Australian Government
Commonwealth Environmental Water Office

UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

COMMONWEALTH ENVIRONMENTAL WATER OFFICE LONG TERM INTERVENTION MONITORING PROJECT: LACHLAN RIVER SYSTEM 2018-19 TECHNICAL REPORT: FINAL

February 2020

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Commonwealth Environmental Water Office
Long Term Intervention Monitoring Project
Lachlan river system 2018-19 Technical Report

FINAL February 2020

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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., Higgisson, W., Allan, H., Thiem, J., Wright, D., Thompson, R. (2019). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Lachlan river system Selected Area 2018-19 Monitoring and Evaluation Technical Report. Commonwealth of Australia, 2019.

Disclaimer

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Document history and status

Version	Date Issued	Issued to	Reviewed by	Approved by	Revision Type
Draft Individual Technical chapters	August 2019	CEWO	Fiona Dyer	Fiona Dyer	Draft
Draft Technical report	November 2019	CEWO	Fiona Dyer & CEWO	Fiona Dyer	Draft
Final Draft	7 February 2020	CEWO	CEWO, Basin Matter Teams	Fiona Dyer	Final Draft

Front cover photo: The Lachlan River at Oxley, April 2019. Photo by Alica Tschierschke, University of Canberra

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ACRONYMS AND ABBREVIATIONS

Accepted Acronym	Standard Term (capitalisation as specified)
ANAE	Australian National Aquatic Ecosystem
BASE	Bayesian Single-station Estimation
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CPUE	Catch per unit effort
CTF	commence to fill
DPI	Department of Primary Industries
DoPIE	Department of Planning, Industry and Environment
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
ER	Ecosystem Respiration
GPP	Gross Primary Production
K	Reaeration
LTIM	Long Term Intervention Monitoring
MDBA	Murray-Darling Basin Authority
MDFRC	Murray-Darling Freshwater Research Centre
OEH	Office of Environment and Heritage
SRA	Sustainable Rivers Audit
VBGM	Von Bertalanffy growth model
WQA	Water quality allowance
WUM	Water Use Minute

ACKNOWLEDGMENTS

The project team as well as the Commonwealth Environmental Water Office (CEWO) respectfully acknowledge the traditional owners of the land on which this work is conducted, 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 five years of project delivery including: Rhian Clear, Damian McRae, Francis Horacek, Ebony Mullin, Bruce Campbell, Paul Packard, Joanne Lenehan, Ugyen Lhendup, Hugh Allen, Mark Lintermans, Yasmin Cross, Kyle McGrath, Joseph O'Connell, Adam Cotterill, Dennis Ryan, Patrick Driver, Sharon Bowen, Joel Honeysett and Daniel Scherrer.

The following volunteers are thanked for their assistance with larval fish sampling: Mark Lintermans, Hugh Allan, Max Mallett, Tim Kaminskas, Karl Moy, Max Clear, Liam Allan, Emily Belton, Sally Hatton, Pat Ross-Magee, Blake Galley, Emily Sprague, Kat Cheshire, Nickey Van Der Meyer, Jackie O'Sullivan, Chris Keogh, Jessica Sharpe, Andy Lowes, Hannah Belnick, Katie Ryan, Laura Caffrey and Daniel Wright.

The following DPI Fisheries staff assisted with field data collection and laboratory processing: Allen Brooks, Tom Butterfield, Jonathan Doyle, Jarryd McGowan, Nicholas O'Brien, Rohan Rehwinkel, Bridget Smith, Christopher Smith, and Sarah Talbot.

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

Vegetation sampling was conducted under NSW Scientific License SL 102011. Fish sampling was conducted under Fisheries NSW Animal Care and Ethics permit 14/10 and scientific collection permit P01/0059(A)-4.0. Larval fish sampling was conducted under NSW DPI permit No: P14/0022-2.0 and under approval from the University of Canberra Animal Ethics Committee (AEC 17-23).

1 INTRODUCTION

Dry conditions prevailed across the Lachlan catchment in 2018-19, with below average annual rainfall and higher than average temperatures combining to produce rapidly declining water resource availability. The effects of the widespread flooding of 2016-17 were still evident in the sustained tree condition across wetland sites, which meant that environmental watering actions focussed on continuing to support the recovery of instream biota, maintaining connectivity and building resilience as the conditions continued to dry.

Four Commonwealth environmental watering actions were delivered to the Lachlan river system in 2018-19, targeting multiple location and ecological objectives. The first two watering actions targeted native fish and stream productivity outcomes across the mid and lower Lachlan River. The first watering action was a spring fresh and commenced with releases from Wyangala dam on the 29th August 2018, passing Booligal in late September. A portion of this first watering action was re-regulated through Lake Brewster and released in October to mimic a small rain event. The multiple components of this watering action were designed to support the movement of native fish and stimulate primary productivity.

The second watering action aimed to prevent rapid drops in water level in the mid-Lachlan River to avoid nest abandonment by native fish. This watering action was subsequently re-regulated to provide a small fresh in the lower Lachlan. By providing flows to support breeding, and the condition of fish, these watering actions in the Lachlan draw on the watering priorities of the Murray Darling Basin Authority for threatened fish to focus on maintaining and improving existing populations of fish.

The third watering action was delivered to Yarrabandai (formerly Burrawang West) lagoon, providing habitat for aquatic species and supporting riparian vegetation. The fourth watering action was a late autumn-winter fresh and was designed to provide connectivity and variability in flows to the Lower Lachlan river system. In doing so, it targeted longitudinal connectivity in the lower Lachlan river system and the central reedbeds of the Cumbung Swamp. This watering action commenced at Lake Brewster on the 9th June and releases ceased on the 28th June. These latter watering actions contributed to the watering priorities of the Murray Darling Basin Authority for longitudinal and lateral connectivity that support natural nutrient and carbon cycling processes.

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 2018-19 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) and the condition and diversity of vegetation.

At the request of the CEWO, additional monitoring activities were undertaken in the Mid and Lower Lachlan river system in 2018-19. This included the monitoring of stream flows (hydrology), stream metabolism and water quality (dissolved oxygen and temperature) and fish (including larval fish) in the Mid Lachlan river system, and a trial of eDNA for monitoring fish populations in the Mid and Lower Lachlan river systems.

This report provides the technical reports for the final of five years of monitoring and evaluation of Commonwealth environmental watering in the Lower Lachlan river system. It is designed as a record of the supporting technical material for the summary report (Dyer et al. 2018).

This report describes the context in which the water was delivered, the environmental objectives of the watering actions, the monitoring activities undertaken, and evaluates the outcomes of the watering actions. A focus this year is given to evaluating the combined effects of environmental watering since 2014.

2 LOWER LACHLAN RIVER SYSTEM – SELECTED AREA

The area of the Lower Lachlan river system (referred to as the Selected Area) identified as the focus for the LTIM Project is the western end of the Lachlan River, and extends from the outlet of Lake Brewster to the Great Cumbung Swamp (Figure 1). It encompasses anabranches, flood runners, billabongs and terminal wetlands, such as Merrowie Creek, Booligal Wetlands and Lachlan Swamp but excludes Middle Creek and other creeks to the north. The river system is complex, with a diversity of in-channel and floodplain features that provide a variety of habitats for the species in the region. Flows and water levels are naturally variable and unpredictable providing temporally complex habitats.

The Lachlan River catchment supports many flora and fauna listed as vulnerable or endangered under federal or NSW state legislation, including the Sloane’s froglet, Australian painted snipe, osprey, blue-billed duck and the fishing bat. The Selected Area comprises the majority of the Lachlan River endangered ecological community. In addition, the Great Cumbung Swamp is one of the most important waterbird breeding areas in eastern Australia and supports one of the largest remaining stands of river red gums in NSW.

Like many rivers of the Murray Darling basin, flow regulation in the Lachlan river catchment has had a significant effect on the average annual flow as well as inter-annual and seasonal variability (Driver et al. 2004, Higgisson et al. 2019b). This is believed to have been a key driver in a deterioration of the freshwater ecosystems within the catchment. The Lower Lachlan river system has previously been assessed as being in poor ecosystem health as part of the Murray-Darling Basin Authority’s Sustainable Rivers Audit (SRA) (MDBA 2012b) (Davies et al. 2008). This assessment was primarily due to having an extremely poor native fish community (with low native species richness and poor recruitment) and poor hydrological condition. Macroinvertebrate communities were assessed as being in moderate condition whereas the physical form of the river and the vegetation were assessed as being in poor to moderate condition, respectively.

The millennium drought (2001-2009) resulted in large areas of river red gums becoming stressed, and in wetlands, vegetation became dominated by terrestrial, drought tolerant species (Thurtell et al. 2011). Some recovery of the wetlands and rivers has been observed since 2010, attributed to natural flow events and environmental watering actions. In 2016, the Booligal wetlands supported the largest and most successful breeding colony of straw-necked ibis in the Murray Darling Basin since 1984.

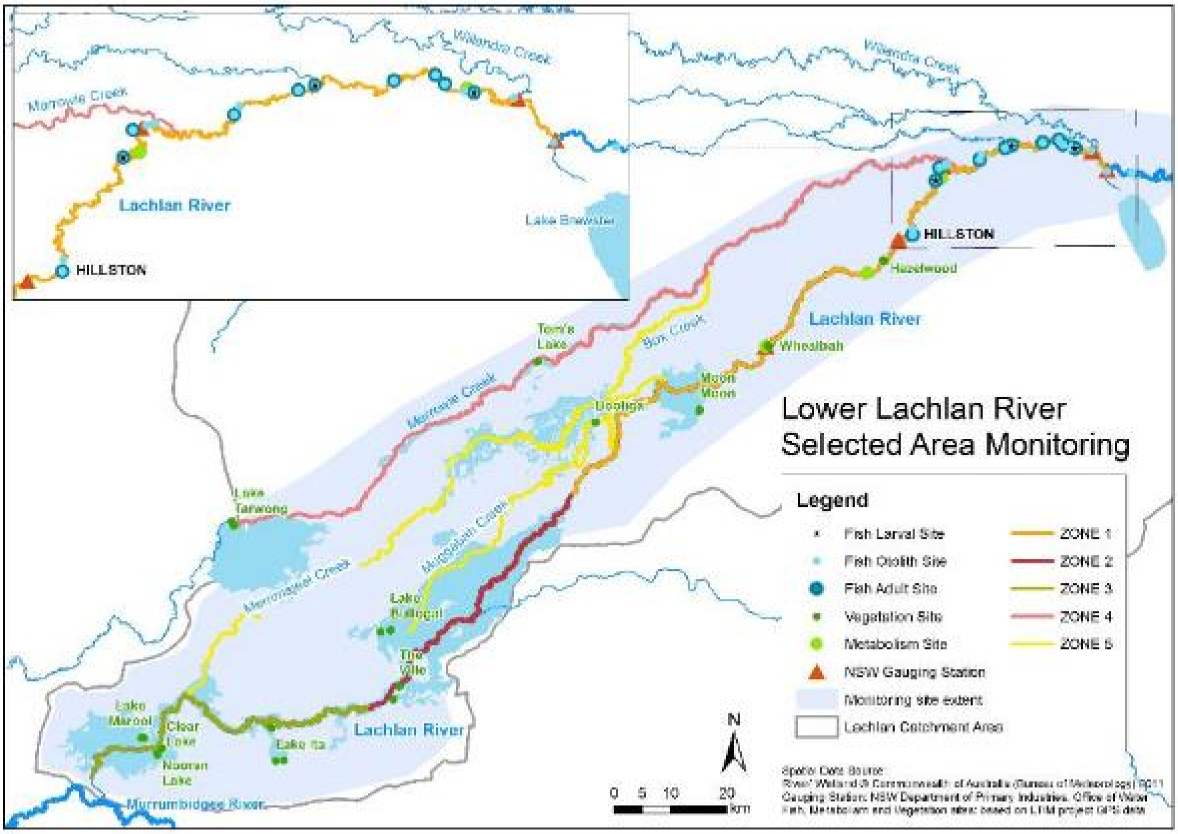


Figure 1. The Lower Lachlan river system showing the region for the LTIM Project.

In 2018-19, monitoring activities extended into the mid Lachlan river system, which encompasses the reach from Forbes to Lake Brewster (Figure 2).

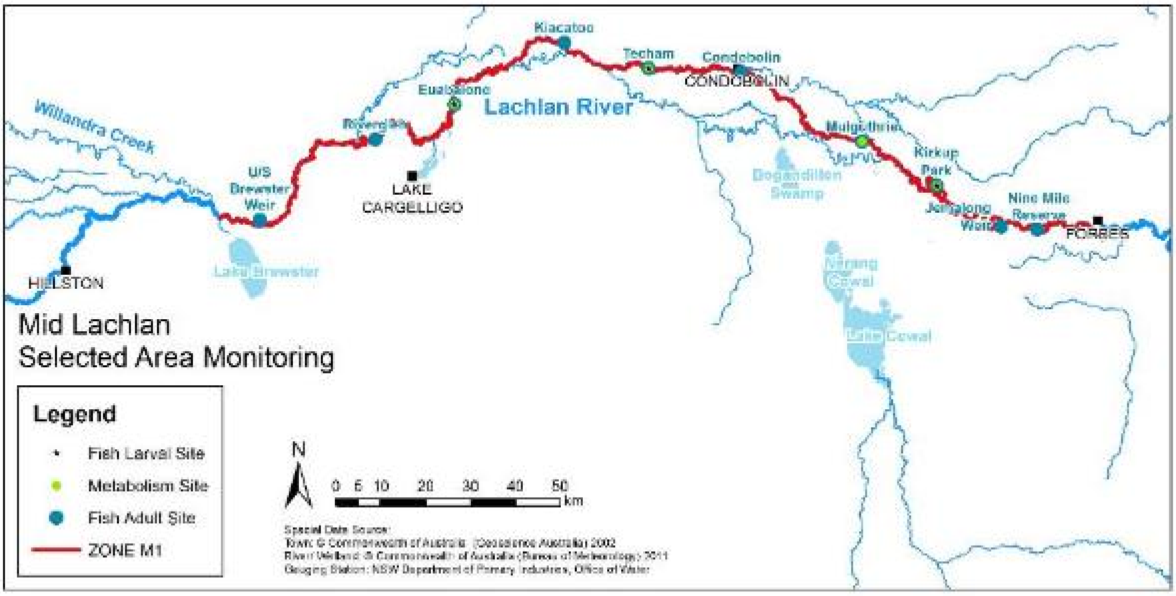


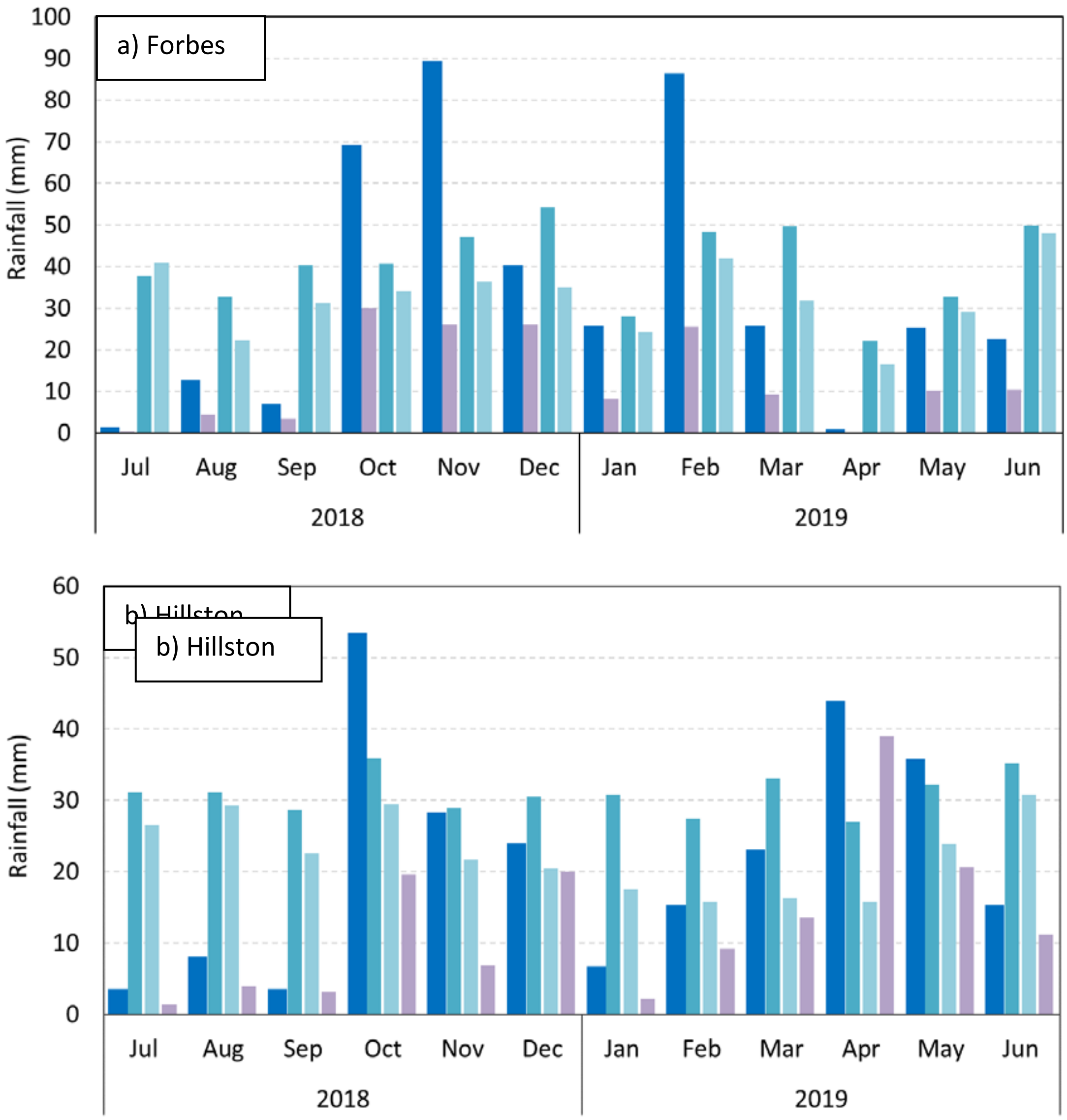
Figure 2. The mid Lachlan river system showing the region for the 2018-19 additional monitoring activities.

3 2018-19 WATERING ACTIONS

Environmental watering actions are influenced by a combination of catchment and climate conditions as well as the volume of water holdings. Catchment condition also is the context for evaluating ecosystem responses to watering.

3.1 CATCHMENT AND WEATHER CONDITIONS

Conditions across the lower and mid Lachlan catchment had been dry since January 2017 with below average annual rainfall in both 2017 and 2018 (Dyer et al. 2018). July to September of 2018 was particularly dry, with markedly lower than average rainfall (Figure 3). October 2018 saw a return to rainfall of a higher or similar magnitude to the long-term monthly median (Figure 3).



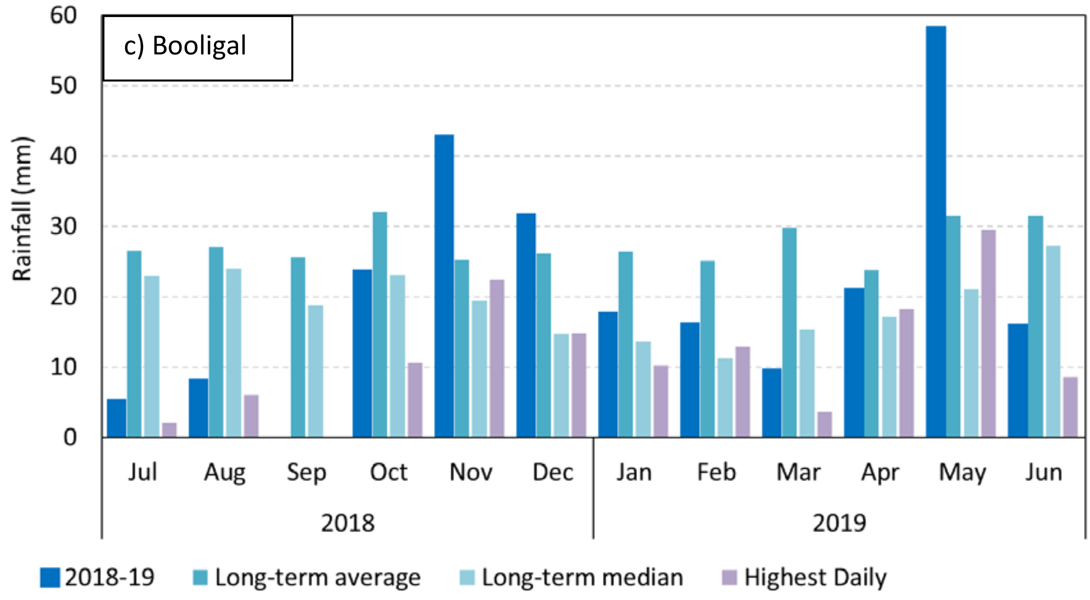
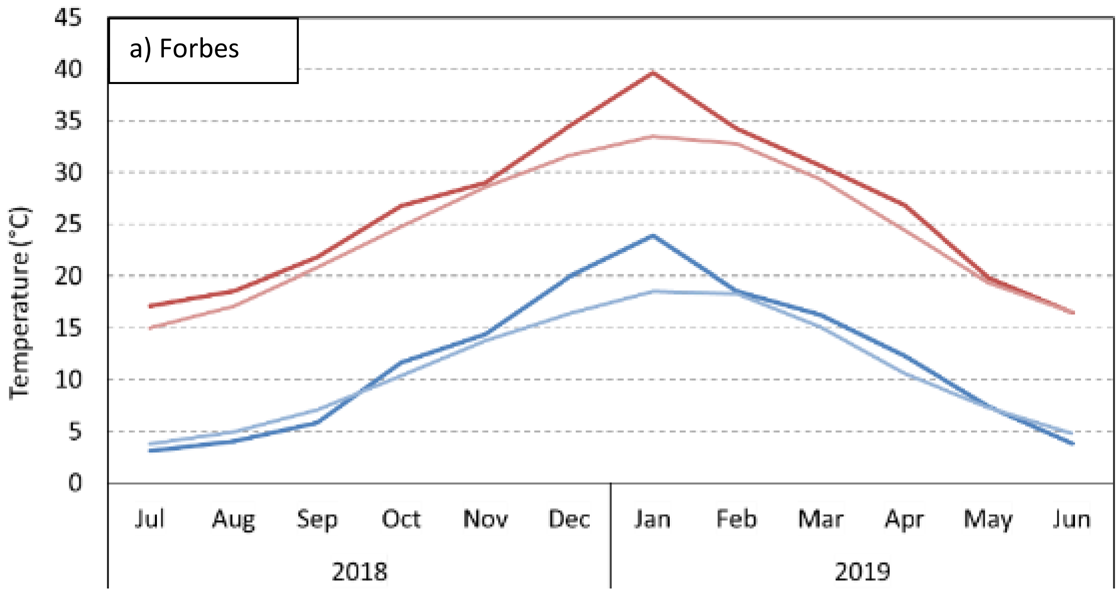


Figure 3. Monthly rainfall at a) Forbes Airport (065103), b) Hillston Airport (075032) and c) Booligal (075007) during 2018-19 compared with the mean and median rainfall for the entire period of record, and daily highest rainfall events per month.

Data sourced from Climate Data Online, Bureau of Meteorology.

Note: a) Forbes on larger scale.

Temperatures were generally 1-2 degrees above average throughout 2018-19 (Figure 4). They were markedly warner during summer with average daily January temperatures 5 degrees above the long-term average.



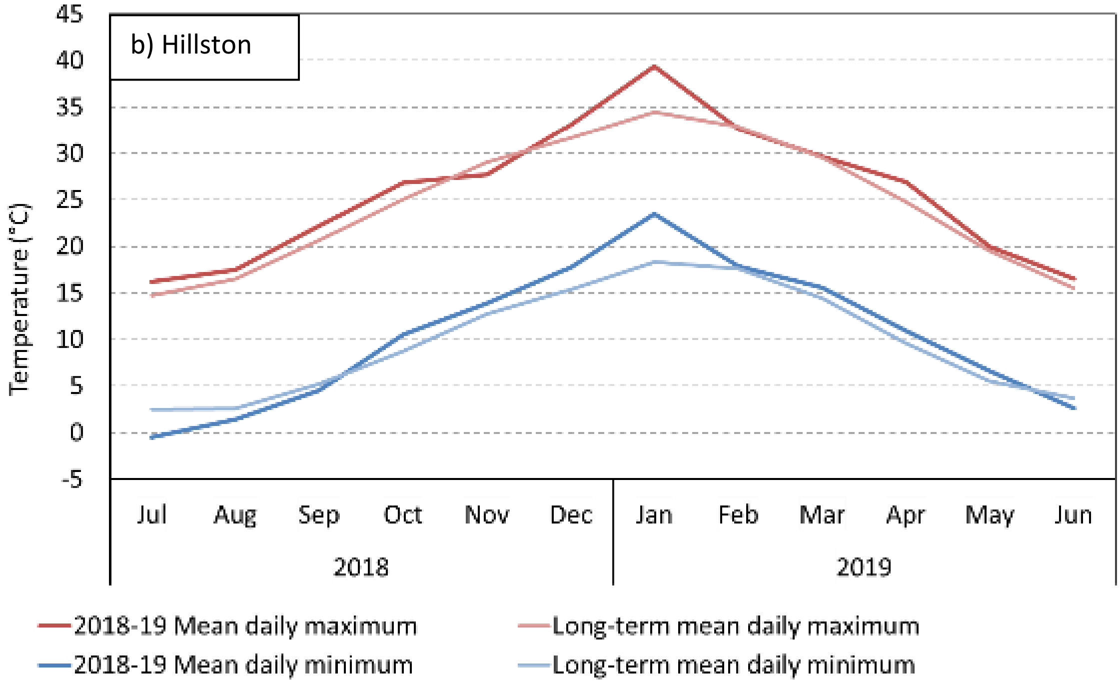


Figure 4. Monthly average daily maximum and minimum temperatures for a) Forbes Airport (065103), b) Hillston Airport (075032) during 2018-19 compared with the long-term average daily maximum and minimum temperatures.

3.2 ENVIROMENTAL WATER HOLDINGS

Environmental water has been allocated to the Lachlan River since 1992 (from NSW) and more recently the river system has received Commonwealth environmental water. Thus, environmental water for the Lachlan River comprises both Commonwealth government holdings of water entitlements (Commonwealth environmental water) and NSW government-held licensed environmental water (NSW environmental water holdings) and planned water under the Lachlan Regulated Water Sharing Plan (https://legislation.nsw.gov.au/#/view/regulation/2016/365/full). Commonwealth water holdings have been consistent since 2014-15 and at the beginning of the 2018-19 water year, the Commonwealth government held a total of almost 87 856 ML in entitlement (Table 1).

Table 1. Environmental water holdings in the Lachlan River Valley as at 1 July 2018.

	WATER HOLDINGS (ML) BY ENTITLEMENT TYPE		
WATER HOLDER	HIGH SECURITY	GENERAL SECURITY	**TOTAL**
CEWH	933	86 923	**87 856**
NSW	1,795	36 569	**38 364**
TOTAL	**2,728**	**123 492**	**126 220**

3.3 PLANNED WATER USE

Planning for environmental watering in 2018-19 was undertaken with rapidly declining water resource availability and the knowledge that the widespread flooding in 2016-17 had sustained tree health well into 2018. This provided opportunities to build on the investment of previous years to continue to support the recovery of native fish populations, maintain core reedbeds in the terminal wetlands and to build the resilience of populations and ecosystems.

The annual watering priorities of the Murray Darling Basin Authority (MDBA 2018) focussed around the southern connected basin, the Barwon/Darling system and generic objectives for threatened native fish, waterbird populations and vegetation. The *Commonwealth Environmental Water Portfolio Management Plan: Lachlan River 2018-19* (Commonwealth of Australia 2018) suggests that the CEWO was aiming to contribute to the following 2018–19 Basin annual environmental watering priorities (denoted A) as well as multi-year priorities (denoted M) relevant to the Lachlan River region

- Support opportunities for lateral connectivity between the river and adjacent low-lying floodplains and wetlands to reinstate natural nutrient and carbon cycling process (A);
- Enable growth and maintain the condition of lignum shrublands (A, M);
- Provide flows to improve habitat and support waterbird breeding (A);
- Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations (A, M);
- Support lateral and longitudinal connectivity (M);

- Maintain and improve the condition and promote recruitment of forests and woodlands (M);
- Improve the abundance and maintain the diversity of the Basin's waterbird population (M).

The 2018-19 plan outlines that the CEWO was considering supplying water in 2018-19 for the following actions:

- To provide flows to support and provide habitat for waterbirds and native aquatic biota (including fish, turtles, frogs and invertebrates). Actions for native fish will be guided by expert advice and the concepts developed for relevant fish functional groups (see NSW DPI (2015) and Ellis et al, 2016).
- In-channel actions would also serve the purpose of providing an end of system flow to the Great Cumbung Swamp, providing water to the reedbeds in that area.
- Contribute to maintaining waterbird habitat within the Lachlan catchment, and potentially link to waterbird habitat in other parts of the Basin (e.g. via waterbird flyways across the Macquarie, Lachlan, Murrumbidgee, Gwydir, Namoi and Mid-Murray catchments (see Waterbird breeding & movements (https://research.csiro.au/ewkrwaterbirds/)), may also be targeted under moderate - wetter scenarios.
- Contributing to flows in distributaries such as Merrowie Creek and other smaller anabranches such as Booberoi Creek in conjunction with stock and domestic replenishment flows for connectivity, native fish and aquatic vegetation outcomes.

Low numbers of large bodied native fish were observed in monitoring of the Lower Lachlan in early 2017 compared with previous years of monitoring (Dyer et al. 2017). This was considered to have been likely caused by hypoxic blackwater associated with the flooding in 2016-17. Thus priority was given to actions that would support native fish recovery (and redress some of the effects of river operation) during breeding and dispersal.

3.4 IMPLEMENTED WATERING ACTIONS

3.4.1 COMMONWEALTH ENVIRONMENTAL WATER DELIVERY

The total Commonwealth environmental water delivery to the Lachlan river system in 2018-19 was 18 173 ML and through a process of re-regulation, was used to target multiple locations and ecological objectives at different times through the river system (Table 2). Complementary watering actions by NSW OEH were used to target other locations and ecological objectives during 2018-19 (Table 3).

Releases for the 2018-19 watering actions targeting native fish and stream productivity outcomes in both the mid and lower Lachlan River commenced at Wyangala dam on 29th August 2018. This spring fresh (hereafter Watering Action 1) was managed as a 'run of river' flow, passing through Hillston in mid-September and Booligal in late September. A portion of the spring fresh (1,820 ML) was held over in Lake Brewster and released between the 20th and 23rd October to mimic a small rain event, creating variability in river height in the lower Lachlan. This latter volume was again managed as a 'run of river' flow reaching the edge of the Cumbung Swamp in mid-November.

The spring fresh was followed with a watering action targeting minimum stable flows in the mid Lachlan river (hereafter Watering Action 2). Releases commenced from Wyangala Dam on the 17th October and the hydrological objectives were to maintain the river above 800 ML/day and avoid rapid drops in water level during October and November. These objectives were designed to support the nesting period for native fish such as Murray cod and freshwater catfish whose nests are vulnerable to exposure from rapidly changing water levels. Releases for this watering action ceased on the 3rd December 2018.

A small watering action targeting riparian vegetation and habitat for aquatic species in Yarrabandai (formerly Burrawang West) Lagoon commenced on the 18th March 2019 (hereafter Watering Action 3). This action was completed with three water transfers with the last delivering finishing on the 29th May. This action was not monitored under the LTIM Project in 2018-19.

The final watering action targeting the Great Cumbung Swamp (hereafter Watering Action 4) commenced with increasing flows from Lake Brewster on the 9th June with releases ceasing on the 28th June. The target was for 9 days of 500 ML/day at Booligal, however operational constraints prevented the design hydrograph from being achieved. A total of 5,338 ML was delivered from Lake Brewster

3.4.2 NSW WATERING ACTIONS

In 2018-19, Commonwealth and NSW watering actions were separate actions, targeting different outcomes within the river system. A summary of the NSW actions is included in Table 3. This monitoring and evaluation report is focussed on the Commonwealth actions, with no evaluation of the NSW watering actions has been undertaken.

High water temperatures and low flows, combined with a series of catastrophic fish kills in other parts of the Murray Darlin Basin triggered the use of the Water Quality Allowance (WQA) in February 2019 to target water quality outcomes in the Lower Lachlan River. Around 5,000 ML was used between the 5th February and April to prevent blue green algal blooms from developing and dissolved oxygen concentrations from dropping in the lower Lachlan river system.

Table 2. The 2018-19 Commonwealth environmental watering actions.

DESCRIPTION	DETAILS			
Action	1	2	3	4
Target Asset	Mid Lachlan River, main channel and Booberoi Creek, main channel	Mid Lachlan River, main channel	Yarrabandai (formerly Burrawang West) Lagoon	Lower Lachlan River, main channel below Lake Brewster terminating in Great Cumbung Swamp
Reference	WUM10081-01	WUM10081-01	WUM10081-02	WUM10081-03
Accounting Location	Lachlan River at Forbes (Cotton's Weir) Booberoi Creek off take	Lachlan River at Forbes (Cotton's Weir)	Yarrabandai (formerly Burrawang West) Lagoon	Lachlan River at Booligal
Flow component	Fresh flow	Base flow	Wetland watering	Fresh flow
Volume (CEW)	10 391 ML (accounted at Forbes) and includes 761 ML delivered to Booberoi Creek, 6,355 ML system flow and 1,820 ML held and re-released from Brewster Weir	2,032 ML (accounted at Forbes)	412 ML	5,338 ML (accounted at Booligal)
Total Volume (ML)	10 391 ML	2,032 ML	412 ML	5,338 ML
Re-use	761 ML re-regulated from the Forbes flow and accounted at the Booberoi Creek Offtake			
Objectives	To support the movement of native fish prior to the spawning season and support the ability of native fish to achieve good pre-spawning condition. To be of short duration to prevent early nesting at higher river level. To mobilise carbon from the riverbank and benches to stimulate primary productivity (i.e. create food) To support spawning success of native fish that may have spawned early, such as Australian smelt. To provide a gradual recession to periods of high flow.	To inundate areas of the river channel containing large woody habitat (snags) which is the preferred spawning habitat for nesting native fish such as Murray cod, River blackfish and freshwater catfish. Avoid rapid drops in water level from late September to early December to prevent nest abandonment by native fish. Promote the dispersal of larval/juvenile Murray cod, River blackfish and freshwater catfish with a short rise in flows at the end of November as fish leave their nest site within days-weeks post-hatching. It may also provide an additional productivity boost and hence replenish food sources for larvae as they begin to feed on their own.		Protect the core reedbeds and other non-woody vegetation communities as the catchment continues into a dry period Provide connectivity and variability to flows along the lower Lachlan during autumn-winter Encourage native fish movement in the lower Lachlan River and improve the condition of native fish before winter. Limit the opportunity for carp breeding, particularly in the river channel (carp are spring-summer spawners)

DESCRIPTION	DETAILS			
Action	1	2	3	4
	To provide flows into distributary Creeks, including Booberoi Creek. To provide early spring watering for areas of riparian native vegetation along the river channel that may not have been watered since March or June 2018	Recede flows towards the end of this period to extend duration of downstream dispersal by larval and juvenile fish and extend upstream movement opportunities for adolescents and adult fish		
Basin Annual watering priorities 2018-19	Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations. Support opportunities for lateral connectivity between the river and adjacent low-lying floodplains and wetlands to reinstate natural nutrient and carbon cycling processes. Maintain and improve the condition and promote recruitment of forests and woodlands. Support lateral and longitudinal connectivity.	Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations. Support lateral and longitudinal connectivity.	Support opportunities for lateral connectivity between the river and adjacent low-lying floodplains and wetlands to reinstate natural nutrient and carbon cycling processes Support lateral and longitudinal connectivity.	Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations. Support opportunities for lateral connectivity between the river and adjacent low-lying floodplains and wetlands to reinstate natural nutrient and carbon cycling processes. Support lateral and longitudinal connectivity.

Table 3. The 2018-19 NSW environmental watering actions.

ACTION	TARGET ASSET	ACCOUNTING LOCATION	VOLUME (ML)	WATER SOURCE
LAC18/19-01	Merrowie Creek (Murphy's Lake, Cuba Dam)	Merrowie Creek off take	1,669	NSW licensed environmental water
LAC18/19-03	Lake Brewster outflow wetlands	Lake Brewster (Ballyrogan Channel)	6,879	
LAC18/19-05	Noonamah Black Box wetlands	Private license and meter	139	
LAC18/19-06	Mid Lachlan River channel Booberoi Creek	Forbes (Cotton's Weir) Booberoi Creek Off take	5,979 300 (re-used)	Environmental water allowance accrued under the Water Sharing Plan for the Lachlan Regulated River Water Source 2016.
LAC18/19-08	Mid Lachlan River channel	Forbes (Cotton's Weir)	2,340	
LAC18/19-10	Booberoi Creek	Booberoi Creek Off take	952	
LAC18/19-11	Booberoi Creek	Booberoi Creek Off take	304	
LAC18/19-12	Lower Lachlan River channel	Booligal	4,936	Water Quality Allowance

3.5 DESIGNING FLOWS FOR FISH

The focus of the 2018-19 watering actions on providing a flow regime that better supports native fish in the river used a conceptualised hydrograph to underpin the design of the flow regime (Figure 5). The conceptual hydrograph is based on current understanding of the components of the flow regime thought to be relevant to native fish communities (Ellis et al. 2016), i.e. the attributes of the flow regime required to support native fish populations in the river. In 2018-19 the interest in the Lachlan River system was directed at medium/large bodied fish recovery (in particular Murray cod), building on actions in 2017-18 to support recovery after the 2016 floods.

Murray cod spawn in spring, cued by rises in water temperature and increases in day length (Rowland 1998, Humphries 2005). Spawning often follows significant upstream migration if flow conditions permit. Female Murray cod lay their eggs on hard surfaces in the river and they are fertilized by the male. The female Murray cod then leave the nesting site and the male remains to guard the eggs during incubation (6-10 days) and the early hatching period. Approximately 1 week after hatching the larvae disperse from the nesting site by drifting downstream (Humphries 2005, Koehn and Harrington 2005).

Thus the relevant flow components identified were:

- Late winter/spring small to large freshes that connect aquatic habitats, promote the exchange of nutrients (particularly carbon) and increase productivity.
- High spring base flows to maximise the available nesting habitat.
- A small fresh at the end of the nesting season to aid dispersal of larvae and provide a productivity pulse.
- Summer freshes that provide variability in habitat availability, promote the exchange of nutrients and improve water quality.
- Autumn freshes that maintain refuges, improve water quality and mix.

It was not possible to provide all the flow components identified in the conceptual hydrograph using a combination of Commonwealth and NSW environmental water and planned water use targeted the maintenance of available nesting habitat and the provision of a small fresh to support fish condition prior to breeding.

Maintaining habitat availability during nesting

The majority of the water in the river during the spring breeding season is delivered from storages (predominantly Wyangala Dam) to meet irrigation needs. River levels can fluctuate considerably depending on water orders and periods of low demand can result in very low flows. This places Murray cod nesting sites at risk. To avoid sudden drops in river heights, a minimum flow target of 800 ML/day at Cottons Weir (Forbes) was maintained for approximately 52 days (19/9 to 10/11/2018 at Cottons). Environmental water was only required if downstream demand and WaterNSW operational releases fell below the 800 ML/day target.

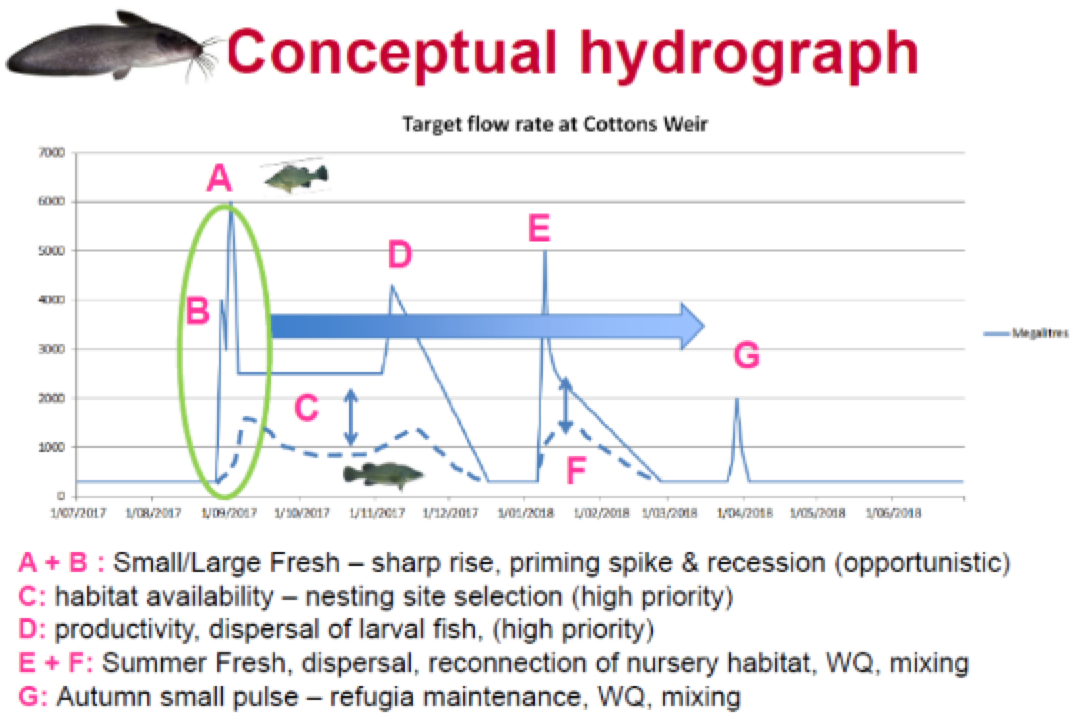


Figure 5. Conceptual hydrograph identifying key flow components to support Murray cod populations.
Source: Sam Davis, NSW Fisheries based on the work of Ellis et al. (2016).

4 HYDROLOGY

4.1 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 section 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). The hydrological outcomes are linked to ecological outcomes and this section provides the analysis of the managed flow and water levels that will underpin the interpretation of the outcomes presented in later sections.

The context in which the 2018-19 environmental watering actions were delivered was one in which the river system was continuing to dry. Conditions were very similar to the very dry conditions observed in the first year of the LTIM Project (2014). While water from the 2016-17 floods had persisted across the landscape well into 2017, below average rainfall in 2017 and 2018, accompanied by higher than average temperatures saw a rapid decline in water availability. The focus for environmental water delivery in 2018-19 was to build on the investment of previous years to continue to support the recovery of instream biota and build the resilience of populations and ecosystems as the catchment continued to dry.

Four watering actions involving Commonwealth environmental water were delivered to the Mid and Lower Lachlan river system in 2018-19 (Table 2, p. 26), all of which were designed to support lateral and longitudinal connectivity. The first two actions targeted outcomes for native fish in the main channel of the mid (Forbes) and lower (Hillston) Lachlan River, the third targeted aquatic habitat outcomes in Yarrabandai Lagoon (mid Lachlan River) and the fourth action targeted the Great Cumbung Swamp at the end of the system. Water from these actions was regulated and re-regulated to achieve environmental outcomes at multiple locations (see section 3.4: Implemented watering actions, p. 24 for further details).

The first watering action was designed to provide a spring pulse in the mid Lachlan to support native fish outcomes. This watering action also provided a small flow into Booberoi Creek and part of the in-stream flow was re-regulated through Brewster weir pool and subsequently used to provide flow variability in river height in the lower Lachlan. Both elements of this watering action provided flow to the central reedbeds of the Great Cumbung Swamp to create longitudinal connectivity.

The second watering action was designed to prevent rapid drops in river level that are caused by river operations and potentially expose native fish nesting sites. Commonwealth environmental water was used to keep the river above 800 ML/day in the mid Lachlan (Forbes). This water was also passed through the system to provide variability in water levels in the lower reaches of the river and provided flow to the central reedbeds of the Great Cumbung Swamp to create longitudinal connectivity.

The third watering action targeted Yarrabandai Lagoon and involved the delivery of 412 ML over nearly 2 months into the wetland to prevent it from drying out. In doing so, it aimed to generate lateral connectivity and provide habitat for a range of water dependent species.

The fourth watering action was designed to provide water to the central reedbeds in the Great Cumbung Swamp, and thus provide connectivity and variability in flows along the lower Lachlan during autumn and winter.

The outcomes for both riverine and wetland hydrology are examined in this technical report and the following questions addressed:

4.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to habitat for native fish and other water dependent vertebrate species?
2) What did Commonwealth environmental water contribute to hydrological variability in the Lower Lachlan during periods of low flow?

4.1.2 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

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

Table 4. The 2018-19 Commonwealth environmental watering actions in the Lower Lachlan river system and their hydrological objectives.

ACTION	TARGET	FLOW COMPONENTS	VOLUMES DELIVERED	HYDROLOGICAL OBJECTIVES	SPECIFIC FLOW TARGETS
1a	Main channel Mid Lachlan River (Forbes)	Fresh Flow	10 391 ML	To be of short duration; To provide gradual recession to periods of high flow; To provide flows into distributary Creeks, including Booberoi Creek; To provide early spring watering for areas of riparian native vegetation along the river channel; Support lateral and longitudinal connectivity.	Ramp flows at Cotton's Weir, Forbes to 2,600 ML/day (releases commencing Wyangala 24th of August) Allow flows accounted at Forbes to bypass regulating structures to provide a run of river
1b	Lower Lachlan River (Hillston)	Fresh Flow	1,820 ML (re-regulated from the Forbes flow – Action 1a)	No explicit objectives, but the provision of variability in water level is implied in the objectives for primary production.	Release flow to mimic a small fresh.
2	Main channel Mid Lachlan River (Forbes)	Base Flow	2,032 ML	To avoid rapid drops in water level from late September to early December to protect native fish spawning activities.	Maintain flows at or above 800 ML/day between 17/10/2018 and 3/12/2018
3	Yarrabandai Lagoon	Wetland flow	412 ML	Support lateral and longitudinal connectivity.	Provide Commonwealth environmental water to fill the lagoon which occurred between the 18th March and the 29th May
4	Main channel Lower Lachlan River (Booligal)	Fresh flow	5,338 ML	Provide connectivity and variability to flows along the lower Lachlan during autumn-winter; Support lateral and longitudinal connectivity.	500 ML/day for 9 days at Booligal

4.2 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 6) and from the mid Lachlan (Figure 7). 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.

Data apportioning the daily contribution of Commonwealth and NSW environmental water (ML/day) to the flow in the river 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 illustrating the relative contribution to the flow.

River levels were obtained from the gauges and the water levels in the absence of Commonwealth and NSW environmental water were estimated from the rating curves at each site or were modelled based on empirical relationships between sites.

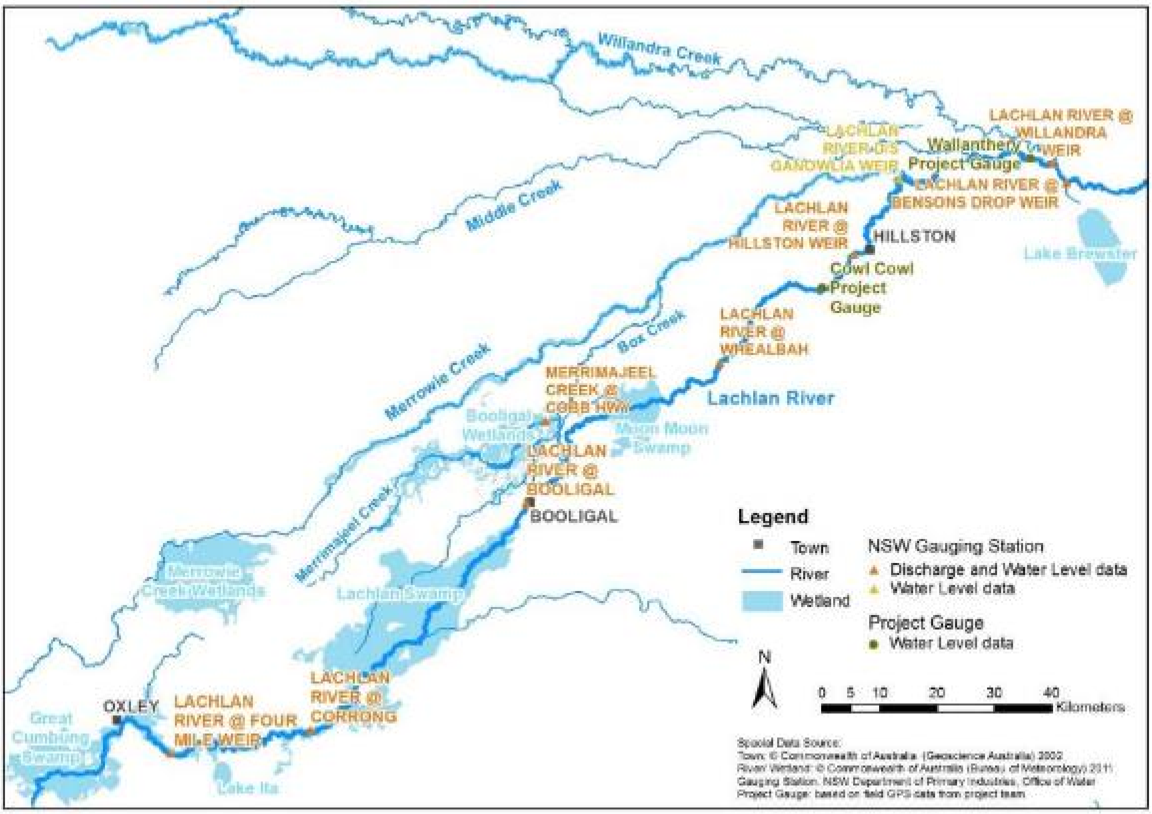


Figure 6. The location of relevant gauging stations in the Lower Lachlan river system.

