will help develop an understanding of the vegetation responses to watering and in combination with future years of data will inform future watering options. The questions posed are therefore answered in response to the aggregate environmental water and where inference is possible in relation to Commonwealth environmental watering actions, this is also provided.

1) What did environmental water contribute to vegetation species diversity?

There was an increase in the number of groundcover plant species recorded in 2015-16 compared with 2014-15 and the species were dominated by native terrestrial species. Complete inundation of sites with environmental water in 2015-16 reduced the groundcover diversity whereas sites that remained dry or were only partly inundated retained a relatively high diversity. The reduction in diversity was the result of the few completely inundated sites becoming dominated by a particular species (for example, sneeze weed, *Centipeda cunninghamii* at Moon Moon Swamp) in response to the watering and is likely part of the natural patterns of vegetation responses to watering in the wetlands.

2) What did environmental water contribute to vegetation community diversity?

All 13 sites had a reasonably high degree of 'nativeness' with more than 60% of the identified groundcover species being native. This is likely to be an overestimate because the sampling does not identify grasses to species but the effect is considered small as few grass species were observed at the majority of sites. Only one of the sites showed a noticeable change in the proportion of native species with a drop in native species and increase in exotic species with complete inundation. The proportion of native and exotic species at sites that remained dry or were only partially watered was reasonably constant.

The groundcover vegetation was dominated by terrestrial species, most of which are adapted to dry conditions. Very few species dependent on damp or inundated conditions were observed in the groundcover vegetation in 2014-15. This was not unexpected given the infrequent watering of sites over the past 15 years. Following the 2015-16 watering there was a noticeable increase in the proportion of species dependent on damp or inundated conditions at sites that were either partially or completely inundated. This indicates that the vegetation community within the catchment is responsive to watering which is positive.

Observations and measurement made during the years immediately after the drought (2010-2012) suggested some degree of drought recovery was occurring within wetland vegetation communities, but at least by early 2012 aquatic vegetation was starting to show drought effects again, such as within the Great Cumbung Swamp, Lake Bullogal and Lake Merrimajeel (Driver et al. 2011, Driver et al. 2013a, Driver et al. 2013b). The addition of water in 2015-16 at a number of sites resulted in a slight shift in community composition, indicating that the vegetation community at the sites is able to respond to watering.

3) What did environmental water contribute to the condition of floodplain and riparian trees?

There was an improvement in tree condition between the two monitoring years with an improvement in foliage cover and a slight reduction in dead canopy in 2015-16. The response appears to be greater at sites that were either completely or partially inundated by environmental water indicating a positive response to the provision of water.

Given the positive responses of the floodplain and riparian trees to watering of sites, it is inferred that Commonwealth environmental Watering Action 2 in the Booligal Wetlands (which was the majority of the watering action in these wetlands) was the major contributor to the improved condition of the trees in the Booligal wetlands.

4) What did environmental water contribute to populations of long-lived organisms?

As in 2014-15, recruitment of trees was observed at most sites. There was a marked response to environmental watering in Moon Moon Swamp and Whealbah Billabong with a large number of red gum recruits recorded following site flooding. As noted in last years report, a notable pressure on the success of recruitment was observed to be grazing of the sites, by both stock and feral species. Field observations of grazing are not necessarily reflected in the number of seedlings and saplings present as it does not record the number of plants that were affected (thus only obvious if completely removed by grazing). This is known to mute the desired response to flow within some key wetland species. For example, grazing plots within the mid-Lachlan show that the exclusion of grazing impacts allows for much greater establishment of key fringe wetland plants (typically amphibious species); notably of Lignum (*Duma florulenta*), Warrego Summer Grass (*Paspalidium jubiflorum*), Creeping Knotweed (*Persicaria prostrata*) and river red gum seedlings (Driver et al. 2013b). Future years of monitoring will provide some insight into the longer term effects of grazing pressure.

7.5 FINAL COMMENTS AND RECOMMENDATIONS

- The health of the riparian and wetland trees has improved at sites that were either completely or partially inundated with environmental water. Sites that were not watered did not decline in health. To achieve broader catchment scale outcomes for riparian and wetland trees, sites that were not watered in 2015-16 should be a priority for future watering.
- While the greatest benefit to riparian and wetland trees occurred with inundation or partial inundation, it appears there was also some benefit from watering adjacent wetlands. While data collected from future monitoring will enable us to determine if this pattern of response is widespread, there may be opportunity to benefit sites that are difficult to inundate, by providing water to adjacent wetlands.
- There are currently community concerns that the timing of the delivery of environmental water promotes nuisance vegetation growth within the distributary channels. All of the sites monitored are either riparian or wetland sites and no monitoring of in-channel vegetation has been undertaken. Our monitoring activities indicate that only one of the monitored floodplain sites displayed an increase in exotic species with watering, but our current program of activities is unable to usefully inform this debate and it would be worth considering future monitoring targeted at answering specific questions associated with in-channel plant growth.

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