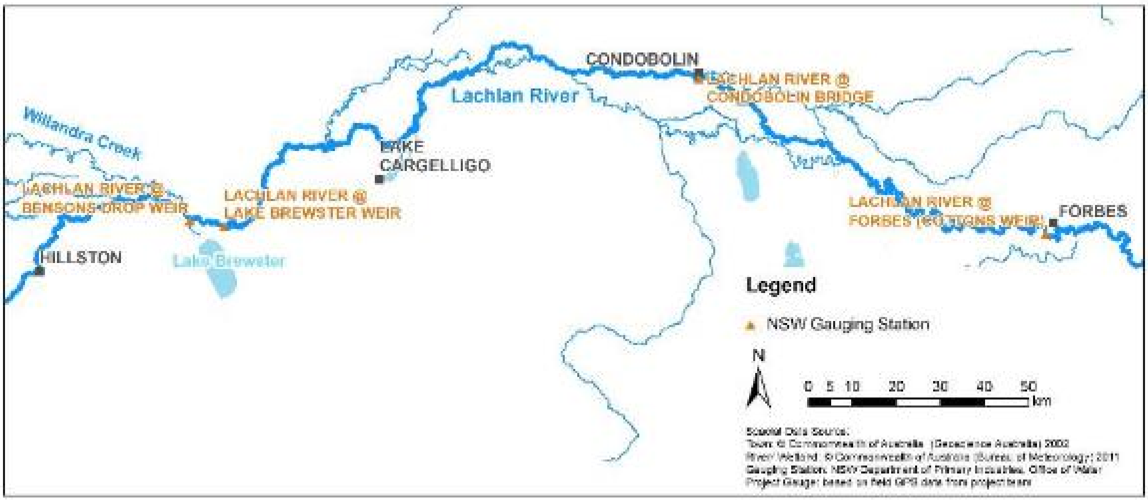


Figure 7. The location of relevant gauging stations in the mid Lachlan river system.

4.3 RESULTS

A total of 18 173ML of Commonwealth environmental water was used in the Lachlan river system in 2018-2019. This contributed approximately 4% of the flow in the river at Forbes, 11% at Hillston and 24% at Booligal (Table 5). The latter figure is an overestimate as losses have not been taken into consideration.

Table 5. The 2018-19 accounted Commonwealth environmental water in the Lower Lachlan river system.

	TOTAL ANNUAL FLOW (ML)	COMMONWEALTH ENVIRONMENTAL WATER (ML)
Forbes (Cotton's Weir)	458 838	18 173
Hillston Weir[1]	98 131	10 834
Booligal[1]	44 063	10 834

[1] Assumes that all flow except that delivered to Yarrabandai Lagoon reaches Hillston Weir and then Booligal Weir and a 40% loss rate applied between Cotton's Weir and Hillston Weir based on data from NSW Water. No loss applied between Hillston Weir and Booligal.

While the volume of Commonwealth environmental water was a small proportion of the annual flow in the river at Forbes (4%), it was a significant proportion of the flow in the lower river (24% of annual flow at Booligal). Commonwealth environmental water was strategically delivered in both the mid and Lower Lachlan to modify the flow regime to support specific ecological objectives. The details of each of the watering actions are described in the following sections.

4.3.1 WATERING ACTIONS 1 AND 2: SUPPORTING NATIVE FISH OUTCOMES

The first two watering actions were delivered to provide flow components that support native fish outcomes. This included:

1. a spring fresh which aimed to support the condition and movement of native fish, such as Murray cod prior to the spawning season, and
2. maintaining a base flow in the river to prevent a drop in river level below 800 ML/day at Forbes (Cotton's Weir) and the potential for nesting sites to be exposed or abandoned.

The targets were set for Forbes (Cotton's Weir). No flow targets were set for the Lower Lachlan river system, but the flows were to continue through the river system to provide a 'run of river'.

Watering action 1 commenced on the 29th August at Forbes (Cotton's Weir) rising quickly to around 2,600 ML/day for around 6 days with a peak of just over 2,700 ML/day on the 2nd September before receding until the 15th September (Figure 8). This watering action built on operational releases to increase water levels to almost 2,700 ML/day and modified the operational recession to generate a more natural hydrograph as water levels dropped to just below 1,000 ML/day.

Watering action 2 made Commonwealth environmental water available to keep the river above 800 ML/day at Forbes (Cotton's Weir) between the 17th October and the 3rd December. During this period, operational releases maintained flows above the specified level for the majority of the time, with only 2,032 ML of Commonwealth environmental water used between the 22nd and the 30th October to prevent water levels dropping (Figure 8). The use of Commonwealth water prevented the river from dropping between 0.05 and 0.25 m, depending on location in the river. Small drops were prevented in the weir pools such as Cotton's Weir (Figure 8) and greater drops prevented in the free flowing river such at Iron Bridge (Figure 9).

No Commonwealth environmental water was used after the 30th October and flows dropped below 800 ML/day to between 730 and 775 ML/day for four days at the start of November before returning to flows that were well above 800 ML/day. This was a drop of less than 5 cm in water level.

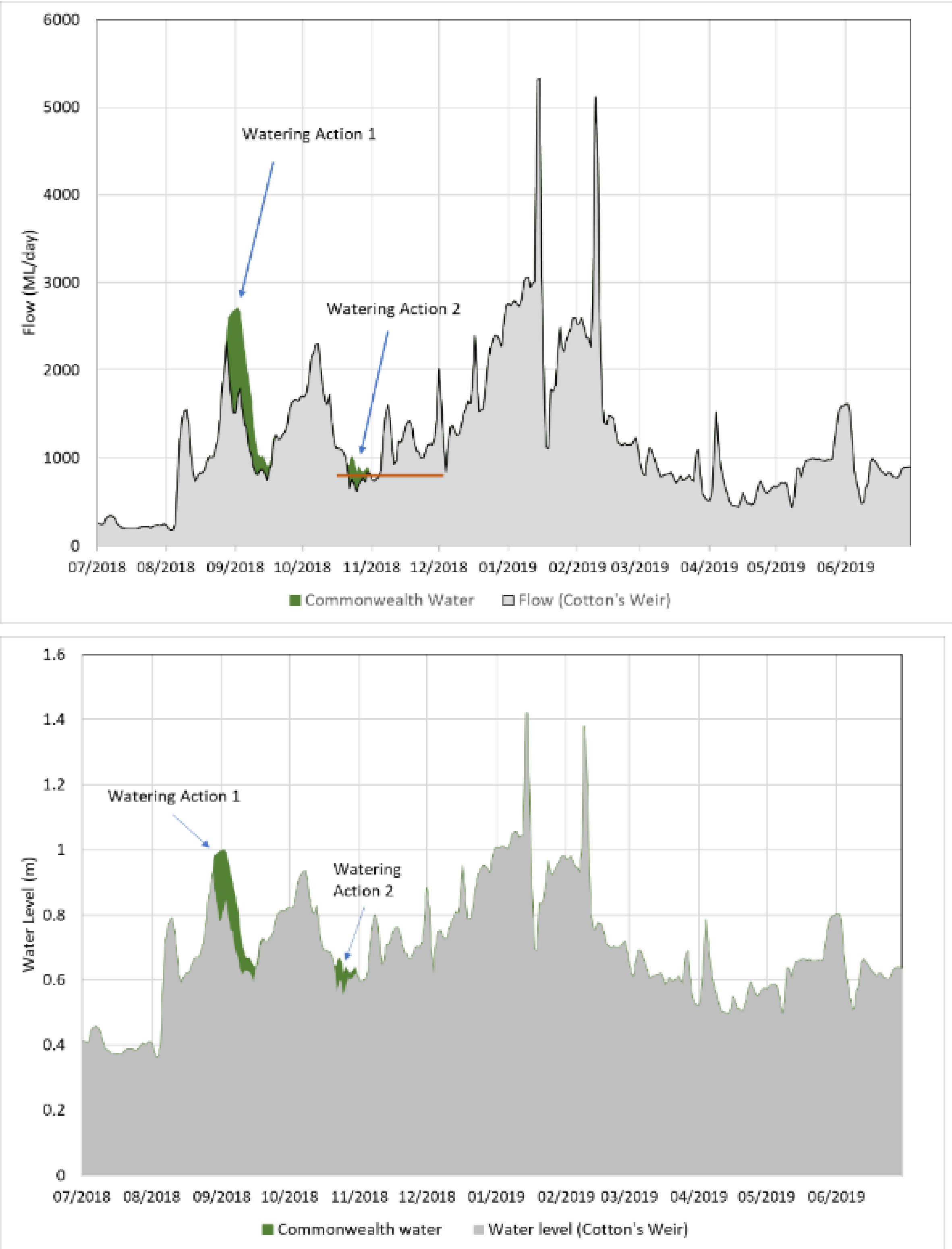


Figure 8. Flow (top) and estimated water level (bottom) at Cotton's Weir (Forbes) for the period 1 July 2018 to 30 June 2019 showing Watering Actions 1 and 2.
Commonwealth (green) environmental water are shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey. The orange horizontal line shows the target 800 ML/day. Refer to Figure 7 for gauge location.

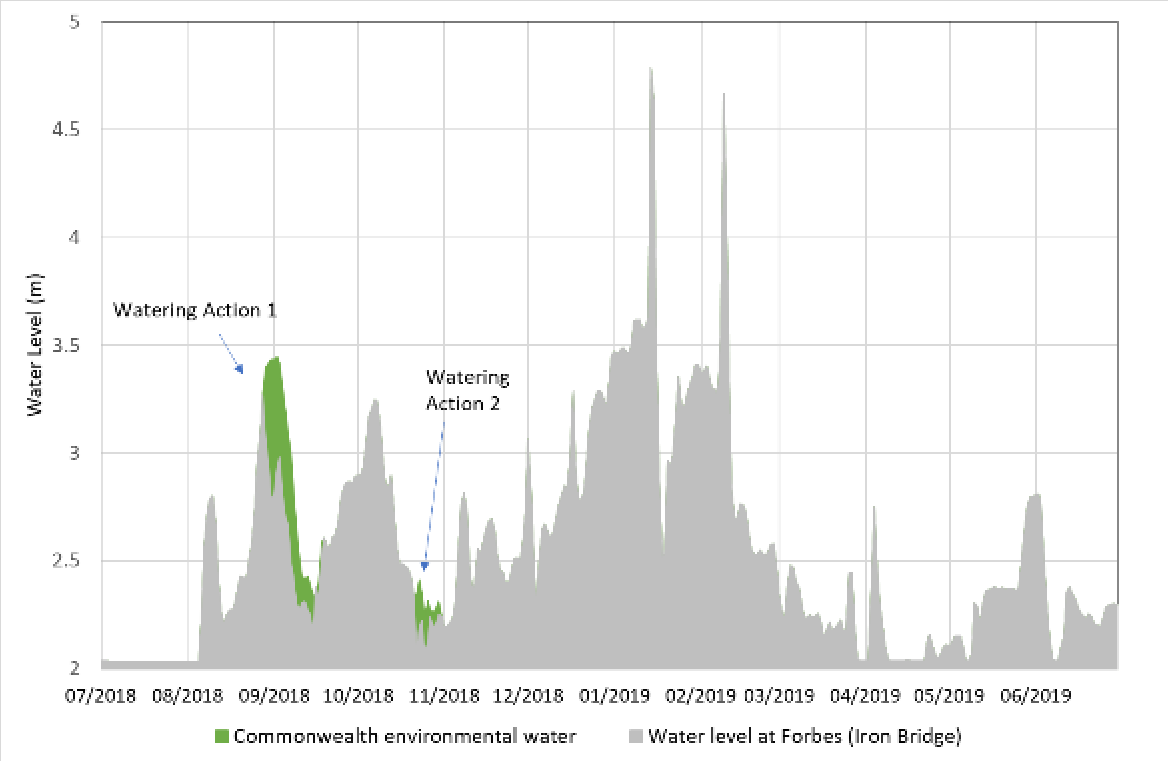


Figure 9. Estimated water level at Iron Bridge (Forbes) for the period 1 July 2018 to 30 June 2019 showing Watering Actions 1 and 2.
Commonwealth (green) environmental water are shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey. The orange horizontal line shows the target 800 ML/day. Refer to Figure 7 for gauge location.

Watering Actions 1 and 2 were passed through the river system as a 'run of river'. Watering Action 1 reached Hillston on the 15th September with a peak of 950 ML/day on the 18th September. Part of Watering Action 1 was re-regulated through Brewster Weir and released as a small fresh between the 20th and 24th October. This fresh passed Hillston between the 22nd and 28th October (Figure 10) with a peak of 528 ML/day on the 24th October, just prior to the passage of Watering Action 2 which peaked at 471 ML/day on the 11th November.

Watering Action 1 increased water levels during the September fresh at Hillston Weir by approximately 0.2 m and the re-regulated late October component increased water levels by approximately 0.3 m (Figure 10). Watering Action 2 increased water levels at Hillston Weir by approximately 0.15 m. Weir pools, by nature, are not representative of the rest of the river channel, tending to attenuate peaks in flow. The water level changes associated with these freshes in the river channel were far greater as illustrated by the estimate of water level changes at Whealbah (Figure 11) downstream of Hillston weir, where the changes in water level associated with the Commonwealth watering actions were between 0.7 and 1.5 m. It should be noted that the data used to generate Figure 11 have not been adjusted for losses or for licensed extractions and are an illustration only.

The three small freshes passed Booligal between the end of September and November (Figure 12) and Corrong between October and December (Figure 13) before passing into the Great Cumbung Swamp (Figure 14). In combination the water management during this period introduced 3 freshes into the Lower Lachlan river system that would otherwise not have occurred.

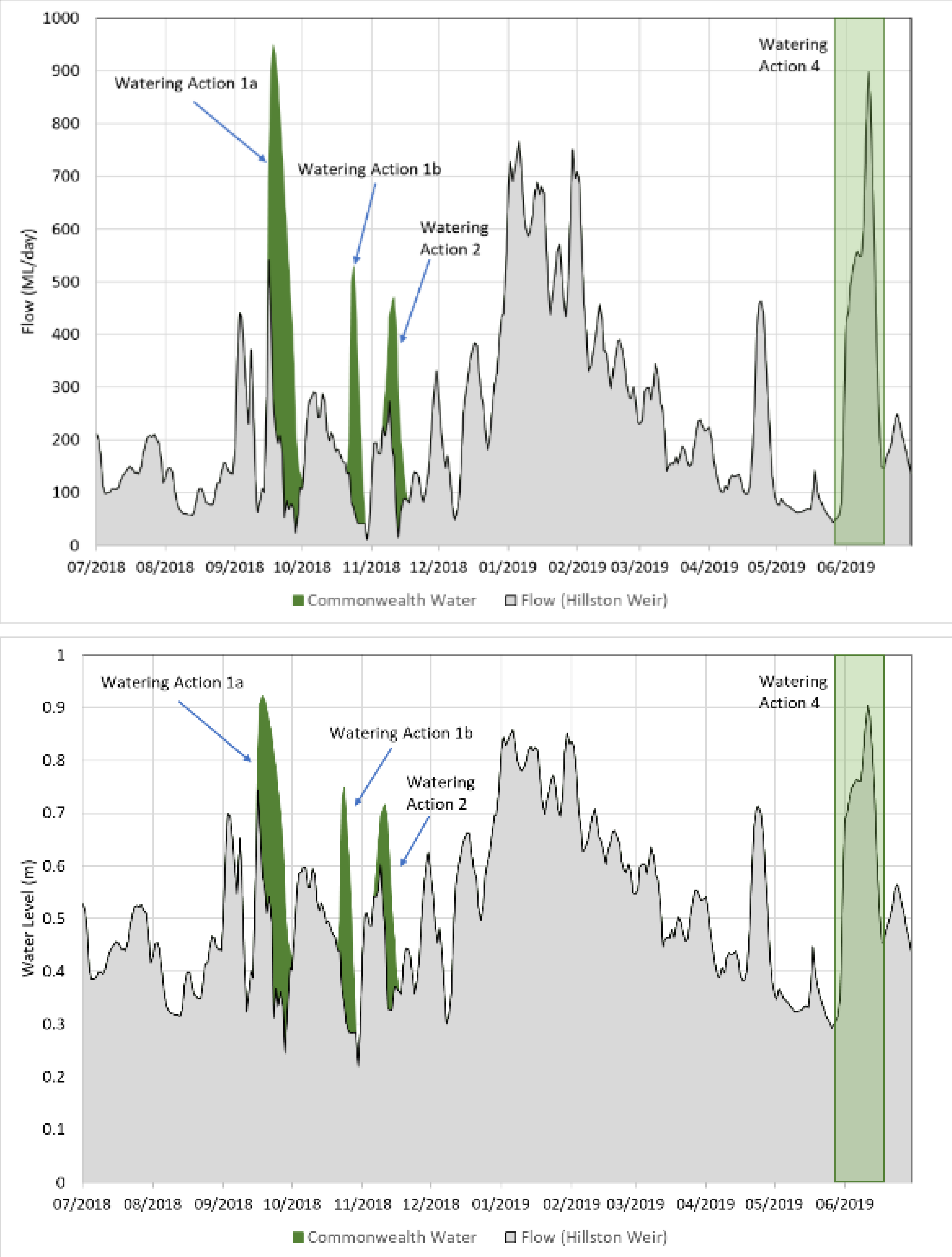


Figure 10. Flow at Hillston Weir (top) and estimated water level (bottom) for the period 1 July 2018 to 30 June 2019 showing Commonwealth Watering Actions 1 and 2 as well as the approximate timing of Watering Action 4.
Commonwealth environmental water (green) is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey. Refer to Figure 6 for gauging location and to text for the explanation of the watering actions.

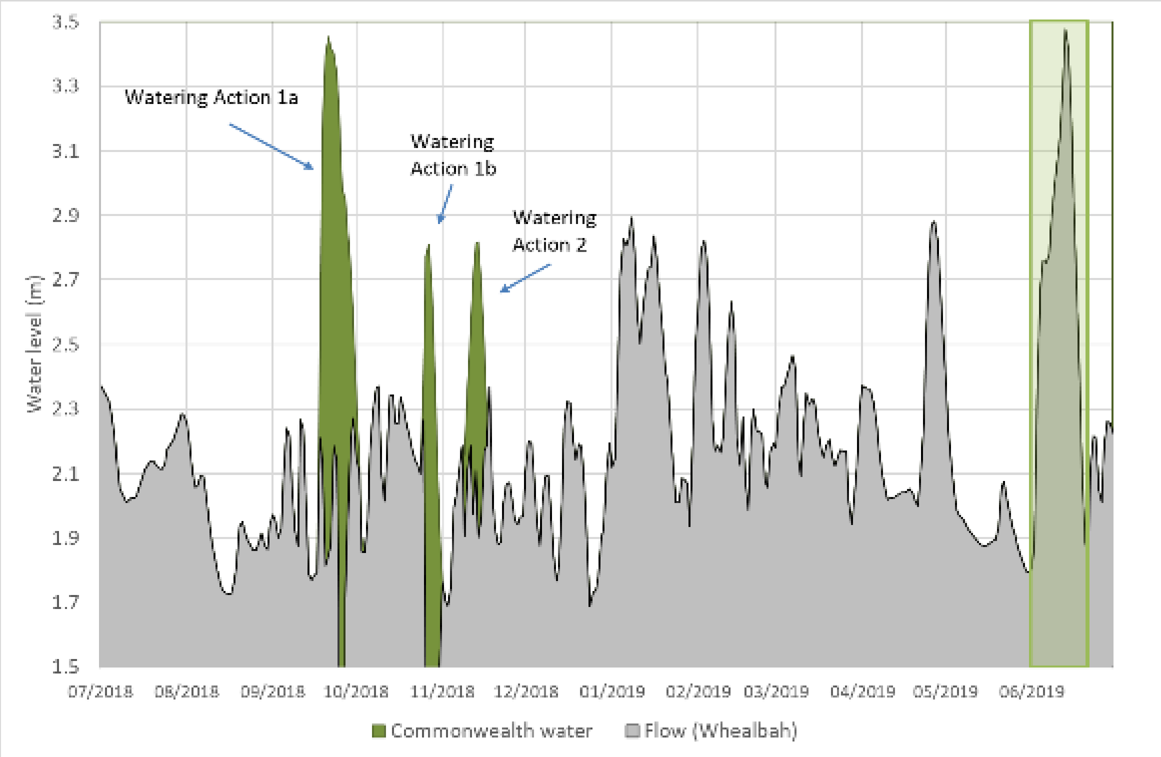


Figure 11. Estimated water level at Whealbah for the period 1 July 2018 to 30 June 2019 showing Commonwealth Watering Actions 1 and 2, along with the timing of Watering Action 4. Commonwealth environmental water (green) is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey. Refer to Figure 6 for gauging location and to text for the explanation of the watering actions.
Note that the data used to generate this figure have not applied any losses to Commonwealth water nor have they taken into consideration licensed extraction that may have occurred.

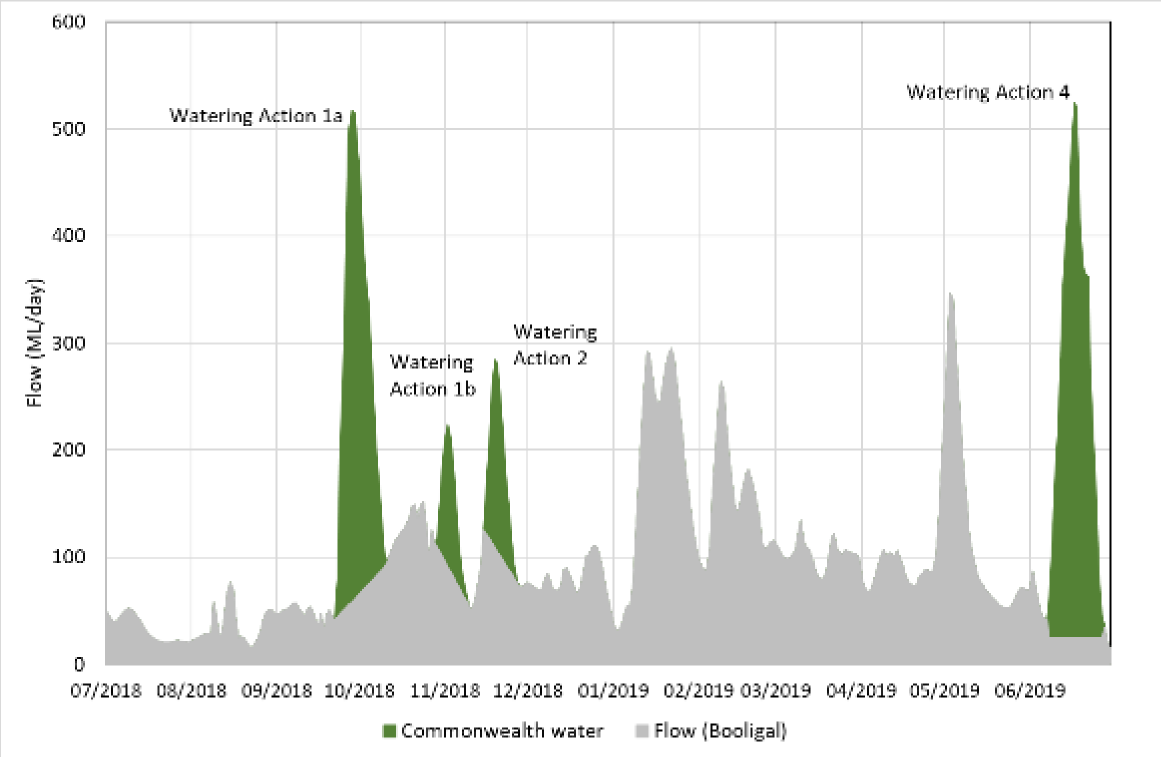


Figure 12. Flow at Booligal for the period 1 July 2018 to 30 June 2019 showing estimated Watering Actions 1 and 2 and accounted Watering Action 4.
Commonwealth environmental water (green) is estimated as is river flow (flow including the licensed delivery of water but not including environmental water) in grey. Refer to Figure 6 for gauging location and to text for the explanation of the watering actions.

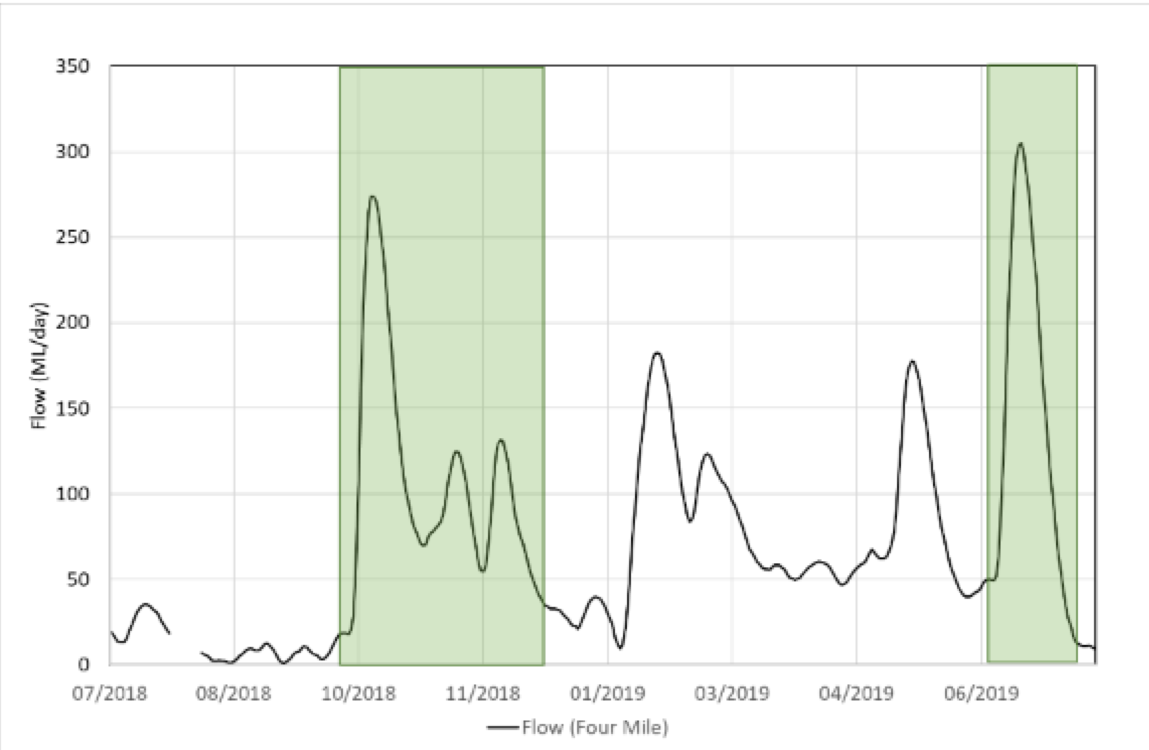


Figure 13. Flow at Corrong (Four Mile) for the period 1 July 2018 to 30 June 2019.
The approximate timing of the Commonwealth environmental watering actions are shown in green. Refer to Figure 6 for gauging location and to text for the explanation of the watering actions.

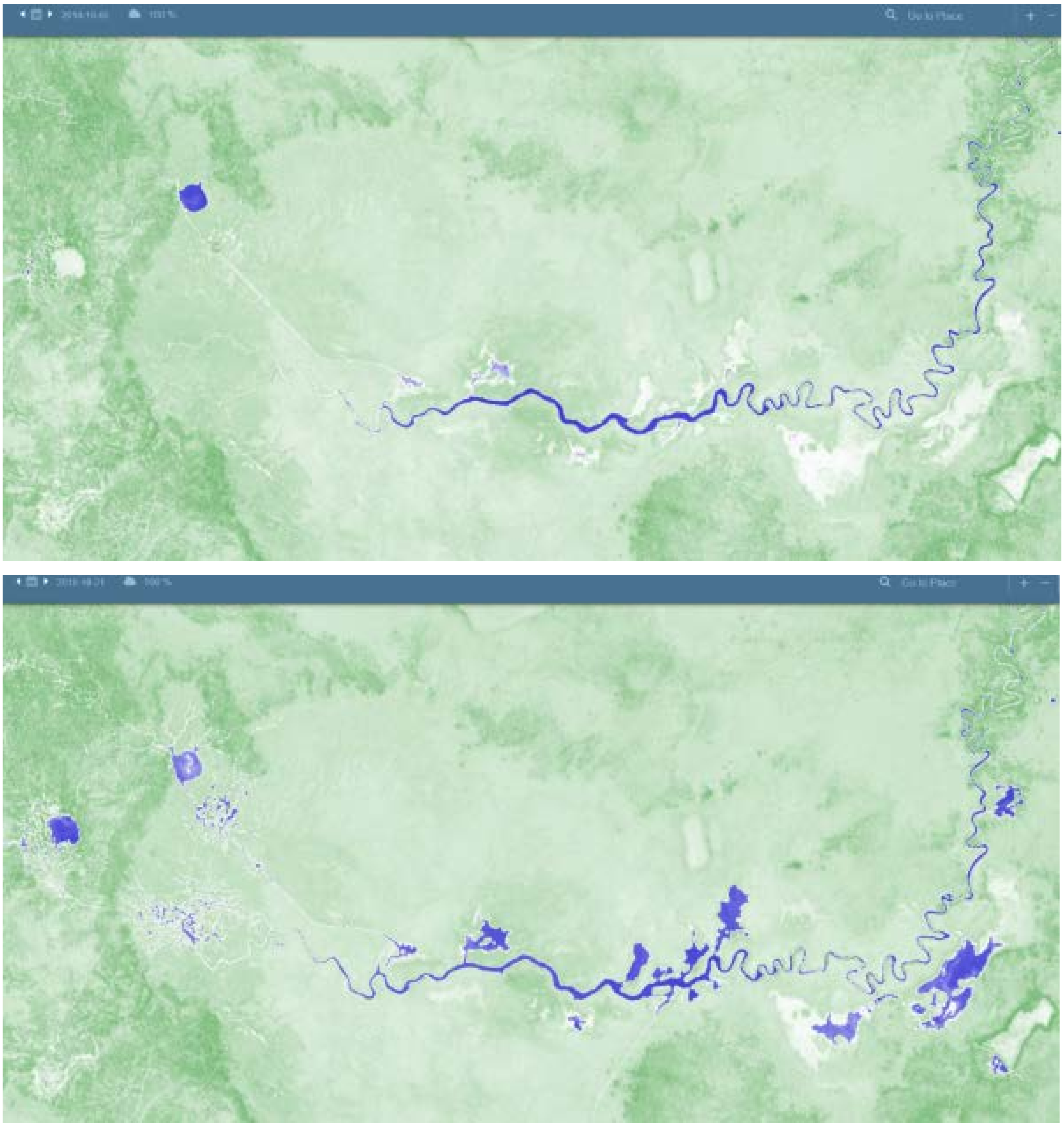


Figure 14. Sentinel imagery from the Great Cumbung Swamp prior to the arrival of environmental water (6th October 2018, upper image), and at the peak of the spring/summer watering (21st October 2018, lower image).
Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground

4.3.2 WATERING ACTION 3: YARRABANDAI LAGOON

The third Commonwealth environmental watering action targeted riparian vegetation and habitat for aquatic species in Yarrabandai (formerly Burrawang West) Lagoon (Figure 15). A total of 412 ML of Commonwealth environmental water was delivered across three water transfers (250 ML, 100 ML and 62 ML) between the 18th March and the 29th May 2019 to fill the lagoon (Figure 16). This action was not monitored under the LTIM Project in 2018-19.

A bird survey of the site was conducted on 6th of April 2019 by NSW DPIE.

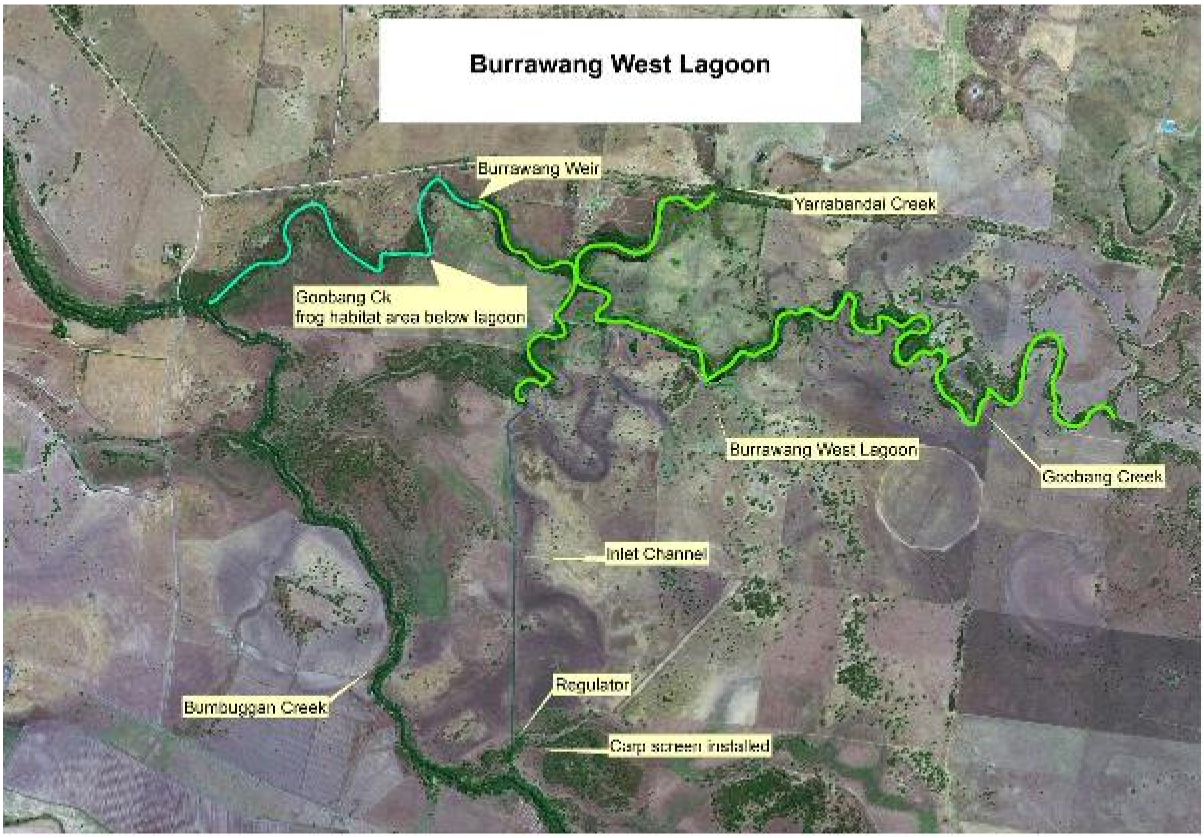


Figure 15. Map showing the location of Yarrabandai Lagoon (formerly known as Burrawang West Lagoon). Map by NSW DPIE.

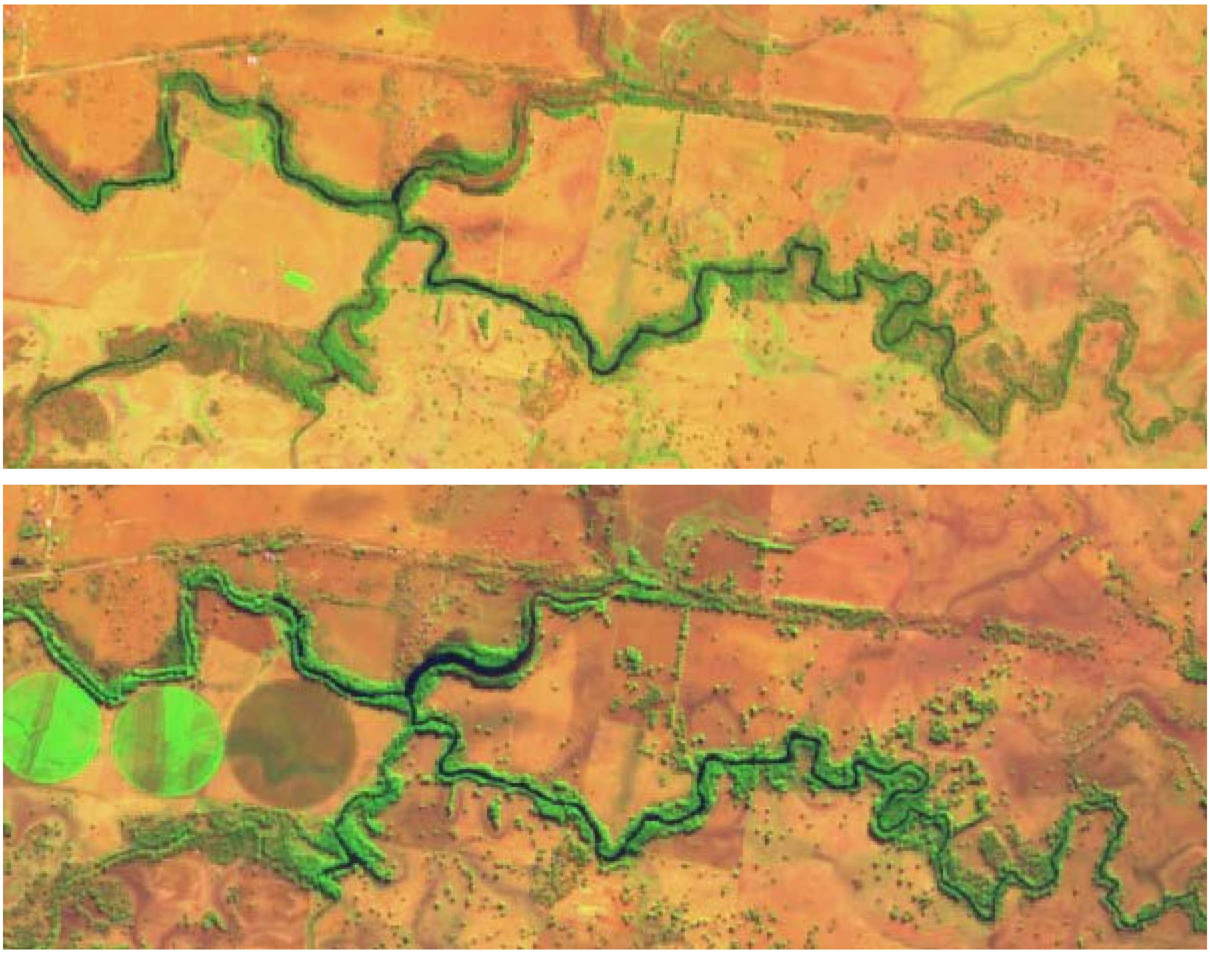
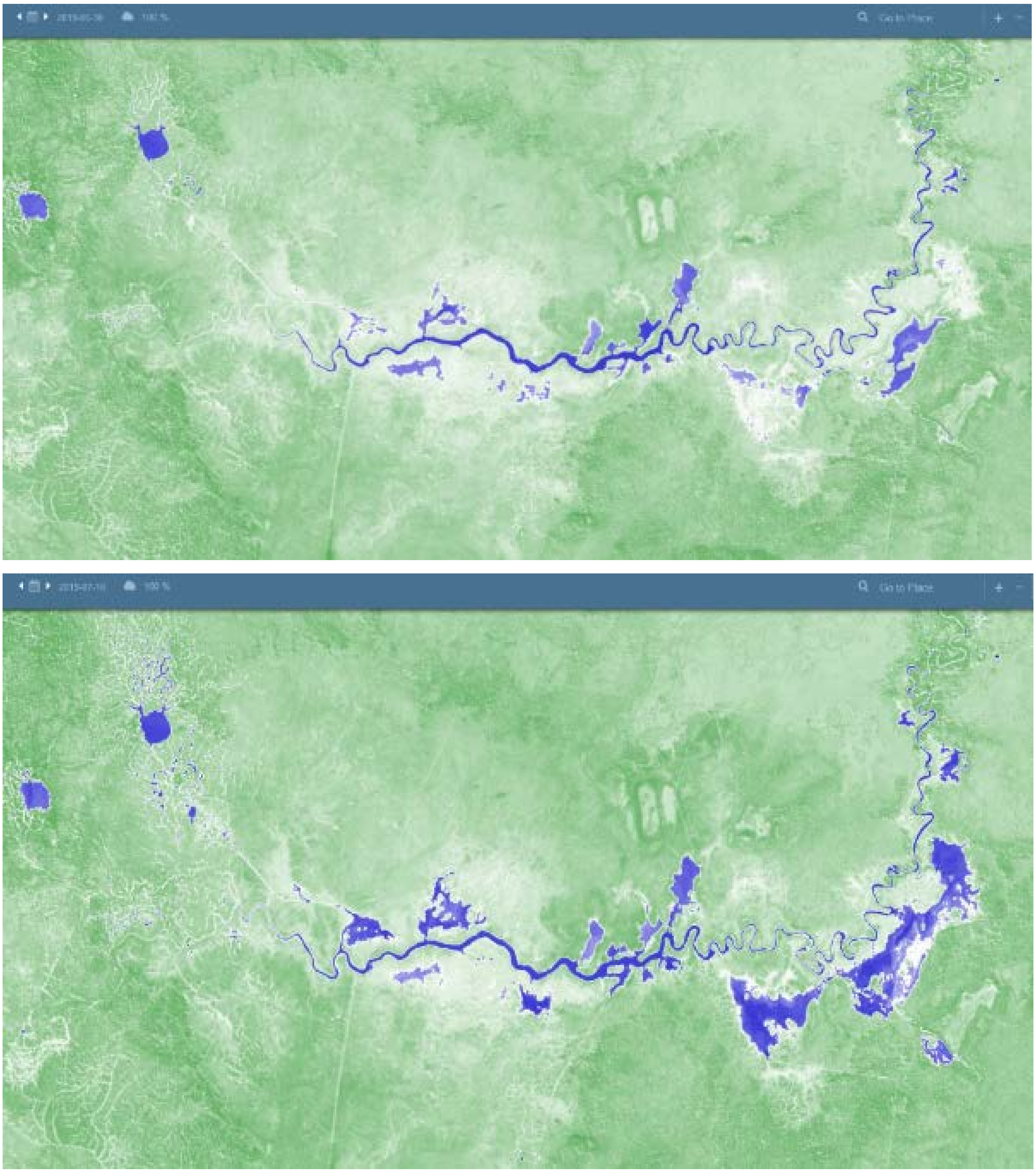


Figure 16. Sentinel imagery of Yarrabandai Lagoon area prior to the arrival of environmental water (1st March 2019, upper image), and towards the peak of the watering (30th May 2019, lower image). Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground

4.3.3 WATERING ACTION 4: AUTUMN-WINTER FRESH

Watering action 4 passed Booligal between the 7th and 27th June (Figure 12). It peaked at just over 500 ML/day on the 17th June but did not achieve the planned 9 days of 500 ML/day because of operational constraints. This watering action had reached the Great Cumbung Swamp by the 30th June with an observable increase in surface water (Figure 17). The surface water peaked around the 10th July and had completely receded by the 17th August 2019 (Figure 17).



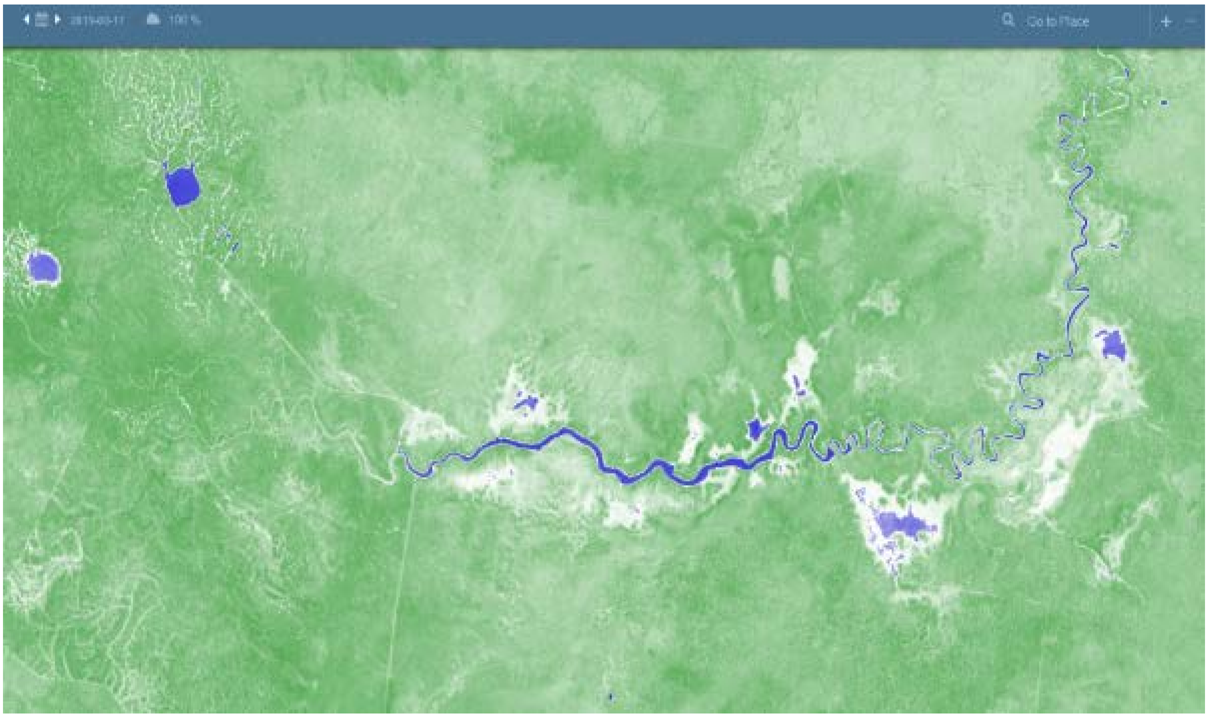


Figure 17. Sentinel imagery from the Great Cumbung Swamp as the autumn/ winter pulse arrived (30th June 2019, upper image), at maximum extent of inundation (10th July 2019, middle image) and once the water had receded (17th August 2019, lower image).
Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground

4.4 EVALUATION

The hydrological analysis presented here provides the context for evaluating observed ecological responses. The evaluation provided in this section is confined to the hydrological metrics, subsequent chapters address the ecological outcomes and evaluate the efficacy of the watering actions for achieving ecological outcomes.

The four environmental watering actions delivered in 2018-19 were modest, using a third of the Commonwealth's available volume in the Lachlan River system. In combination, the volumes delivered contributed approximately 4% of the flow in the river at Forbes, 11% at Hillston and 24% at Booligal in 2018-19. While Commonwealth environmental water made an almost negligible contribution to the mid Lachlan (4% of the flow at Forbes), it provided almost one quarter (24%) of the flow at Booligal illustrating the relative importance of Commonwealth water in the lower reaches of the river.

In relation to the effects of Commonwealth environmental water, the evaluation questions are addressed as follows:

1) What did Commonwealth environmental water contribute to habitat for native fish and other water dependent vertebrate species?

The first watering action provided an early spring fresh in the mid Lachlan river system reshaping the operational hydrograph, increasing the peak by 0.2 m (in total the river rose almost 0.4 m) and achieving a smooth recession. By leveraging operational flows, this watering action provided an efficient opportunity for a boost in productivity in the river channel and opportunities for short term movement of fish prior to spawning.

As Watering Action 1 passed downstream, the contribution to habitat became more noticeable. Through a process of re-regulation, it provided two small freshes in the lower river, with rises in river height of up to 0.4 m at Booligal. This magnitude of river rise was maintained to the edge of the Great Cumbung Swamp, likely inundating in-channel habitats. This water then passed into the Great Cumbung Swamp (Figure 14) providing almost 6 weeks of inundation to side channels and low lying areas in the Swamp in mid to late spring.

Additionally, part of the first watering action (761 ML) was delivered to Booberoi Creek providing habitat for fish and other water dependent species.

The second watering action maintained water levels in the river at Forbes between October and early December at around 0.6 m, preventing the river from dropping between 0.05 and 0.25 m during peak fish breeding season. While the river at the accounting point is trapezoidal in shape, there is some variability in channel shape in the mid Lachlan and the maintenance of water level will have prevented the exposure of small sections of banks during this time. During this time, normal operational flows in the river resulted in water levels that fluctuated between 0.6 and 0.9 m in height, sometimes with sharp drops in river level of almost 0.3 m.

2) What did Commonwealth environmental water contribute to hydrological variability in the Lower Lachlan during periods of low flow.

Three of the watering actions provided in 2018-19 strategically provided small freshes in the river. In the mid reaches, a single fresh was provided at Forbes in early spring. This fresh provided one of few (4) pulses to exceed 2,000 ML/day and one of 3 pulses that exceeded a river height of 0.9 m during the 2018-19 watering year.

In the lower reaches (Booligal), the watering actions resulted in four small freshes: three in spring and a fourth in early winter. These more than doubled the number of freshes at Booligal that exceeded 200 ML/day during 2018-19 and provided the only freshes to reach 500 ML/day for the watering year.

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

The watering actions delivered in 2018-19 connected in-channel habitats and provided flow to the end of the river system. Commonwealth environmental water achieved short periods of connectivity in channel, raising river levels between 0.1 and 0.4 m in height. As the water progressed downstream, environmental water became a greater proportion of the flow in the river, with around 24% of the flow in the river at Booligal provided by Commonwealth environmental water.

The longitudinal connections provided by Commonwealth environmental water were significant with the environmental flows providing water to the Great Cumbung Swamp for six weeks in late spring. This generated opportunities for water birds to access habitat and provided water to the aquatic vegetation.

4.5 FINAL COMMENTS AND RECOMMENDATIONS

The hydrological analysis presented here provides the context for evaluating observed ecological responses. The watering actions delivered were designed for specific ecological outcomes and the responses observed will be used to inform the design of future watering actions. Recommendations specific to hydrology are limited and relate to the relationship between the flow and the inundation of specific habitat. Further recommendations relating to the potential of the watering actions to achieve the ecological objectives are addressed in subsequent chapters of the technical report.

- The use of environmental water to maintain a flow rate of 800 ML/day used 2,032 ML to prevent the river from varying by 5-25 cm. While possible, it is unlikely that a drop in river level of less than 25 cm would have resulted in significant exposure of nesting sites, particularly as it was noted that there were significant changes in water level as a result of the delivery of water orders that were above the 800 ML/day threshold. In future, it is recommended that the establishment of threshold flow values be based on an analysis of where the critical flow-water level thresholds are within the river and habitat mapping that can better inform the water level required to maintain nesting habitats.
- It would be useful to evaluate the consequences of the sudden drops in water level that were above 800 ML/day, as it may be valuable to work with operational delivery to modify the rate of recession to mitigate sudden drops rather than establish a fixed floor. This is addressed in further detail in the larval fish chapter.
- The style of environmental water management employed in the Lachlan catchment for the past three years is responsive and uses a single parcel of water to achieve multiple benefits throughout the river system. While such as approach is an efficient and effective use of water it has presented substantial challenges for evaluating the watering actions. Documentation of the watering actions has improved considerably in 2018-19, but there remain some difficulties, particularly with the timely provision of accounting data. Accounting of the spring watering actions was provided early which was incredibly valuable for timely reporting, however data for the winter fresh were not provided until September which was challenging. It remains a recommendation that more regular accounts be prepared to support the reporting requirements.

5 STREAM METABOLISM AND WATER QUALITY

5.1 INTRODUCTION

The energetic base of food webs 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 such as leaves, wood and organic carbon dissolved in the water (Bunn et al. 2006). Those processes are both influenced by the availability of key nutrients, particularly nitrogen and phosphorus, and water temperature and light. Primary production (referred to as gross primary production, GPP) and organic matter processing or decomposition (known as ecosystem respiration, ER) can be measured through continuous monitoring of changes in the concentration of oxygen in the water (described as measurements of open channel stream metabolism).

The delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream (Boulton and Lake 1992, MDFRC 2013, Stewardson et al. 2013).

In this section we evaluate the outcomes of providing Commonwealth environmental water to the Lower and Mid Lachlan river system in terms of measured changes in water nutrients and GPP, ER, K and the GPP/ER ratio. The 2018-19 Commonwealth environmental watering actions in the Lower and Mid Lachlan river system are described in detail in sections 3: 2018-19 Watering Actions (p. 20).

On the 14th of March 2018 the CEWO requested that due to the presence of blue-green algae in the Lachlan River at Willandra Weir, that all proposed autumn watering actions be suspended where there is a risk of adverse impacts on downstream communities. As a consequence, flows were maintained at reasonably low levels in autumn, with flow deliveries concentrated later in the year after cooler temperatures had reduced blue-green algae.

Briefly here, four watering actions were delivered in 2018-19 totalling 18 173 ML of environmental water, targeting multiple locations and ecological objectives at different times through the river system. Complementary watering actions by NSW OEH were used to target other locations and ecological objectives during 2018-19.

Watering Action 1 was a spring fresh commencing on 29th August 2018 targeting native fish and stream productivity outcomes in the mid and lower Lachlan River. Some of this flow was held in Lake Brewster and released between 20th - 23rd October to mimic a small rain event.

Watering Action 2 sought to generate minimum stable flows of 800 ML/day in the mid Lachlan River, preventing rapid drops in flow which could expose Murray cod and catfish nests. Releases of CEW for this action occurred between 22nd - 30th of October, complementing operating flows which were provided between the 17th of October and 3rd December 2018.

Watering Action 3 was a small watering action targeting riparian vegetation and habitat for aquatic species in Yarrabandai (formerly Burrawang West) Lagoon. Delivery of this flow occurred from 18th March - 29th May 2019.

Watering Action 4 targeted the Great Cumbung Swamp in the lower Lachlan and sourced 5,338 ML of water from Lake Brewster between 9th - 28th June.

In evaluating the outcomes of providing Commonwealth environmental water to the Lower and Mid Lachlan river system the following evaluation questions are addressed.

5.1.1 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to primary production in the mid and lower Lachlan River?
2) What did Commonwealth environmental water contribute to patterns and rates of ecosystem respiration (ER) and primary productivity (GPP) in the mid and lower Lachlan River?

5.2 METHODS

The evaluation of the stream metabolism and water quality outcomes used a combination of river height data (as described in section 4, Hydrology), water quality data and stream metabolism data (dissolved oxygen measurements modelled to calculate GPP, ER, and reaeration K).

Data are collected from four Lower Lachlan sites (Wallanthery (WAL), Whealbah (WB), Cowl Cowl (CC) and Lanes Bridge (LB), Figure 18) and four Mid Lachlan sites (Euabalong (EB), Techam (TH), Mulgutherie (MG), Kirkup Park (KP), Figure 19). The water quality parameters dissolved oxygen and temperature were measured using the automatic stream metabolism loggers. Conductivity, pH and turbidity are manual point measures and were recorded using a handheld water quality meter. For nutrients and chloroplyll a water samples were taken 2 meters from the water's edge at one meter depth. These were placed on ice and returned to University of Canberra (UC) for analysis by ALS for total nitrogen, nitrate/ nitrite, total phosphorus, dissolved reactive phosphorus and ammonia. Chlorophyll a are analysed at UC

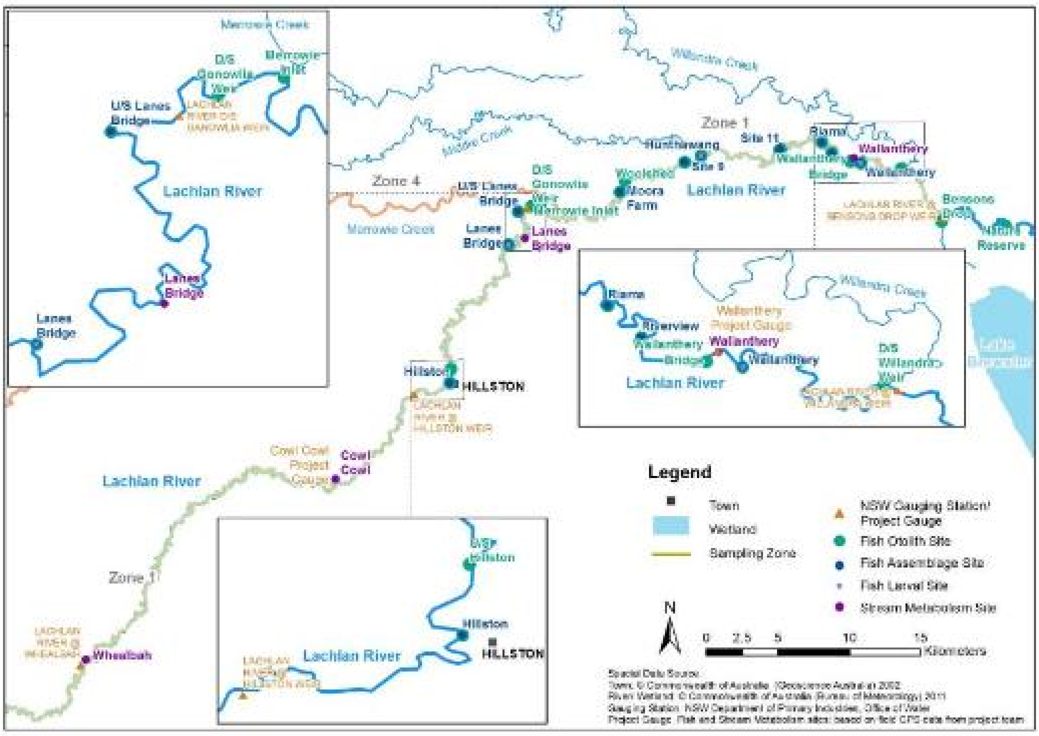


Figure 18. Map of monitoring sites for fish, larval fish and stream metabolism in the Lower Lachlan River Zone L1.

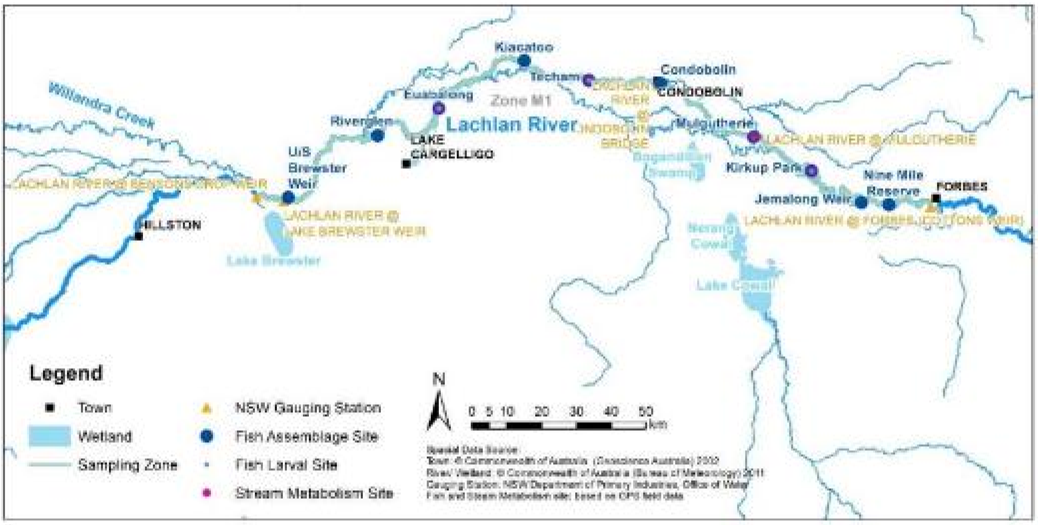


Figure 19. Map of monitoring sites for fish, larval fish and stream metabolism in the Mid Lachlan River Zone M1.

Stream metabolism was measured applying the standard methods for the LTIM Project. An oxygen logger was installed in the water column at the edge of the stream (3 sites), but mid-stream for Mulgutherie (MG) to ensure the logger remained wet (Figure 20 and Figure 21).

Figure 20. Stream metabolism sites in the Lower Lachlan (top left to bottom: LB, WAL, WB (CC not shown but similar to LB).

Figure 21. Stream metabolism sites in the Mid Lachlan (top left to bottom right: MG, TH, EB, KP)

Dissolved oxygen (DO) and water temperature were logged at 10-min intervals using D-Opto dissolved oxygen sensors (Zebra-Tech, Nelson, New Zealand) and MiniDOT sensors (Precision Measurement Engineering Inc., Vista, USA). Photosynthetic active radiation (PAR) was measured in an adjacent unshaded location 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 (BAyesian Single-station Estimation) (Grace et al. 2015) to estimate primary production and respiration on a daily basis. Estimates derived from curve fits with $R^2 < 0.90$ and/or CV for GPP of > 50% were discarded. The version of the model used incorporated a series of updates which have been applied across the LTIM Project and was current from the 18th of June 2018 (V2.3.3).

5.3 RESULTS

The results are presented firstly for the Lower Lachlan River, then the Mid Lachlan. The Lower Lachlan River data is a continuation of the dataset generated under the LTIM Project whereas the Mid Lachlan River data are a single year of data generated captured as short term intervention monitoring.

5.3.1 WATER QUALITY – 2018-19

5.3.1.1 Lower Lachlan River (Long Term Intervention Monitoring)

Water temperature showed a typical seasonal pattern, ranging from 7.8 degrees Celsius in winter, to 31 degrees Celsius in summer, with no clear association with flow events (Figure 22, Figure 23). The same patterns were evident in the dissolved oxygen (DO) data (Figure 22) with lower values in summer. There was also a very low DO period (down to 2.6 mg/L) at Wallanthery during October 2018, likely as a consequence of a rapid drop in flow in September from 1,000 to 100 ML/ day within 10 days (see Figure 35 for discharge from Willandra gauging station), and an associated increase in water temperature and concentrations of dissolved organic carbon.

There was no clear association between pH and environmental watering actions, but some evidence of reductions in turbidity and potentially salinity following the small October fresh delivered from Lake Brewster as a component of Watering Action 1 (Figure 23). This may be indicative of initial dilution of ions and fine sediment associated with the flow event.

Results for major nutrients (Figure 24) were consistent with those for the water quality parameters above. Total nitrogen was relatively consistent across sampling events, with low levels of nitrate/nitrite. These values showed no clear association with the environmental watering events, although there is some evidence for a slight increase after the October watering events (second stage of Watering Action 1, and Watering Action 2). Patterns for total and reactive phosphorus were broadly similar although values were more variable. There is some evidence for increased total phosphorus and reactive phosphorus after the delivery of Watering Action 2, leading into the pulse generated by irrigation delivery flows in late December. This is consistent with mobilisation of organic materials. Ammonium values were highly variable and showed no relationship with environmental flow delivery. For Watering Actions 4 no statements can be made, as no samples had been taken.

Data for key basal resources, dissolved organic carbon (DOC) and chlorophyll (a measure of algal biomass) were also relatively sparse (Figure 24), making determining clear associations with environmental water delivery difficult. However, there is evidence of higher DOC and chlorophyll values during delivery of environmental flows in October and December; notably high DOC values in late September, following delivery of Watering Action 1, and high chlorophyll values in late November during Watering Action 2. There was very high variability in measurements on these occasions, suggestive of patchiness of these resources.

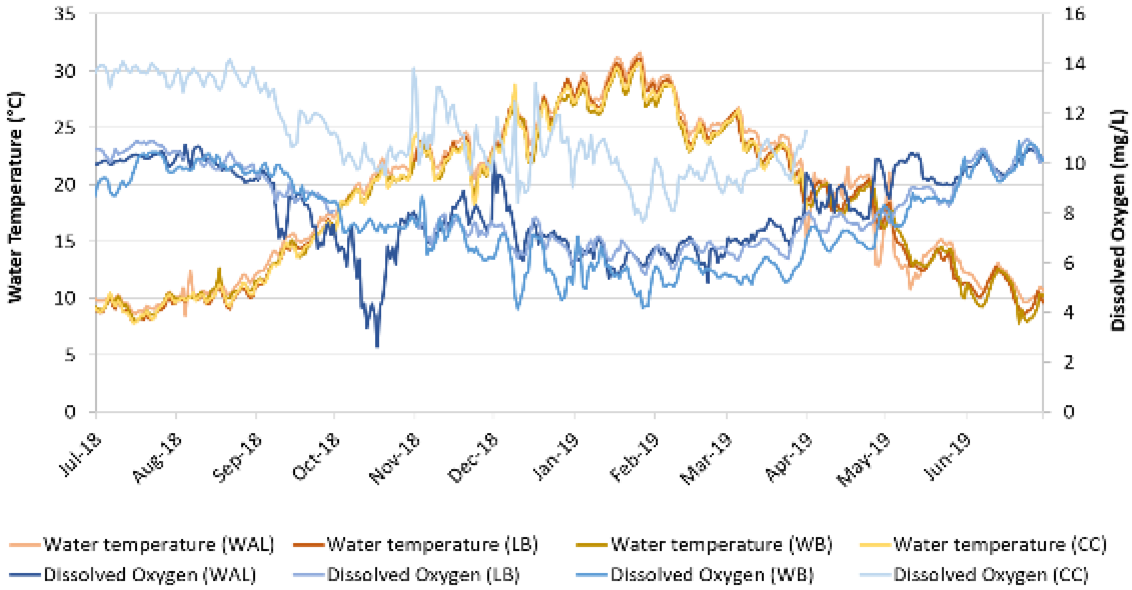


Figure 22. Water temperature and dissolved oxygen for the four Lower Lachlan sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2018-19.

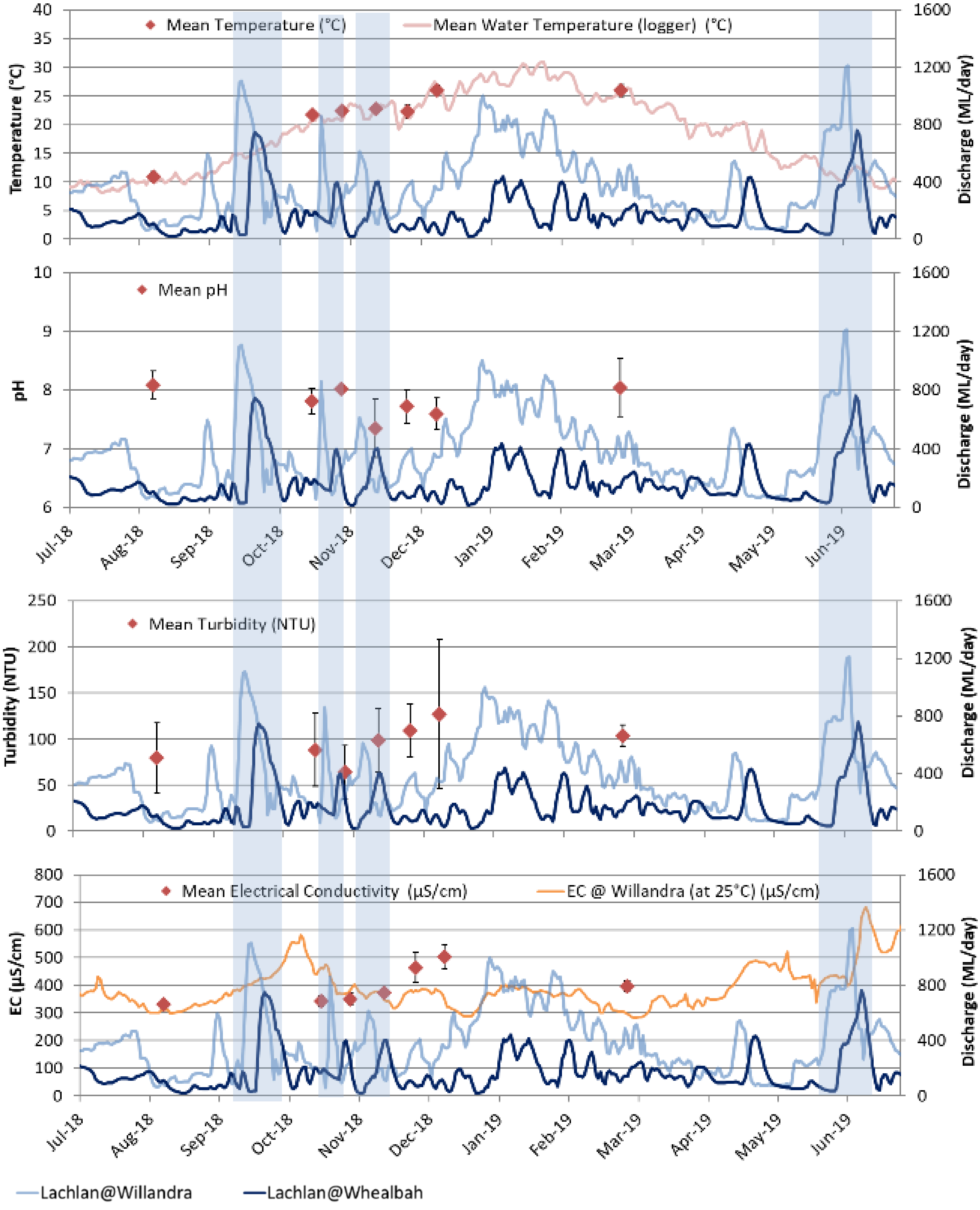


Figure 23. Mean water quality measurements (± standard error) for the four Lower Lachlan sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2018-19: physico chemical attributes.
Blue shaded vertical bars indicate watering actions.

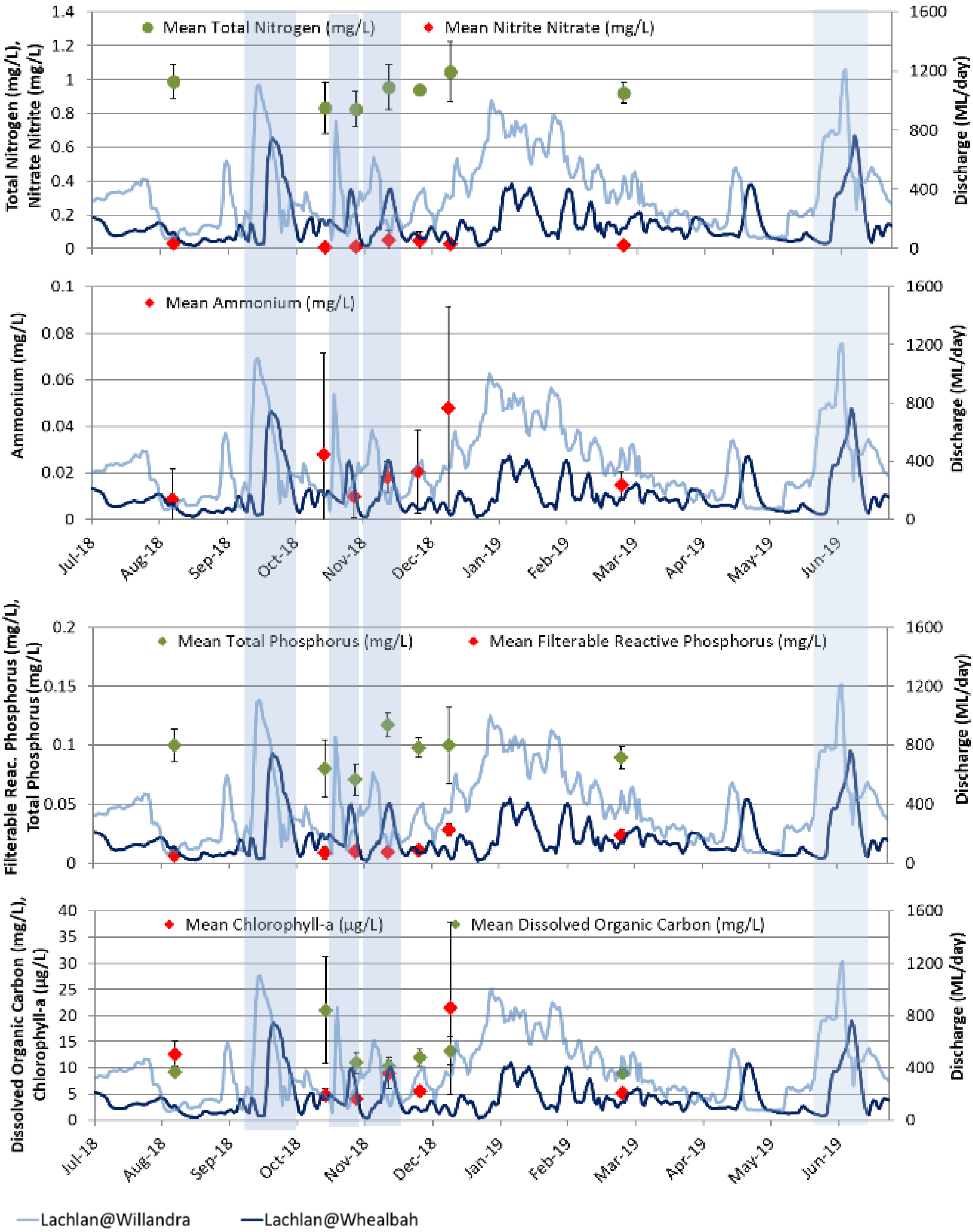


Figure 24. Mean water quality measurements (± standard error) for the four Lower Lachlan sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2018-19: nutrients and chlorophyll a.
Blue shaded vertical bars indicate watering actions.

5.3.1.2 Mid Lachlan River (Short Term Intervention Monitoring)

As expected, water temperature and dissolved oxygen patterns for the mid Lachlan sites were very similar to those for the lower Lachlan sites ranging from 10.5 degrees Celsius in winter, to 26 degrees Celsius in summer (Figure 25, Figure 26) with lower values in summer. The mid reaches were cooler that the lower reaches in the river, likely as a consequence of high volumes of water and potential localised effects of shading and groundwater inflows. There was a general trend towards lower DO during highest water temperatures, which is consistent with physical properties and potential increases in rates of microbial respiration in warmer water (Figure 25). Turbidity, pH and conductivity were also consistent with the downstream sites (Figure 26). There was no definitive association between these values and the provision of environmental flows, although higher turbidity was observed during the early phases of Watering Action 2.

As for other water quality parameters, results for major nutrients (Figure 27) were consistent with those seen in the lower Lachlan. Total nitrogen was relatively consistent across sampling events, with low levels of nitrate/nitrite. Patterns for total and reactive phosphorus were broadly similar. There is some evidence for increased levels of both nitrogen, phosphorus and ammonium during delivery of environmental flows during the early phases of Watering Action 2 (late October 2018). This may be a consequence of mobilisation of materials from the floodplain or agricultural run-off, as there had been 68 mm in October at Forbes (see chapter 3.1: Catchment and weather conditions, p. 20).

Concentrations of key basal resources, dissolved organic carbon (DOC) and chlorophyll were variable, but there was strong evidence for higher levels of DOC during delivery of Watering Action 2 in late October (Figure 27). Presumably there is an interaction between flow and temperature – flow affects the amount of carbon being mobilised, but temperature affects residence time and break down rates. Lag times of weeks are realistic where carbon enters via shallow groundwater system, is larger material (e.g. leaves, wood) or when temperatures are cooler. Chlorophyll values were initially lower during early phases of this flow, but increased and peaked during the latter stages of delivery of Watering Action 2, in early December (Figure 27). As for the lower Lachlan, variability in measurements was suggestive of patchiness of these resources.

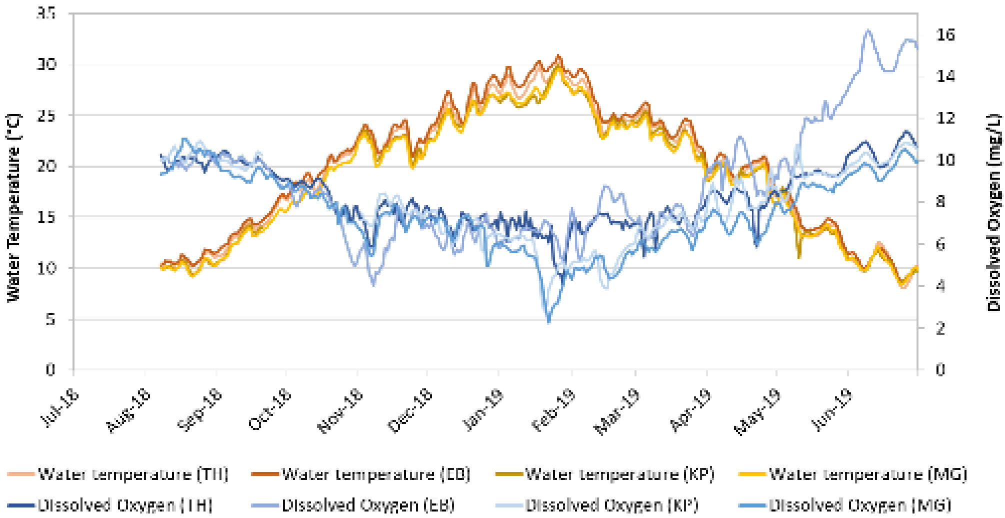


Figure 25. Water temperature and dissolved oxygen from the Mid Lachlan River for the four study sites each over the sampling period 2018-19

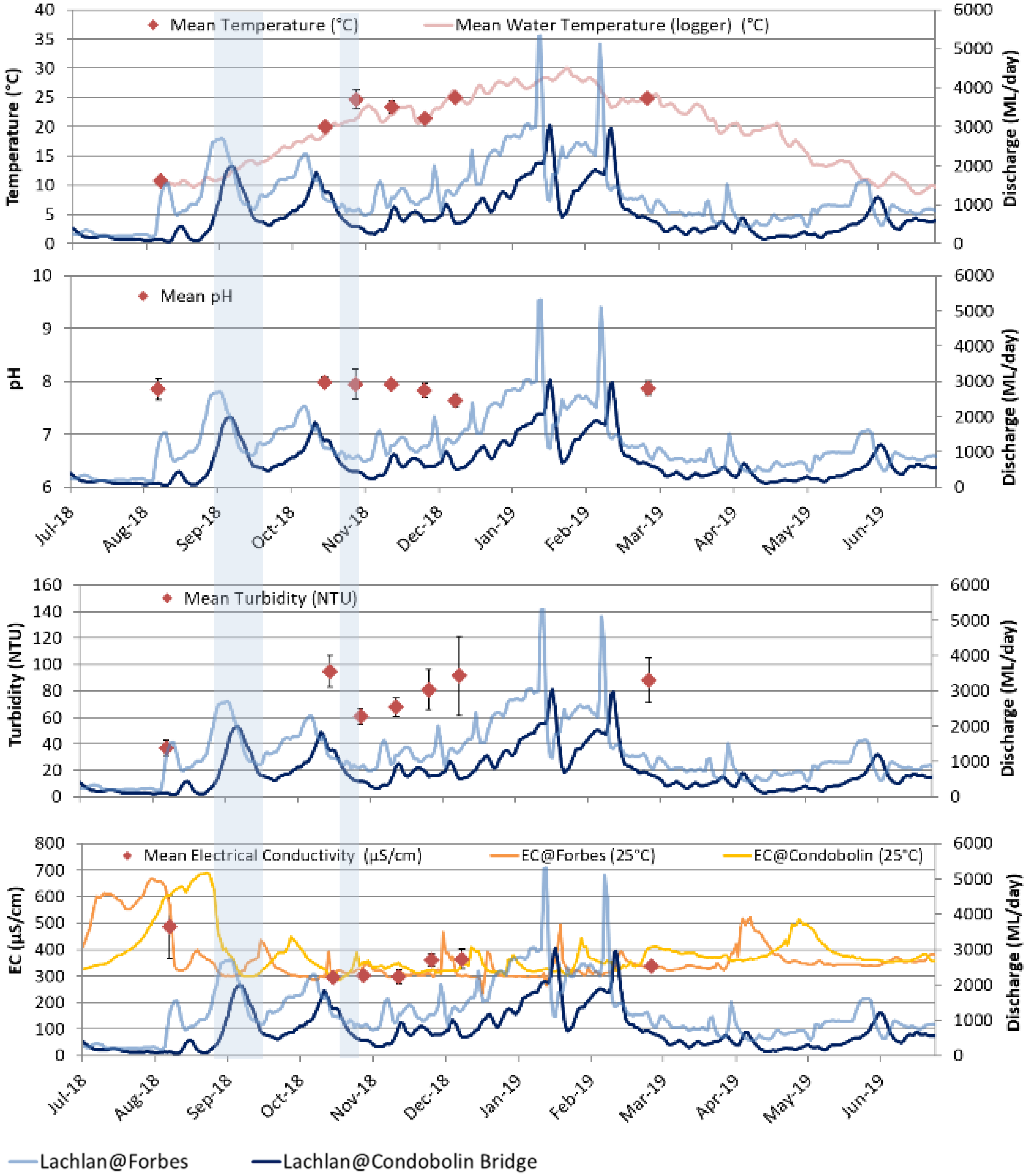


Figure 26. Mean water quality measurements (± standard error) for four Mid Lachlan sites (Euabalong, Techam, Mulgutherie, Kirkup Park) over the sampling period 2018-19: physico chemical attributes.
Blue shaded vertical bars indicate watering actions.

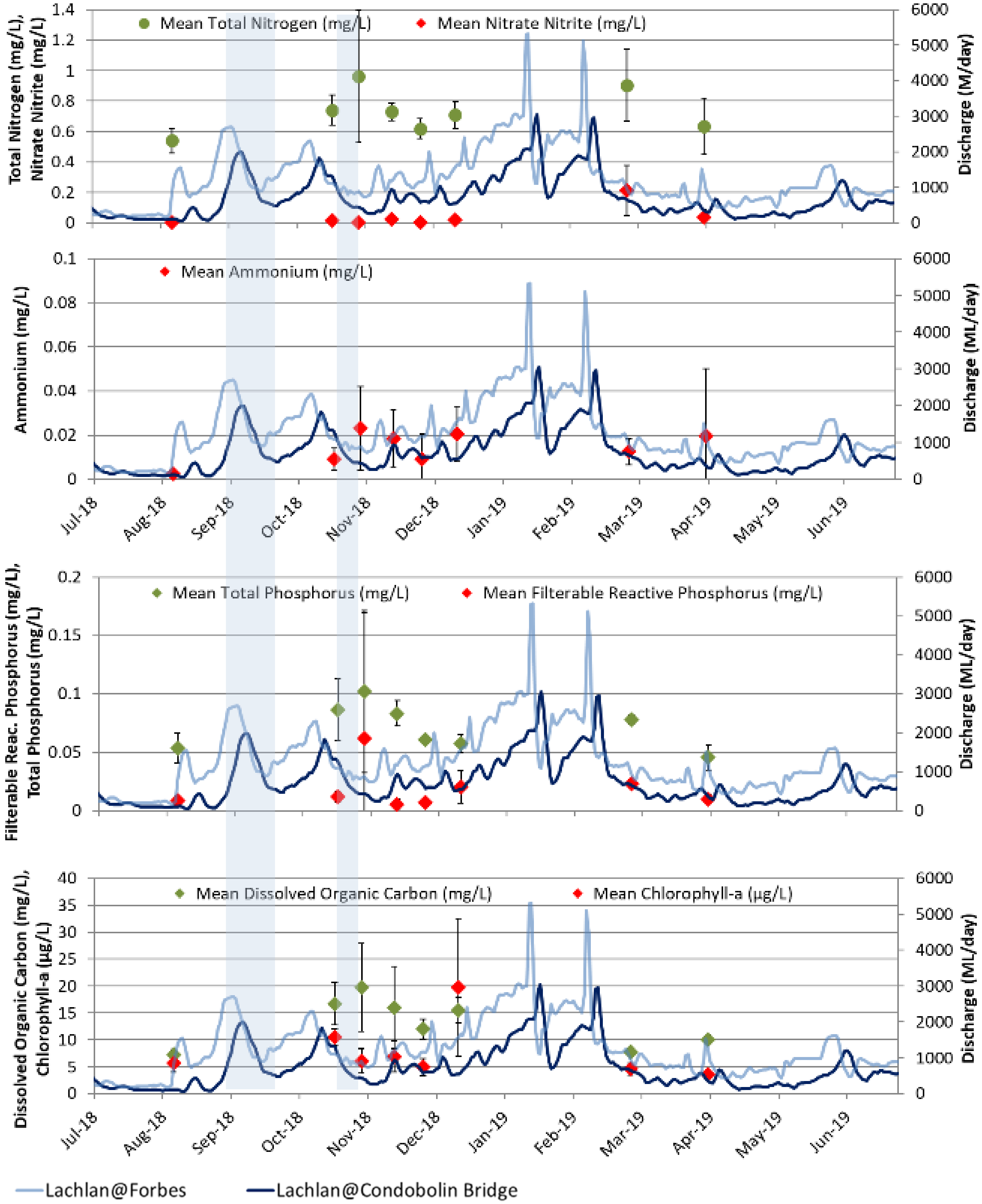


Figure 27. Mean water quality measurements (± standard error) for the four Mid Lachlan sites (Euabalong, Techam, Mulgutherie, Kirkup Park) over the sampling period 2018-19: nutrients and chlorophyll a.
Blue shaded vertical bars indicate watering actions.

5.3.2 WATER QUALITY – 2014-19

The consolidated water quality data set from the lower Lachlan site shows some clear overall patterns.

1. Strong seasonality in temperature data, with any effect of environmental flow delivery being very slight against this natural variability.
2. High variability in parameters, which is likely to reflect genuine patchiness in water quality as a consequence of low rates of mixing and inputs from shallow groundwater systems and tributaries.
3. Striking effects of a large natural flood in 2016-17.
4. Evidence of a pattern of increased turbidity, higher DOC and periodically higher nutrients and algal concentrations associated with environmental flow delivery indicating likely mobilisation of material in the channel and dilution of ions.

Water temperature and dissolved oxygen showing a strong typical seasonal pattern (Figure 28). Years with lower or higher inflows did not show any deviation from this general pattern.

Turbidity, pH and conductivity were relatively variable (Figure 29), but showed clear evidence of lower values associated with the large natural flow event, likely reflecting dilution as a consequence of the very high inflows. Environmental flow events had much smaller effects on these parameters and were limited to slight increases in turbidity consistent with mobilisation of organic material.

Results for major nutrients (Figure 30) showed striking effects of the large natural flow which was associated with high concentrations of total nitrogen, phosphorus and ammonia. These may be sourced from organic material in channel or from return flows from newly wetted anabranches, wetlands or billabongs. Environmental flows also showed some association with slightly higher concentrations of phosphorus, although of a much lower magnitude than the effect seen during the natural flow

Concentrations of key basal resources were variable, particularly in the case of DOC (Figure 30). The large natural flow event resulted in uniformly higher values of DOC, indicative of carbon being mobilised into the water column. However single values for measurements at low flow or during environmental flows were as large or exceeded the values observed during that high flow event. Several environmental flow events showed evidence of slight increases in DOC consistent with increased carbon availability.

Chlorophyll data were relatively sparse, and effects of variability in flow were much smaller or non-detectable. For both the high natural flow and several environmental flow events there was evidence of initial dilution of algal cells (lower chlorophyll) on the ascending limb of the hydrograph and then a lagged increase after the peak flow. It is not possible to differentiate the physical effects of dilution, proliferation and then concentration from responses to nutrients, which also show the same pattern. However, it appears that environmental flows with even small peaks in nutrient availability were those that were associated with high values of chlorophyll (compare panels in Figure 30). There is a limited amount of data available for making clear conclusions on the effects of environmental water in the lower Lachlan, and interpretation is made more complex by the high year to year variability in inflows.

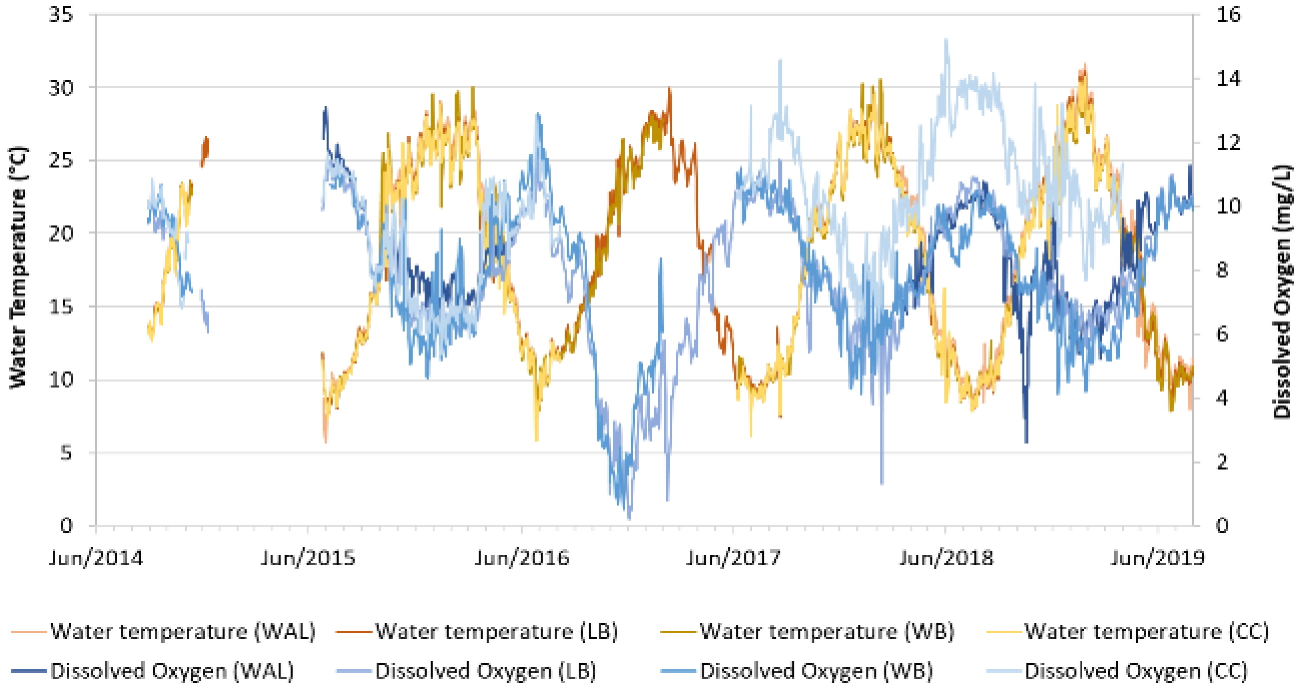


Figure 28. Water temperature and dissolved oxygen for the four study sites from the Lower Lachlan River (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2014-19. Because of initial issues with access to sites, there is incomplete data prior to and including November 2014. Continuous sampling took place from 25th June 2015.

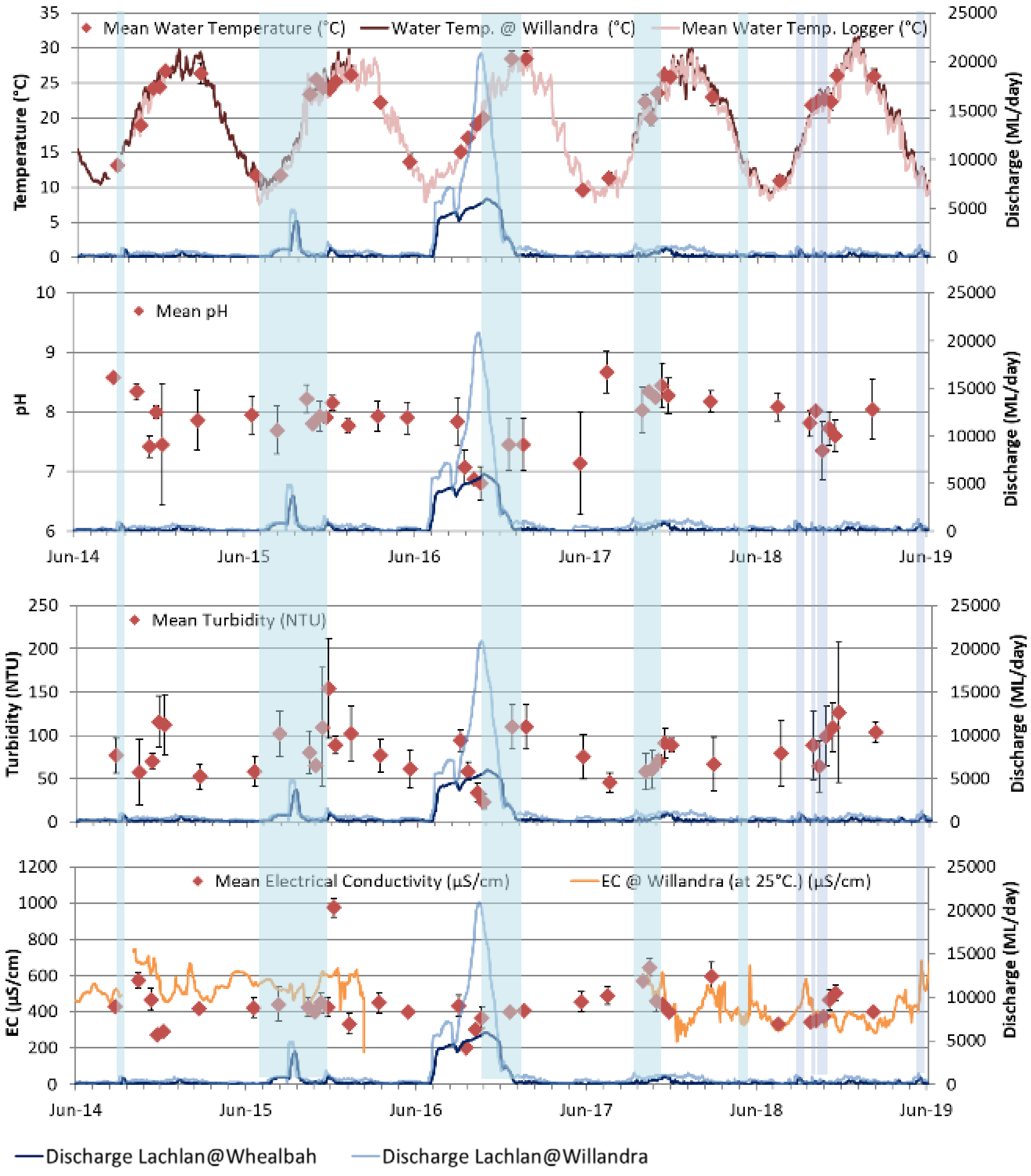


Figure 29. Mean water quality measurements (± standard error) for four Lower Lachlan sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2014-19: physico chemical attributes.
Blue shaded vertical bars indicate watering actions.

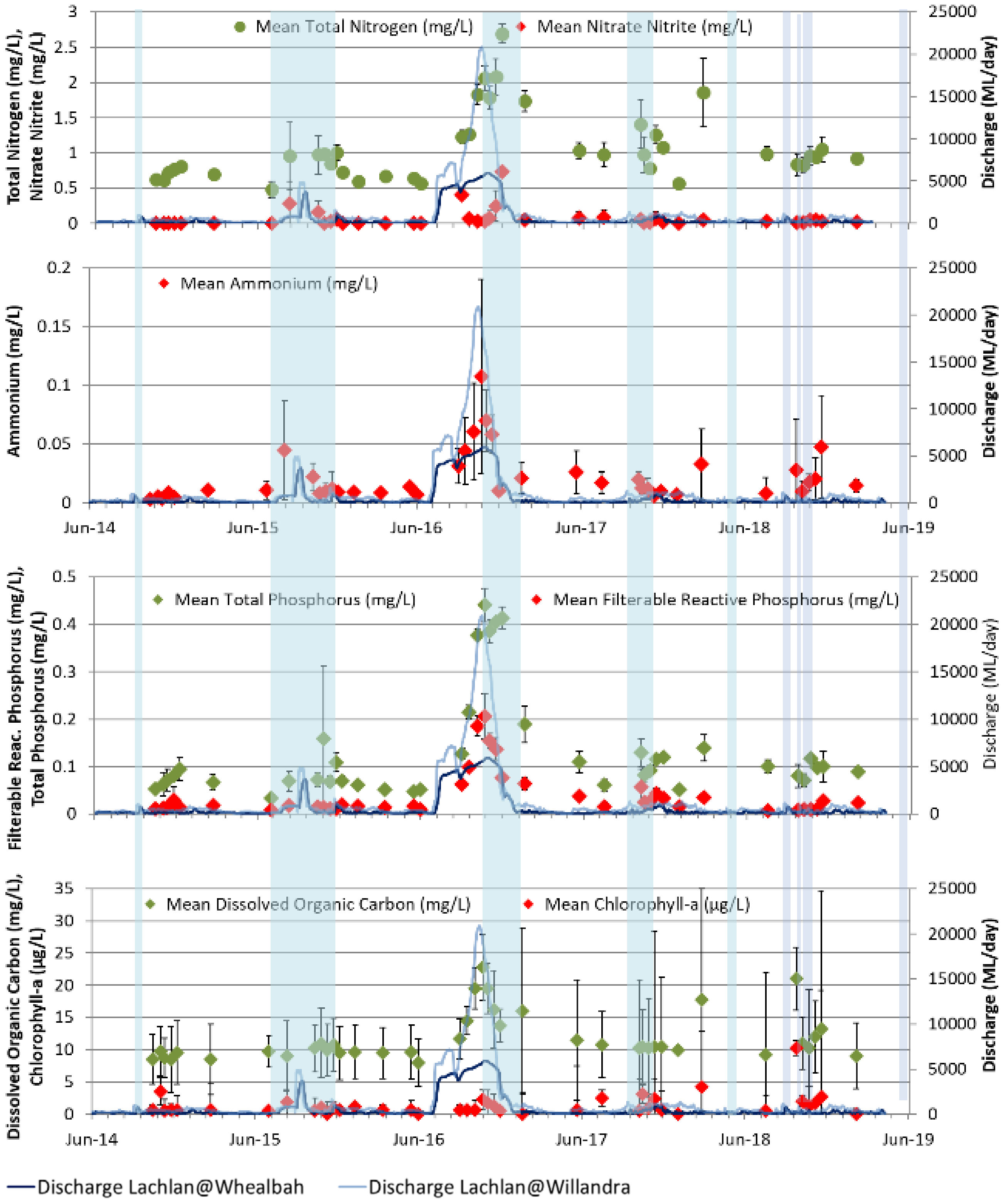


Figure 30. Mean water quality measurements (± standard error) for the four Lower Lachlan sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2014-19: nutrients and chlorophyll a.
Blue shaded vertical bars indicate watering actions.

5.3.3 STREAM METABOLISM – 2018-19

5.3.3.1 Lower Lachlan River (Long Term Intervention Monitoring)

In the 2018-19 period we used miniDOT loggers at the four sites in the Lower Lachlan River (Figure 18), at two sites we installed two loggers (Lanes Bridge and Whealbah).

In Table 6 the percentiles for which a GPP and ER estimate could be modelled under the standard acceptance criteria are shown for the 2018-19 period. At Cowl Cowl the logger stopped earlier (31/03/2019) before deployment in August 2019, and at Lanes Bridge twice in 2018, therefore we have two logging gaps, see notes in Table 6. At Wallanthery and Whealbah we recorded a full calendar year of data.

Stream metabolism data was able to be used from an average of 61% of days (range Cowl Cowl [CC] = 41% to Lanes Bridge [LB] = 83 %, see Table 6). The Cowl Cowl and Wallanthery sites, as in previous years had lower proportions of days which could be modelled relative compared to the other two sites (Dyer et al. 2018). To nearly 100% the cause for rejection of a logged day would be through the appliance of the criteria: $R2 < 0.9$.

After applying the standard numerical acceptance criteria, we visually inspected plotted GPP, ER and K values and rejected one from Whealbah and 27 data days from Wallanthery, ($K > 35$ indicating the likelihood of exposure of the probe to air).

In order to model stream metabolism in some critical periods (e.g. at peak flows) K values > 5 (relate Figure 31, plus section 5.7: Appendix 1: Stream metabolism plots for additional sites in the Lower Lachlan River 2018-19) were accepted in order to allow any estimates to be extracted. It should be noted that high K values lead to potential over-estimates of ER.

Table 6. Stream metabolism data obtained from the four sites in the Lower Lachlan river system during the sampling period 2018-19.
Shown is the number of logged days for each site with the count (Y) and percentile (%) for which a GPP, ER and K estimate could be modelled under the standard acceptance criteria.

ZONE	SITE	TIME PERIOD	# LOGGED DAYS	Y	%	NOTES (GAPS IN LOGGING, ODDITY WITH APPLICATION OF CRITERIA)
LOWER LACHLAN (L1)	COWL COWL (CC)	1/07/2018 - 31/03/2019	274	113	41	Logger stopped recording End of March 2019
	LANES BRIDGE (LB)	1/07/2018 - 30/06/2019	332	277	83	gap of 4 days (05/08 - 08/08/2018), gap of 29 days (01/10 - 29/10/2018)
	WALLANTHERY (WAL)	1/07/2018 - 30/06/2019	365	150	41	
	WHEALBAH (WB)	1/07/2018 - 30/06/2019	365	280	77	

Time series plots of logged temperature, dissolved oxygen (DO) are shown in Figure 22 on p. 54. Discharge (from the nearest NSW gauging station), logged DO, Gross Primary Production (GPP), Ecosystem Respiration (ER), reaeration (K) and the GGP/ER ratio for Lane's Bridge as an example from the lower Lachlan are shown in Figure 31, and in section 5.7: Appendix 1: Stream metabolism plots for additional sites in the Lower Lachlan River 2018-19 can be found.

Watering Action 1 was a spring fresh commencing on 29th August 2018 targeting native fish and stream productivity outcomes in the mid and lower Lachlan River. Some of this flow was held in Lake Brewster and released between 20-23rd October to mimic a small rain event, and some was directed down Booberoi Creek.

Watering Action 2 sought to generate minimum stable flows of 800 ML/day in the mid Lachlan River, preventing rapid drops in flow which could expose Murray cod and catfish nests. Releases of CEW for this action occurred between 22nd-30th of October, complementing operating flows which were provided between the 17th of October and 3rd December 2018.

Watering Action 4 targeted the Great Cumbung Swamp in the lower Lachlan and sourced 5,338 ML of water from Lake Brewster between 9th-28th June.

The watering actions undertaken in the lower Lachlan in 2018-19 took the form of four relatively defined flow pulses. While data are available for two of the four monitored sites for Watering Action 1, two sites have limited data as a consequence of poor curve fits (Figure 31, Figure 35 to Figure 38). This does not appear to be due to high values for reaeration (Figure 31, Figure 37). There is some evidence for increasing GPP over November and December when Watering Action 2 was being delivered, although this is also a period of warmer water conditions (Figure 28, p. 61) and the rising limb of an irrigation delivery flow (Figure 31, Figure 35). Results for ER also showed some sign of an increase over this period, particularly at the Whealbah site (Figure 31, Figure 36). The ER rates are generally significantly higher than the corresponding GPP rates, meaning that the sites are predominantly heterotrophic (GPP/ ER<1). Stream metabolism is mainly driven by external sources of organic carbon rather than from that created by photosynthesis within the site. The increases in GPP and ER are highly correlated (Figure 31, Figure 38), suggesting of increased photosynthetic activity and mobilisation/ consumption of organic matter. This is consistent with evidence from the water quality data which suggests mobilisation of both nutrients and carbon generating an increase in basal resources and productivity.

Watering Action 4 occurred under cooler conditions in June 2019, and yielded metabolism data only from Wallanthery, Lanes Bridge and Whealbah. There was no clear evidence for an effect of this flow on GPP (Figure 31, Figure 35), but there were observed increased in ER, particularly at the Whealbah site (Figure 31, Figure 36). For this flow there was evidence of increased reaeration (Figure 31, Figure 37), which may lead to over-estimates of ER. There was some evidence for changes in GPP/ER ratios associated with the rising limb of this flow indicative of an increase in ER without a correlated increase in GPP (Figure 31, Figure 38). It is not possible to determine whether these changes are a consequence of increased reaeration alone, or whether there was a true increase in respiration due to inundation and consumption of organic matter. It is clear however that flow delivery under these cooler conditions did not yield a detectable increase in GPP.

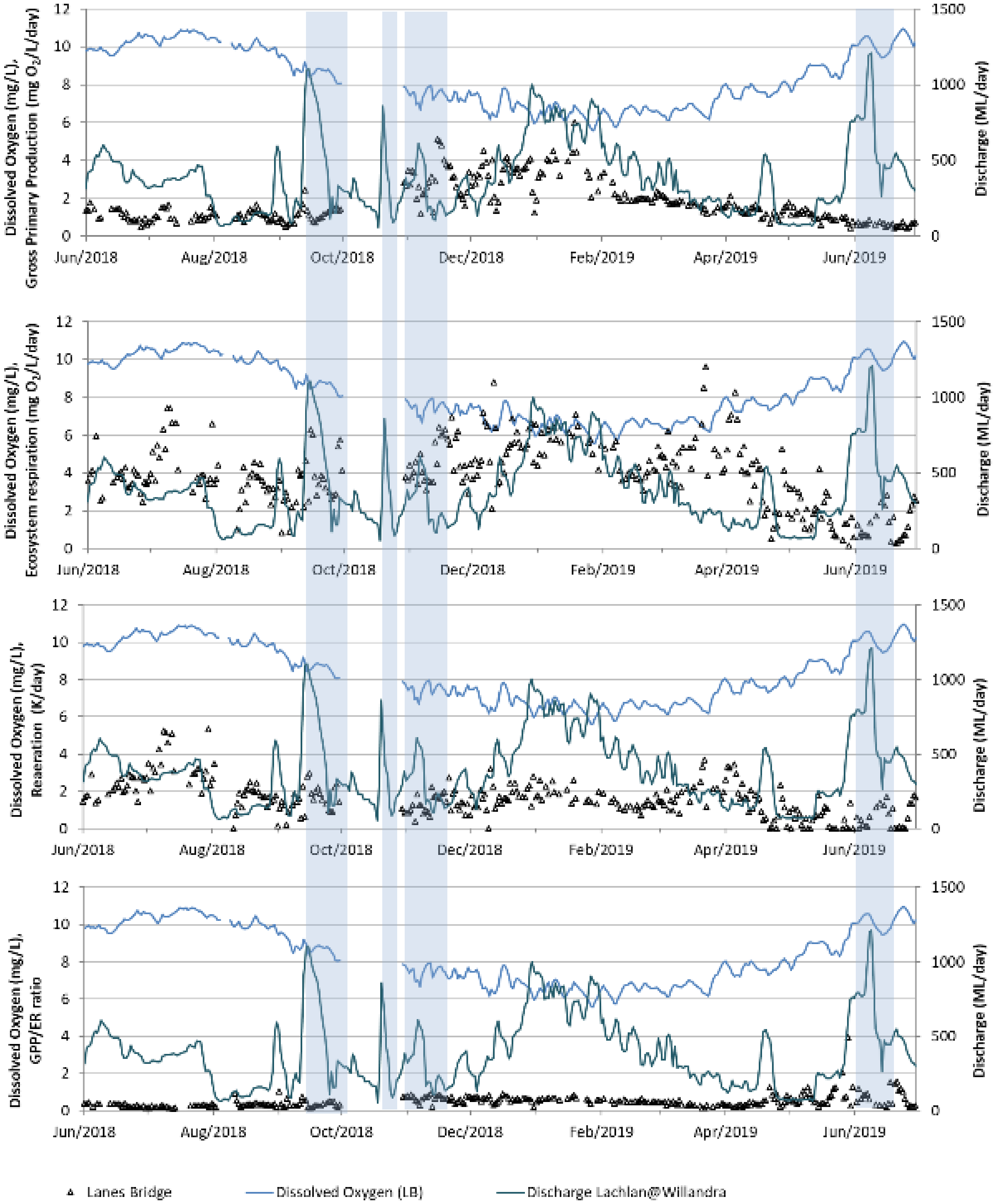


Figure 31. Gross primary production (GPP), Ecosystem respiration (ER), Reaeration (K) and the GPP/ ER ratio from Lane's Bridge in the Lower Lachlan, July 2018 - June 2019
Blue shaded vertical bars indicate watering actions.

5.3.3.2 Mid Lachlan River (Short Term Intervention Monitoring)

In August 2018 miniDOT (Precision Measurement Engineering Inc., Vista, USA) loggers were deployed at four sites in the Mid Lachlan (Figure 19), logging DO and water temperature at 10-min intervals. Photosynthetic active radiation (PAR) was measured in an adjacent unshaded location at 10-min intervals using a photosynthetic irradiance logger (Odyssey, Christchurch, New Zealand) at the Techam site. At Kirkup Park data were not able to be obtained for 42 days, see note in Table 8. At the other three sites data were obtained for an uninterrupted 328 day period from August 2018 to June 2019.

Curve fitting was applied using the BASE model as described above in order to estimate values for GPP and ER. Stream metabolism data was able to be used for GPP and ER estimate on an average of just 38% of days (range Euabalong [EU] = 30% to Kirkup Park [KP] and Mulgutherie [MG] with each = 42 %, see Table 7). To nearly 100% the cause for rejection of a logged day would be through the appliance of the criteria: R2 < 0.9.

After applying the standard numerical acceptance criteria, we visually inspected plotted GPP, ER and K values and rejected three data days from Kirkup Park, and one from Euabalong (high K values indicating the likelihood of exposure of the probe to air).

Table 7. Stream metabolism data obtained from the four sites in the Mid Lachlan river system during the sampling period 2018-19.
Shown is the number of logged days for each site with the count (Y) and percentile (%) for which a GPP, ER and K estimate could be modelled under the standard acceptance criteria.

ZONE	SITE	TIME PERIOD	# LOGGED DAYS	Y	%	NOTES (GAPS IN LOGGING, ODDITY WITH APPLICATION OF CRITERIA)
MID LACHLAN (M1)	EUABALONG (EB)	8/08/2018 - 30/06/2019	327	99	30	elimination of all 123 logged days after 28/2/2019
	KIRKUP PARK (KP)	7/08/2018 - 30/06/2019	286	119	42	gap of 42 days (21/09-01/11/2018)
	MULGUTHERIE (MG)	7/08/2018 - 30/06/2019	328	139	42	elimination of all 113 logged days before 28/11/2018
	TECHAM (TH)	7/08/2018 - 30/06/2019	328	123	38	

Time series plots of logged temperature, dissolved oxygen are shown in Figure 25 on p. 57. Discharge from the nearest NSW gauging station, logged DO, GPP, ER, reaeration (K) and the GGP/ER ratio for Techam as an example from the mid Lachlan sites are shown in Figure 32, and in section 5.8: Appendix 2: Stream metabolism plots for additional sites in the Mid Lachlan River 2018-19 can be found.

Watering Action 1 commenced on 29th August 2018 and delivered 10 391 ML of water targeting native fish and stream productivity outcomes in the mid Lachlan. Data for GPP and ER were relatively sparse for this flow event, with no data available from Mulgutherie and poor curve fits for the other three sites. There was no clear consistent effect of this event on either GPP or ER, although there was a small increase observed in GPP at Condobolin (*Figure* 32, Figure 39, Figure 40). There is some evidence for a slight increase in GPP and ER during the delivery of Watering Action 2, although the increase in ER could be as a consequence of increased reaeration (Figure 41), particularly at the Techam site (*Figure* 32). The high degree of correlation in GPP and ER responses during both watering actions meant that there was no observed effect of environmental flows on GPP/ER ratios (*Figure* 32, Figure 42). The increases in GPP and ER are consistent with a small amount of increased photosynthetic activity and mobilisation/consumption of organic matter. This is consistent with evidence from the water quality data which suggests mobilisation of both nutrients and carbon generating an increase in basal resources and productivity.

Small flow peaks later in the season, in June 2019, did not appear to be associated with an increase in either GPP or ER. The Mulgutherie site showed markedly different results to the other three sites, with a marked increase in ER, and an evident but smaller increase in GPP from February onwards (Figure 39, Figure 40). This was also correlated with an increase in reaeration at this site (Figure 41). Our interpretation of this data is that the logger was becoming exposed to highly oxygenated water, potentially due to being too close to the water surface. An alternate explanation may be that the logger itself experienced a progressive failure.

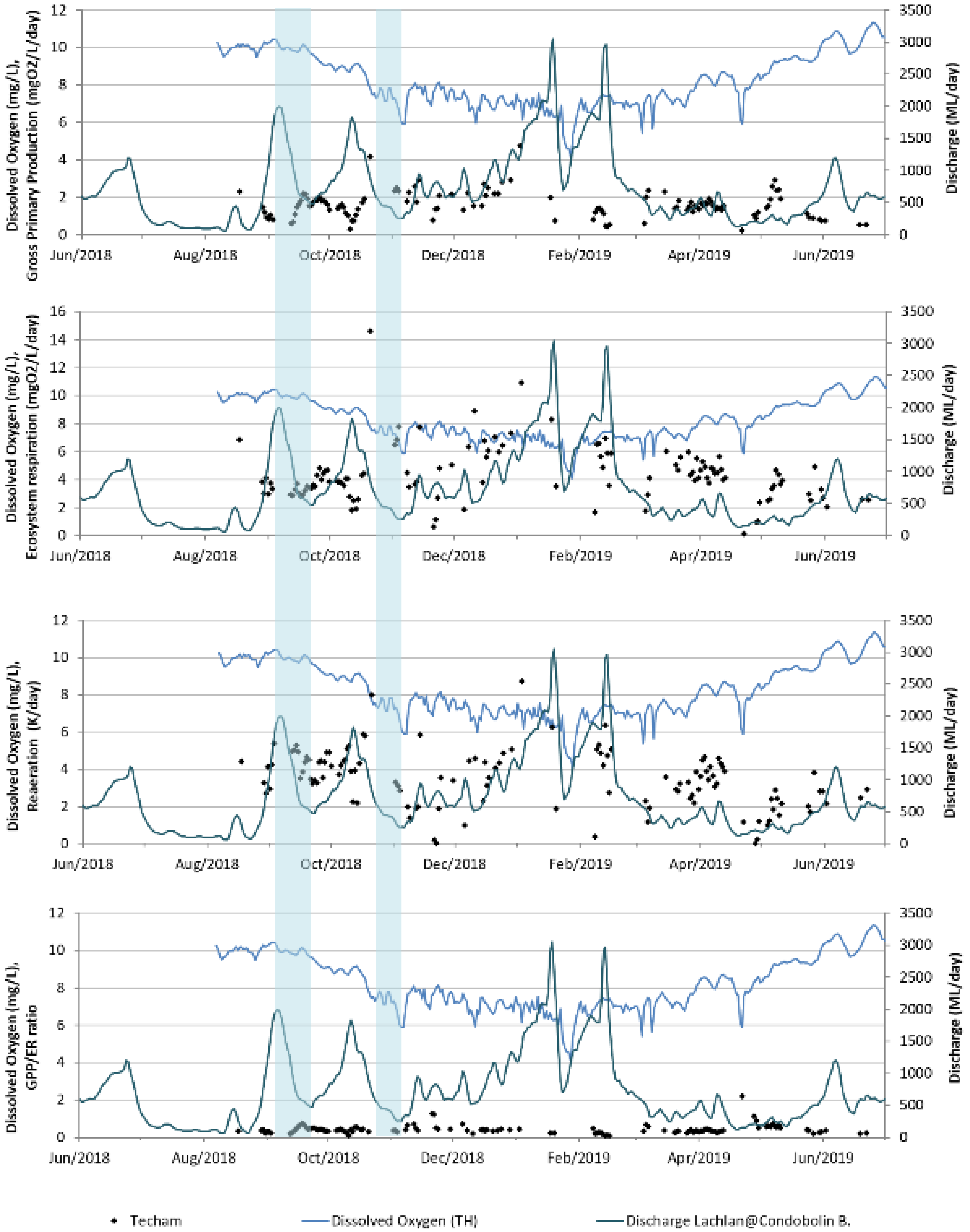


Figure 32. Gross primary production (GPP), Ecosystem respiration (ER), Reaeration (K) and the GPP/ ER ratio from Techham in the Mid Lachlan, August 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Ecosystem respiration (ER) graph on a higher scale.

5.3.4 STREAM METABOLISM – 2014-19

The consolidated metabolism data from the lower Lachlan shows clear overall patterns.

1. Strong seasonality in Gross Primary Production and Ecosystem Respiration, indicating a close coupling with water temperature. Effects of environmental flow delivery on GPP and ER are marked even when considered against this natural variability.
2. High variability in both GPP and ER, which appears to be both a consequence of variability in the physical process of reaeration and biological responses in the parameters. This variability means that there are large intervals where estimates for GPP and ER cannot be calculated, and these correlate with times of higher flows, including the large natural flood in 2016-17 and environmental flow events.
3. Evidence of a pattern of increased GPP and ER correlated with higher DOC and higher nutrient and algal concentrations during environmental flow delivery, particularly if this was associated with warm water conditions. In cooler conditions, the GPP response was considerably less, whereas the ER response appeared to be maintained.

GPP and ER showed a seasonal pattern (Figure 34, Figure 43, Figure 44, p. 84), strongly correlated with seasonal variation in temperature (Figure 22, p. 61 and 62). This pattern was particularly marked for GPP (Figure 34, Figure 43). However environmental flows in warmer months were also associated with increased GPP, generally lagged by a short period after the flow delivery commenced. ER responses were also seasonal, but the pattern was less marked and there were also intermittent very high values (Figure 34, Figure 43). Some of these values are likely to be artefacts of loggers becoming exposed to the air, however there were clear high ER events that were not simply correlated with flow – for example at Cowl Cowl in June 2016, preceding the large natural flood (Figure 44). Very high variation in reaeration (Table 9) is characteristic of the Lachlan, reflecting the complex nature of the banks and the presence of in-stream structure, which appears to generate a complex reaeration response as flows rise and fall (Figure 33). ER rates were generally significantly higher than the corresponding GPP rates, meaning that the sites are predominantly heterotrophic (P:R<1) and dominated by externally-sourced organic carbon rather than in situ photosynthesis.

Figure 33. In-stream structures at Whealbah.

Fluctuations in ER in particular create considerable variability in GPP/ER ratios through time. This relationship appears to vary in space – at Cowl Cowl there is evidence for a response to environmental flows which is marked, but at the other three sites there is no clear pattern (Figure 34, Figure 46).

There is a limited amount of data available for making clear conclusions on the effects of environmental water in the lower Lachlan, and interpretation is made more complex by the high year to year variability in inflows (Table 8).

Table 8. Stream metabolism data obtained from the four sites in the Lower Lachlan river system during the whole sampling period 2014-19.
Shown is the number of logged days of oxygen data for each site (data days = Y) and the percentile (%) for which a GPP/ER /K estimate could be modelled under the standard acceptance criteria.

Site	Count logged days	Y	%
Cowl Cowl (CC)	1141	521	46
Lanes Bridge (LB)	1519	988	65
Wallanthery (WAL)	797	305	38
Whealbah (WB)	1413	888	63

Table 9. Stream metabolism data averages for all four variables and all four Lower Lachlan River sites over the sampling period 2014-2019

SAMPLING PERIOD	COWL COWL (CC)	LANES BRIDGE (LB)	WALLANTHERY (WAL)	WHEALBAH (WB)	AVERAGE
	Gross primary production (GPP)				
2014-15	1.8	1.4		2.4	1.4
2015-16	1.9	1.6	3.1	2.5	2.3
2016-17	0.8	2.9		2.5	2.1
2017-18	4.0	2.6	2.5	3.0	3.0
2018-19	5.4	1.8	2.4	2.6	3.1
AVERAGE	2.8	2.1	2.0	2.6	2.4
	Ecosystem respiration (ER)				
2014-15	2.2	2.1		2.8	1.8
2015-16	4.6	3.9	4.0	4.6	4.3
2016-17	2.0	6.1		4.1	4.1
2017-18	3.2	4.7	7.8	4.7	5.1
2018-19	2.6	3.9	4.8	5.8	4.3
AVERAGE	2.9	4.1	4.1	4.4	3.9
	GPP/ER ratio				
2014-15	1.0	0.7		0.9	0.6
2015-16	0.5	0.4	0.8	0.6	0.6
2016-17	0.5	0.6		0.7	0.6
2017-18	7.1	0.6	0.4	0.7	2.2
2018-19	5.4	0.5	0.6	0.5	1.7
AVERAGE	2.9	0.6	0.5	0.7	1.1
	Reaeration (K)				
2014-15	2.0	1.0		1.3	1.5
2015-16	3.0	2.0	2.8	1.4	2.3
2016-17	1.5	1.9		1.3	1.5
2017-18	1.4	1.4	4.2	1.1	2.0
2018-19	1.7	1.5	2.3	1.6	1.8
AVERAGE	1.9	1.6	3.1	1.3	2.0

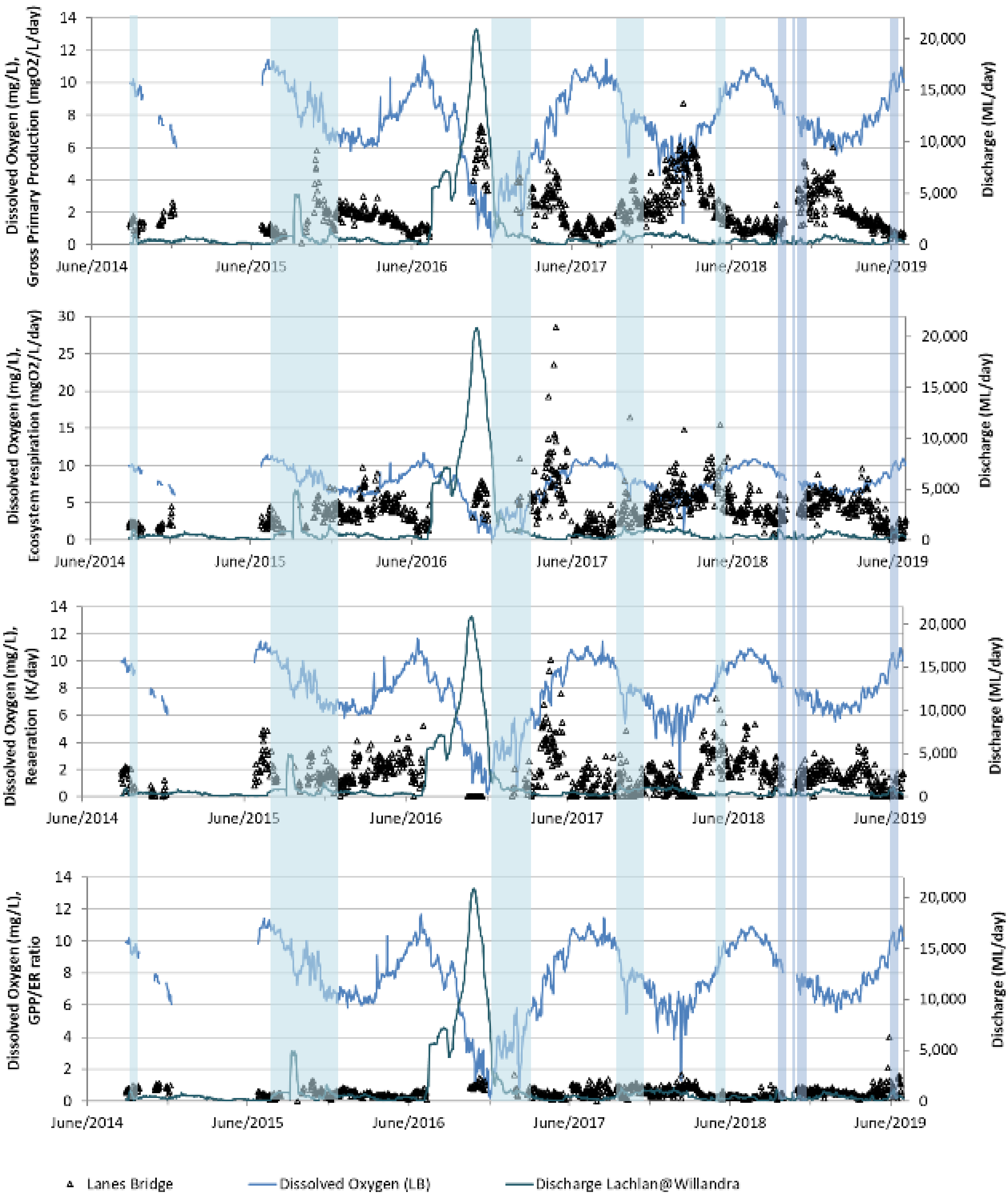


Figure 34. Gross primary production (GPP), Ecosystem respiration (ER), Reaeration (K) and the GPP/ ER ratio from Lane's Bridge in the Lower Lachlan, August 2014 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Ecosystem respiration (ER) on higher scale.

5.4 DISCUSSION

The sampling period featured four environmental watering actions in the Lower Lachlan, three in early summer and an additional one in late autumn. Water quality data suggested that the summer events mobilised nutrients and carbon, with a response in productivity. The delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream (e.g. Baldwin et al. 2016, Wallace and Furst 2016). There was evidence of a peak in GPP and in ER in November and December associated with delivery of environmental water. Similar small peaks were evident in the June flow, but were smaller, more transient in nature and not observed across all sites. Results for ER during the second flow may suggest mobilisation of carbon from in-stream benches, but are confounded by changes in reaeration due to physical processes.

5.4.1 WATERING ACTION 1

The 2018-19 watering action in September 2018 targeted native fish and productivity outcomes in the mid reaches of the Lachlan River and Booberoi Creek, with retention and later release of water from Lake Brewster generating a small secondary flow pulse in late October in the lower Lachlan. The watering action was designed to support the movement of native fish prior to the spawning season and stimulate primary productivity to support improvements in fish condition.

This event appeared to mobilise nutrients and carbon in channel, resulting in increases in algal biomass and a measurable increase in both GPP and ER. This is suggestive of basal productivity from both organic carbon from the banks and from photosynthesis. This pulse of productivity, if it is transferred to zooplankton consumers, would be an important resource in supporting larval fish.

5.4.2 WATERING ACTION 2

The environmental flow provided over November 2018 sought to generate minimum stable flows of in the mid Lachlan River to protect Murray cod and catfish nests. CEW water release for this action occurred between 22-30th October, compensating for lower operational flows over this period.

When re-regulated to provide a small fresh in the Lower Lachlan, this event appeared to mobilise nutrients and carbon in channel, resulting in increases in algal biomass and a measurable increase in both GPP and ER that appeared to exceed that seen in the earlier environmental flow. This is suggestive of enhanced basal productivity from organic carbon inputs and algae, with potential benefits to consumers higher up the food chain.

5.4.3 WATERING ACTION 4

The environmental flow provided 5,338 ML of water in June 2019, targeting productivity responses in the Great Cumbung Swamp in the Lower Lachlan river system.

There was evidence for increases in ER, although high reaeration values mean that interpreting these values just as a consequence of increased respiration is not absolutely reliable. Relatively smaller increases in GPP may have been affected by lower water temperatures.

5.4.4 WATERING OVER THE PERIOD 2014-19

There is a strong seasonal pattern in GPP and ER, but despite this there is evidence for effects of environmental flow delivery on GPP and ER. Both GPP and ER increase during flow delivery, correlated with higher DOC and higher nutrient and algal concentrations. This pattern is particularly evident during warmer conditions. In cooler conditions, the GPP response was considerably less, whereas the ER response appeared to be maintained.

High variability in both GPP and ER is a consequence of variability in the physical process of reaeration and biological responses in the parameters. Reaeration becomes the dominant process during higher flows, meaning that estimates for GPP and ER cannot be calculated during peak flows. This complicates determining the magnitude of metabolism responses.

Delivery of small autumn flows has now been achieved several times in the Lachlan. Despite lower water temperatures at this time, there is evidence that this produces increases in ecosystem respiration, and smaller but detectable increases in algal production. It is not clear what role this may play in determining the magnitude of spring responses in the following year.

5.5 EVALUATION

Evaluation is complicated by major changes in the climatic context for flow responses over the five years program to date. A dry year in 2015-16 was followed by one of the wettest years on record in 2016-17, with natural flooding completely dominated the watering of the Lower Lachlan river system. The 2017-18 year was much dryer and environmental flows were responsible for relatively large flow events in comparison to operational flows. The most recent period has been dryer still, with smaller amounts of CEW water delivered against a progressively drying background and substantively lower operational flows.

In relation to the effects of Commonwealth environmental water, the evaluation questions are addressed as follows:

1) What did Commonwealth environmental water contribute to water quality outcomes?

There is evidence that watering events can alter water quality parameters, particularly through increasing carbon and nutrients, although these effects appear to be relatively transient and can be highly variable in magnitude in both space (site to site) and time. These effects are much smaller than those observed during large natural flows.

2) What did Commonwealth environmental water contribute to patterns and rates of ecosystem respiration (ER) and primary productivity (GPP)?

There was evidence for watering events generating short pulses of GPP and ER, with GPP responses being larger in warmer conditions. Relatively minor changes in nutrients and carbon (relative to background variability) do appear to support relatively larger (compared to background variability) responses in productivity.

5.6 FINAL COMMENTS AND RECOMMENDATIONS

Commonwealth environmental water was used strategically in 2018-19 to support fish breeding in the mid and lower Lachlan and appears to have generated productivity pulses at times that are likely to have benefited higher consumers. Later smaller flows under cooler conditions yielded detectable, but more transient and spatially variable pulses in production.

a) There was no clear evidence for either positive or adverse effects of CEW on water quality. Temperature was dominated by seasonal cycles, with consequent effects on dissolved oxygen. This is reflective of the lack of sources of nutrients to be mobilised by flows of this scale, and the relatively small volumes of water being applied. Larger volumes of water can be an effective management tool in terms of mobilising or diluting dissolved organic carbon, as has been evident in previous watering actions. Large natural flows can dramatically alter water chemistry parameters, but far exceed the volumes available for environmental watering.

b) Concentrations of key basal resources (DOC and chlorophyll) were variable with some evidence of effects of environmental flows. There was evidence of initial dilution of algal cells on the ascending limb of the hydrograph and then a lagged increase after the peak flow. Several environmental flow events showed evidence of slight increases in DOC consistent with increased carbon availability. Environmental flows with even small peaks in nutrient availability were associated with high values of chlorophyll. As for water chemistry more broadly, values of DOC during large natural flows event indicated large scale mobilisation of carbon.

c) There is evidence for productivity responses to environmental flow delivery in the lower Lachlan River, particularly when water temperatures are warmer. While the river was generally heterotrophic (dominated by external carbon rather than in situ photosynthesis), it tended to be more autotrophic during environmental flows. This may be suggestive of generating higher quality local production. Flows targeting productivity responses or supporting fish larvae should be targeted to warmer conditions.

d) Provision of environmental water as a short term, relatively small event in autumn appeared to meet the objective of generating a small resource pulse in-channel. These may be important ecologically in providing resources at a relatively resource poor period, supporting maintenance of fish condition into the winter period.

Based on these outcomes the following can be recommended:

I. Provision of flows to generate productivity responses to support fish larvae and to improve food availability is realistic and will generate the greatest responses when associated with warmer water conditions.

II. Provision of environmental flows during cooler periods does not produce as large a productivity response, and the response appears to be dominated by carbon respiration rather than primary production by algae. Provision of resources at this time may ‘prime’ ecosystems and contribute to fish condition, allowing for more rapid and larger responses to spring flows in the subsequent year. Additional years of data will enable greater understanding of these processes and their role in the Lachlan river system.

5.7 APPENDIX 1: STREAM METABOLISM PLOTS FOR ADDITIONAL SITES IN THE LOWER LACHLAN RIVER 2018-19

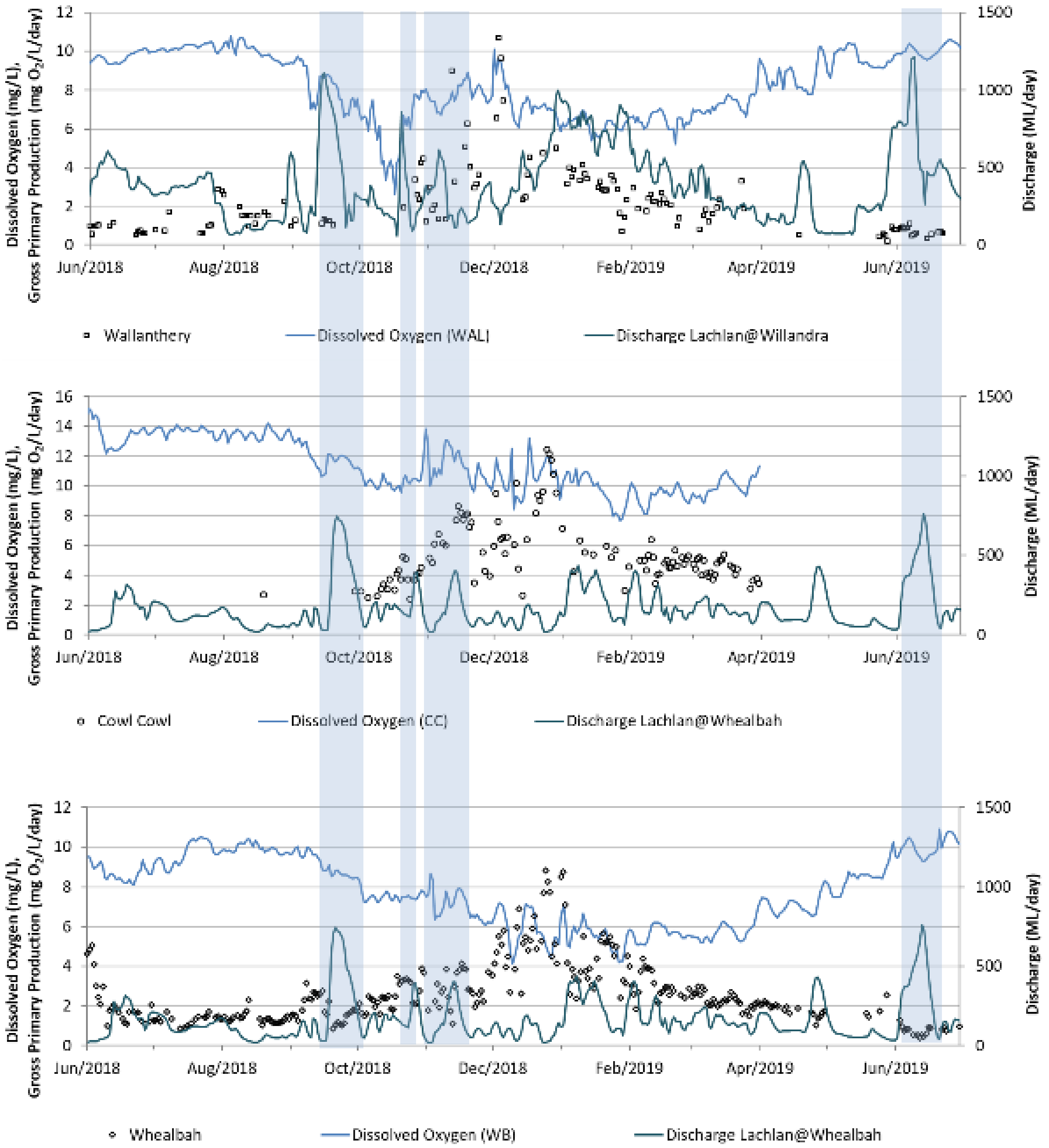


Figure 35. Gross primary production (GPP) from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, June 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Cowl Cowl on a higher scale for dissolved oxygen and GPP.

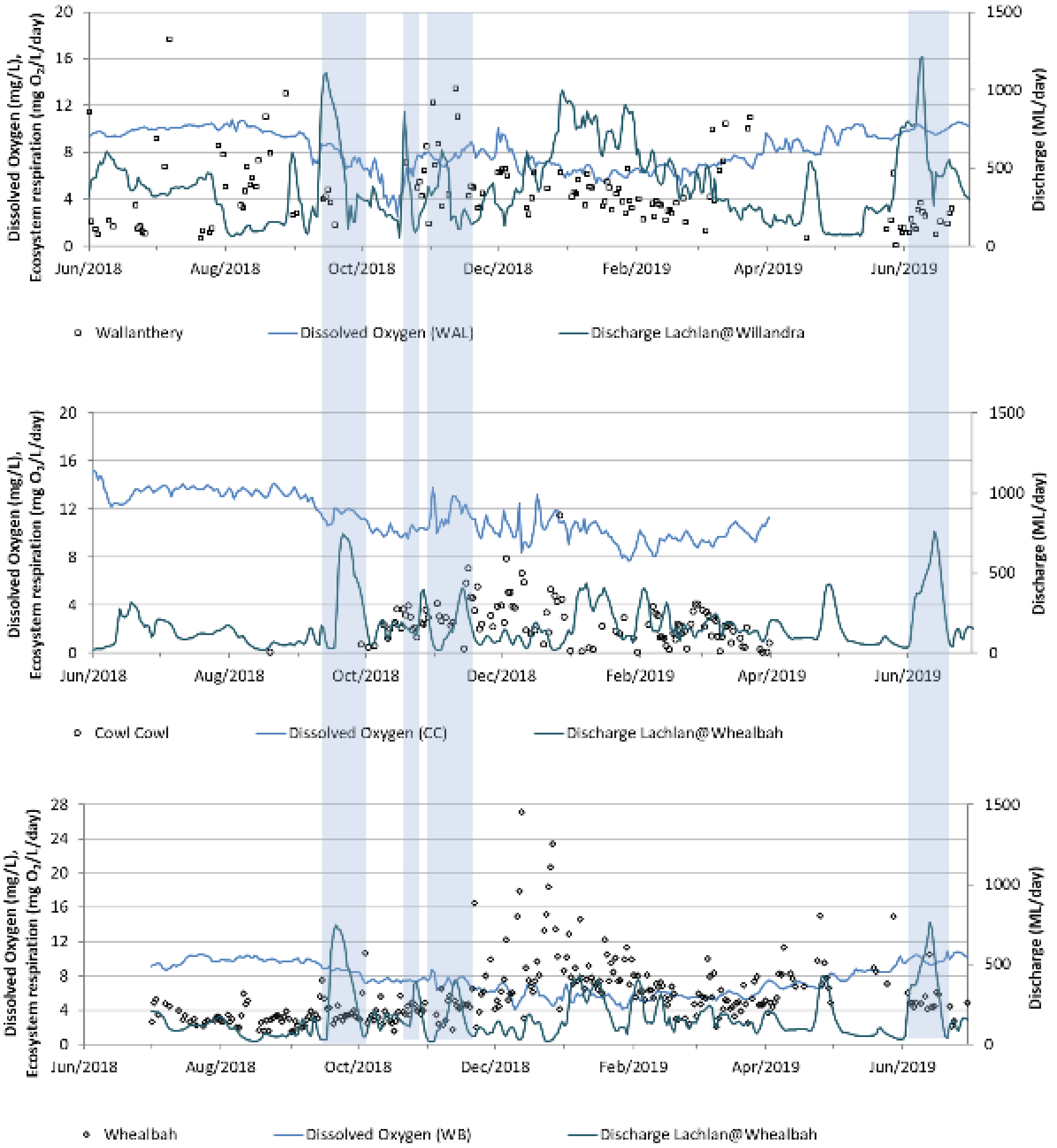


Figure 36. Ecosystem respiration (ER) from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, June 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Whealbah on a higher scale for dissolved oxygen and ER.

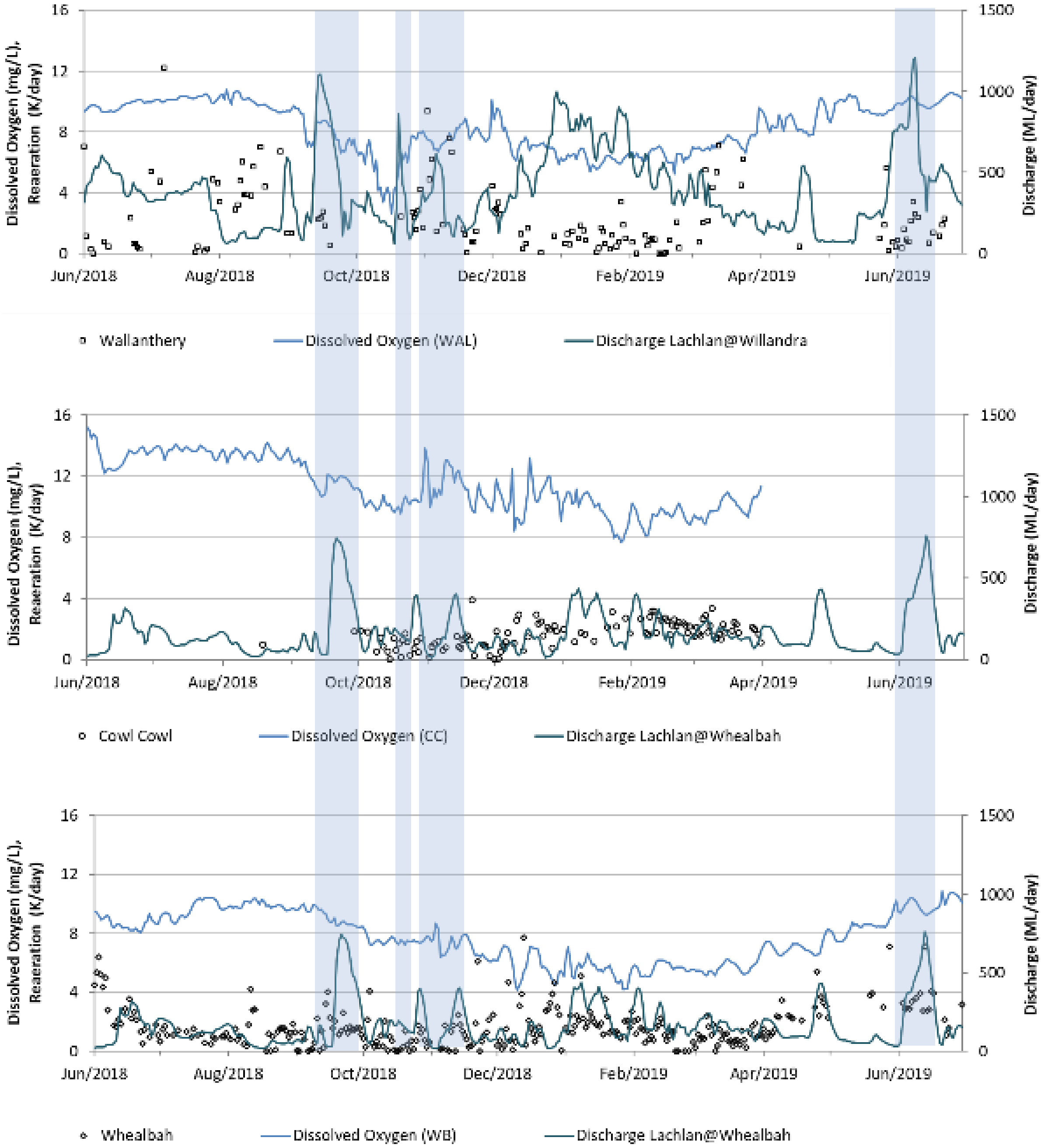


Figure 37. Reaeration (K) from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, June 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.

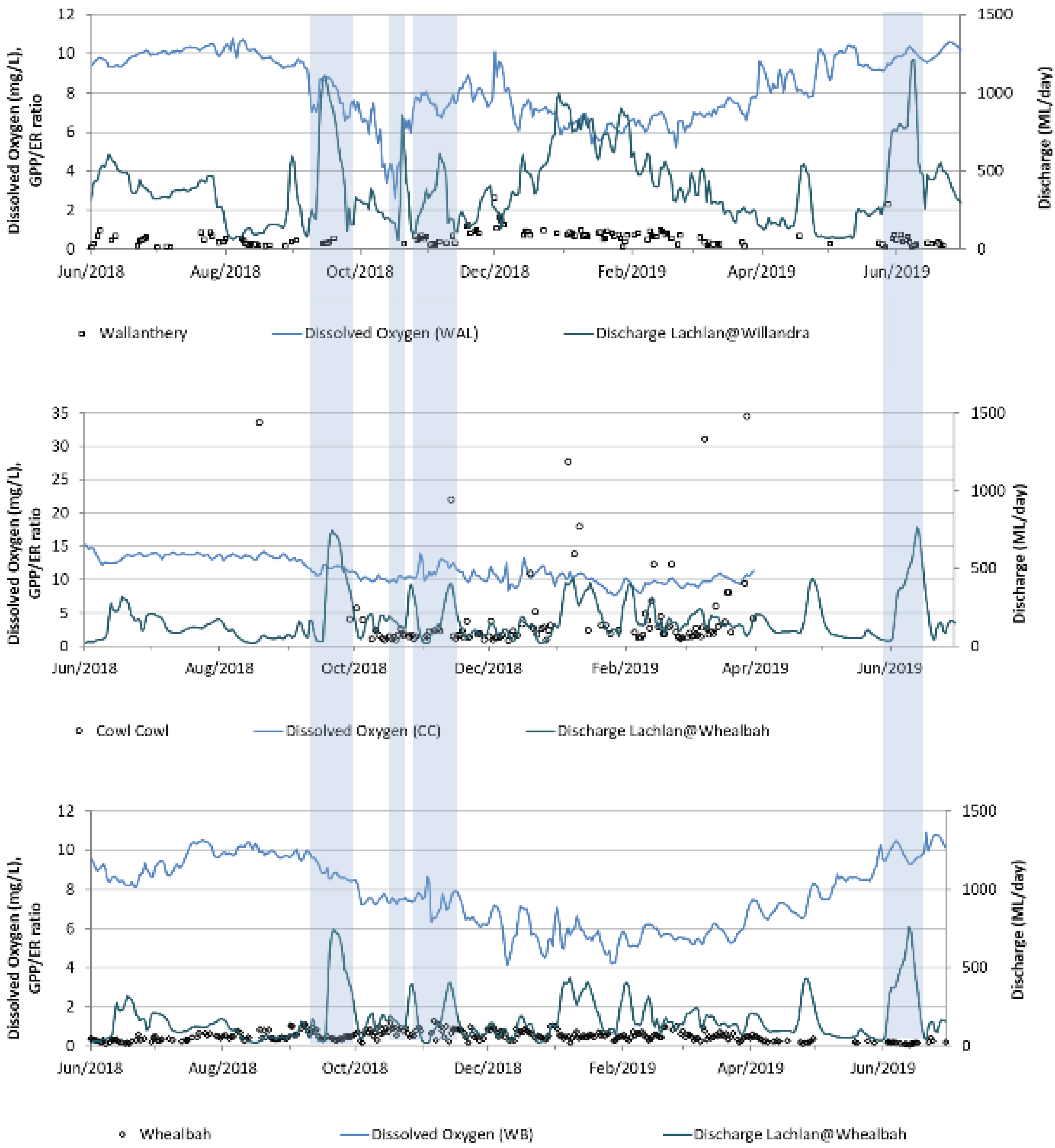


Figure 38. GPP/ ER ratio from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, June 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Cowl Cowl on a higher scale for dissolved oxygen and the GPP/ ER ratio.

5.8 APPENDIX 2: STREAM METABOLISM PLOTS FOR ADDITIONAL SITES IN THE MID LACHLAN RIVER 2018-19

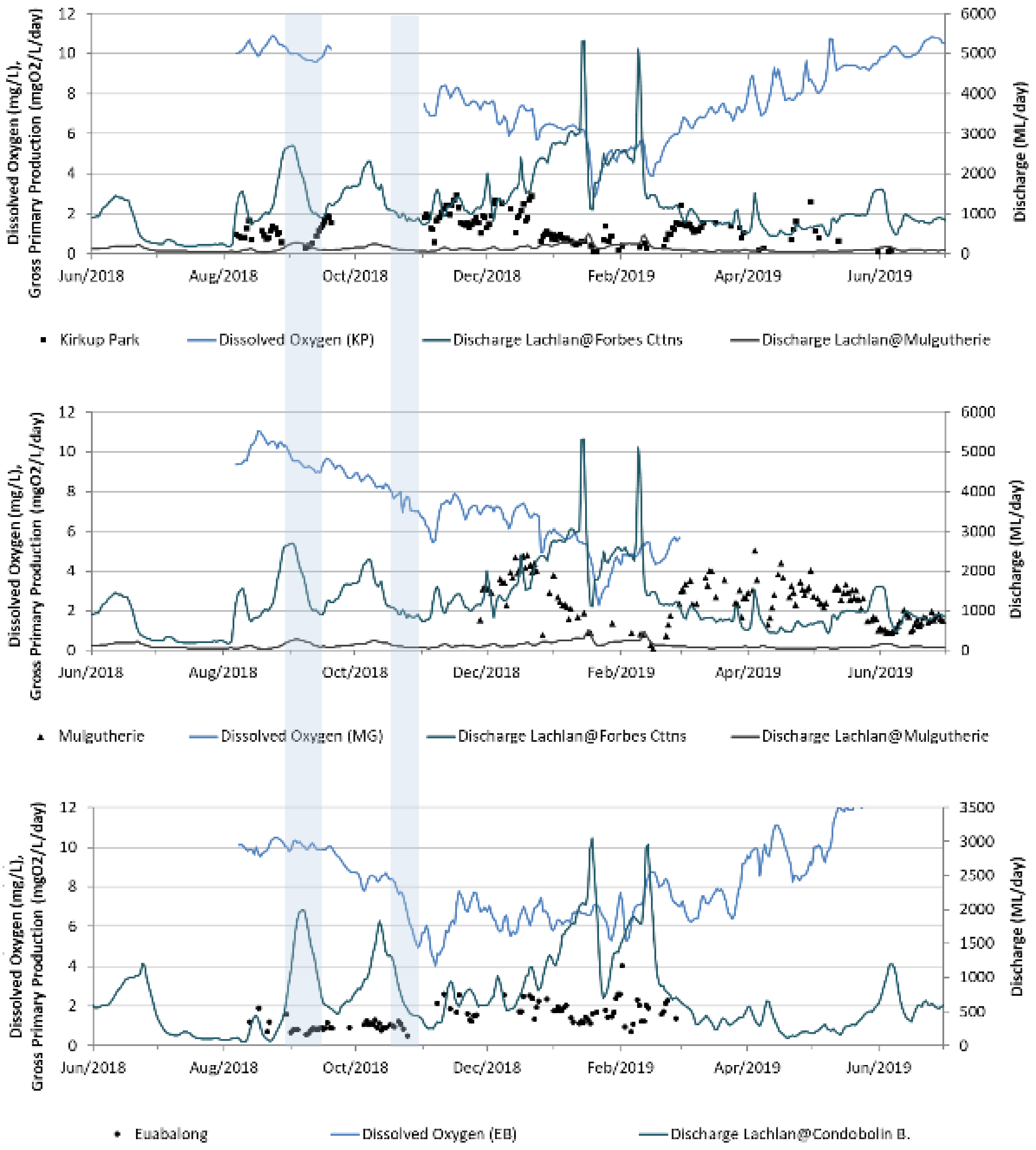


Figure 39. Gross primary production (GPP) from Kirkup Park, Mulgutherie and Euabalong in the Mid Lachlan, August 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Euabalong on a lower scale for discharge.

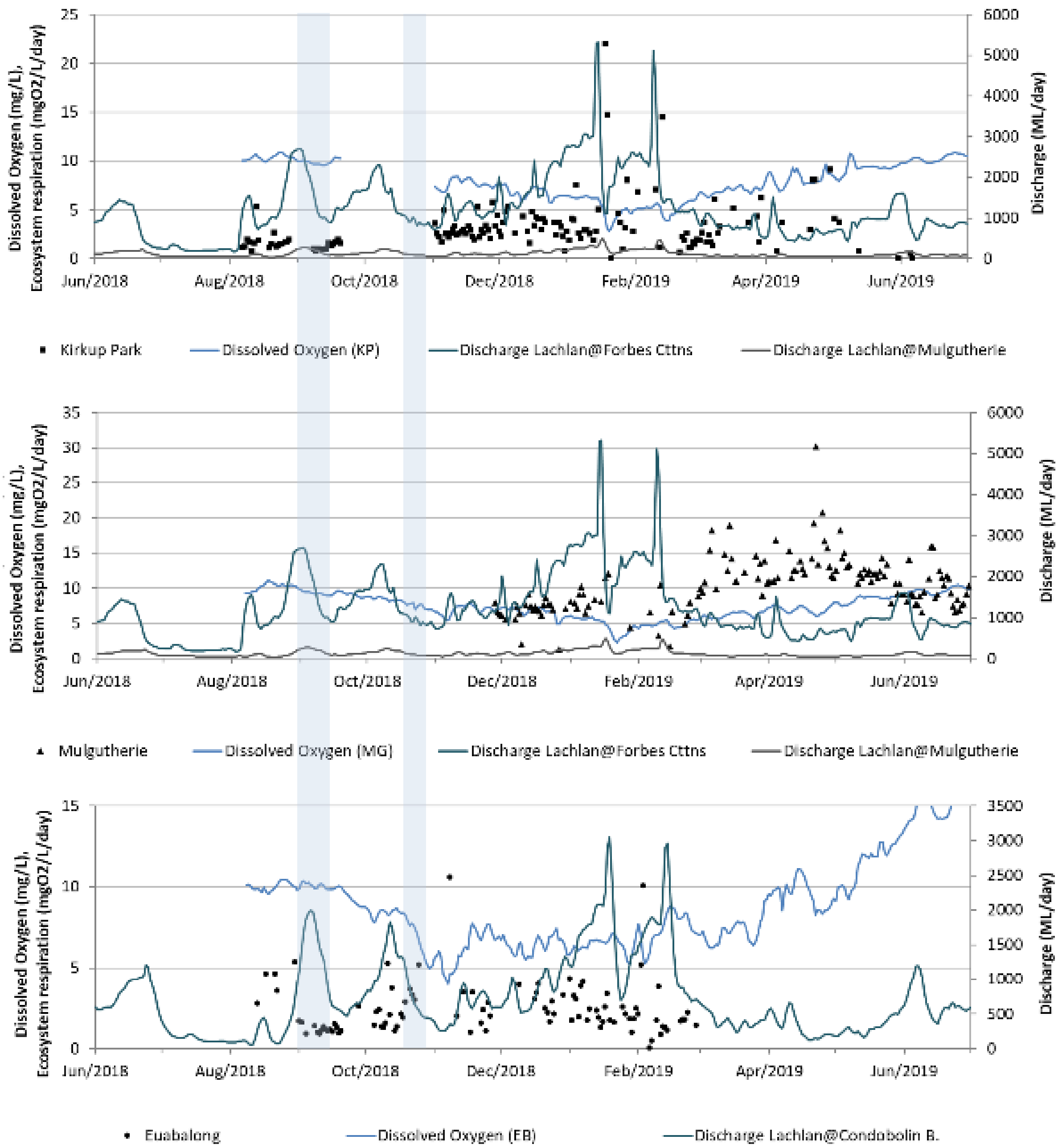


Figure 40. Ecosystem respiration (ER) from Kirkup Park, Mulgutherie and Euabalong in the Mid Lachlan River, August 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: All sites on different scales for dissolved oxygen and ER. Euabalong on a lower scale for discharge.

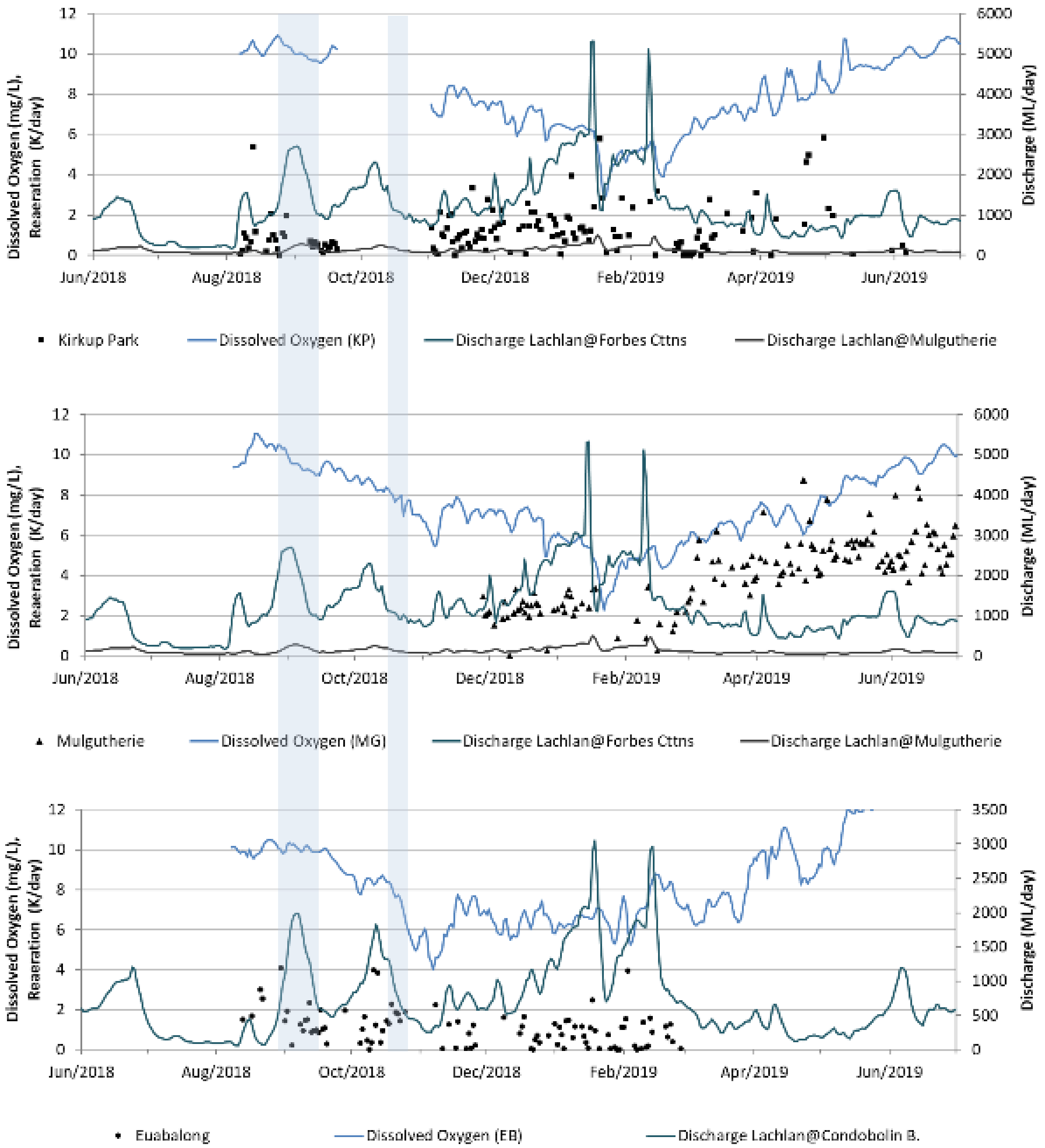


Figure 41. Reaeration (K) from Kirkup Park, Mulgutherie and Euabalong in the Mid Lachlan River, August 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Euabalong on a lower scale for discharge.

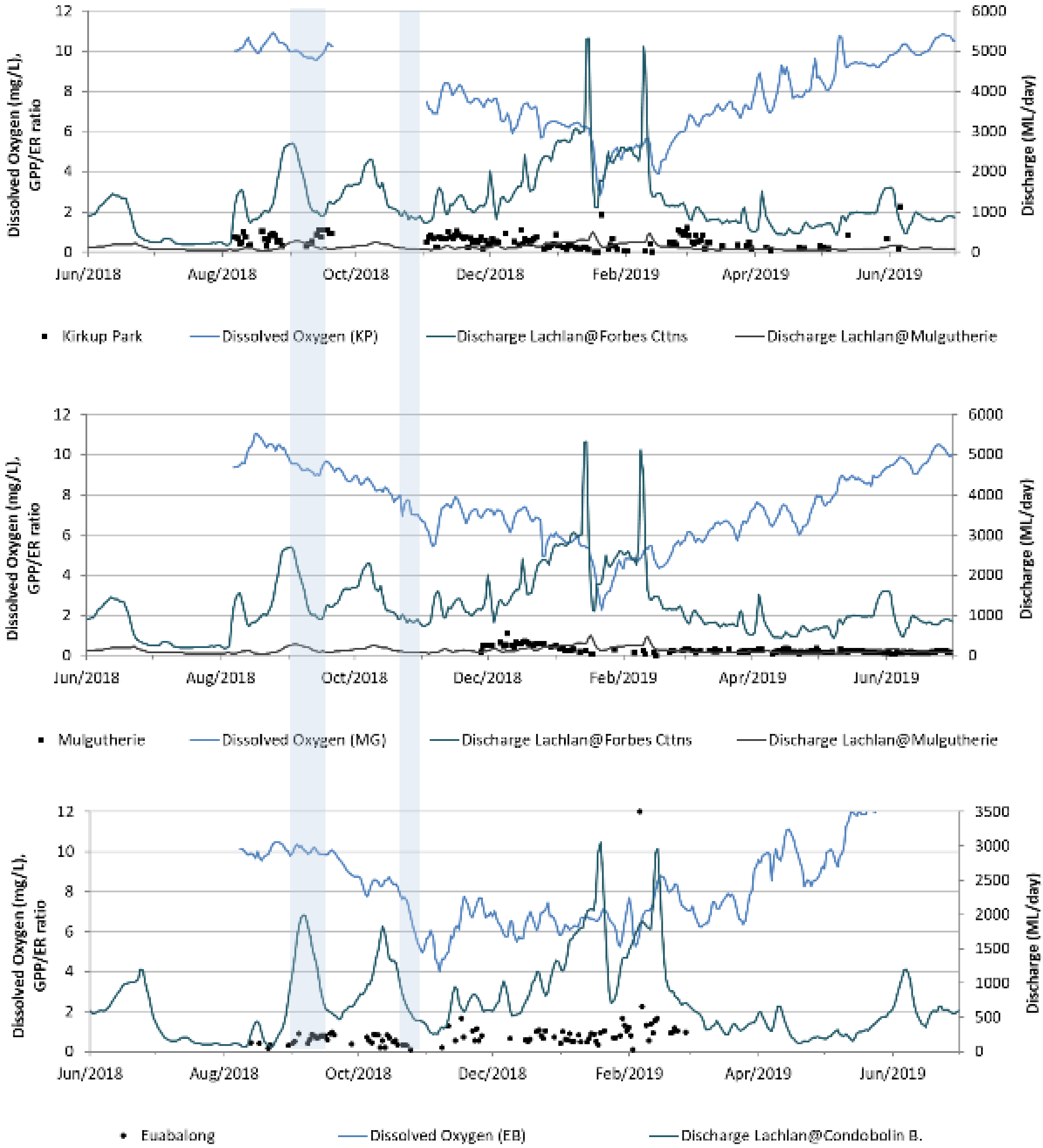


Figure 42. GPP/ ER ratios from Kirkup Park, Mulgutherie and Euabalong in the Mid Lachlan River, August 2018 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Euabalong on a lower scale for discharge.

5.9 APPENDIX 3: STREAM METABOLISM PLOTS FOR ADDITIONAL SITES IN THE LOWER LACHLAN RIVER 2014-19

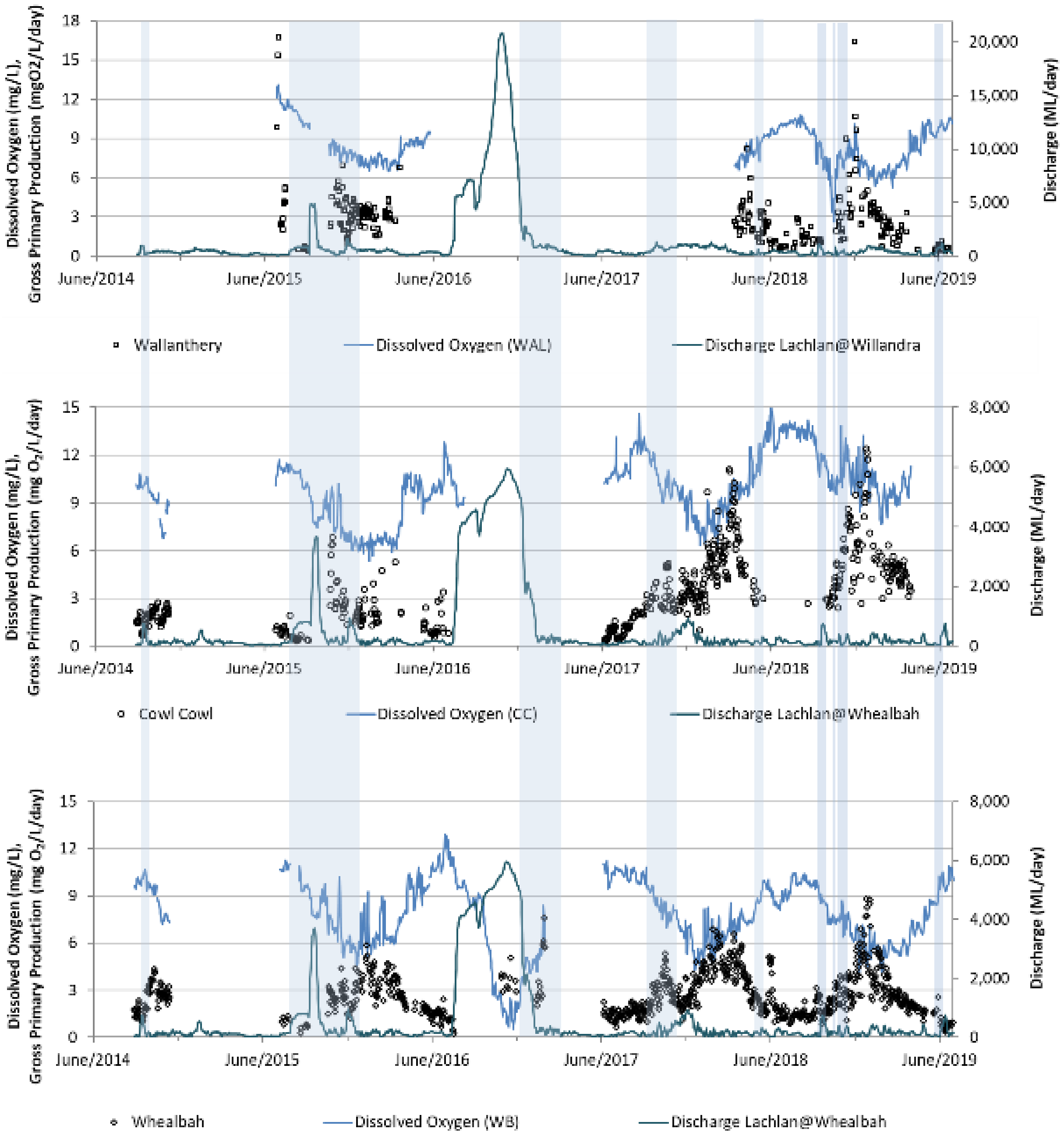


Figure 43. Gross primary production (GPP) from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, August 2014 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Wallanthery on a higher scale for dissolved oxygen and GPP. Wallanthery on a higher scale for discharge.

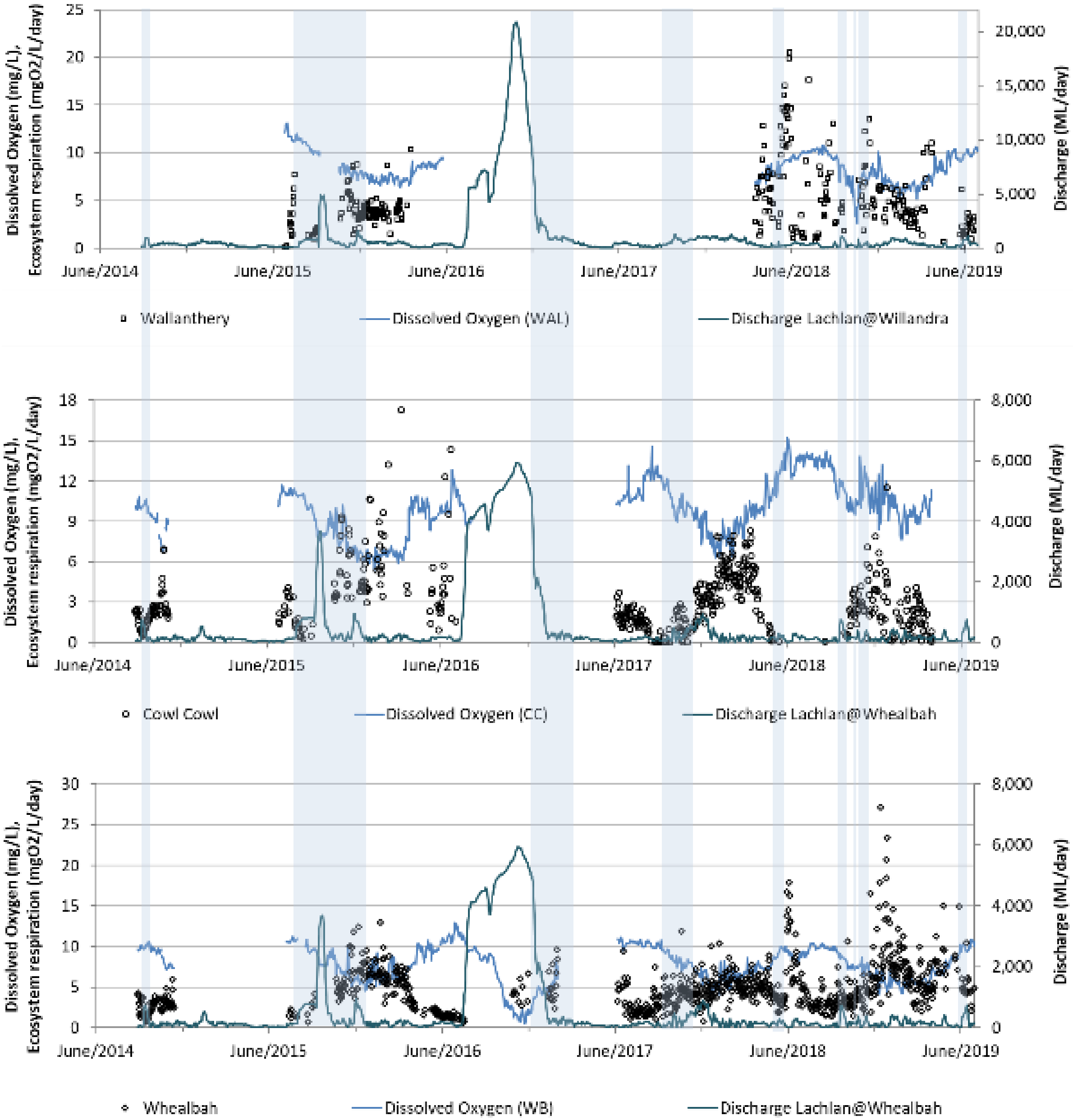


Figure 44. Ecosystem respiration (ER) from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, August 2014 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: All sites on a different scale for dissolved oxygen and ER. Wallanthery on a higher scale for discharge.

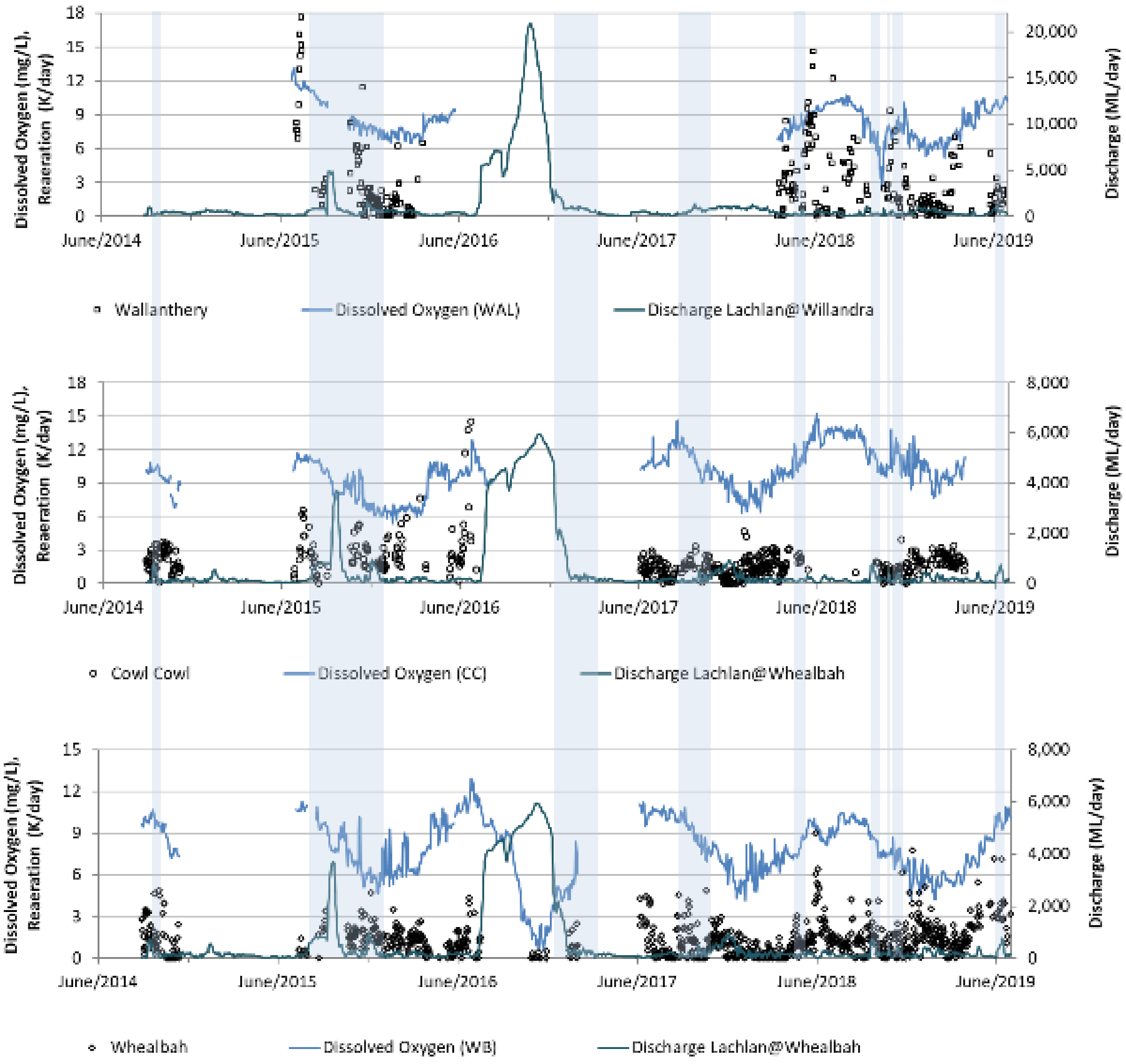


Figure 45. Reaeration (K) from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, August 2014 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Whealbah on a lower scale for dissolved oxygen and reaeration. Wallanthery on a higher scale for discharge.

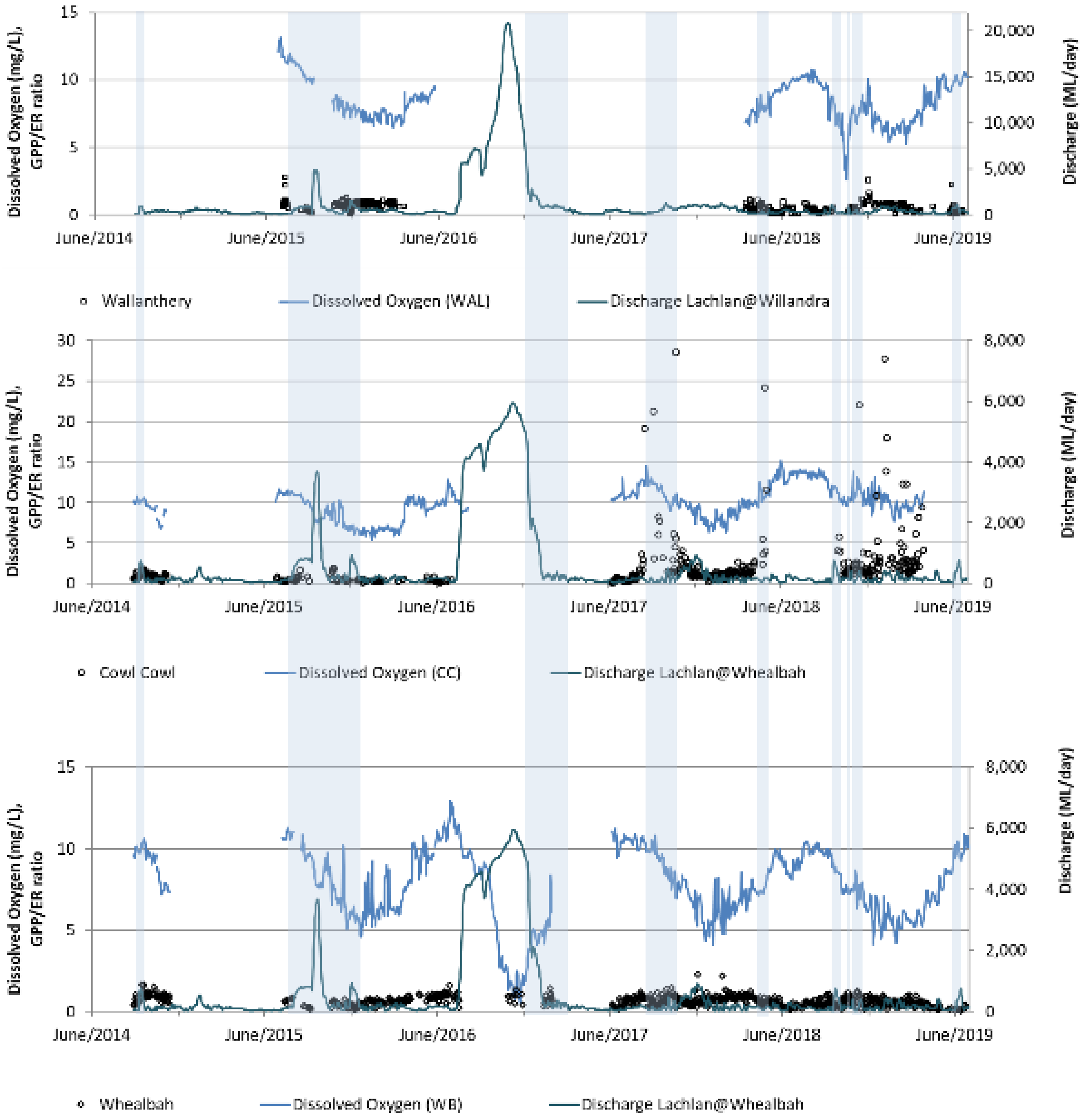


Figure 46. GPP/ ER ratio from Wallanthery, Cowl Cowl and Whealbah in the Lower Lachlan, August 2014 - June 2019.
Blue shaded vertical bars indicate watering actions.
Note: Cowl Cowl on a higher scale for dissolved oxygen and the GPP/ ER ratio. Not shown are 3 outlier for Wallanthery and 20 outlier for Cowl Cowl for the GPP/ ER ratio above 30. Wallanthery on a higher scale for discharge.

6 FISH COMMUNITY

6.1 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, Turak and Linke 2011). The advantages of using fish as indicators of aquatic ecosystem condition include; i) fish are relatively long-lived and 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 (Table 17, p. 113) are believed to have occurred in the mid- and 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 or extremely rare (NSW DPI, *unpublished data*). These four species are 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-gudgeon (*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. 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 (e.g. 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. Flushes of fresh water (freshes) also provide movement triggers and facilitate longitudinal connectivity within the system. Persistence of native species is dependent on the provision of natural spawning triggers, and subsequent boosts in primary production, which facilitate successful recruitment. For all fish species, access to high quality refugia during drought is critically important for ecosystem resilience as, unlike many other taxa, fish have no mechanisms to cope with 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. In 2019, monitoring the fish community at a second reach (the mid-Lachlan River) was added for a single year.

A number of Commonwealth environmental watering actions relevant to riverine native fish communities were delivered in 2018-19, including flows to support the movement of native fish (Action 1), flows to inundate preferred nesting habitat for species including Murray cod and freshwater catfish as well as to promote instream productivity and larval dispersal opportunities (Action 2), and flows to support native fish movement and survival in autumn-winter 2019 (Action 4) (Dyer et al. 2018). To assess the contributions of Commonwealth environmental water to the fish community, the relevant short term and long-term questions to be evaluated are:

6.1.1 SHORT-TERM (ONE-YEAR) QUESTIONS:

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

6.1.2 LONG-TERM (FIVE-YEAR) QUESTIONS:

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

In 2018-19, the aim of this component of the Lachlan LTIM Project was to assess changes in the fish community, in terms of abundance, biomass and community health, in the Lower Lachlan river system Selected Area in relation to the general hydrological regime, and thereby provide a basis for determining potential changes in relation to current and future use of environmental water. The aim of the fish community monitoring in the mid-Lachlan River was to develop a baseline condition of the fish community assemblage, and to evaluate the effectiveness of 2018 – 2019 watering actions released in the reach which had the following objectives relating to native fish:

1. To support the movement of native fish prior to the spawning season and support the ability of native fish to achieve good pre-spawning condition.
2. To be of short duration to prevent early nesting at higher river level.
3. To support spawning success of native fish that may have spawned early, such as Australian smelt.
4. To inundate areas of the river channel containing large woody habitat (snags) which is the preferred spawning habitat for nesting native fish such as Murray cod, River blackfish and freshwater catfish.
5. Avoid rapid drops in water level (because of variation in irrigation demands) from late September to early December to prevent nest abandonment by native fish.
6. Promote the dispersal of larval/juvenile Murray cod, River blackfish and freshwater catfish with a short rise in flows at the end of November as fish leave their nest site within days-weeks post-hatching. It may also provide an additional productivity

boost and hence replenish food sources for larvae as they begin to feed on their own.
7. Recede flows towards the end of this period to extend duration of downstream dispersal by larval and juvenile fish and extend upstream movement opportunities for adolescents and adult fish.

The current study reports on the fifth year of the five-year Long Term Intervention Monitoring Project in the lower Lachlan River and the first and only year of monitoring thus far in the mid-Lachlan River.

6.2 METHODS

Fish community data was collected from 20 in-channel sites, 10 each from the Lower Lachlan river system Selected Area, from Wallanthery to Hillston and from the mid-Lachlan River reach from Forbes to Lake Brewster (see Figure 18 and Figure 19, p. 51). 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, 2012). Sampling was undertaken in March-April 2019, 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) and small fyke nets (n=10) (Hale et al. 2014). Additionally, large fyke nets were used at each site to target freshwater catfish (n=4). Decapods were also surveyed and these were sampled using baited opera house traps (n=5).

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".

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 in the lower Lachlan River selected area (2015, 2016, 2017, 2018 and 2019) abundance and biomass data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008). This analysis was done using the vegan package (Oksanen et al. 2019) in R (R version 3.6.1, R Development Core Team 2019). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between years.

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 recruits and non-recruits. Large-bodied and generally longer lived species (maximum age >3 years) were considered recruits when length was less than that of a one year old. Small-bodied and generally short-lived species, that reach sexual maturity in less than one year, were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 10). 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 10. 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)
flatheaded 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)
redfin perch	60 mm (maximum reported by Heibo et al. 2005)

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), and the average proportion of total abundance of each species that are new recruits (Robinson 2012).

The three indicators above 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).

6.3 RESULTS

6.3.1 LOWER LACHLAN RIVER (LONG TERM INTERVENTION MONITORING)

A total of 8,365 fish comprising six native and three alien species were captured across 10 in-channel sampling sites in 2019 (Table 2). In order, bony herring, carp gudgeon, eastern gambusia (*Gambusia holbrooki*), and common carp were the most abundant species (Table 11; **Error! Reference source not found.**). In order, common carp, golden perch, Murray cod and bony herring contributed the greatest overall biomass in 2019 (Figure 48).

New recruits (juveniles) were detected in two native longer-lived species; bony herring (9 of 10 sites) and Murray cod (4 of 10 sites, **Error! Reference source not found.**, Figure 49), and two native short-lived species (Australian smelt (1 of 10 sites) and carp gudgeon (10 of 10 sites, **Error! Reference source not found.**, Figure 49). No golden perch new recruits were captured (**Error! Reference source not found.**, Figure 49). New recruits of three alien species were captured (common carp (*Cyprinus carpio*) (9 of 10 sites), goldfish (*Carassius auratus*) (4 of 10 sites) and eastern gambusia (2 of 10 sites, **Error! Reference source not found.**, Figure 49).

Sustainable Rivers Audit indices fell within different bands for the target reach. Nativeness was classed as "Good" (mean ± SE score: 82.3 ± 5.0), Expectedness was "Very Poor" (29.8 ± 3.0) and Recruitment was "Very Poor" (38.0; zone metric). The Overall Condition of the fish community was classed as "Very Poor" (27.6 ± 2.6) (Table 12, Figure 50 on p. 100 Figure 53 on p. 105).

There were significant differences in the abundance (*Pseudo-*$F_{4, 45}$ = 11.353, $P < 0.001$) of the fish community among years. Pair-wise comparisons indicated that the differences in abundance were between all combinations of years except between 2015 and 2016 (t=1.316, P=0.137). These differences were primarily driven by a higher abundance of alien common carp in 2017, native carp gudgeon and Australian smelt in 2018, and carp gudgeon in 2019 (Table 13).

Similarly, differences in biomass occurred among years (*Pseudo-*$F_{4, 45}$ = 5.503, $P < 0.001$), with these differences between all combinations of years except between 2016 compared to 2015 (t = 1.237, P = 0.204) and 2019 (t = 1.4396, P = 0.0761). Differences in biomass were driven by a higher biomass of native Murray cod in 2015 and 2016, alien common carp in 2017, and native bony herring and Murray cod in 2018 (Table 14).

Table 11. Total (non-standardised) catch from the Lower Lachlan river system target reach. Sampling was undertaken in autumn 2019 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	6					**6**
bony herring	2410	14	14			**2438**
carp gudgeon complex	4	364		7	1	**376**
flatheaded gudgeon		5				**5**
freshwater catfish						**0**
golden perch	106		5			**111**
Murray cod	40					**40**
un-specked hardyhead						**0**
Fish (Alien species)						
common carp	184		9			**193**
eastern gambusia	11	192				**203**
goldfish	17					**17**
redfin perch						**0**
Turtles						
long-necked turtle			2			**2**
Murray River turtle						**0**
Decapods						
freshwater prawn		4463	83	205	131	**4882**
freshwater shrimp		57			13	**70**
freshwater yabby		17	1	2	2	**22**

Table 12. Summary of SRA fish indices over the five LTIM sampling years in the Lower Lachlan River.

	NATIVENESS	EXPECTEDNESS	RECRUITMENT	OVERALL CONDITION
2015	Good	Very poor	Extremely poor	Very poor
2016	Good	Poor	Very poor	Very poor
2017	Very poor	Poor	Poor	Very poor
2018	Moderate	Poor	Very poor	Very poor
2019	Good	Very Poor	Very poor	Very poor

Table 13. Contributions of fish species abundance to variability among years in the Lower Lachlan River, determined through SIMPER analysis.
Note that only the top 3 species contributing (dissimilarity) to changes in community composition are included. Comparisons between 2015 and 2016 are not included as there were no significant differences in abundance.

INDICATOR	YEAR COMPARISON	SPECIES	CONTRIBUTION TO DIFFERENCE (%)	YEAR WITH GREATER VALUE	
ABUNDANCE	2015-2017	common carp	28		2017
		eastern gambusia	13		2017
		Murray cod	13	2015	
	2015-2018	carp gudgeon	28		2018
		Australian smelt	17		2018
		bony herring	13		2018
	2016-2017	common carp	29		2017
		carp gudgeon	11		2017
		goldfish	11		2017
	2016-2018	carp gudgeon	26		2018
		Australian smelt	18		2018
		bony herring	12		2018
	2017-2018	common carp	23	2017	
		carp gudgeon	17		2018
	2015-2019	carp gudgeon	18		2019
		Murray cod	13		2015
		goldfish	12		2019
	2016-2019	carp gudgeon	18		2019
		bony herring	13	2016	
		eastern gambusia	13	2016	
	2017-2019	common carp	32	2017	
		eastern gambusia	14	2017	
		goldfish	11	2017	
	2018-2019	Australian smelt	25	2018	
		carp gudgeon	22	2018	
		bony herring	16	2018	

Table 14. Contributions of fish species biomass to variability among years in the Lower Lachlan River, determined through SIMPER analysis.
Note that only the top 3 species contributing (dissimilarity) to changes in community composition are included. Comparisons between 2015 and 2016 are not included as there were no significant differences in biomass.

INDICATOR	YEAR COMPARISON	SPECIES	CONTRIBUTION TO DIFFERENCE (%)	YEAR WITH GREATER VALUE	
BIOMASS	2015-2017	Murray cod	34	2015	
		common carp	20		2017
		golden perch	12	2015	
	2015-2018	Murray cod	25	2015	
		goldfish	14		2018
		common carp	14		2018
	2016-2017	Murray cod	28	2016	
		common carp	27		2017
		goldfish	12		2017
	2016-2018	Murray cod	22	2016	
		common carp	17		2018
		goldfish	13		2018
	2017-2018	Murray cod	27		2018
		common carp	21	2017	
		goldfish	15	2017	
	2015-2019	Murray cod	25	2015	
		common carp	14	2015	
		golden perch	13	2015	
	2017-2019	common carp	26	2017	
		Murray cod	24		2019
		goldfish	13	2017	
	2018-2019	bony herring	17	2018	
		common carp	17	2018	
		goldfish	16	2018	

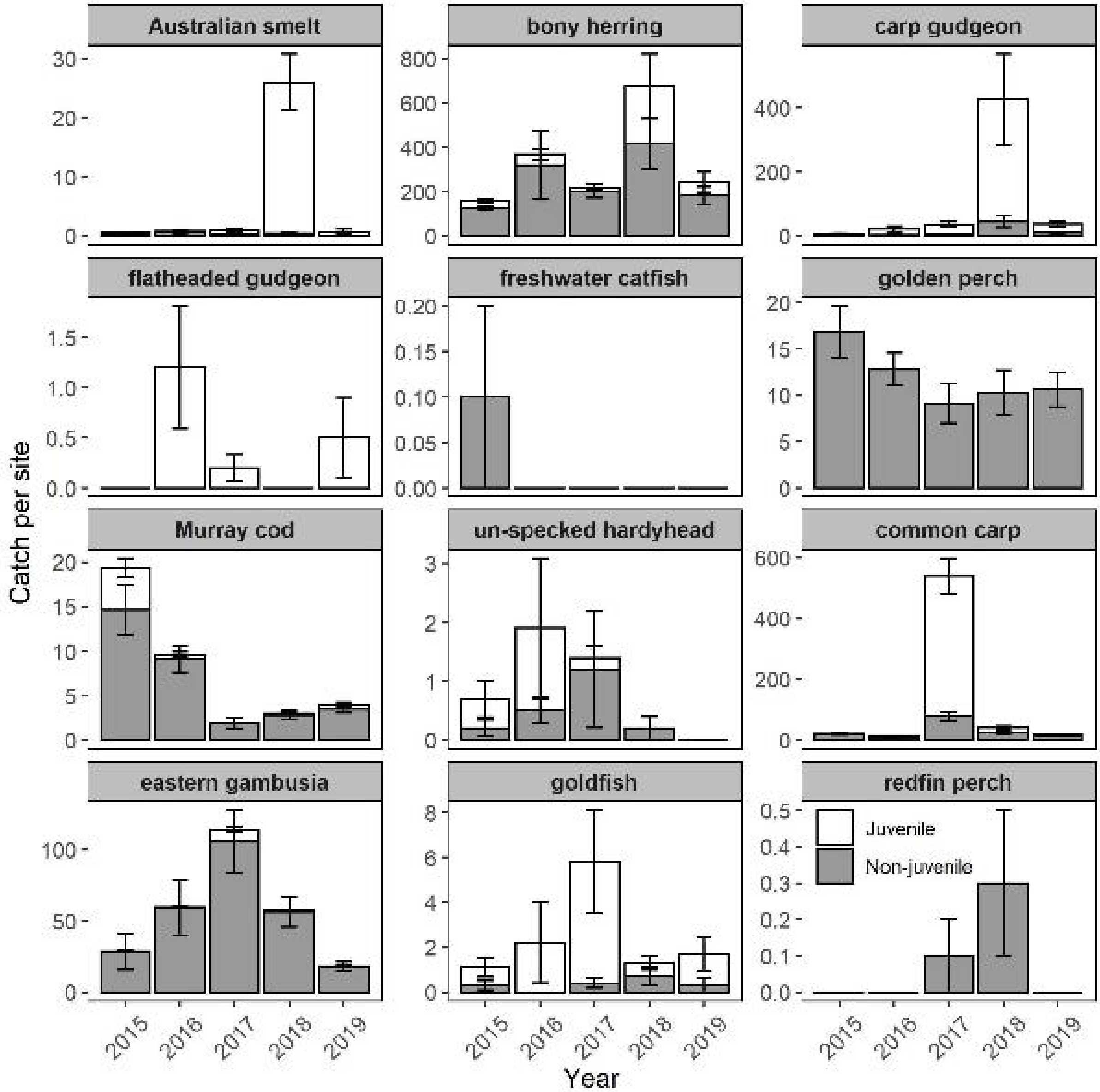


Figure 47. Catch per site (number of fish; mean ± SE) of each fish species within the Lower Lachlan river system target reach, sampled from 2015-2019. Cumulative stacked bars separate the catch of juvenile (white bars) and non-juveniles (grey bars).

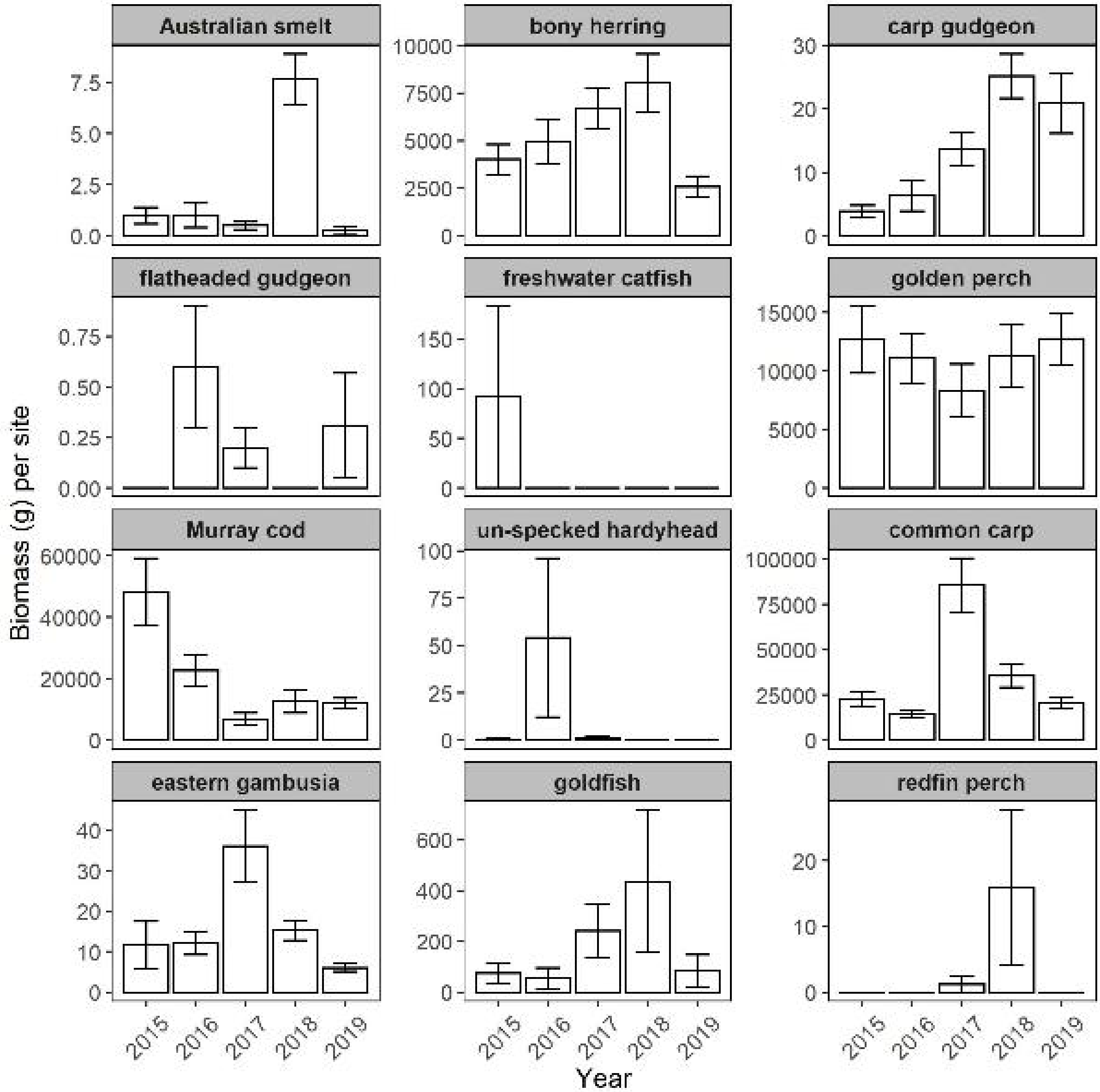


Figure 48. Biomass per site (g; mean ± SE) of each fish species within the Lower Lachlan river system target reach, sampled from 2015-2019.

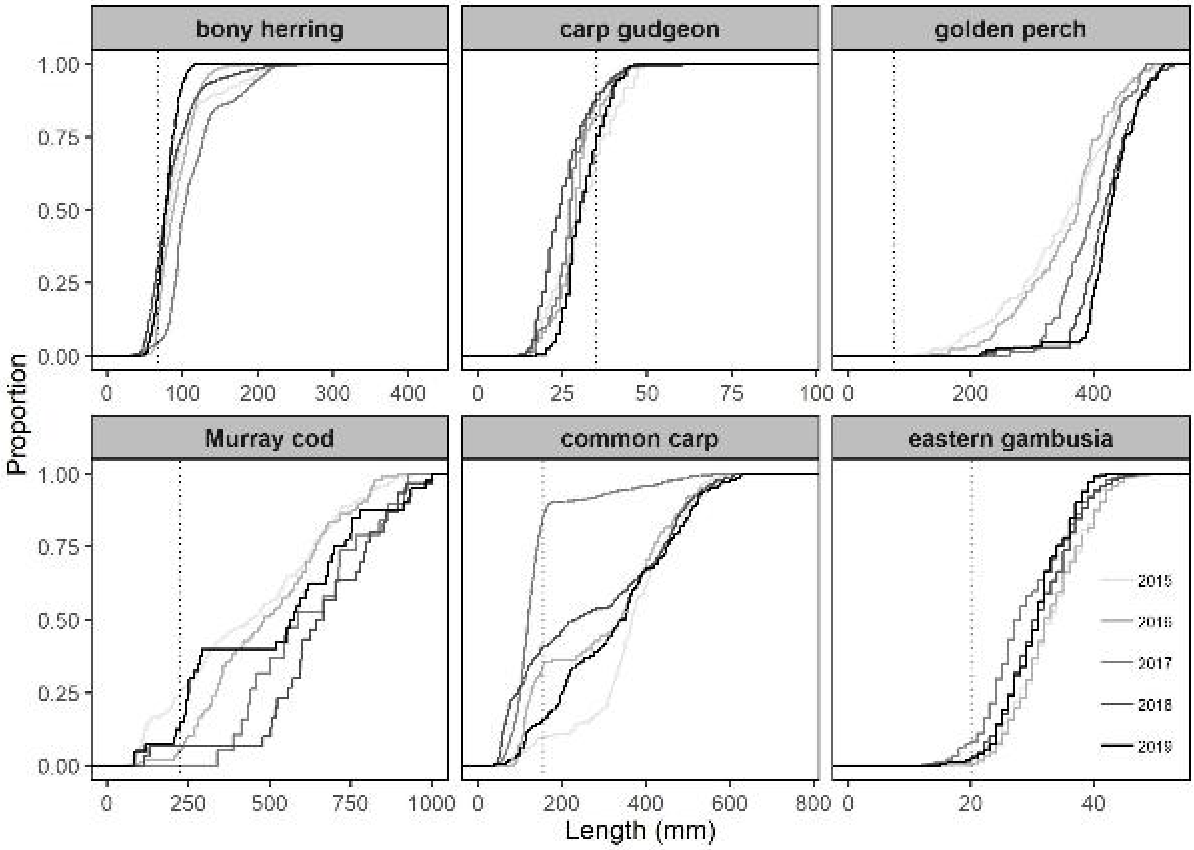


Figure 49. Proportionate length-frequencies of the six most abundant species captured in the Lachlan River from 2015–2019.

The dashed line indicates approximate size limits used to distinguish new recruits for each species (see Table 10, p. 91).

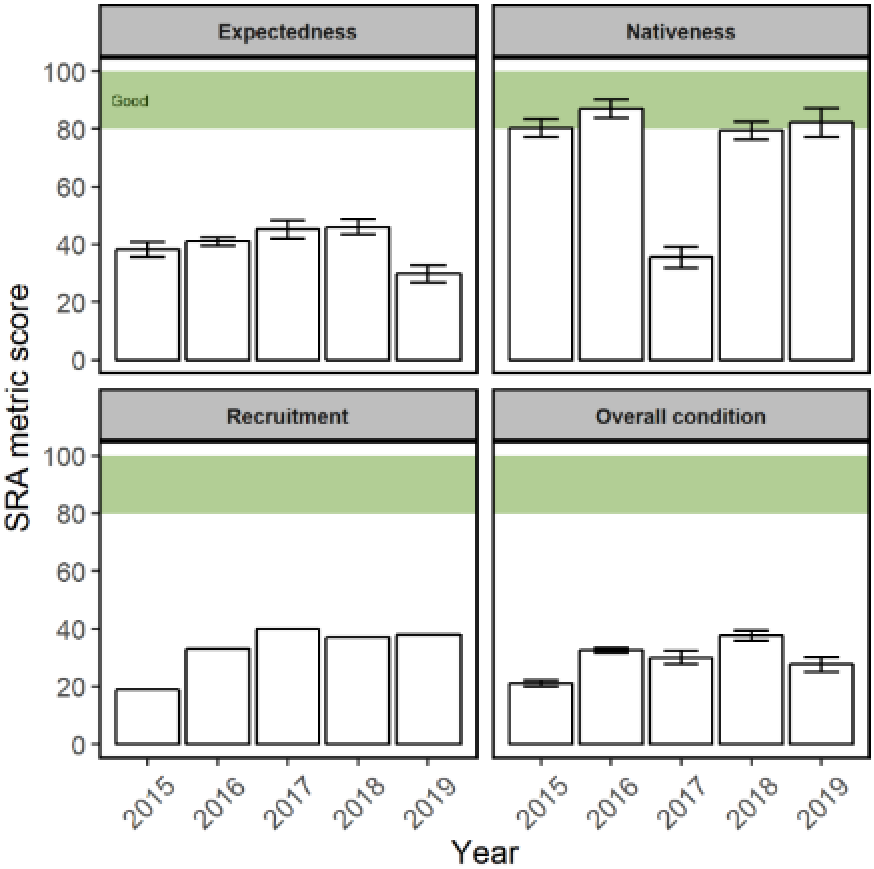


Figure 50. SRA metrics (score out of 100, mean ± SE) for the Lower Lachlan River system target reach from 2015–2019.
Note that recruitment is given a single zone-level score, rather than many site-level scores given for other metrics, and so standard error cannot be calculated. Green shading represents the "good" categorical band for metric scores.

6.3.1.1 By-catch

A total of 2 long-necked turtles were captured during fish community monitoring (Table 2). Freshwater prawns were the most abundant taxa in small mesh fyke nets, bait traps and opera house (Table 11). Only a small number of Yabbies (n=22) and Freshwater shrimp (n=70) were captured across the 10 monitoring sites (Table 11, p. 94).

6.3.2 MID LACHLAN RIVER (SHORT TERM INTERVENTION MONITORING)

A total of 5349 fish comprising seven native and four alien species were captured across 10 in-channel sampling sites in the mid-Lachlan river in 2019 (Table 16). This included two species listed as threatened: silver perch (vulnerable; Fisheries Management Act 1994) and Murray cod (vulnerable; EPBC Act). In order, flat headed gudgeon, carp gudgeon , bony herring, common carp, eastern gambusia and Murray cod were the most abundant species, respectively (Table 16, Figure 51). In order, common carp, golden perch and Murray cod contributed the greatest overall biomass in 2019 (Figure 52).

New recruits (juveniles) were detected in two native longer-lived species at multiple sites bony herring (at 2 of 3 sites) and Murray cod (8 of 9 sites, Figure 51, Figure 53), and three native short-lived species (Australian smelt (2 of 4 sites), carp gudgeon (8 of 9 sites) and flatheaded gudgeon (8 of 8 sites, Figure 51, Figure 53). No golden perch or silver perch new recruits were captured (Figure 51, Figure 53). New recruits of all alien species were captured (common carp (3 of 10 sites), goldfish (4 of 5 sites) and eastern gambusia (1 of 7 sites); Figure 51, Figure 53). No new recruits were detected for redfin perch (Figure 51, Figure 53).

Sustainable Rivers Audit indices varied substantially in the mid-Lachlan River reach sites and varied across SRA zones. Nativeness rated "Poor" for both slopes and lowland zones (mean ± SE score: 59.2 ± 4.5 and 57.1 ± 4.2, respectively). Expectedness at slopes sites was "Very Poor" (17.1 ± 3.1) and at lowland sites was "poor" (32.6 ± 6.0). Recruitment was "poor" (57) at slopes sites and "moderate" (64.4) at lowland sites. The Overall Condition of the fish community is rated "Very Poor" at both slopes (23.6 ± 4.2) and lowland sites (35.9 ± 4.2).

Table 15. Summary of SRA fish indices for each SRA altitudinal zone and a mean of all sites within the mid-Lachlan River in 2019 (n = number of sites sampled with each zone).

	NATIVENESS	EXPECTEDNESS	RECRUITMENT	OVERALL CONDITION
Slopes (n=4)	Poor	Extremely poor	Poor	Very poor
Lowland (n=6)	Poor	Very Poor	Moderate	Very poor
All sites (n=10)	Poor	Very Poor	Moderate	Very poor

Table 16. Total (non-standardised) catch from the mid-Lachlan River. Sampling was undertaken in autumn 2019 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		16				**16**
bony herring	1	556	15	55		**627**
carp gudgeon complex	8	4		1912		**1924**
flathead gudgeon	80	171		1868		**2119**
golden perch		47	5			**52**
Murray cod		106	2			**108**
silver perch		4				**4**
Fish (Alien species)						
common carp		243	4			**247**
eastern gambusia		36		195		**231**
goldfish		16				**16**
redfin perch		4		1		**5**
Turtles						
long-necked turtle		1				**1**
Murray River turtle						0
Decapods						
freshwater prawn	334		15	4009	44	**4402**
freshwater shrimp	56		1	1145		**1202**
freshwater yabby			1	1	2	**4**

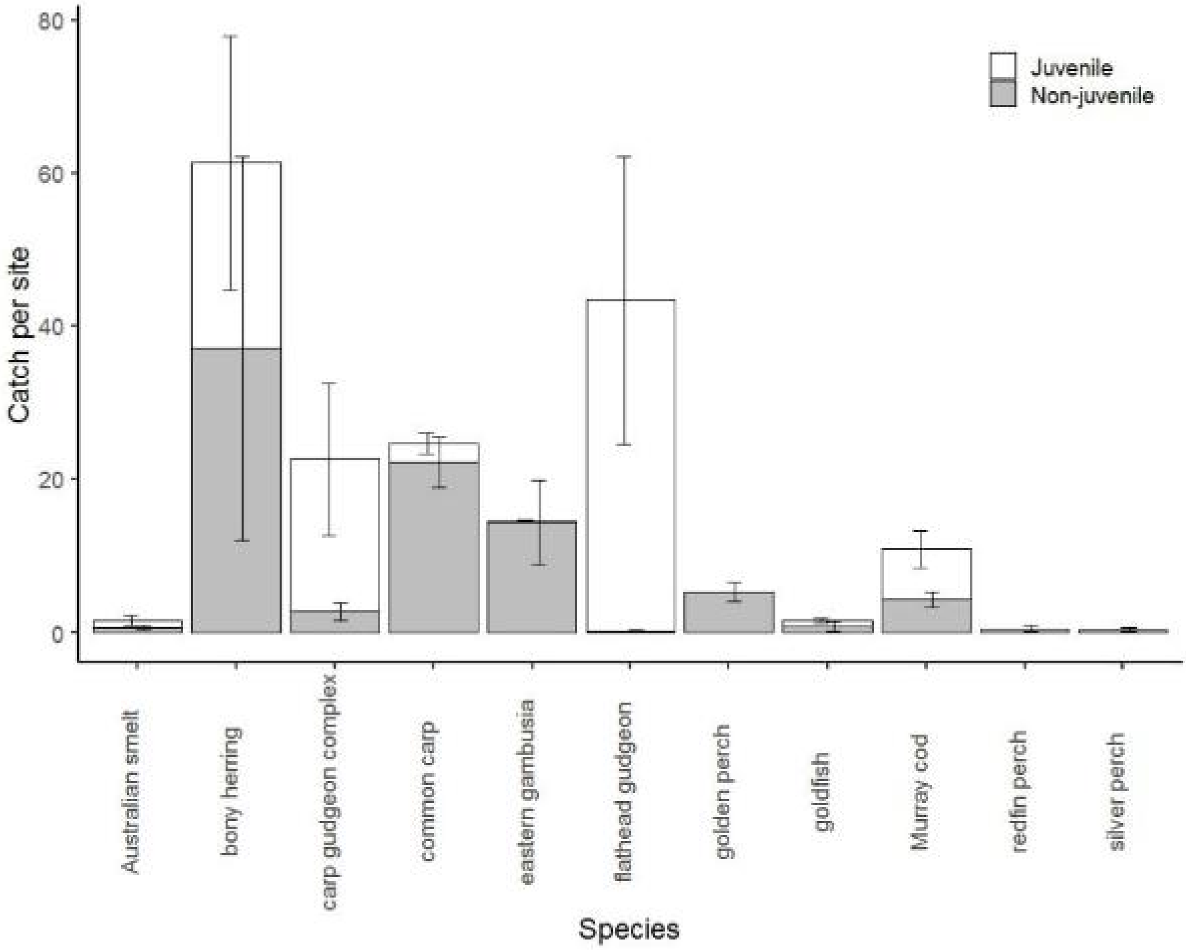


Figure 51. Catch per site (number of fish; mean ± SE) of each fish species within the mid-Lachlan river system sampled in 2019.

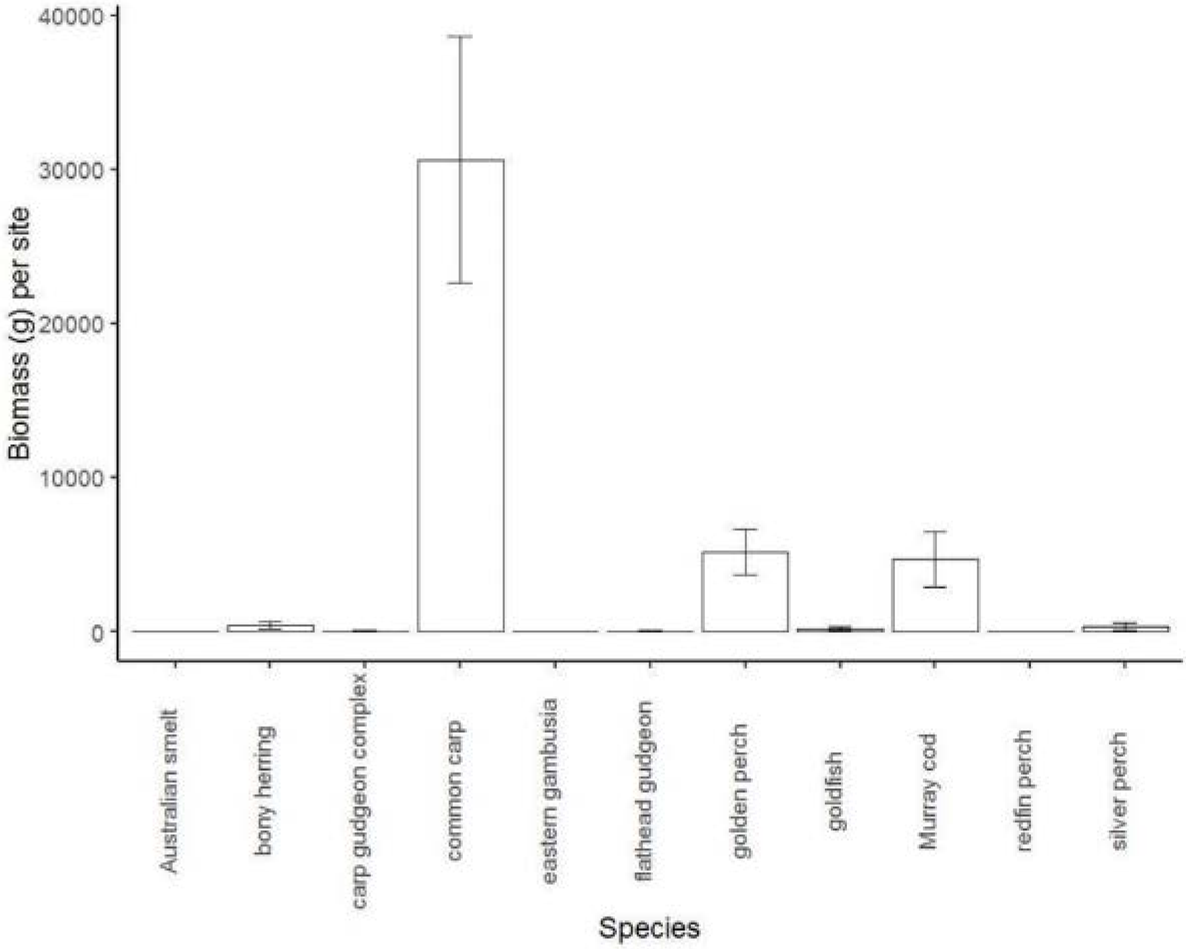


Figure 52. Biomass per site (g; mean ± SE) of each fish species within the mid-Lachlan river system sampled in 2019.

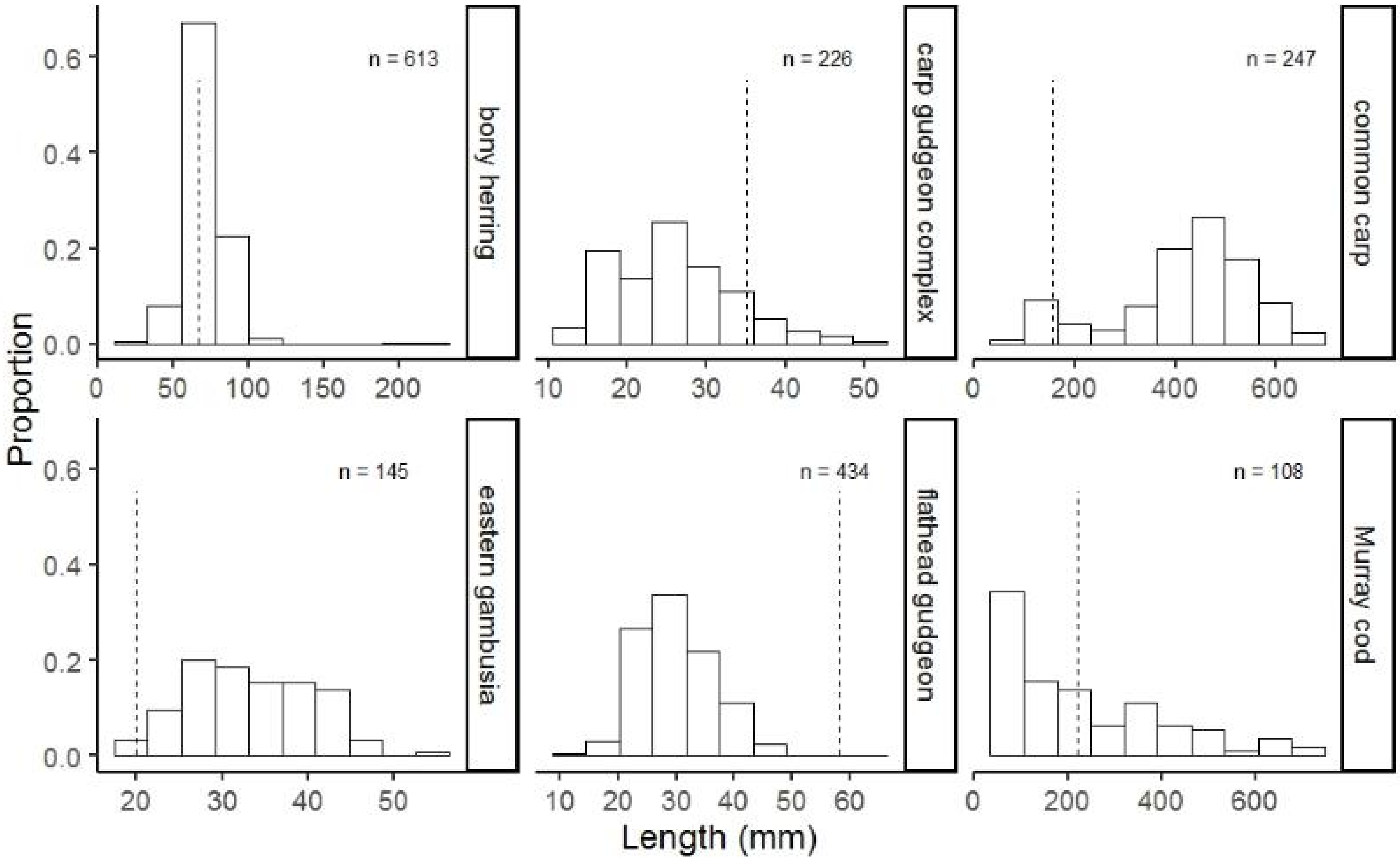


Figure 53. Proportionate length-frequencies of the six most abundant species captured in the mid-Lachlan River in 2019. The dashed line indicates approximate size limits used to distinguish new recruits for each species (see Table 10, p. 91).

6.3.2.1 By-catch

A total of four turtles were captured during fish community monitoring, two long-necked turtles and two Murray River turtles (Table 16, p. 102). Freshwater shrimp and prawns were the most abundant taxa in small mesh fyke nets and bait traps (Table 16). Only a small number of yabbies were captured across the 10 monitoring sites (Table 16).

6.4 DISCUSSION

6.4.1 LOWER LACHLAN RIVER (LONG TERM INTERVENTION MONITORING)

Six native species of freshwater fish were captured in the Lachlan Selected Area in 2019. Freshwater catfish were not caught in 2019 even though extra targeted sampling for this species took place using large fyke nets. Un-specked hardyhead were also absent in 2019, despite being captured during sampling from 2015 to 2018. Two native species, Murray-Darling rainbowfish and silver perch, are presumed to have been historically common in lowland sections of the Lachlan Basin, but are now rarely encountered within the target reach and were not detected in the current study (Table 17, p. 113). Consistent with previous results, four native fish species (flathead galaxias, olive perchlet, southern purple spotted gudgeon and southern pygmy perch), which were historically present, were not detected in 2019. Of these, olive perchlet is the only species to have been recently detected (Wallace and Bindokas 2011, DPI Fisheries, unpublished data). Despite the absence of a number of native species, the native species richness in the Lower Lachlan Selected Area is generally higher than in other parts of the catchment.

Based on SRA metrics, the native fish community composition stayed in the same 'Overall Condition (Very Poor)' in 2019 as in previous years (2015–2018). New recruits of two longer-lived species (bony herring and Murray cod) and two smaller native species (Australian smelt and carp gudgeon) were observed, but no longer-lived golden perch recruits were found. As a result, the 2019 Recruitment score remained at 'Very Poor' as in 2018. This score surpassed that in 2015 of 'Extremely poor' when recruitment of freshwater catfish was undetected, but fell below the 2017 score of 'Poor' when recruitment of flatheaded gudgeon was detected. Nativeness, which reflects a key measure of the proportional abundance and biomass of native and alien species, returned to a score of 'Good' in 2019, also seen in 2015 and 2016. Low Nativeness scores of 'Poor' in 2017 and 'Moderate' in 2018 were the result of reduced abundance (and biomass) of large long-lived golden perch and Murray cod and higher abundance (and biomass) of common carp. Expectedness fell to 'Very Poor' in 2019; the lowest among LTIM sampling years in the Lachlan River. This was caused by the detection of only five native fish species using SRA methods (12 electrofishing operations and unbaited bait traps) compared to six or seven species in sampling from 2015–2018. However, six native species were caught within the broader sampling of 2019, involving an additional 20 electrofishing operations, small and large fyke netting, and opera house bait traps.

One would expect differing flow regimes across years to favour varying suites of species. In response to hydrological conditions in 2018–2019 including Commonwealth watering actions, several native species (i.e. carp gudgeon, Australian smelt and bony herring) had reduced abundance compared with 2018. Carp gudgeon and Australian smelt are shorter-lived species described as foraging generalists (Baumgartner et al. 2014) that are not flow dependent spawners and can become more abundant under drought conditions. Conversely, small increases in abundances were detected for other native species, such as Murray cod and golden perch, in conjunction with the 2018–2019 Commonwealth watering actions. These longer-lived species declined in abundance following poor water quality as a result of the 2016–2017 floods and are expected to slowly recover in the coming years if satisfactory conditions persist. It is possible that watering actions aimed at facilitating the movement and re-distribution of these species contributed to this result, although this cannot be tested as fish movement is not a monitored indicator in the Lachlan Selected Area.

The declines in abundances of several fish species from 2015 to 2017 were attributed to dissolved oxygen concentrations at or below those inducing mortality in several large-bodied native species during 2016-17 (i.e. 3.1 mg/L, Small et al. 2014). While widespread fish kills were not observed, anecdotal reports from local landholders suggest that hypoxia-related fish kills most likely explained the reduced abundance (and biomass) of Murray cod in the focal reach. Substantial fish kills occurred in other parts of the (southern) Murray-Darling Basin in both 2010-11 (Hladyz et al. 2011, King et al. 2012, Whitworth et al. 2012) and 2016-17 flooding events (DPI Fisheries, *unpublished data*). Encouragingly, recent evidence from the Edward-Wakool system indicates that recovery of the Murray cod population from the 2010-11 fish kills was predominantly driven by localised spawning and recruitment originating from surviving remnant adults (Thiem et al. 2017). Given evidence in the Lachlan Selected Area of a remnant adult population, as well as documented localised spawning under this LTIM Project, it is anticipated that natural processes are the most likely recovery pathway for this species. It is therefore important that future water delivery continues to provide breeding opportunities, by facilitating the movement of pre-spawning fish and maintaining spawning habitat during nesting periods to prevent rapid water level drops and nest abandonment or desiccation.

As in 2015–2018, golden perch recruits were not captured in 2019. However, this result does not provide definitive evidence of a lack of spawning within the lowland Lachlan River. Other Selected Areas (e.g. the Murrumbidgee; Wassens et al. 2015) have detected spawning but rarely encountered new recruits. This may be explained by 1) high larval mortality, 2) inappropriate sampling methods or locations, or 3) a combination of both. Golden perch abundance in 2019 was similar from 2017–2018 but was reduced compared with 2015–2016, following a similar trend to Murray cod. 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 (http://www.dpi.nsw.gov.au/fishing/recreational/resources/stocking and 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 (e.g. Hunt et al. 2010). As golden perch are "Flow pulse specialists", which rely on freshes to trigger spawning responses (Baumgartner et al. 2014), it is important that freshes occur in the Lachlan River, in order to promote increased spawning and subsequent recruitment for this species.

In response to an environmental watering event to inundate preferred nesting habitat for Murray cod and promote instream productivity and larval dispersal opportunities in 2018–2019, we detected Murray cod recruits in the lower Lachlan reach in 2019. This similarly occurred in previous LTIM years, excluding in 2017 when no recruits were observed following hypoxia-related fish kills in 2016–2017. However, recruits comprised 13% of all captured individuals in the lower Lachlan reach - higher than in other LTIM years (0–7%), except in 2015 when 24% were recruits before the hypoxia-related fish kills in 2016–2017. These results along with the successful spawning of Murray cod in 2018–2019 (larval chapter) suggest that the targeted Commonwealth environmental watering action was a contributing factor.

6.4.2 MID LACHLAN RIVER (SHORT TERM INTERVENTION MONITORING)

Monitoring of the mid-Lachlan River 2019 provides a benchmark from which changes in the fish community in response to Commonwealth environmental watering can be made in future years. Seven native fish species were captured in the mid-Lachlan fish community sampling in 2019. Despite being captured in the larval fish monitoring, freshwater catfish were not captured in 2019, despite extra effort being deployed to target this species (large-mesh fyke nets). Larvae of this species were captured in the larval sampling in 2018 at one site (see section: 7 Spawning and larval fish), confirming this species is present, but probably low densities.

Other species that historically were present in the reach that weren't captured in 2019 were flathead galaxias, unspecked hardyhead, olive perchlet, southern purple spotted gudgeon and southern pygmy perch. Unspecked hardyhead and olive perchlet are the only two of these species that were captured within the catchment recently (Wallance and Bindokas 2011, NSW DOI unpublished data). Despite these missing taxa, the native species richness in the mid-Lachlan is relatively high compared to the lower Lachlan selected area.

The SRA Overall condition index of the fish community was rated "Very poor" for both zones in the mid-Lachlan in 2019. Overall condition of the fish community, as determined by the current study, in the mid-Lachlan River (very poor) was similar to that of the lower-Lachlan River (very poor) in 2019. When compared with previous large-scale condition programs in the lowland Lachlan Basin, the mid-Lachlan reach currently supports a healthier native fish community, with a previous assessment rating both zones in the Lachlan River catchment as extremely poor in 2009 (Davies et al. 2012). While these results are not directly transferable to the findings of the current study given the narrower spatial scale of interest here, the data indicate that the fish communities of the broader region are generally unbalanced towards alien species, and that the target reach supports a greater proportionate abundance and biomass of native fish (Gilligan et al. 2010).

Recruitment was detected for five native fish species in the mid-Lachlan in 2019. Of these, Murray cod was a target for two environmental watering events in the mid-Lachlan reach; a spring pulse (to encourage movement) and a hydrological 'floor' which was set to prevent sudden drops in water level during the Murray cod spawning season, to reduce the likelihood of nest abandonment and egg desiccation. Murray cod recruits were detected at 80% of sites sampled, and overall recruits comprised > 50% of the Murray cod population captured in 2019, which constitutes a significant recruitment event (OEH 2018). This also supports results from the larval fish monitoring (see section: 7 Spawning and larval fish) which suggested that Murray cod spawning and recruitment to early juveniles was successful. These combined results indicate that conditions were suitable in 2019 for a significant Murray cod recruitment event in the mid-Lachlan River. The results of the 2019 fish community monitoring indicate that objectives of the watering actions around providing cues for movement, stable conditions for nesting and opportunities for dispersal and growth were met for Murray cod in the mid-Lachlan River. It is important to note, that this result is based on a single monitoring year without recent baseline data to compare against. Repeating the strategy or trialling a different strategy would provide further information about the contribution of the strategy to the significant recruitment events of Murray cod in the mid-Lachlan River.

The spawning season of 2018 appears to have been successful for flatheaded gudgeon in the mid-Lachlan River, with the majority of captures comprising juvenile individuals. This could be somewhat expected as flatheaded gudgeon have been found to increase spawning intensity with an increase in food abundance (Llewellyn 2007). The spring pulse increased basal food production (gross primary productivity and ecosystem respiration – see chapter 5: Stream metabolism and water quality) which may have resulted in increased spawning and recruitment activity in the mid-Lachlan river, albeit patchy at the site scale. The large numbers of juvenile flatheaded gudgeon captured in the community sampling were somewhat incongruent with the results of the larval fish monitoring, which only detected low numbers of larval flatheaded gudgeon at the monitored sites in 2018 (see section: 7 Spawning and larval fish). The likely reason behind the discrepancy is that the vast majority of flatheaded gudgeon were captured at two sites only (the most upstream two sites), indicating that recruitment was somewhat site specific (and these two sites were not monitored for larval fish). At the zone scale, it appears as though objectives around supporting spawning success of flatheaded gudgeon were achieved.

The hydrological regime did not appear to result in a significant recruitment event for Australian smelt, with juveniles rare in the community sampling. This is congruent with the results of the larval fish monitoring, which together indicate that is it likely that there was not a significant spawning event of Australian smelt in the mid-Lachlan River. As this is based on a single year of data, inferential power of causality of the restricted spawning of Australian smelt in the mid-Lachlan River is limited at this stage. However, it does not appear as though objectives of the watering event around supporting spawning success may have been hampered by the lack of spawning and / or survival to early larvae.

As for the lower-Lachlan selected area, there was no evidence of golden perch recruitment in the mid-Lachlan reach in 2019. This continues a trend of apparent lack of recruitment in the catchment as part of the current study over the past five years, despite good populations of adults present, and positive spawning detected in nearby catchments (Murrumbidgee River, Wassens et al. 2018). As mentioned above, addressing the knowledge gaps around the lack of detection or golden perch spawning should be a priority for the mid and lower Lachlan River.

6.5 EVALUATION

6.5.1 LOWER LACHLAN RIVER (LONG TERM INTERVENTION MONITORING)

In relation to the effects of Commonwealth environmental water, the short and long term evaluation questions are addressed as follows:

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

In 2019, resilience and survival of the Lower Lachlan native fish community was maintained compared to previous years as a result of hydrological conditions, including Commonwealth environmental water. For instance, the Overall Condition remained Very Poor in 2019, as in previous LTIM years. The targeted watering action appeared to benefit spawning and recruitment in 2019.

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

The Lower Lachlan native fish population was most affected by fish kills in 2016–2017 during LTIM years, which reduced the biomass of large-bodied Murray cod in 2017 and promoted the spawning and subsequent recruitment of common carp. This significant event likely drowned out other effects on the fish community over the study period. Commonwealth environmental watering actions may have contributed to the post-kill recovery of native fish populations in 2018 and 2019, however it is unknown if this recovery would have differed without it.

There has been a slight decline in Lower Lachlan native fish diversity from 7 species detected from 2015–2017 to 6 species in 2018–2019, with changes to the suite of species observed. This may relate to the hypoxia-linked fish kills in 2016–2017 or the opportunistic detection of rare species (e.g. freshwater catfish). The role of Commonwealth environmental water in this result is again difficult to ascertain.

6.5.2 MID LACHLAN RIVER (SHORT TERM INTERVENTION MONITORING)

In relation to the effects of Commonwealth environmental water, the short-term evaluation questions are addressed as follows:

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

By contributing to strong recruitment of multiple native species, Commonwealth environmental water contributed to increasing fish community resilience by improving population structure of native fish species in the mid-Lachlan River. Successfully rearing fish through to larval and early juvenile phases is a critical factor determining year class strength and ultimately contribution to adult stock.

Productivity pulses delivered in spring and early summer increase stream productivity (see section 5) which would likely have increased food resources, and growth and juvenile native fish species. Adequate food resources during early larval fish development are critical to survival by preventing starvation (during a period where mortality can be highest). Early growth and development would also decrease predation as individuals increase in size and swimming ability predation risk can decrease.

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

Watering actions of the 2018 / 2019 watering year supported strong recruitment for at least two native fish species. Watering actions would have contributed to connectivity, food resources and dispersal. The watering year saw a significant recruitment event for Murray cod with watering action likely supporting connectivity and movement early juvenile food resources and dispersal (increasing survival). Flatheaded gudgeon and carp gudgeon recruits were also in high abundance, indicating that the watering year was also successful in supporting recruitment of these small bodied species.

6.6 RECOMMENDATIONS

6.6.1 LOWER LACHLAN RIVER (LONG TERM INTERVENTION MONITORING)

- Future water delivery, focussing on native fish outcomes, should utilise natural triggers such as tributary inflows.
- During low water resource years the primary focus of environmental flows should be on maintenance of native fish populations and the provision of refuge habitat where possible.
- The source (stocked or wild) of the existing golden perch population should be investigated to establish whether recent hydrological events may have led to wild-spawning and recruitment.
- Watering actions to support golden perch are likely only possible during years of good water availability. Given that the 5 years of the LTIM Project have identified a range of conditions that DON'T result in the golden perch spawning, it would be valuable in a year of high water availability to design watering actions for golden perch based on learning to date to see if spawning can be triggered in the lower Lachlan river system. Building on knowledge gained from other catchments being monitored as part of LTIM (e.g. Goulburn River) would further refine these releases for golden perch spawning outcomes.
- It is important that future water delivery continues to provide breeding opportunities for Murray cod, by facilitating the movement of pre-spawning fish and maintaining spawning habitat during nesting periods to prevent rapid water level drops and nest abandonment or desiccation.
- It is possible that watering actions aimed at facilitating the movement and re-distribution of long lived species contributed to the small increase in abundances in 2018-19, although this cannot be tested as fish movement is not a monitored indicator in the Lachlan Selected Area. To better understand the outcomes from using environmental water to generate movement in fish species, it is recommended that some targeted monitoring of movement is undertaken. This would require some co-design of the monitoring activities around actions that aim to facilitate movement and could test assumptions around increases in flow providing access to more habitat.

6.6.2 MID LACHLAN RIVER (SHORT TERM INTERVENTION MONITORING)

- Where possible, stable water levels should be maintained during Murray cod spawning season to prevent nest abandonment and egg desiccation, especially in the years following any significant reduction in the adult Murray cod to assist in population recovery. This can largely be achieved using a small amount of Commonwealth water to modify water level changes caused by operational flows. (See also Hydrology recommendations).
- Addressing knowledge gaps around golden perch recruitment in the mid and lower Lachlan River should be a priority (e.g. sources of recruitment, adult movement)

6.7 APPENDICIES

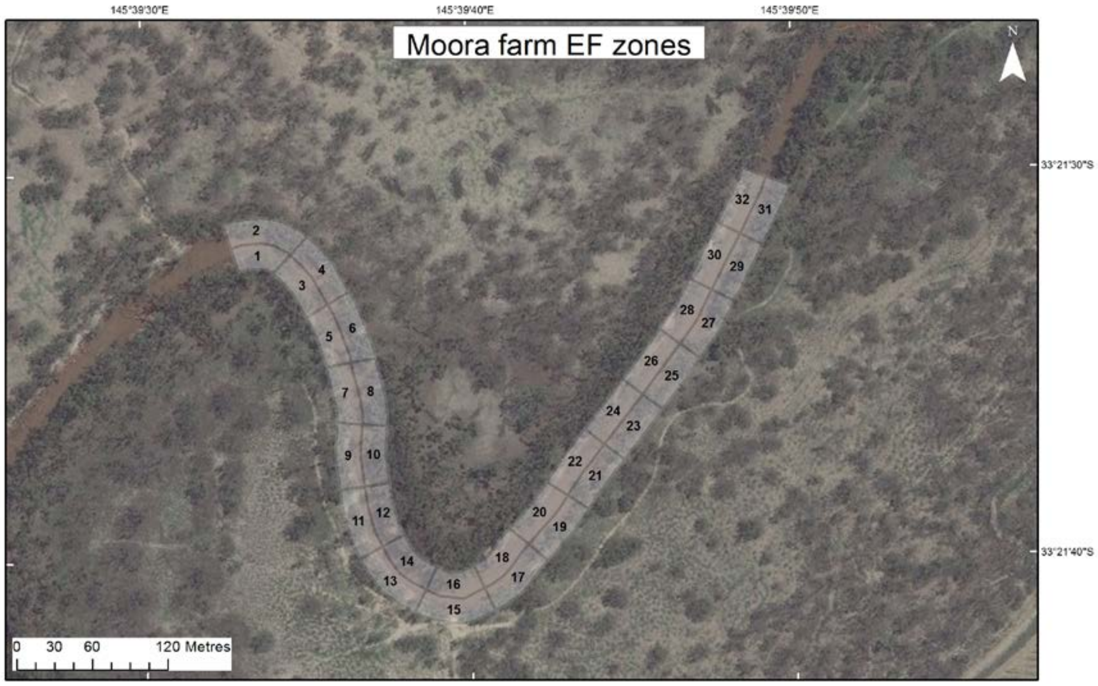


Figure 54. Example of mapped boat electrofishing units used for Category 1 fish community sampling in the Lachlan River. Each unit was sampled using 90 seconds of 'on-time'.

Table 17. Pre-European (PERCH = Pre-European Reference Condition for fisH) list of the expected native fish species present in the lowland Lachlan Basin, their associated rarity and subsequent detection during the LTIM 2016 census.

Descriptions of predominance (occurrence) correspond to reference condition categories for the Murray-Darling Basin SRA program and are used to generate fish condition metrics.

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
flathead 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		

7 SPAWNING AND LARVAL FISH

7.1 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 to adulthood is largely driven by spawning success, 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 two Commonwealth environmental watering actions in 2018 – 2019 that targeted outcomes for native fish reproduction in the main channel of the mid (Forbes) and lower (Hillston) Lachlan River. In the lower Lachlan River system, these were:

1) A spring pulse (mid-late September 2018) in the mid Lachlan to support native fish outcomes (Watering Action 1). This watering action was re-regulated through Brewster weir pool and provided two spring pulses in the lower Lachlan.
2) The protection of a Hydrological 'floor' from mid-October until end of November to prevent water level drops that may lead to Murray cod nest abandonment in the mid Lachlan (Watering Action 2). This watering action was passed through the system to provide a third late spring pulse in the lower Lachlan.

These watering actions had the following expected outcomes relating to reproduction of native fish:

1) To support native fish condition, movement, reproduction, larval abundance and recruitment opportunities

The larval fish monitoring implemented within the Lower Lachlan River system is directed at Basin scale evaluation and was confined to a single zone within the Lower Lachlan River system Selected Area from 2014 – 2017. Specific Commonwealth environmental watering actions aimed at native fish recruitment have been targeted in the mid-Lachlan River. Specifically, a hydrological floor was designed to prevent sudden decreases in water level during Murray cod spawning season (Watering Action 2) to prevent nest abandonment and eggs desiccation. To monitor this, in 2018 a second zone (mid-Lachlan between Forbes and Lake Brewster) was monitored for larval fish mainly to address area specific questions. 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 reaches (i.e. Zone 1 and mid-Lachlan) (Dyer et al. 2014). There are two components to the evaluation provided in this report. The first evaluates the 2018-19 watering actions in relation to the specific objectives for fish in each reach, the second aims to address the short-term and long-term evaluation questions for the lower reach only.

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

7.1.1 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?

7.1.2 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?

7.2 METHODS

7.2.1 FIELD SAMPLING

Larval fish were sampled at six sites (Dyer et al. 2014) on the Lower and mid Lachlan River system (Wallanthery, Hunthawang and Lanes Bridge in the lower-Lachlan and Kirkup Park, Techam and Euabalong in the mid-Lachlan, see Figure 18 and Figure 19, p. 51). This is the fifth year of monitoring in the lower Lachlan River and the first year of monitoring in the mid-Lachlan River. 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). Samples collected from drift nets were processed separately. Samples collected from light traps were pooled per site per trip. Five sampling events were undertaken at fortnightly intervals between 15th October and 14th December 2018:

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 gudgeon (*Hypseleotris spp.*) and un-specked hardyhead (*Craterocephalus stercusmuscarum*).

7.2.2 LABORATORY PROCESSING

Preserved samples were examined in the laboratory and all fish were removed. Extracted fish were identified where possible (using Serafini and Humphries 2004) and measured (standard length) under magnification using a digital graticule to the nearest 0.001 mm. If individuals were not able to be identified, individuals were measured and labelled "unidentified". Only the first 50 individuals were measured per species per site per trip per operation (operation = an individual drift net or 10 light traps), with the other individuals being counted only.

7.2.3 DATA ANALYSIS

For catch per unit effort figures, catches of larval fish for drift nets was standardised as the number of individuals per m^3 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). Total larval fish captures (all trips grouped by site) between years for the lower-Lachlan River selected area were examined using a permutational analysis of variance (PERMANOVA) with Type I sum of squares. Raw captured data was fourth-root transformed, then a resemblance matrix was constructed with the Bray-Curtis similarity measure. All species were included as variables, with year as a fixed factor and site as a random factor nested within year for a maximum of 9999 permutations. Principal Component analysis ordinations (PCoA) of the transformed data were arranged into resemblance matrices using the Bray-Curtis Similarity measure. Vectors are the raw Pearson's correlations for the taxa that are most correlated (> 0.5) with each of the PCoA axes. Similarity percentage analysis (SIMPER) was performed to determine which larval fish taxa contributed to any observed differences between years (see Appendix 2, Table 21, section 7.8)

7.3 RESULTS

7.3.1 LOWER LACHLAN RIVER SELECTED AREA

A total of 4710 larval fish were captured across the five sampling events of spring-summer 2018 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 18). Light traps captured the majority of larval fish, though this was mostly driven by extremely high abundances of flat headed gudgeon and Australian smelt (92% of individuals captured in 2018) (Table 18). Numbers of larval fish were variable between sampling events, with trips 1 and 3 capturing the majority of fish (57 % of all trips).

Larval fish were captured for only two of the six target species in 2018: one Equilibrium species, Murray Cod, and one Opportunistic species, carp gudgeon (Table 18). No Periodic representative species (golden perch or bony herring) were collected during larval sampling in 2018 (Table 18). Murray cod were captured in the first four trips only, with the majority (71%) of individuals captured from a single site during sampling event 2 (Lanes Bridge) (Figure 55). Larval Murray cod ranged in length from 5.7 – 10.9 mm, corresponding to ages of 0 – 27 days old (Figure 56). Estimated spawning window for Murray cod in 2018 was between 23/9/18 – 17/11/18, with the largest peak between 3/10/18 – 17/10/18 (see Figure 62, section7.7). Mean length of Murray cod was relatively consistent between sampling events (Figure 56).

Table 18. Capture summary of larval fish from sampling conducted between mid-October to mid-December 2018 in the Lower Lachlan River system Selected Area.

SPECIES	DRIFT NETS	LIGHT TRAPS	TOTAL
Murray cod	224	74	**298**
flat headed gudgeon	380	2432	**2812**
Australian smelt	76	1449	**1525**
carp gudgeon	3	25	**28**
freshwater catfish	0	0	**0**
golden perch	0	0	**0**
eastern gambusia	1	45	**46**
common carp	1	0	**1**
TOTAL	**685**	**4025**	**4710**

Three opportunistic species were collected during larval sampling in 2018, these were Australian smelt, flat headed gudgeons and a carp gudgeon. Australian smelt were captured in light traps during all five sampling events and in drift nets in four of the five sampling events. Australian smelt larvae were detected on all sampling events, though were most abundant on sampling event 1 (70 % of individuals captured) (Table 18 and Figure 55). Australian smelt were captured at each site, though were most numerous at Hunthawang (69%). Australian smelt captured ranged in size from 7.3 – 42 mm (Figure 56) and ranged in estimated age from 0 – 121 days old. Length frequency distribution and associated back calculation of estimated spawning dates indicate that Australian smelt had an extended spawning window spanning early-August to mid-November in 2018 (see Figure 62, section 7.7). Peaks in spawning activity occurred around late August / early September and late September / late October, when water temperatures were around 11 – 13 °C and 17 – 22 °C, respectively (see Figure 62, section 7.7). Mean length of Australian smelt was greatest in trips 4 and 5 (Figure 56).

Flat headed gudgeon were captured in all sampling events in 2018, though were in highest abundance in trip 2 (46% of individuals). The majority (86%) of flat headed gudgeon were captured in light traps. Flat headed gudgeon ranged in length from 6.05 – 22.8 mm (Figure 56), with an estimated age of 23 – 124 days old. This corresponds to an estimated spawning window from late July to late October, with an extended peak between late-August and late-september 2018 when water temperatures were ~11 – 17 °C (see Figure 62, section 7.7). Mean length of flat headed gudgeons increased between sampling events 2 and 4, then decreased slightly in trip 5 (Figure 56).

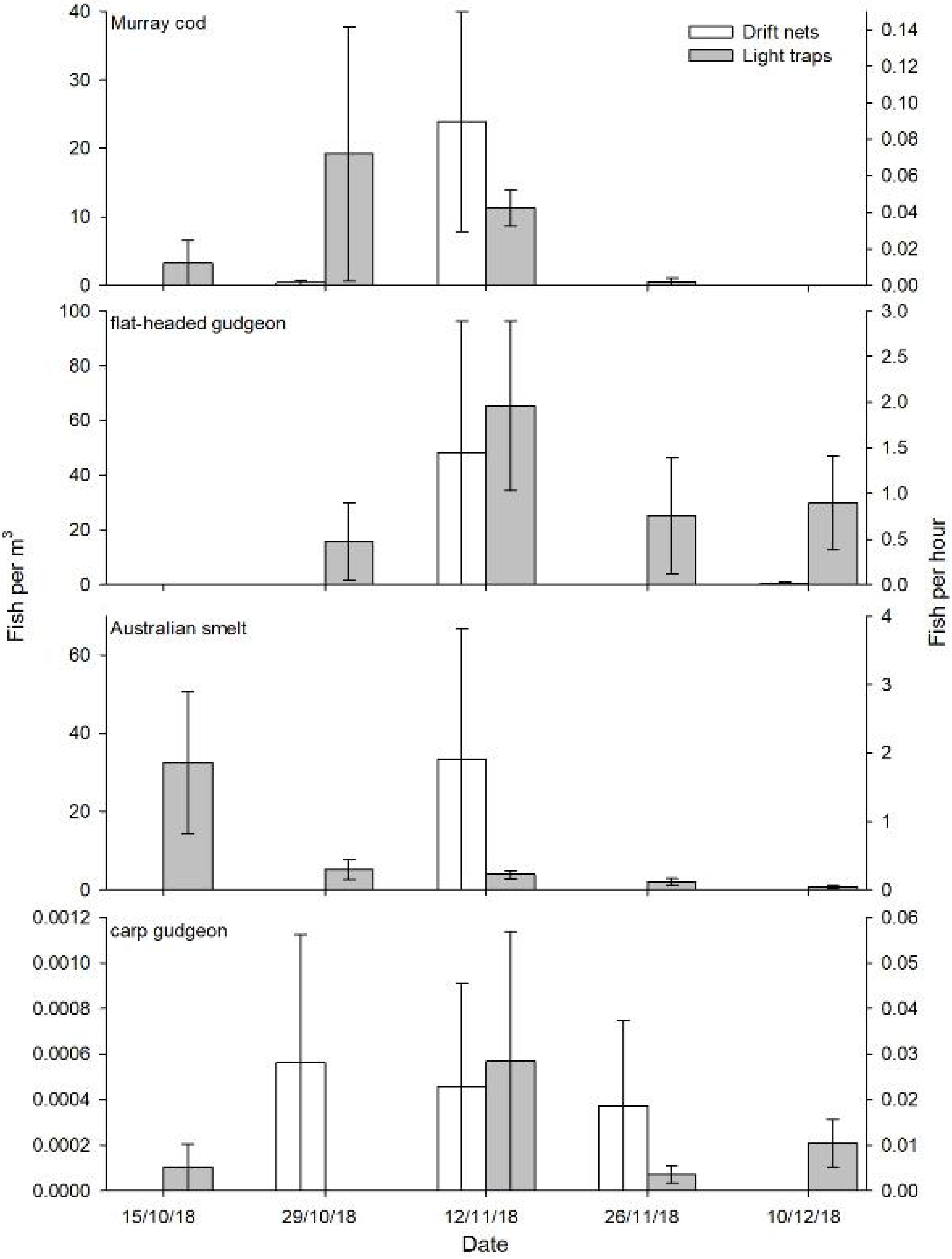


Figure 55. Mean catch per unit effort (± standard error) of the commonly caught larval native fish for drift nets (left axis, white bars) and light traps (right axis, grey bars) per sampling event in spring summer 2018 in the lower Lachlan catchment.

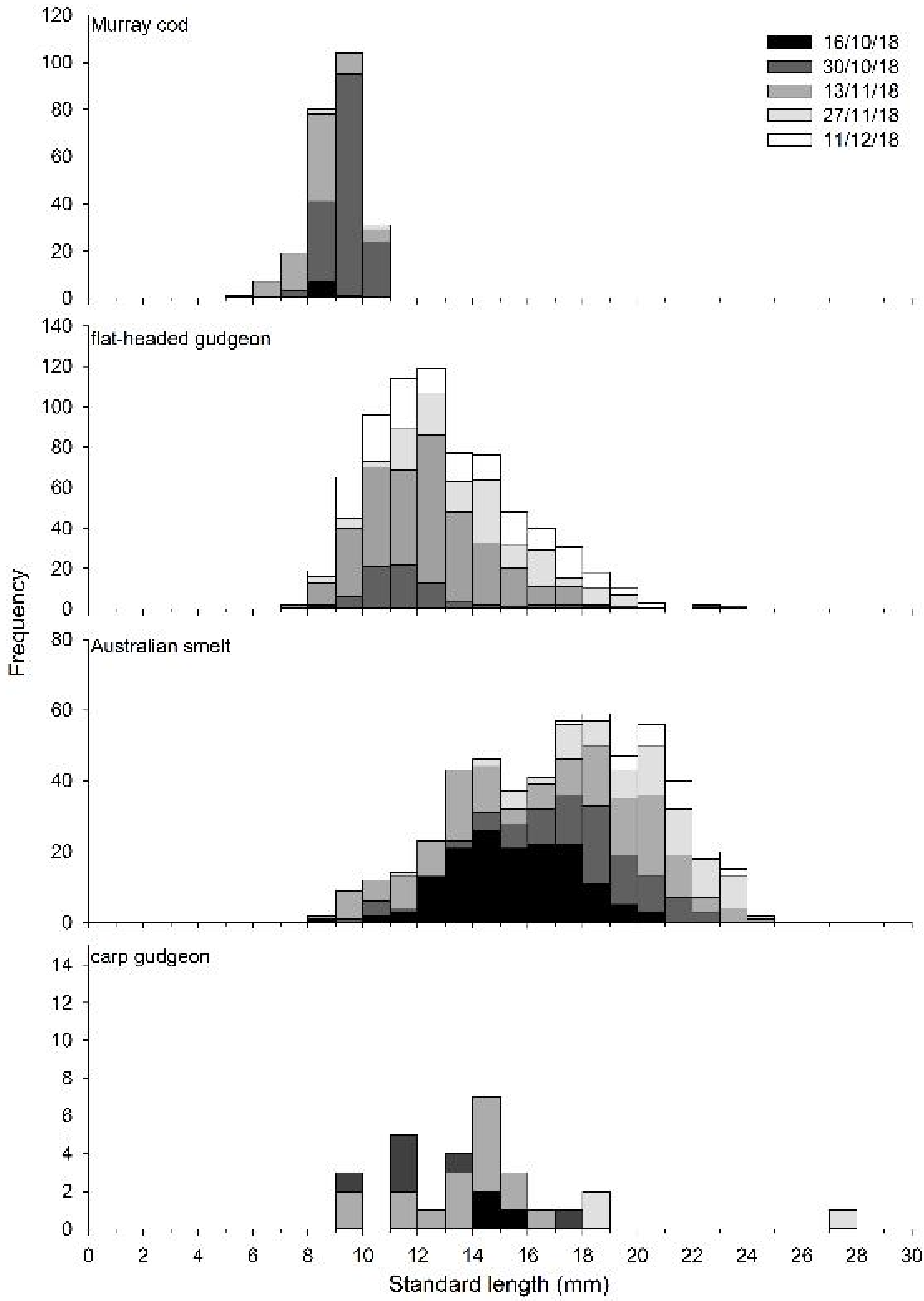


Figure 56. Length frequency histograms for each sampling event of commonly captured larval native fish species with site (n = 3) and sampling technique (n = 2) combined for 2018.

A total of 47 alien fish larvae were captured in 2018 across the three sites, comprising 1 common carp and 46 eastern gambusia (Table 18). Most of the eastern gambusia (66%) were captured in sampling trips 1 and 2. Eastern gambusia ranged in size from 7 – 30 mm and were between 17 and 73 days old (based on estimated length vs age estimate equations presented in Humphries et al. 2008). Estimated spawning dates range for eastern gambusia was 25/8/18 – 4/10/18 (peak September).

7.3.2 2018 VS PREVIOUS YEARS

There was a significant difference in the larval fish community between years in the lower Lachlan River selected area (Table 19). Although 2014 and 2015 were similar, differences between these two years are driven by higher abundances of flat headed gudgeon and common carp in 2015 (Figure 57, Figure 58 and section 7.8). The large abundance of common carp was the discriminating factor between 2016 and all other years, contributing between 15 – 26% to dissimilarity estimates (Figure 57, Figure 58 and section 7.8). The larval fish community in 2017 was typified by far higher abundances of Australian smelt than all other years (Figure 57, Figure 58 and section 7.8) whereas in 2018 the community was typified by far higher abundances of flat headed gudgeon than all other years (Figure 57, Figure 58 and section 7.8).

Table 19. Results of PERMANOVA analysis of larval fish captures (fourth-root transformed numerical data from drift net and light traps combined) in the Lower Lachlan River selected area 2014 – 2018.

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Year	**4**	**21580**	**5395**	**16.85**	**0.0001**	**9892**
Site(Year)	10	3201.8	320.18	No test		
Total	14	24782				

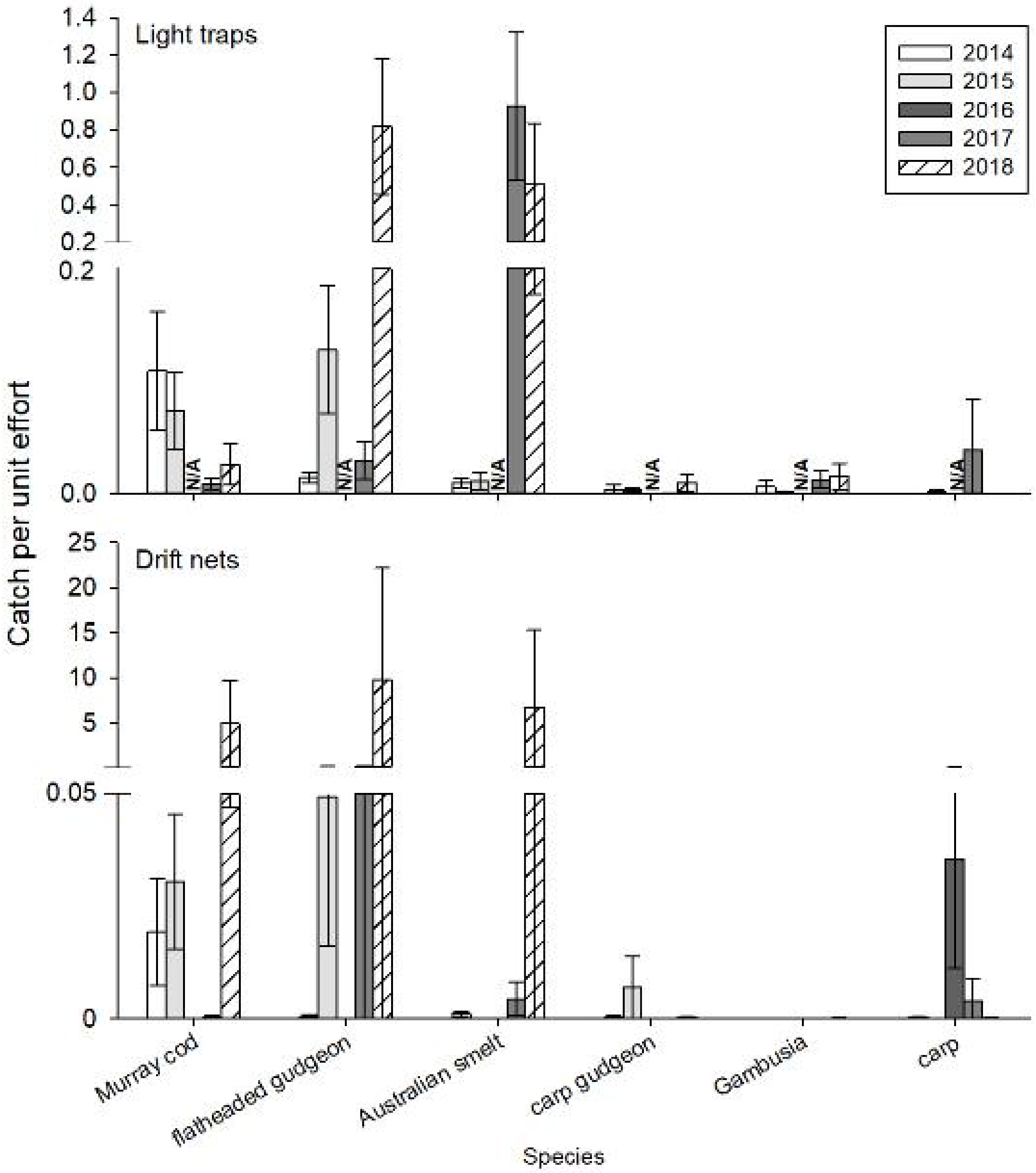


Figure 57. Mean catch per unit effort (± standard error) of larval fish species captured in light traps (CPUE = catch-per-hour, top) and drift nets (CPUE = individuals capture per m^3 of water sampled; bottom) from spring – summer 2014 – 2018.
Note: N/A indicates gear type was not used in that sampling year.

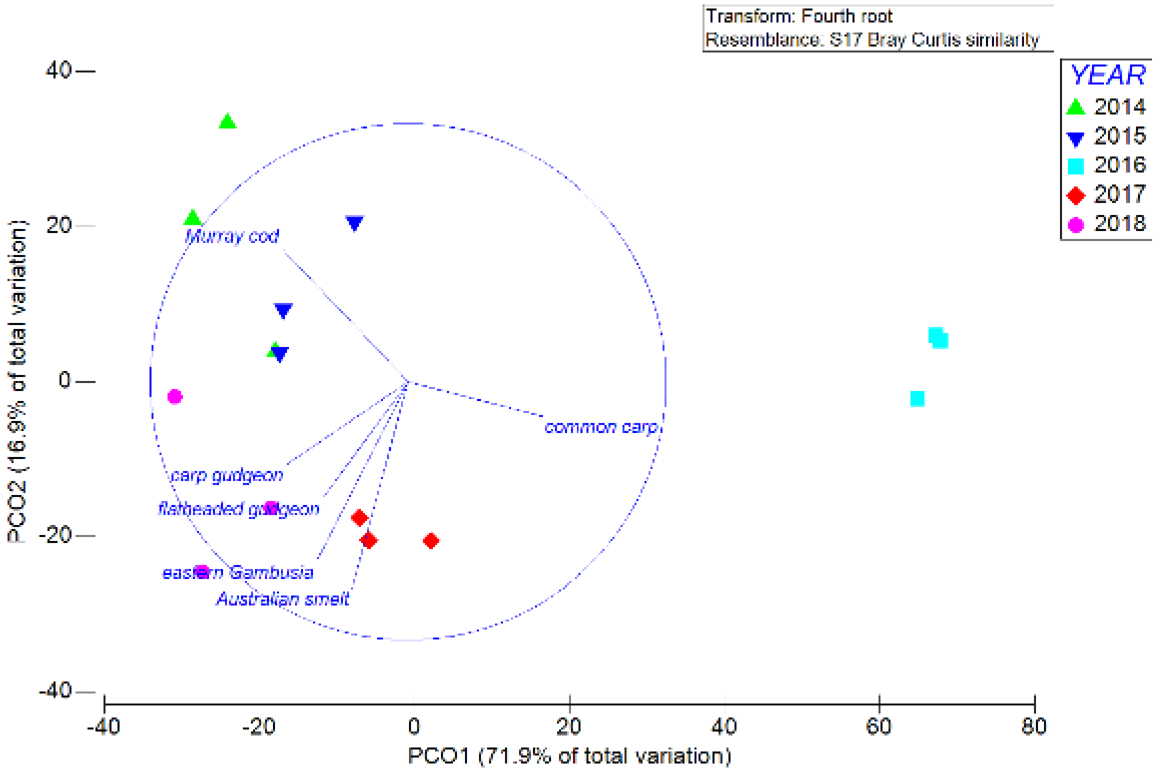


Figure 58. Annual larval fish community composition per site (plotted in multidimensional space via principal component analysis ordination) captured from the lower Lachlan River Selected Area using drift nets and light traps from spring/summer 2014 – 2018.

7.3.3 MID LACHLAN RIVER SHORT-TERM INTERVENTION MONITORING: 2018

A total of 473 larval fish were captured across the five sampling events of spring-summer 2018 comprising five native species (Murray cod, freshwater catfish, flat headed gudgeon, Australian smelt and carp gudgeon) and one alien fish species (eastern gambusia) (Table 20). Light traps captured the majority of larval fish (62%) (Table 20). Numbers of larval fish were variable between sampling events, with trips 2, 3 and 4 capturing the majority of fish (88% of all trips) comprising 46%, 25% and 17%, respectively. Murray cod were by far the most numerous species caught, comprising 76% of the total number of larval fish captured in 2018 (Table 20).

Larval fish were captured for only three of the six target species in the mid-Lachlan in 2018: two Equilibrium species, Murray Cod and freshwater catfish, and one Opportunistic species, carp gudgeon (albeit a single individual) (Table 20). No Periodic representative species (golden perch or bony herring) were collected during larval sampling in 2018 (Table 20). Murray cod were captured in the last four sampling trips, with the majority (88%) of individuals captured from sampling trips 2 and 3 (Figure 59). Larval Murray cod ranged in length from 5.9 – 16.5 mm, corresponding to ages of 0 – 65 days old (Figure 60). Estimated spawning window for Murray cod in 2018 was between 12/9/18 – 30/11/18, with two peaks between 6/10/18 – 21/10/18 and 31/10/18 – 15/11/18 when water temperatures were 17 - 21 and 20 – 24 °C, respectively (see Figure 63, section 7.7). Mean length of Murray cod was similar between sampling trips 2 and 3 but increased in trips 4 and 5 (Figure 60).

Table 20. Capture summary of larval fish from sampling conducted between mid-October to mid-December 2018 in the mid-Lachlan River system.

SPECIES	DRIFT NETS	LIGHT TRAPS	TOTAL
Murray cod	150	208	**358**
flat headed gudgeon	0	13	**13**
Australian smelt	0	40	**40**
carp gudgeon	2	22	**24**
freshwater catfish	26	0	**26**
golden perch	0	0	**0**
eastern gambusia	0	12	**12**
common carp	0	0	**0**
TOTAL	**178**	**295**	**473**

Three opportunistic species were collected during larval sampling in the mid-Lachlan STIM in 2018, these were Australian smelt, flat headed gudgeons and a carp gudgeons. Australian smelt were captured in all five sampling events, though were most abundant during trips 1 and 2 (Figure 59). Australian smelt were captured at each site and were most numerous at Euabalong. Australian smelt captured ranged in size from 5.881 – 22.96 mm (Figure 60) and ranged in estimated age from 8 – 68 days old. Length frequency distribution and associated back calculation of estimated spawning dates indicate that Australian smelt had an extended spawning window spanning late-July to early-December in 2018 (see Figure 63, section 7.7). Peaks in spawning activity occurred around mid-September and again around mid-October, when water temperatures were around 11 – 14 °C and 19 – 21 °C, respectively (see Figure 63, section 7.7). Mean length of Australian smelt generally increased between sampling events (Figure 60).

Flat headed gudgeon were only captured at a single site (Euabalong) on a single sampling trip (trip 1), and all were captured using light traps. Flat headed gudgeon ranged in length from 8.0 – 13.5 mm (Figure 56), with an estimated age of 25 – 54 days. This corresponds to an estimated spawning window from mid-October to early November when water temperatures were ~18 – 24 °C (see Figure 62, section7.7).

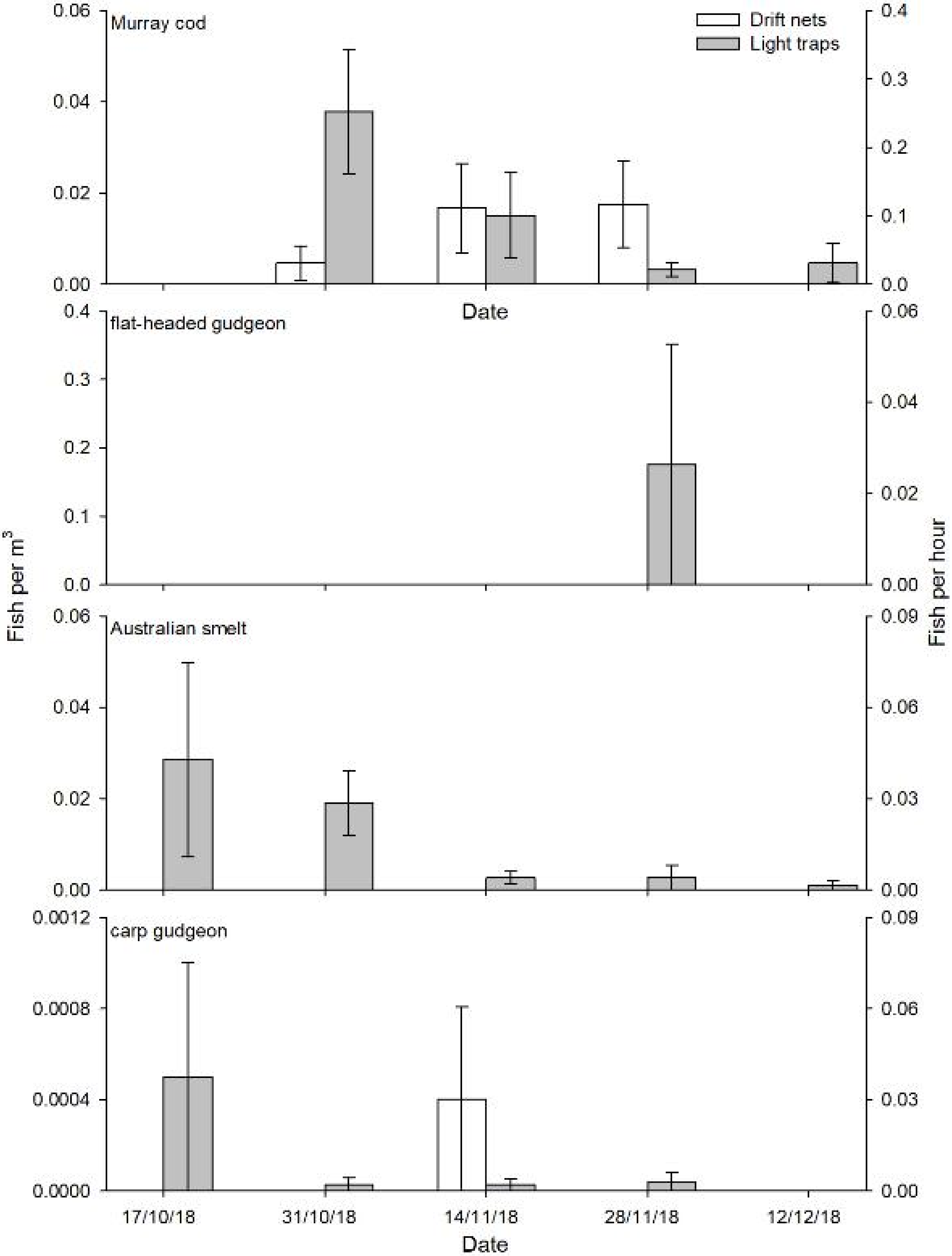


Figure 59. Mean catch per unit effort (± standard error) of the commonly caught larval native fish for drift nets (left axis, white bars) and light traps (right axis, grey bars) per sampling event in spring summer 2018 in the mid-Lachlan River catchment.

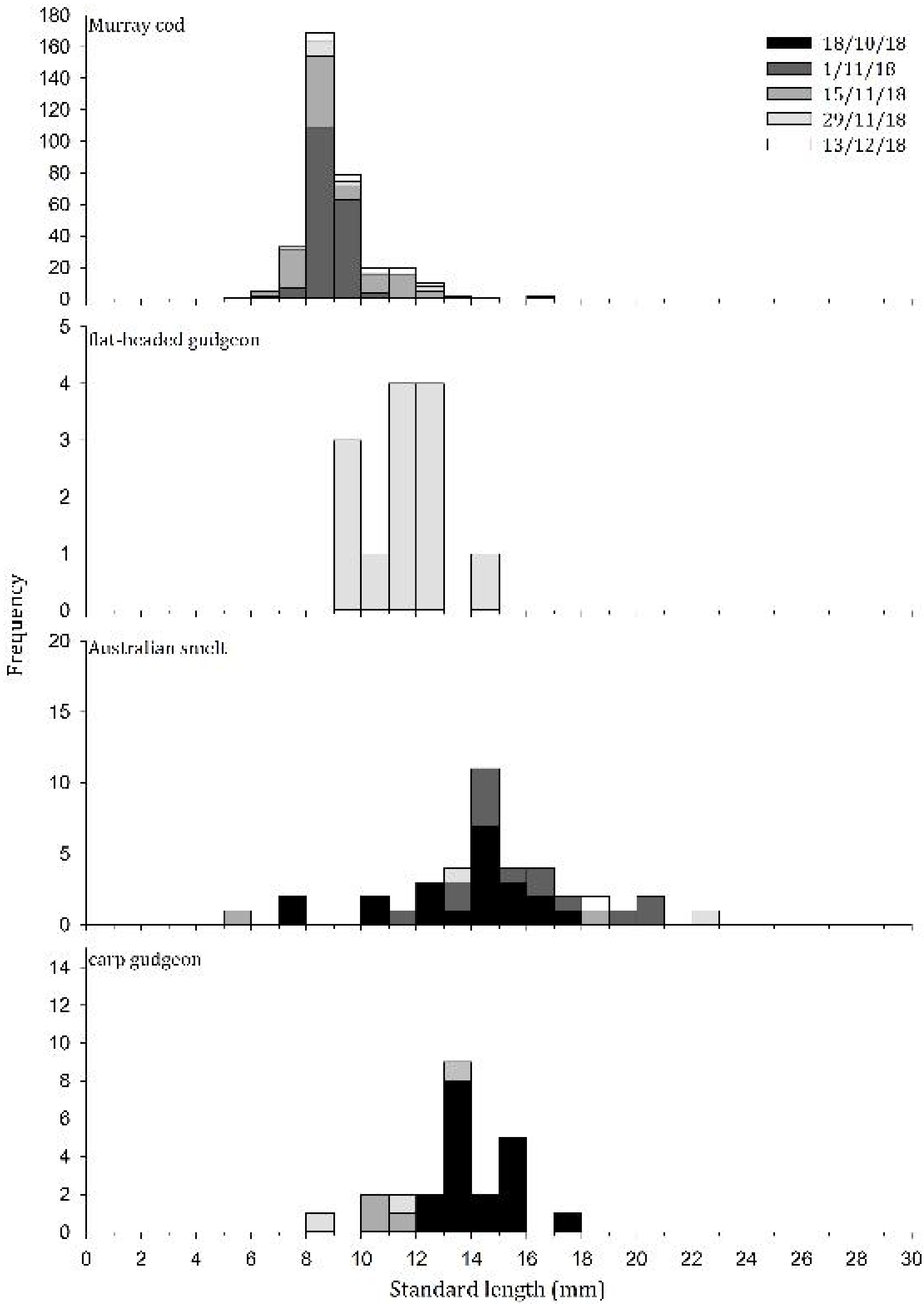


Figure 60. Length frequency histograms for each sampling event of commonly captured larval native fish species with site (n = 3) and sampling technique (n = 2) combined for 2018 in the mid-Lachlan River catchment.

7.4 DISCUSSION

7.4.1 LOWER-LACHLAN RIVER SELECTED AREA

In 2018, Commonwealth environmental watering actions aimed to provide suitable cues and access to habitat for spawning as well as larval growth and survival. Larval fish monitoring in 2018 suggests that these objectives were met. Spawning was evident for non-flow dependent species; however, there was no evidence in the larval monitoring (in terms of eggs or larvae) of flow dependent species (i.e. golden perch) or bony herring spawning in September-December 2018. Subsequent sampling in autumn 2019 detected young-of-year bony herring indicating that spawning of this species occurred – (see section 6).

The spring pulse appears to have been ideally delivered to promote spawning movement behaviour of adult Murray cod. This pulse was followed by relatively stable flow which coincided with the estimated peak spawning timing of Murray cod in the lower Lachlan River selected area (appendix 1). The combination of a pulse to promote movement and stable water levels appears to have been suitable to promote a relatively strong recruitment year for Murray cod, at least to early juvenile stages. This is ideal timing as it follows two relatively poor recruitment years following the 2016 floods and associated demise of the adult Murray cod in the target reach (see Section 6).

As for the first four years of monitoring, there was no evidence of natural recruitment of golden perch in the selected area (either larval fish or 0+ recruits in the fish community sampling). The reasons behind lack of golden perch spawning since monitoring began in 2014 remain largely unresolved. This is despite golden perch being noted for the ability to display opportunistic spawning behaviour (Ebner et al. 2009). Previous studies suggest that golden perch require water temperatures of greater than 19 °C (King et al. 2005, Stuart and Jones 2006) in the southern Murray-Darling Basin to initiate spawning and that temperatures of 23 °C are often regarded as optimal for spawning associated with an increase in discharge (Lake 1967, Roberts et al. 2008).

The spawning season of 2018 did see spikes in discharge in mid-September, late October and mid-November, with water temperatures exceeding 21 °C in the latter two peaks (ideal range based on previous literature). Despite suitable temperature ranges, the latter rises failed to result in a detectable spawning event of golden perch in the target reach. A potential factor contributing to the lack of golden perch spawning may be that suitable hydraulic conditions for golden perch spawning were not created with the flows provided. There is a growing belief that hydraulics, and in particular flow velocity, is important in native fish spawning and recruitment (Mallen-Cooper and Zampatti 2018). However, relationships at this stage are not well established. Currently a degree of uncertainty exists regarding the lack of spawning response of golden perch specific to the Lachlan River.

As for all other monitoring years, bony herring were again not detected during larval monitoring in 2018. This continues to be surprising given that recruits were detected at the majority of sites in the fish community monitoring in early 2019 (see Chapter 6). This species is known to spawn in December and January when water temperatures reached 21–23 °C in the lower Murray River (Puckridge 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 Chapter 6) suggests that spawning of bony herring occurred outside the temporal or spatial range of the sampling program.

As in 2017, small bodied native species dominated larval fish captures in 2018, suggesting that conditions were suitable for a range of small bodied species to spawn. Flat headed gudgeon were especially abundant in 2018, which may still be related to the flood event of late 2016 – early 2017. The main mechanisms by which flooding could contribute to elevated abundances of larval native small bodied fish would be inundation of new off channel habitats and / or boosts to productivity (resulting in increased food resources for Australian smelt). King et al. (2003) found that Australian Smelt utilised inundated floodplain habitats to recruit.

Relative abundance of larval flatheaded gudgeon in 2018 were the highest of the five years of monitoring to date (nearly 8-fold more than the next highest year 2015). Spawning of this species was found to be initiated by increases in food resources in earthen ponds (Llewellyn 2007), which is somewhat congruent with the results of the current monitoring program. The two years with the highest abundance of larval flatheaded gudgeon (2015 and 2018) were years in which spring pulses were delivered in mid-September. It appears as though spawning and survival to early juvenile stage of flatheaded gudgeon may be related to whether or not a spring pulse was delivered just prior to the estimated spawning window.

As for 2017, larval Australian smelt abundances were high in 2018. The spring pulse delivered in mid-September followed the estimated peak spawning time of Australian smelt in the lower Lachlan River selected area. The timing of the pulse and likely associated increase in food resources appear to have been suitable for survival and growth of Australian smelt in 2018.

Larval carp gudgeon were again rare in 2018, which is surprising as fish community data from autumn 2018 (Dyer et al. 2018) recorded large numbers of juveniles that may have been expected to have spawned in late 2018. This species has been observed to have enhanced recruitment during flooding (associated with wetland inundation) (Beesley et al. 2012) or used floodplain inundation for recruitment (King et al. 2003), which may partially explain the high numbers of juveniles found in autumn the previous year (following significant flooding in the catchment in 2016 – 2017). So it may have been expected that the floods of late 2016 and early 2017 would have increased the abundances of carp gudgeon in the system for the prevailing few years. Fish community sampling conducted in autumn 2019 detected low relative abundances of young-of-year carp gudgeon, which is congruent with the findings of the larval fish monitoring that 2018 spawning was not a significant event. At this stage, it is unclear why captures of larval carp gudgeon were rare in 2017 and 2018.

Only one common carp was captured in 2018. This suggests common carp spawning (as detected in the larval fish monitoring) in the targeted area was minimal. This is despite several peaks in flow during the possible carp spawning window, which indicates that in channel rises can be released with low risk of creating suitable conditions for a large common carp spawning event. It must be noted that young-of-year carp were common in all years of sampling during fish community monitoring (see section 6).

7.5 EVALUATION

7.5.1 LOWER-LACHLAN RIVER SELECTED AREA

There were two Commonwealth environmental watering actions in the lower Lachlan River system that targeted outcomes for native fish reproduction in 2018 – 2019 (4.3.1 Watering Actions 1 and 2: Supporting native fish outcomes):

A. Watering action 1: Large spring pulse (mid-late September 2018)
B. Re-release from watering action 1: Smaller spring pulse (late October 2018)

These watering actions had the following expected outcomes relating to reproduction of native fish:

1) To support native fish condition, movement, reproduction, larval abundance and recruitment opportunities

The first pulse appears to have been delivered with ideal timing to promote spawning movements of Murray cod, based on estimated spawning dates of larval Murray cod captured in 2018 (see Appendix 1: Estimating fish spawning dates 2018, p. 135). Murray cod have been found to undertake movements immediately prior to spawning (Koehn et al. 2009), likely to find a mate or suitable spawning habitat. Larval Murray cod abundances in 2019 were similar to those before the 2016 flood, indicating that hydrological conditions of the spawning season of 2018 were suitable for recruitment to early juvenile stage of Murray cod in the lower Lachlan River selected area.

The first spring pulse also occurred during and just after the peak estimated spawning of flatheaded gudgeon and Australian smelt, respectively. This pulse, which resulted in a river rise of greater than 1 m, would have inundated new habitat (potentially spawning habitat for flatheaded gudgeon) and likely boosted food resources at an ideal time for these two species. Results from the stream metabolism component of this study are congruent with this and found that this watering event resulted in measurable increases in gross primary productivity (GPP) and ecosystem respiration (ER) (basal food production). A previous study of captive bred flatheaded gudgeon revealed that an abundant food supply was essential for initiating spawning (Llewellyn 2007). Conditions brought about by the first spring pulse appear to have been well suited to spawning and early recruitment of opportunistic small bodied native fish species in the lower Lachlan River.

The second spring pulse (which was a component of Watering action 1) was delivered during the estimated spawning window of Murray cod in the lower Lachlan River selected area. It must be noted that this pulse was delivered following a relatively stable flow period and after the estimated spawning peak. Similarly to the first watering action, this second pulse mobilised nutrients and resulted in localised increases in ER and there was some evidence of a small increase in GPP, which would likely result in increases to food availability for larval Murray cod. Furthermore, it is likely that the second spring pulse provided opportunities for larval Murray cod to disperse.

The second spring pulse resulted in a rise in river level of approximately 1.1 metre (based on gauge downstream of Ganowlia Weir) and was delivered when water temperatures were approximately 21 ^{o}C. Although not an expected outcome from the watering actions, based on timing of the river rise associated with this pulse, it may have been expected that golden perch may have spawned. Previous studies suggest that golden perch 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 associated with an increase in discharge (Lake 1967, Roberts et al. 2008). Water temperatures during the spring 2018 pulse appeared to be within suitable range for golden perch spawning, so the lack of spawning response is more likely related to other factors (such as antecedent flow conditions, hydraulics or population connectivity).

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?

In 2018 – 2019 Commonwealth environmental water made a positive contribution to the spawning of Murray cod, flat headed gudgeon and Australian Smelt in the lower Lachlan River system. Based on the evidence at hand (strong relative abundances of larval fish in 2018, especially small bodied species), the spring pulse delivered in mid-late September was successful in achieving expected outcomes for fish reproduction in the lower Lachlan selected area. In the absence of Commonwealth environmental water (specifically the first spring pulse), it is likely that such a magnitude in spawning response to flatheaded gudgeon would not have been observed.

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. A subsample of larval fish have been sent for aging, but results have not yet been received. However, increases in mean length of larval fish captures were observed per sampling trip for Australian smelt and flatheaded gudgeon indicating that conditions during early development of these species were suitable for survival and growth. Furthermore, the presence of 0+ individuals (Australian smelt, flatheaded gudgeon, carp gudgeon, Murray cod and bony herring) in the fish community monitoring (see Section Fish Community) provides an indication that growth and survival did occur for small bodied native fish, one medium bodied native fish and one large-bodied native fish in the selected area.

Long-term (five year) evaluation questions:

3) What did Commonwealth environmental water contribute to native fish populations in the Lower Lachlan River system?

When undertaking long-term (5 year) evaluation of the contribution of Commonwealth environmental water to native fish in the lower Lachlan River it is important to set the evaluation in the context of the greater hydrological regime of the river system. The five years of monitoring undertaken thus far have been hydrologically vastly different, with two years being very dry (2014 – 2015 and 2018 – 2019), one being wet (2015 – 2016), one being somewhat dry (2017 – 2018) and one containing the second largest flood on record in the catchment (2016 – 2017). This makes disentangling responses of native fish populations to environmental water difficult, with responses potentially masked or overwhelmed by natural hydrological variation and a longer-time frame is required to begin to understand population responses.

Across the five years of the monitoring program, seven Commonwealth environmental watering actions have been released that have had expected outcomes for native fish. The majority of these flows were aimed at promoting spawning activity (movement, spawning) and / or providing a productivity pulse to increase food resources. So far, Commonwealth environmental water has failed to produce a detectable spawning response of golden perch within the lower Lachlan River selected area, though it appears as though other factors may be reducing the likelihood of success (e.g. hydraulic conditions, barriers to movement). How to achieve a spawning response from golden perch in the lower Lachlan river selected area is still an outstanding knowledge gap, and one that warrants further attention in the coming years

The hydrological floor set to provide Murray cod with ideal spawning conditions in 2017 was successfully delivered, but the response of larval Murray cod abundances were limited by low adult stock remaining following depletion during the 2016 floods and resultant blackwater event. Hydrological variability during the spawning window of Murray cod was relatively low, and the relative abundance of Murray cod larvae increased from 2017, which indicates that recovery of this population is underway and environmental flows will likely have a role in expediting this recovery.

The spring pulse delivered in spring 2018 appears to have driven a large spawning response in flatheaded gudegon, with larval abundances in 2018 nearly 8-fold the next most abundant year. This follows on from a relatively large spawning response in 2015 (a years where high spring flows were also observed). Although being recognised as a flow dependent spawner, increased food resources that accompanied an increases in flow during spring looks to be a likely driver of spawning and early recruitment intensity in the lower Lachlan River selected area.

One watering action was delivered to provide water quality improvements on the recession of the 2016 flood, though this was primarily focussed on the mid-Lachlan and recognised that there were few if any improvement options available to the lower-Lachlan (Symes 2017). Any water quality improvements (primarily dissolved oxygen) that many have occurred, may have provided some respite for native fish (especially Murray cod) during this time, and would have increased chances of survival and ability of the population to recover.

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

The contribution of Commonwealth environmental water to native species diversity in the lower Lachlan River selected area is marginal over the five years of the program thus far. Certainly, there has been no evidence of a reduction in native fish diversity since the program commenced in 2014, but likewise, there is no evidence of increased native fish species diversity. The potential of Commonwealth environmental water to increase native species diversity in the lower Lachlan River is somewhat minimal with other factors such as barriers to movement (caused by weirs) and regional extirpation of species likely to be greater factors in contributing to native species diversity change.

This is the fifth year of the monitoring program and it is well recognised that environmental water is only one intervention that may contribute to the long-term rehabilitation of native fish communities across the Murray Darling Basin (MDBC 2004, Lintermans 2007). This includes the objectives above of improving native fish populations and species diversity in the Lachlan catchment. While the objectives above define 'long term' as being 5 years, for some species and populations, the long-term rehabilitation process may take decades (e.g. Murray cod reach sexual maturity at 4-7 years of age (Humphries & Walker 2013)). The recommendations below reflect the potential for the CEWO to progress the longer-term fish objectives further.

7.5.2 MID-LACHLAN RIVER SHORT-TERM INTERVENTION MONITORING

There were two Commonwealth environmental watering actions in the mid- Lachlan River system that targeted outcomes for native fish reproduction in 2018 – 2019:

1) Large spring pulse (mid-late September 2018)
2) Hydrological 'floor' from mid-October until end of November to prevent water level drops that may lead to Murray cod nest abandonment.

These watering actions had the following expected outcomes relating to reproduction of native fish:

2) To support native fish condition, movement, reproduction, larval abundance and recruitment opportunities

As for the lower Lachlan selected area, the first pulse appears to have been delivered with ideal timing to promote spawning movements of Murray cod, based on estimated spawning dates of larval Murray cod captured in 2018 (see appendix 1). Murray cod have been found to undertake movements immediately prior to spawning (Koehn et al. 2009), likely to find a mate or suitable spawning habitat. The spring pulse also coincided with the peak estimated spawning season of Australian smelt. Stream metabolism monitoring as part of this study found that this peak increased in algal biomass and had measurable increase in both GPP and ER (see Chapter 5) which would have resulted in a pulse in food resources at the same time as larval Australian smelt would have been hatching in the mid-Lachlan in 2018.

The second watering action which commenced in mid-October 2018 aimed to maintain a hydrological 'floor' of 800 ML day^{-1} at Forbes (Cottons Weir) until the early December 2018. In terms of delivery, this action was successful, with only a small drop below 800 ML day^{-1} recorded (still > 730 ML day^{-1}) for only four days (Figure 61). Given the estimated peak spawning of Murray cod commenced in early October in the mid-Lachlan River (see appendix 1), setting of this floor in future should be undertaken from the start of October to ensure that the peak spawning and nesting times are covered by the floor. The combination of spring pulse to promote movement, then the hydrological floor to protect Murray cod nests appears to have been successful, with raw abundances of Murray cod present, similar to those recorded in the lower Lachlan selected area in 2014 and 2018.

Over the past two spawning seasons, discharge has been manipulated in the mid-Lachlan to prevent sudden decreases in water levels during Murray cod spawning season (to prevent nest abandonment and egg desiccation). To achieve this, two different watering actions have been employed. In the 2017 Murray cod spawning season, a hydrological 'roof' was employed to maintain river level greater than the expected demand for irrigation, and stock and domestic orders. This strategy was successful in preventing sudden decreases in water levels, but was costly in water use (total use 31, 500 ML). For the 2018 Murray cod spawning season, a hydrological 'floor' was set where a minimum discharge was to be maintained (likely below that of irrigation and stock and domestic orders). This strategy proved to be somewhat successful, that some small peaks were still experienced associated with increases in water orders, but was very efficient in terms of water use requiring only 2, 032 ML to complete. Unfortunately, larval fish monitoring was not employed in 2017, so a like for like comparison cannot be made to determine which strategy had the best outcome for Murray cod spawning and recruitment. Our data (and that from the mid-Lachlan fish community sampling) can confidently conclude that water level conditions experienced in 2018 (during the hydrological 'floor') were suitable for Murray cod spawning and recruitment to juveniles.

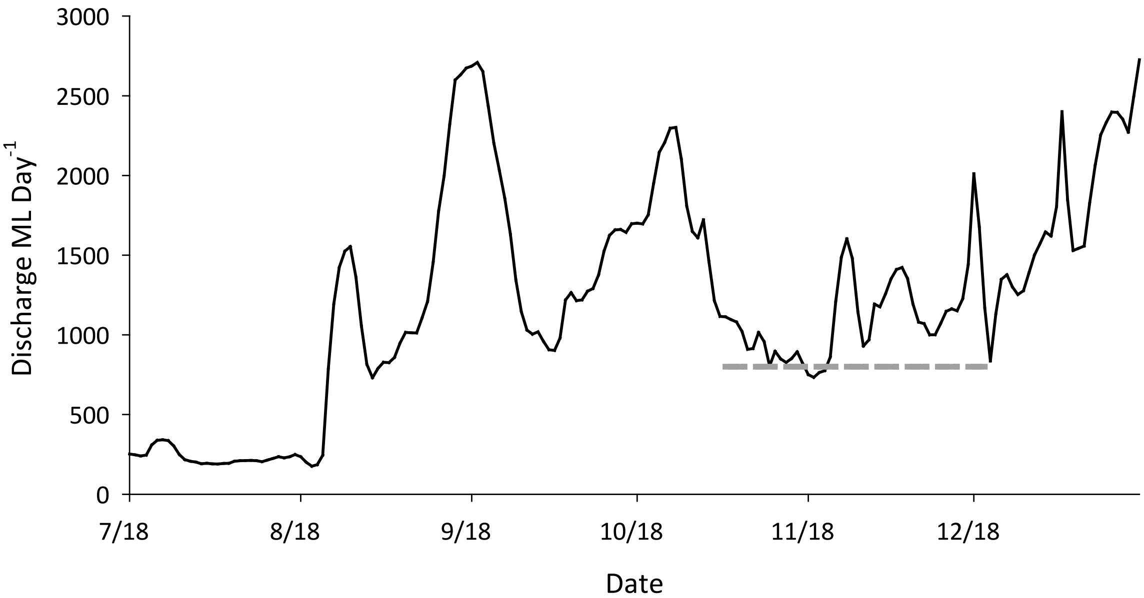


Figure 61. Discharge at Cottons Weir Forbes (solid black line) measured against the minimum discharge target of 800 ML Day^{-1} (dashed grey line) from the 17th October to the 3rd December.

To assess the contribution of Commonwealth environmental water to native fish spawning and recruitment in the mid-Lachlan, the relevant short-term question to be evaluated is:

Short-term (one year) evaluation questions:

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

In 2018 – 2019 Commonwealth environmental water made a positive contribution to the spawning of Murray cod, flat headed gudgeon and carp gudgeon in the mid Lachlan River system. Thus the two watering actions delivered in the mid Lachlan have been successful in supporting native fish reproduction.

7.6 FINAL COMMENTS AND RECOMMENDATIONS

- Small bodied species, especially flatheaded gudgeon and Australian smelt, appear to have benefitted (in terms of increased recruitment) from watering action 1 in mid-September 2018. This is likely because of the productivity pulse generated by the flow pulse.
- Flathead gudgeon larval abundances seem to be positively related to early spring pulses. This likely to be caused by increased spawning initiated by increases in food abundances.
- Murray cod larval abundances have increased from a post flood low in 2016 and 2017. Based on estimated spawning dates, the timing of the spring pulse appears to have been ideal for promoting adult movements in 2018.
- Murray cod are in a state of recovery following the blackwater events associated with the 2016 flood. Future environmental watering should aim to provide conditions that support spawning and early development of this species, including (following Ellis et al. 2016):
  - Flow pulse in late-winter early-spring (recession complete by mid-September)
  - Stable water levels during the nesting period in the lower Lachlan Selected area (mid-September – early November) and mid-Lachlan River (late-September to early December)
  - Dispersal and productivity pulse at the end of the nesting period (mid-November)
- To progress the longer-term fish objectives further it is recommended that the CEWO continues to consider:
  - how it may participate in other intervention options (water quality monitoring, habitat rehabilitation, removal of barriers to movement, use of fish screens on irrigation intakes) that complement the use of environmental water
- The hydrological ‘floor’ set in 2018 in the mid-Lachlan appears to have supported Murray cod spawning and recruitment to juveniles. A hydrological ‘floor’ is a much less water intensive strategy than the hydrological ‘roof’ employed in 2017. At this stage, our data suggests that a hydrological ‘floor’ is suitable strategy to help reduce sudden decreases in water level during Murray cod spawning season.
- Despite an intentional watering action (in 2015) and apparently suitable conditions for spawning in 2018, a spawning or recruitment event for golden perch has not been detected in the lower Lachlan River during this five-year monitoring program.

We recommend against trying to achieve a spawning response from golden perch using a single flow pulse in spring, as this has yet to elicit a spawning response.

7.7 APPENDIX 1: ESTIMATING FISH SPAWNING DATES 2018

The most accurate and precise method of estimating larval fish age and hence deriving a spawning date is by direct daily aging using otoliths of larval fish (Anderson et al. 1992, Campana and Thorrold 2001). Resource constraints meant direct aging was not currently feasible for this project (although larvae captured in 2014 – 2018 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. (2008) 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.

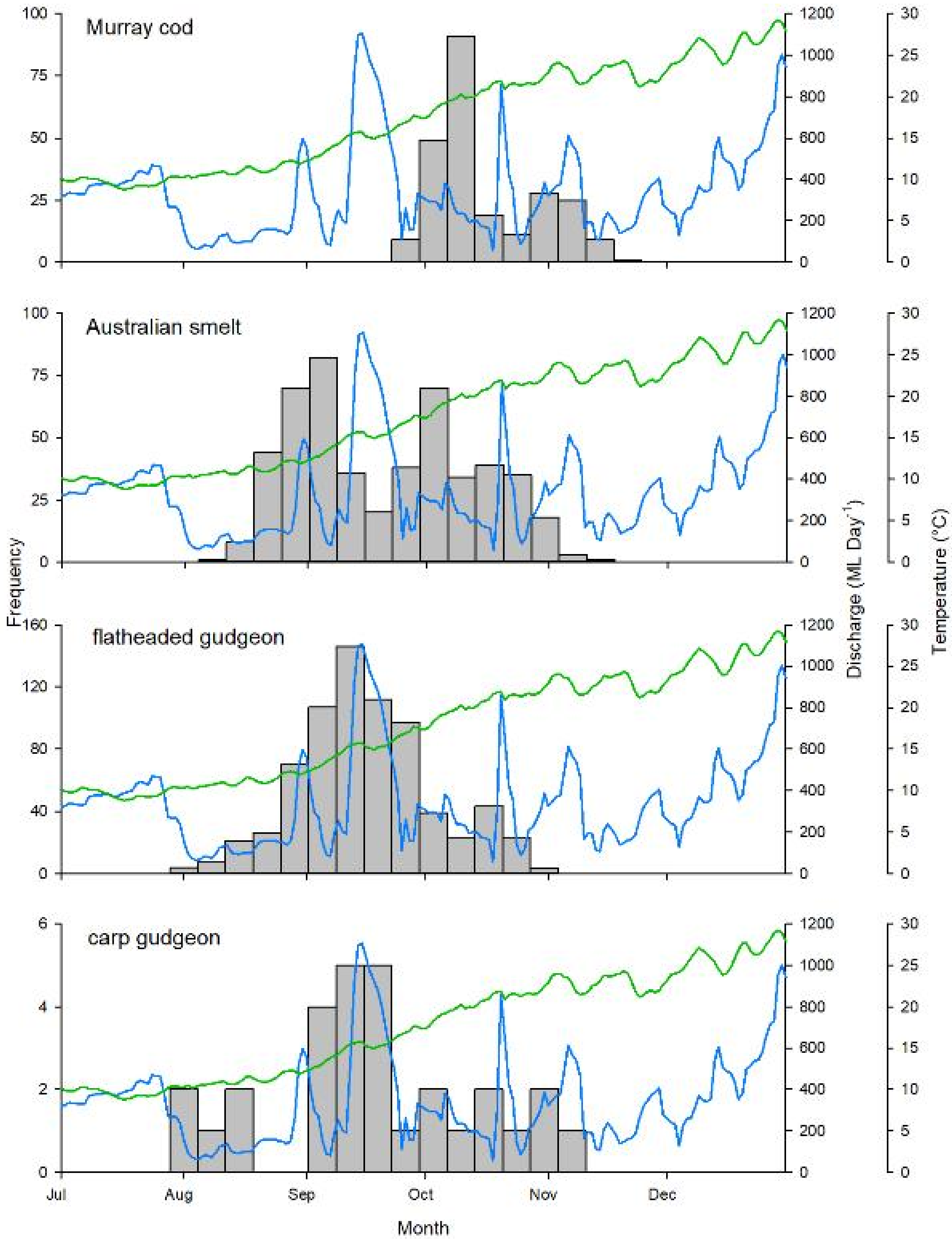


Figure 62. Estimated spawning date frequency (grey bars) and associated discharge and temperature for larval native fish species captured in the lower-Lachlan River in 2018.
Mean daily discharge (blue line) and mean daily temperature (green line) from Lachlan River at Willandra Weir (412038). Data are from all sites and methods combined.

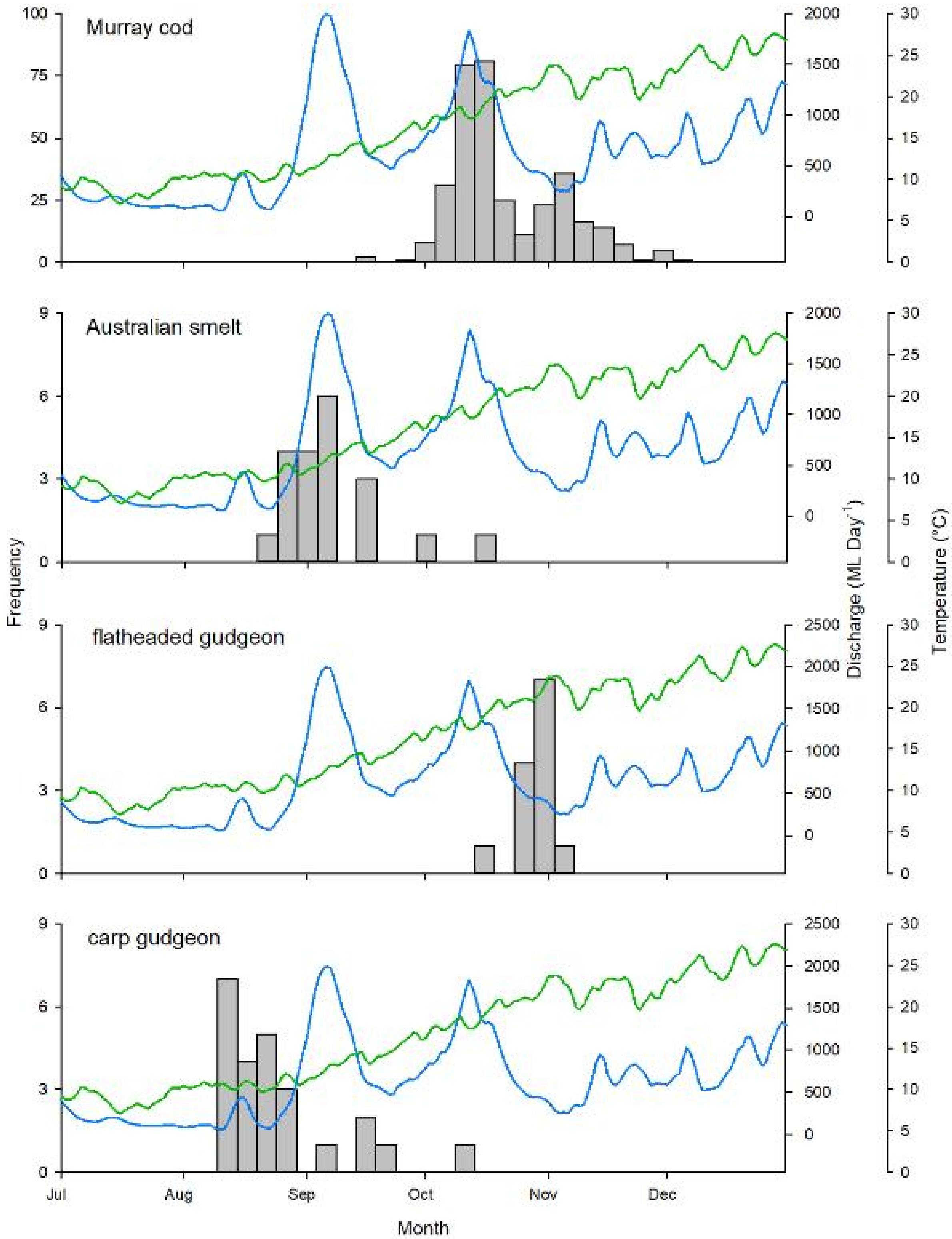


Figure 63. Estimated spawning date frequency (grey bars) and associated discharge and temperature for larval native fish species capture in the mid-Lachlan River in 2018.
Mean daily discharge (blue line) and mean daily temperature (green line) from Lachlan River at Condobolin Bridge (412006). Data are from all sites and methods combined.

7.8 APPENDIX 2: RESULTS OF SIMILARITY PERCENTAGE ANALYSIS (SIMPER) OF ANNUAL DIFFERENCES IN THE LARVAL FISH COMMUNITY IN THE LOWER LACHLAN RIVER SELECTED AREA.

Table 21. Results of Similarity percentage analysis (SIMPER) of annual differences in the larval fish community in the Lower Lachlan River selected area.

Groups 2014 & 2015
Average dissimilarity = 29.37

	Group 2014	Group 2015				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
flatheaded gudgeon	1.75	3.14	6.63	1.58	22.57	22.57
common carp	0	1.14	5.61	3.19	19.09	41.66
Australian smelt	1.71	1.48	3.94	1.64	13.42	55.08
carp gudgeon	0.97	1.35	3.54	0.79	12.05	67.13
eastern gambusia	0.67	0.84	3.49	0.95	11.87	79
Murray cod	3.41	3.86	3.14	1.29	10.68	89.68
freshwater catfish	0.67	0	3.03	1.12	10.32	100

Groups 2014 & 2016
Average dissimilarity = 100.00

	Group 2014	Group 2016				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Murray cod	3.41	0	30.08	2.37	30.08	30.08
common carp	0	3.25	26.28	2.17	26.28	56.36
Australian smelt	1.71	0	14.21	3.73	14.21	70.57
flatheaded gudgeon	1.75	0	13.9	10.33	13.9	84.48
carp gudgeon	0.97	0	6.58	1.11	6.58	91.06

Groups 2015 & 2016
Average dissimilarity = 84.95

	Group 2015	Group 2016				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Murray cod	3.86	0	25.58	8.89	30.11	30.11
flatheaded gudgeon	3.14	0	20.94	4.18	24.65	54.75
common carp	1.14	3.25	13.65	1.27	16.06	70.81
Australian smelt	1.48	0	10.01	1.95	11.78	82.59
carp gudgeon	1.35	0	9.07	3.67	10.68	93.27

Groups 2014 & 2017
Average dissimilarity = 47.79

	Group 2014	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	1.71	5.44	16.55	2.39	34.63	34.63
common carp	0	2.46	10.36	1.94	21.68	56.31
Murray cod	3.41	1.84	6.9	1.84	14.43	70.75
eastern gambusia	0.67	1.84	5.54	1.14	11.6	82.35
flatheaded gudgeon	1.75	2.44	3.37	0.85	7.04	89.39
freshwater catfish	0.67	0	2.58	1.15	5.4	94.78

Groups 2015 & 2017
Average dissimilarity = 38.21

	Group 2015	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	1.48	5.44	15.07	6.53	39.44	39.44
Murray cod	3.86	1.84	7.72	3.59	20.19	59.63
common carp	1.14	2.46	5	1.11	13.1	72.73
carp gudgeon	1.35	0.33	3.94	1.81	10.31	83.03
eastern gambusia	0.84	1.84	3.81	1.51	9.96	93

Groups 2016 & 2017
Average dissimilarity = 73.39

	Group 2016	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	0	5.44	31.5	6.01	42.93	42.93
flatheaded gudgeon	0	2.44	14.38	3.97	19.6	62.53
eastern gambusia	0	1.84	10.79	4.61	14.71	77.23
Murray cod	0	1.84	10.43	21.55	14.21	91.45

Groups 2014 & 2018
Average dissimilarity = 40.57

	Group 2014	Group 2018				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
flatheaded gudgeon	1.75	5.18	13.49	2.80	33.25	33.25
Australian smelt	1.71	4.49	11.00	2.42	27.12	60.37
eastern gambusia	0.67	1.78	5.46	1.56	13.45	73.82
carp gudgeon	0.97	1.68	3.47	1.07	8.55	82.37
Murray cod	3.41	2.92	3.07	1.93	7.58	89.95
freshwater catfish	0.67	0.00	2.43	1.31	6.00	95.94

Groups 2015 & 2018
Average dissimilarity = 29.5

	Group 2015	Group 2018				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	1.48	4.49	10.57	2.93	35.84	35.84
flatheaded gudgeon	3.14	5.18	7.14	1.86	24.19	60.03
Murray cod	3.86	2.92	3.80	1.70	12.89	72.92
eastern gambusia	0.84	1.78	3.75	1.48	12.69	85.61
common carp	1.14	0.33	2.95	1.43	10.01	95.62

Groups 2016 & 2018
Average dissimilarity = 96.8

	Group 2016	Group 2018				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
flatheaded gudgeon	0.00	5.18	26.35	7.96	27.22	27.22
Australian smelt	0.00	4.49	22.88	5.81	23.64	50.86
Murray cod	0.00	2.92	15.43	2.68	15.94	66.80
common carp	3.26	0.33	14.57	1.84	15.05	81.85
eastern gambusia	0.00	1.78	8.93	3.66	9.22	91.07

Groups 2017 & 2018
Average dissimilarity = 29.32

	Group 2016	Group 2018				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
flatheaded gudgeon	2.44	5.18	8.77	3.30	29.91	29.91
common carp	2.46	0.33	6.84	1.67	23.32	53.23
carp gudgeon	0.33	1.68	4.37	2.44	14.90	68.13
Australian smelt	5.44	4.49	3.89	1.44	13.28	81.41
Murray cod	1.84	2.92	3.77	1.27	12.86	94.27

8 DETERMINING AGE, SPAWNING DATES AND GROWTH OF AUSTRALIAN SMELT AND MURRAY COD IN THE LOWER LACHLAN RIVER SELECTED AREA.

8.1 BACKGROUND

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 to adulthood is largely driven by spawning success, as well as 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). Accurate and precise estimates of larval fish age are required to adequately assess the influence of flow on fish reproduction, growth and survival.

Analysis of otolith micro-structure can provide valuable information on a fishes age and growth history (see Campana 2005). Currently, the Category 1 LTIM monitoring program employed in the lower Lachlan selected area does not age larval fish, and spawning date and growth have been crudely estimated using length as a proxy. This results in uncertainty around spawning dates which limits our capacity to link them to daily or sub-daily flow metrics that could inform flow release strategies. By more accurately aging larval fish and examining otolith microstructure, we will be better able to interpret how flow interacts with spawning dates and growth of larval fish in the lower Lachlan elected area.

The energetic base of food webs 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 such as leaves, wood and organic carbon dissolved in the water (Bunn et al. 2006). Both processes are influenced by the availability of nutrients, particularly nitrogen and phosphorus, as well as water temperature and light. Delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients from in-channel surfaces, the floodplain or from upstream (Boulton and Lake 1992, MDFRC 2013, Stewardson et al. 2013). Pulses from in-channel rises have been consistently observed over the past five years in the lower Lachlan River as part of the LTIM program (see section 5: Stream metabolism and water quality). The effect changes in stream productivity and larval fish growth is not clear, especially in Australian lowland rivers. It would be expected that an increase in stream productivity (and be definition, food resources) would lead to an increase in larval fish growth, survival and ultimately recruitment.

The Lower-Lachlan River Selected Area monitoring and evaluation plan required fish otoliths to be collected and analysed in the 1st and 5th years of monitoring. Killing adult large bodied native fish for otolith analysis in the 5th year was deemed inappropriate in the context of the Lachlan River fish (particularly Murray cod) population is still in recovery from the 2016 hypoxic event, and the greater context of fish kills of large bodied natives in other parts of the basin in early 2019. Consequently, unspent funds were directed to analysing historically collected samples and data from the project to:

1) Determine spawning dates of a large bodied and a small bodied larval native fish across four years
2) Determine length at age for a large-bodied and a small-bodied larval native fish across four years
3) Compare growth rates of a large-bodied and a small-bodied larval native fish between years
4) Provide some preliminary insight into the interaction between gross primary productivity and larval fish growth for the lower Lachlan River.

8.2 METHODS

8.2.1 FISH COLLECTION AND OTOLITH ANALYSIS

Larval fish used for otolith analysis were collected as part of the LTIM monitoring undertaken over the past five years (2014 – 2018). Species examined were Murray cod (a large bodied species) and Australian smelt (small bodied species), both commonly captured in larval sampling in the lower Lachlan River. Murray cod and Australian smelt are great candidates to examine early life history – otolith microstructure relationships as both species have been found to deposit daily otolith increments (Humphries 2005, Tonkin et al. 2008b) Furthermore, Australian smelt have been shown to exhibit strong somatic growth – otolith growth relationships (Tonkin et al. 2008a, Tonkin et al. 2008c) These species represent a species targeted by Commonwealth environmental water in the river system (Murray cod) and a small bodied species (Australian smelt) that represents an important food source for larger species in the catchment. This project examined 30 individuals of each species for each year that they were present in samples (2014, 2015, 2017 and 2018). All fish were taken from a single site (Lanes Bridge) to minimise variation among sites. Larval fish sagittal otoliths were removed and processed at Fish Aging Services (Victoria). From this an age estimate and measurements of daily increments were made (Figure 64). A hatch check (otolith increment which is darker and indicates time of hatching, Humphries 2005) was present for Murray cod otoliths at a mean distance from the core of 23.01 ± 0.25 µm (range 17.36 – 30.48 µm). This mark was considered day 0 and age was calculated based on number of increments outside the hatch check increment.

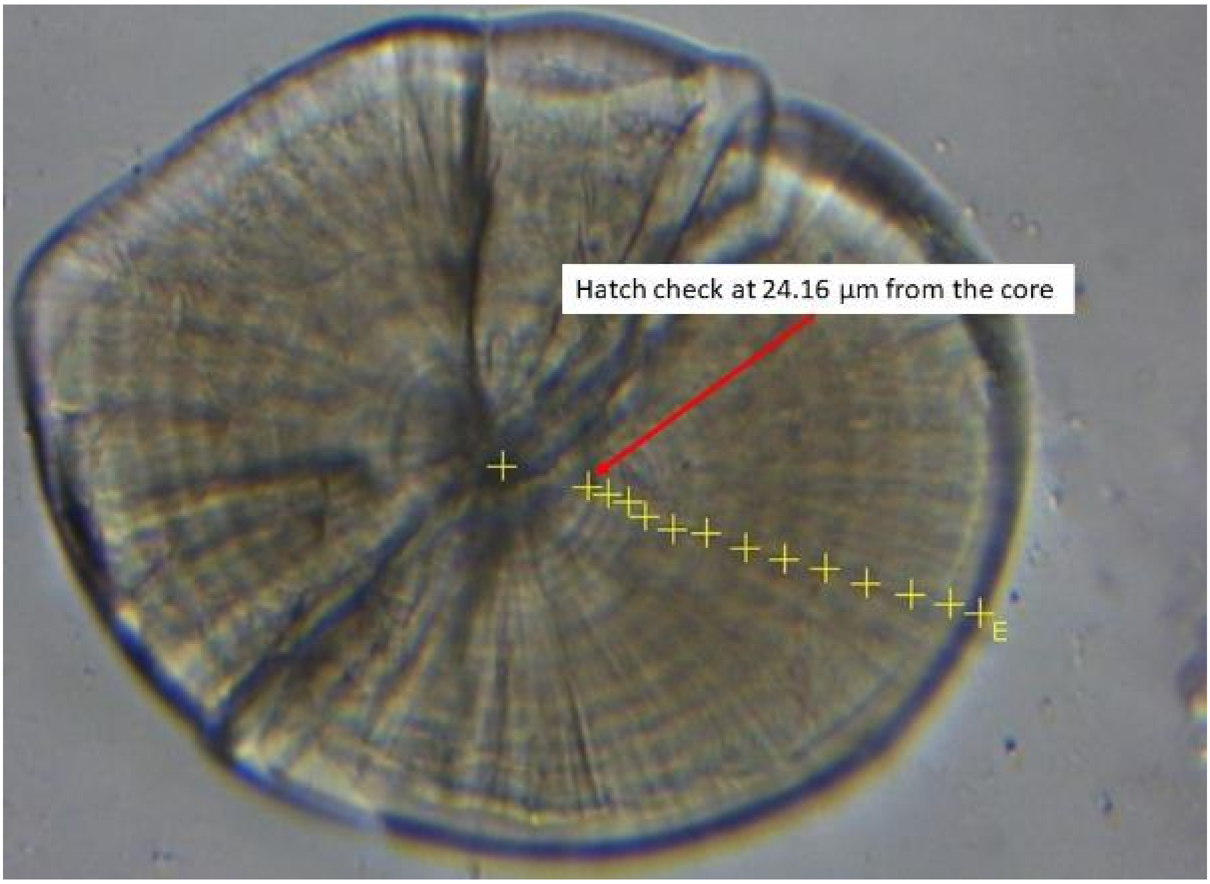


Figure 64. A sagittal otolith from an 8.87 mm long Murray cod larvae with an estimated age of 11 days (Photo: Fish aging services).

8.2.2 STREAM METABOLISM DATA

Stream metabolism data were collected as part of the LTIM monitoring program. Data from the corresponding site (Lanes Bridge) from which the larval fish were collected were used for analysis.

8.2.3 ANALYSIS

Estimated spawning date range for each species was calculated based on known and predicted age of larval fish and the estimated incubation time (based on water temperature related estimates provided by Humphries (2005) for Murray cod). Predicted ages based on 'existing' models that have been used in previous LTIM reporting were as follows:

- *Murray cod* (Linear model – Age (days) = 6.6302*standard length-48.104) (Serafini and Humphries 2004)
- *Australian smelt* (Linear model – Age (days) = (Standard length * 3.63)-13.167 (Humphries et al. 2008)

Distributions of length at age (to infer growth) were compared between years. Daily otolith increment width (as a proxy for fish growth) was examined to determine if a relationship between gross primary productivity and fish growth exists. While this component of the study is a preliminary investigation it has the potential to provide insight into the relationship between changes in gross primary productivity and larval fish growth.

Growth rate of each species was estimated by fitting linear and non-linear models to fish length at age (estimated by otolith microstructure). Three common growth models were considered to model fish growth:

- Linear: Ln = t0 + k*age
- Gompertz Ln = Ln = L_{inf} *e(-e(mu*e(1)/a*(lambda-t)+1))"
- Von Bertalanffy:

$$Ln = L_{inf}(1-e^{-K(Age - t0)})$$

Age = (1/-K)*log(1-(Ln/Linf))+t0

Where Ln = Length at age, L_{inf} = asymptotic length, K = instantaneous growth rate and t0 is the predicted length at which age is 0. Model selection procedures using Akaike's Information Criterion (AIC) were used to select the best fit growth models for each species. Non-linear models were not able to be run for the Murray cod data.

To analyze differences between aging methods on the estimated spawning intensities for each species, a kernel density plot was constructed. This plot is a smoothed histogram with a bandwidth of 5 days.

8.3 RESULTS

8.3.1 DETERMINING LENGTH AT AGE

8.3.1.1 Australian smelt

Model selection applied to the three growth rate models indicated that all three models were very similar in fit, with the Von Bertalanffy growth model (VBGM) the best (AIC = 383.5), followed by the Gompertz model AIC) (386.78) then linear model (AIC = 415.91) (Figure 65). The newly constructed VBGM for the Lachlan was far more accurate in estimating age based on length then the previously applied equation, with 60% of age estimates less than 5 days different from known age (Figure 66). The existing linear model used for age estimates applied previously tended to over-estimate age of individuals. The parameters of the Von Bertalanffy model were estimated to be L_{inf} = 19.738043, K = 0.059904 , t0 = 3.712221. The models developed had L_{inf} of only 19.7 mm (the theoretical longest length) which means that calculation of age for fish greater than this length was not possible. This means that to estimate age from length the following equation is to be applied (i.e. the inverse of the Von Bertalanffy growth model equation):

Age = -1/0.059904*log10(1-Larval fish length/19.738043) + 3.712221

Note: Maximum age in the current study was 56 days, so the predicted age maximum is set at 60 days for calculation of age (i.e. if an individual is longer than 19.738 mm then its age is automatically estimated to be 60 days).

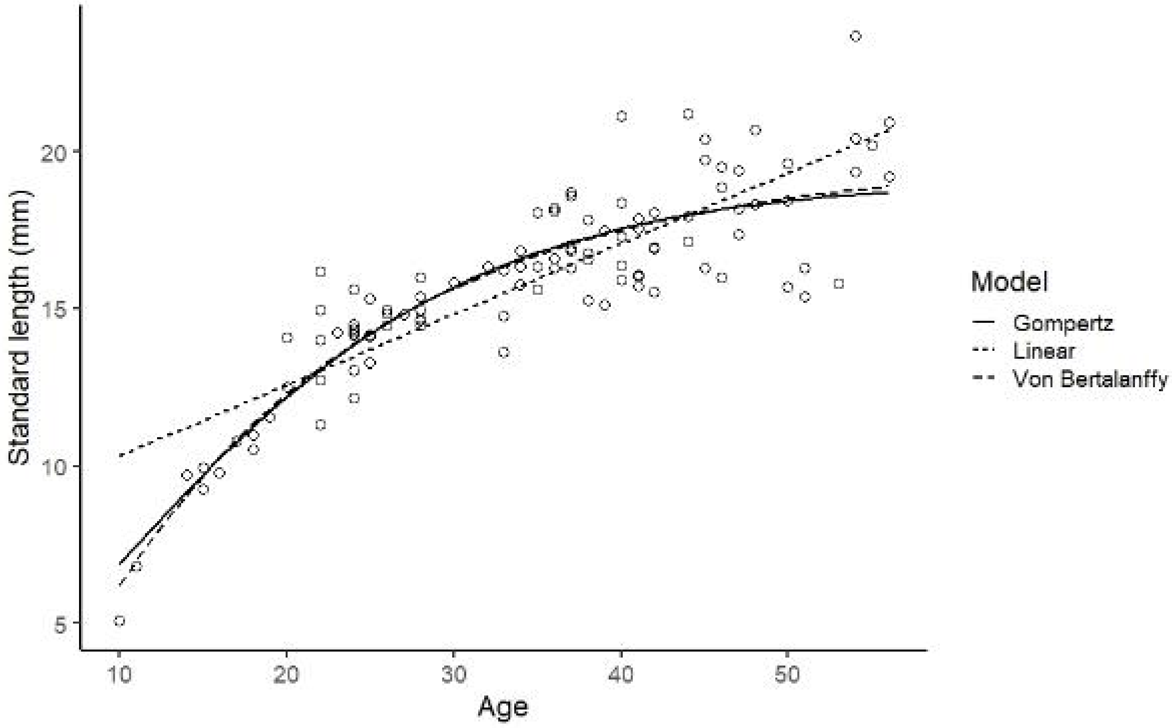


Figure 65. Relationship between standard length (mm) and estimated ages (days) for Australian smelt predicted by the Von Bertalanffy model (dashed line), Gompertz model (solid line) and linear model (dotted line). Open circles indicate actual length age data.

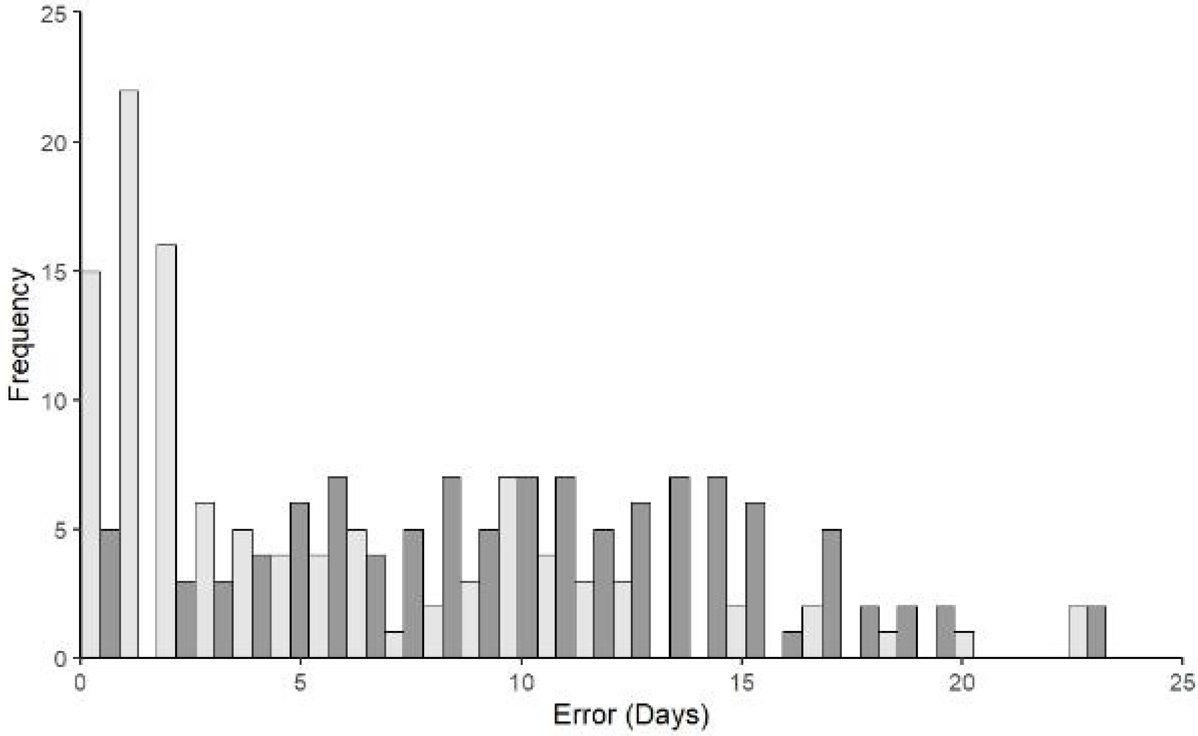


Figure 66. Frequency histogram of error (days) in the estimated age of Australian smelt larvae between existing predictive linear model and newly derived Von Bertalanffy growth model compared with known age of samples (Dark grey = existing age estimate model, light grey indicates newly developed Von Bertalanffy growth model).

8.3.1.2 Murray cod

Only the linear model was appropriate for growth of Murray cod in the lower Lachlan River, which returned a significant relationship ($P < 0.001$) and an r-squared value of 0.3669 between age and growth (Figure 67). The newly constructed linear growth model was slightly more accurate than the existing model being used for the system, with only 13% of estimates having an error of more than 5 days from the known age, compared to 15% of estimates using the existing model (Figure 68).

The revised equation to calculate age of larval Murray cod in the lower Lachlan River based on standard length is:

Age = -14.2478+(2.78*standard length)+1.924

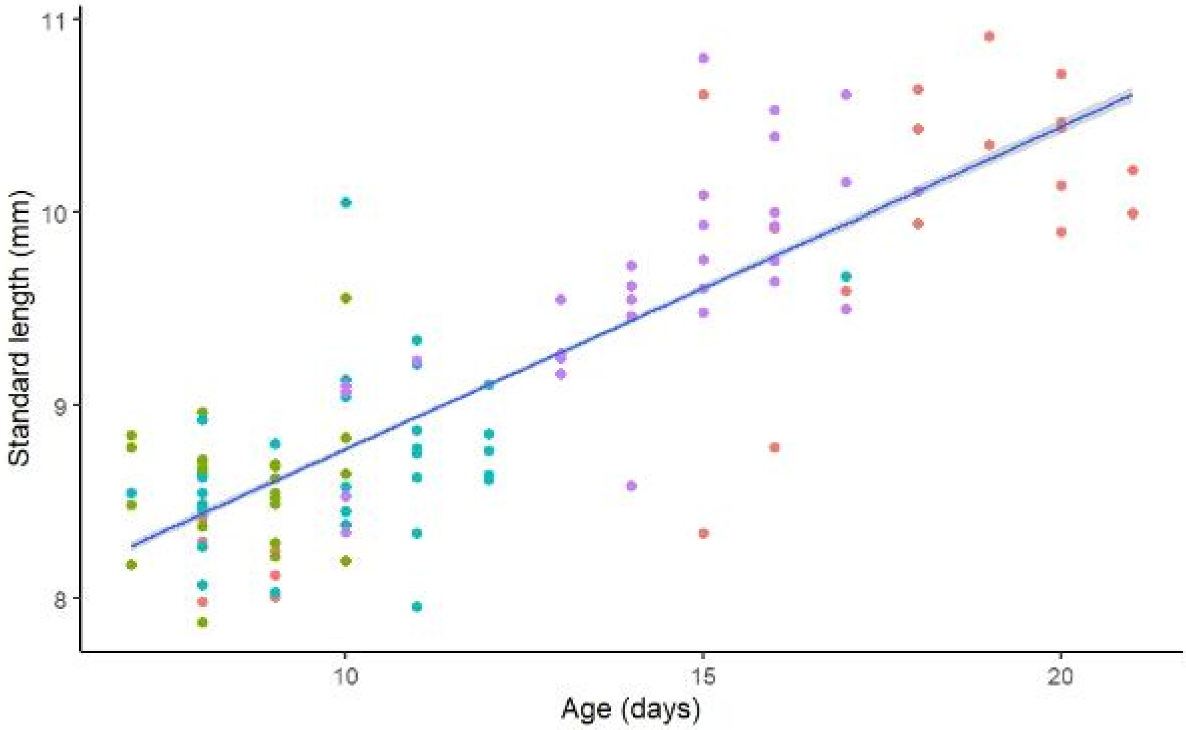


Figure 67. Relationship between standard length and known age for Murray cod (red = 2014, green = 2015, blue = 2017, purple = 2018).

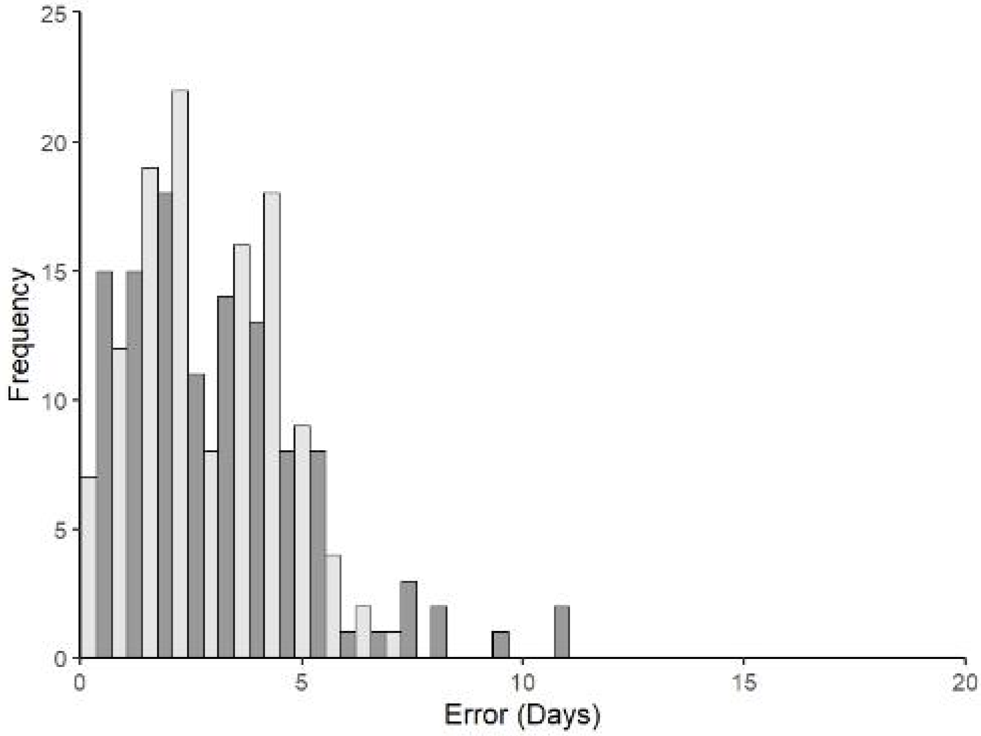


Figure 68. Frequency histogram of error (days) in the estimated age of Murray cod larvae between existing predictive model and newly derived linear model compared with known age of samples (Dark grey = existing age estimate model, light grey indicates newly developed linear model).

8.3.2 ESTIMATING SPAWNING DATES

8.3.2.1 Australian smelt

Estimated spawning ranges of Australian smelt based on age calculations using the VBGM were aligned much more closely with known age spawning estimates than the existing linear model use for previous assessments (Table 22). Spawning density overlap was more consistent between the newly constructed VBGM and the known age estimates for all years except for 2017 (Figure 69).

Table 22. Estimated spawning window on Australian smelt based on known age, new linear model and existing linear model for each year (n = 30 per year).

Estimate method	2014	2015	2017	2018
Known age	30/8 – 3/11/14	16/8 – 26/9/15	11/9 –4/10/17	28/8 – 16/9/18
Von Bertalanffy growth model	2/9 – 2/11/14	16/8 – 26/9/15	11/9 – 13/10/17	13/8 – 11/9/18
Existing linear model	11/8 – 27/10/14	8/8 – 30/9/15	8/9 – 26/9/17	12/8 – 1/9/18

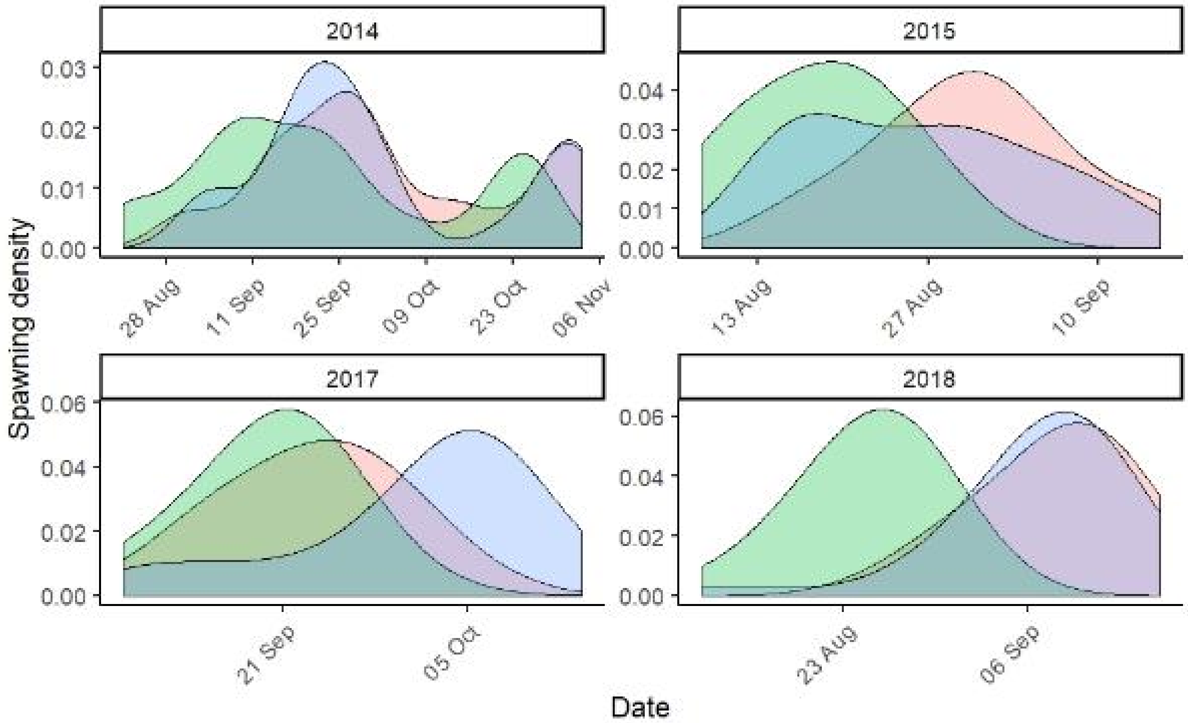


Figure 69. Spawning density estimates for each age model for Australian smelt for each year (red = known age, blue = Von Bertalanffy Growth Model, green = existing linear model).

8.3.2.2 Murray cod

Estimates of spawning windows of Murray cod of both the newly constructed and existing linear models aligned closely with the estimates based on known ages of larvae (Table 23). The main difference being that the existing model tended to estimate onset of spawning window 5 – 10 days prior to the known age spawning estimate. Spawning density estimates had significant overlap between all three estimate methods for each year (Figure 70).

Table 23. Estimated spawning window on Murray cod based on known age, new linear model and existing linear model for each year.

Estimate method	2014	2015	2017	2018
Known age	1/10 – 28/10/14	17/10 – 20/10/15	28/9 – 27/10/17	3/10 – 11/10/18
New linear model	3/10 – 23/10/14	11/10 – 16/10/15	26/9 – 25/10/17	2/10 – 9/10/18
Existing linear model	26/9 – 26/10/14	9/10 – 20/10/15	18/9 – 26/10/17	24/9 – 11/10/18

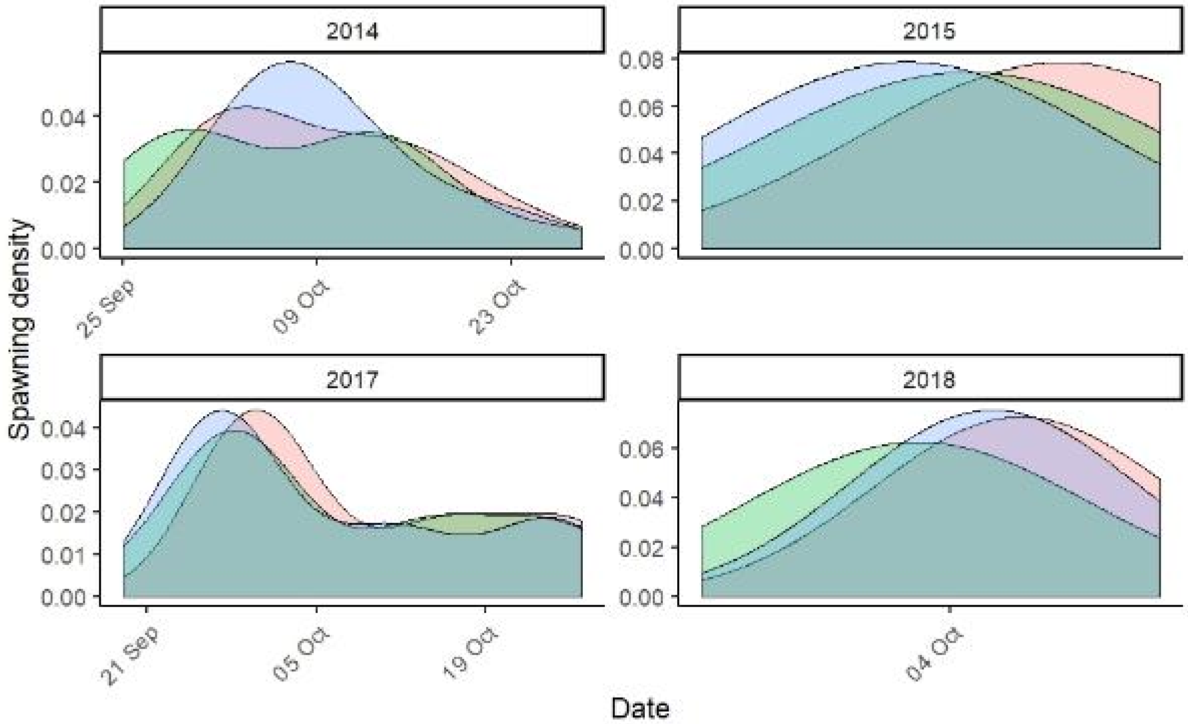


Figure 70. Spawning density estimates for each age model for Murray cod for each year (red = known age, blue = newly constructed linear model, green = existing linear model).

8.3.3 GROWTH

8.3.3.1 Australian smelt

Our data suggest that there were some differences between growth of Australian smelt between years. For the same ages, individuals captured in 2015 were larger than those captured in 2017 (Figure 71). Individuals from 2014 and 2015 appeared to follow the same size at age trajectory and were similar to individuals captured in 2018 (Figure 71). In general, there was a positive relationship between gross primary productivity (GPP) and daily growth of Australian smelt. The exception was 2015 where there was a very weak negative relationship (Figure 72). Relationships between daily growth and GPP were significant for all years and models tested, but the models only provided a weak explanation of the relationship (indicated by low R-squared values). The strongest relationship between GPP and daily growth of Australian smelt occurred in 2014 (Table 24 and Figure 72). Differentials in rolling mean lag (i.e. mean GPP over the previous 3, 5 or 7 days) did not seem to significantly change the strength of the relationships between daily growth and GPP.

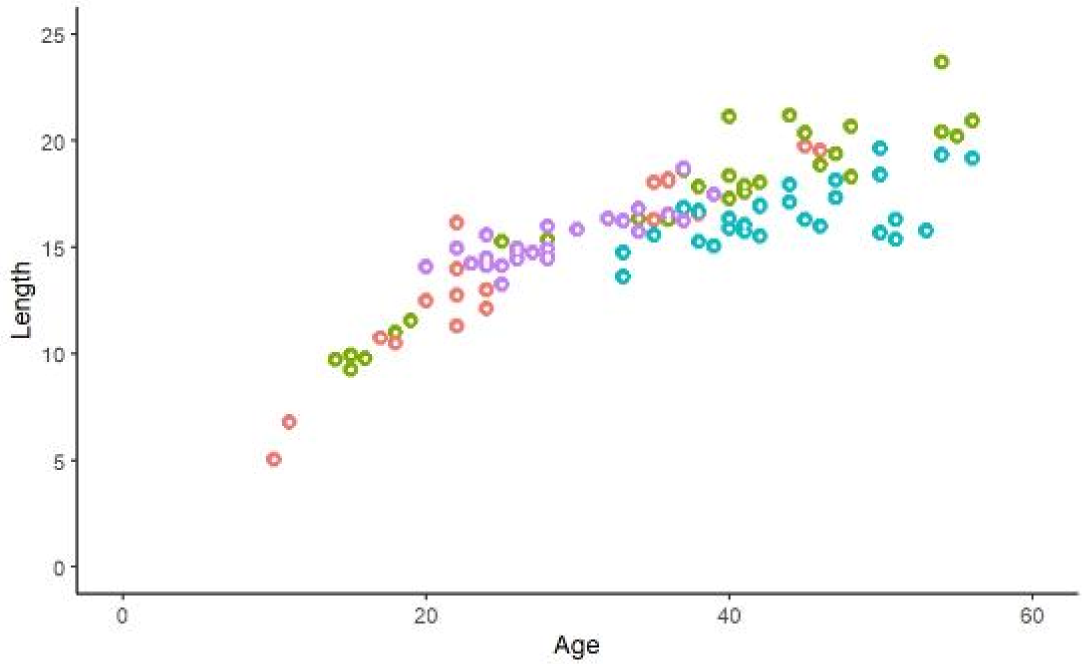


Figure 71. Relationship between standard length (mm) and age (days) for Australian smelt for each monitoring year. Red = 2014, Green = 2015, Blue = 2017 and Purple = 2018.

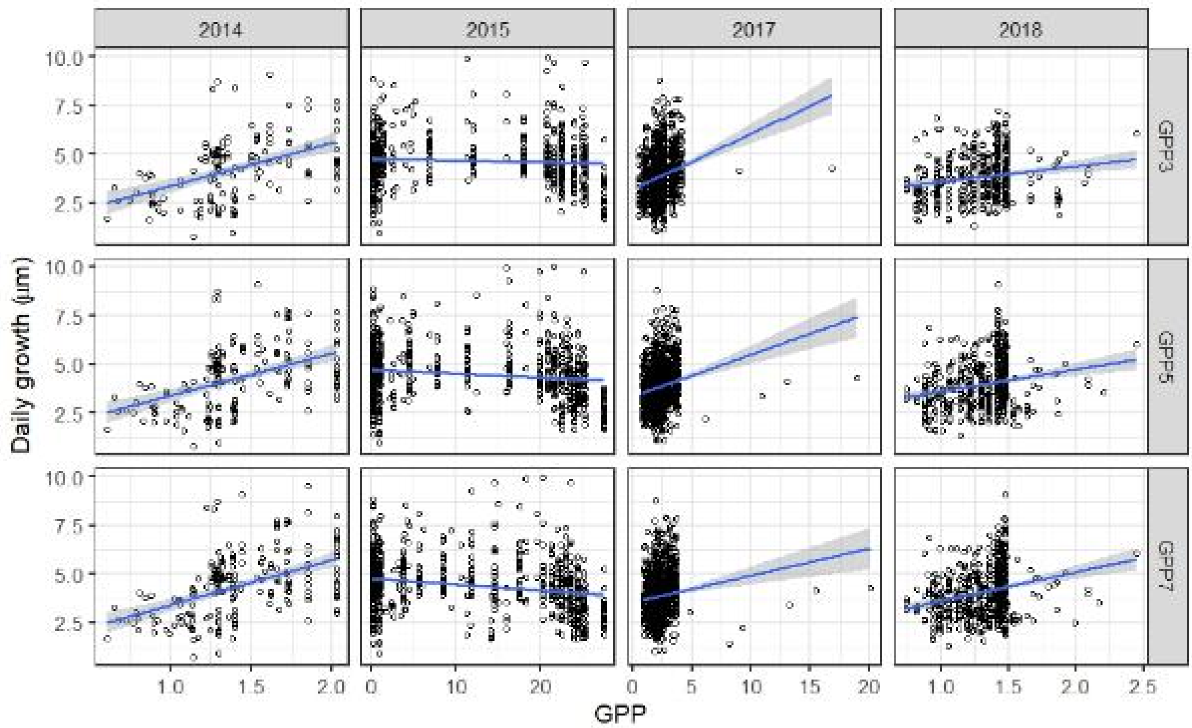


Figure 72. Relationships between Australian smelt daily increment width (daily growth) and rolling mean lag of gross primary productivity in the Lachlan River. (GPP3 = rolling mean lag of GPP for the past 3 days, GPP5 = rolling mean lag of GPP for the past 5 days, GPP7 = rolling mean lag of GPP for the past 7 days). Blue line indicates linear model with dark grey shading indicating 95% confidence intervals.

Table 24. Daily growth of Australian smelt (indicated by slope of linear model) as a function of the linear model between daily growth and rolling lag mean of GPP for rolling lags of 3, 5 and 7 days, for each monitoring year.

Year	GPP lag	Slope	*P*	R^2
2014	GPP3	2.56062052	1.901098e-07	0.22673875
2014	GPP5	2.82324482	5.818659e-08	0.24335118
2014	GPP7	2.88815383	9.308877e-08	0.23679617
2015	GPP3	-0.01405262	3.206809e-02	0.01040025
2015	GPP5	-0.02254497	1.896637e-03	0.02171068
2015	GPP7	-0.03100193	1.613587e-04	0.03186961
2017	GPP3	0.28641504	4.710655e-17	0.05525549
2017	GPP5	0.19934765	1.349347e-10	0.03272069
2017	GPP7	0.12198463	3.045677e-05	0.01393117
2018	GPP3	0.80937792	6.612442e-04	0.02955470
2018	GPP5	1.09137700	9.057340e-05	0.03887146
2018	GPP7	1.26384293	1.196961e-04	0.03756200

8.3.3.2 Murray cod

Frequency distribution of length age ratios of Murray cod indicate that there is some differences in length at age between years (Figure 73). Individuals collected in 2015 had higher length age ratios than all other years, especially 2014 and 2018 (Figure 73). Despite a small number of significant relationships (e.g. 2-15 rolling lag of 3 days, 2017 rolling lags of 3 and 7 days) our results suggest that there is no discernible relationship between GPP and daily growth of larval Murray cod (Table 25 and Figure 74).

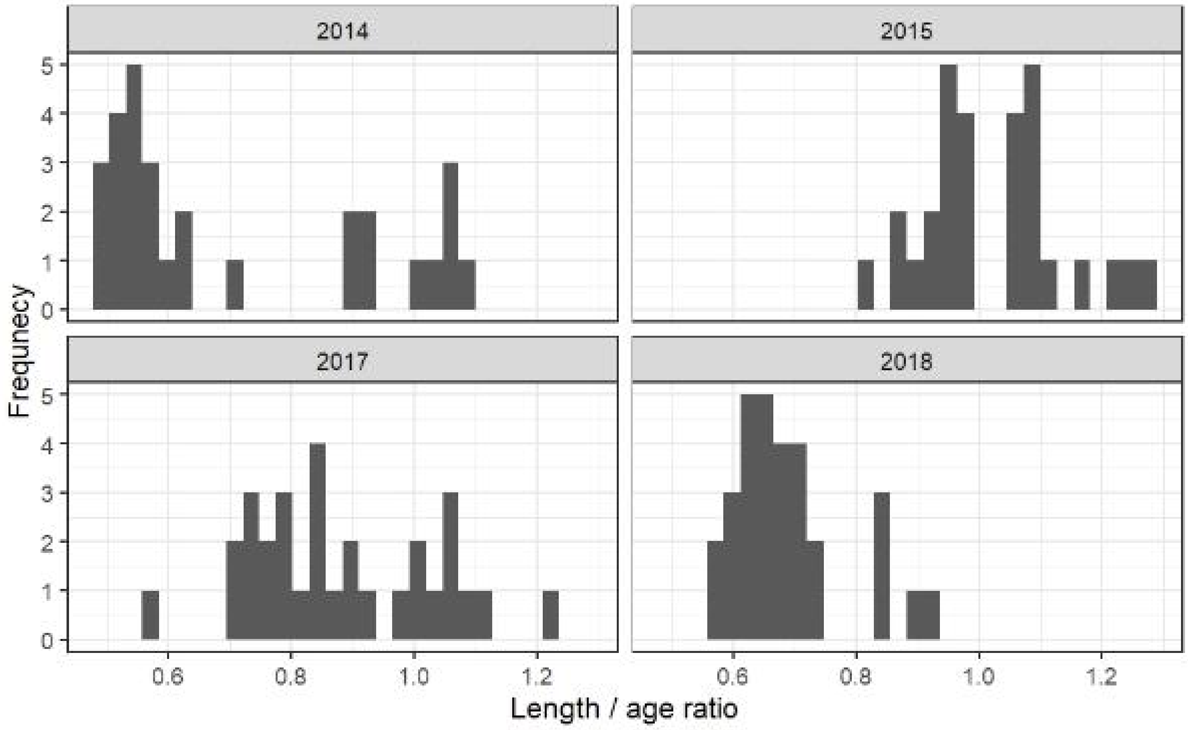


Figure 73. Frequency histogram of length age ratios for larval Murray cod between sampling years.

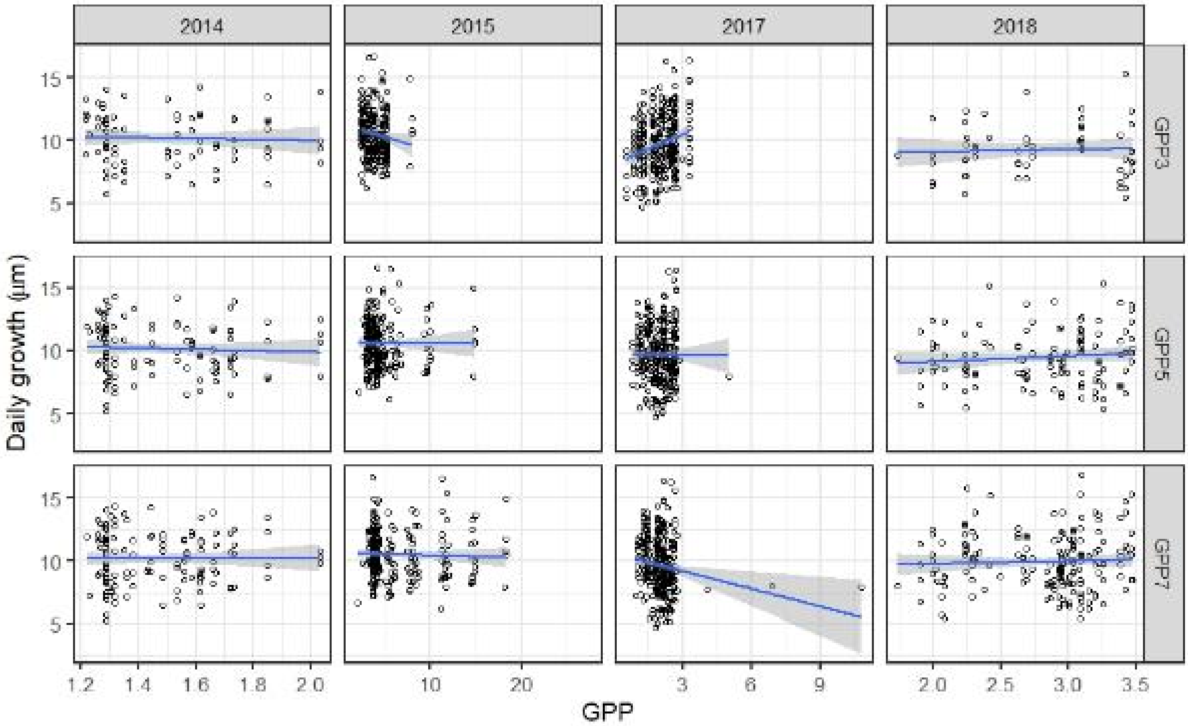


Figure 74. Relationships between Murray cod daily increment width (daily growth) and rolling mean lag of gross primary productivity in the Lachlan River. (GPP3 = rolling mean lag of GPP for the past 3 days, GPP5 = rolling mean lag of GPP for the past 5 days, GPP7 = rolling mean lag of GPP for the past 7 days). Blue line indicates linear model with dark grey shading indicating 95% confidence intervals.

Table 25. Daily growth of Murray cod (indicated by slope of linear model) as a function of the linear model between daily growth and rolling lag mean of GPP for rolling lags of 3, 5 and 7 days, for each monitoring year.

Year	GPP lag	Slope	*P*	R^2
2014	GPP3	-0.0050417283	7.032276e-01	1.823906e-03
2014	GPP5	-0.0058085867	5.680948e-01	3.084112e-03
2014	GPP7	0.0008381241	9.217370e-01	7.453147e-05
2015	GPP3	-0.0824344301	3.590261e-02	1.791440e-02
2015	GPP5	0.0032301759	9.665717e-01	7.212776e-06
2015	GPP7	-0.0803378331	5.430800e-01	1.517780e-03
2017	GPP3	0.0707109289	4.071493e-05	5.396730e-02
2017	GPP5	-0.0020040486	8.909577e-01	6.192341e-05
2017	GPP7	-0.0523359931	6.125678e-03	2.445039e-02
2018	GPP3	0.0121677419	7.213658e-01	2.209430e-03
2018	GPP5	0.0228660687	2.821333e-01	9.796554e-03
2018	GPP7	0.0090550700	5.468287e-01	2.043136e-03

8.4 DISCUSSION

The Von Bertalanffy growth model (VBGM) was the best predictor of the relationship between age and length for larval Australian smelt in this study. Tonkin et al. (2008c) found that the Gompertz growth model was the best fit for their length age data of Australian smelt, though the VBGM was the next best. Similar in our study, Gompertz growth model was very similar to the VBGM in its suitability for predicting age from length of larval Australian smelt. In the current study, the VBGM aligned well with estimate spawning ranges and densities based on known age estimates. The use of less accurate models may fail to detect contributions of environmental water to spawning intensity. Based on our results, we recommend that the VBGM be used for future calculations of age based on length.

The linear model of the relationship between age and growth of Murray cod was robust statistically, and accurate compared to known age samples in this study. Koehn and Harrington (2006) also found a strong linear relationship between length and age for larval Murray cod, though the relationship in that study was statistically stronger for their data. In the current study, spawning date ranges and densities based on the linear model aligned well with those based on known age estimates. Although very similar to the existing length age model being used currently for LTIM, we recommend the use of the newly constructed linear growth model for estimating age based on length for larval Murray cod in the lower Lachlan river as it is more accurate for this system and will lead to more accurate spawning date estimates.

Australian smelt exhibited some difference in growth between years, with 2017 having lower length at age measurements compared to other years. Tonkin et al. (2008b) found that food density had the great effects on growth of Australian smelt. The reason that growth was slower in 2017 compared to other years in the current study may be food related. Abundances of Australian smelt larvae captured in sampling in 2017 were 60-fold that of 2015, which may have resulted in some intraspecific competition for resources and impacted on growth.

Daily growth of Australian smelt appeared to be positively influenced by gross primary productivity, especially in 2014. This is somewhat expected as fish production and growth has been linked to gross primary production or chlorophyll-a concentrations previously (e.g. Yusoff and McNabb 1989, Martino et al. 2019). Furthermore, increase food resources have been found to increase growth of Australian smelt (Tonkin et al. 2008b). It is likely that other factors such as competition and temperature are influencing Australian smelt growth at various timescales. It must be noted, that there were many days where GPP was not able to be measured because of a range of factors (see Section 5), this was especially the case in 2014 and 2015 and during elevated discharges. This study provides some preliminary support for the hypothesis that an increase in GPP will result in increased growth of larval fish. This preliminary investigation indicates that in a year of low flows, the productivity pulse provided by environmental water is likely to be a significant contributor to overall stream productivity and can be observed in the growth of larval fish. Further work is recommended to test this finding further, but it would suggest that in 2014, CEW contributed to the growth of Australian smelt.

In contrast to Australian smelt, there was no discernible relationship between GPP and Murray cod daily growth in the current study. The growth histories (i.e. ages) of Murray cod in the current study (maximum age 21 days, mean 12 days) were far shorter than Australian smelt (maximum age 56 days, mean 34 days), which meant that Murray cod larvae were not as exposed to as large of a range of conditions during their growth. Furthermore, early stage of Murray cod development are supported by remaining yolk sac, even well after leaving the nest (days to weeks) (Humphries 2005, Kaminskas and Humphries 2009) which may mask any daily responses to changes in GPP. Length age ratios of larval Murray cod captured in 2015 were higher than other years and had very high values of GPP during early development of Murray cod. While far from conclusive, this final result indicates that there may be some effect of GPP on larval Murray cod growth but operating at temporal scales not examined in the current study.

8.5 CONCLUSIONS AND RECOMMENDATIONS

- There is some interannual variation in growth of Australian smelt, but the constructed Von Bertalanffy growth model is the most accurate model for predicting age from length for the lower Lachlan River.
- The newly constructed linear model for Murray cod growth is a slight improvement on the existing model, and should be used for back calculating age of Murray cod for the lower Lachlan River.
- Preliminary results suggest some positive relationship between Australian smelt daily growth and gross primary productivity. The effect of GPP on Australian smelt growth warrants further targeted investigation to more accurately determine the relationship
- During years of low flows, environmental watering has the potential to significant contribute to food resources and growth of larval fish
- There was no discernible relationship between daily growth of Murray cod and GPP. It is likely that yolk is being used as a supplementary food source by larval Murray cod, masking any effects of food density in early life history.
- Aging of other species of interest is recommended to develop accurate age : length models for the lower Lachlan river (especially flatheaded gudgeon).
- Examination of the effect of changes in GPP to changes in daily growth should be explored for other native small bodied species (Flat headed gudgeon).

9 VEGETATION

9.1 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 reedbeds (*Phragmites australis*) and substantial areas of riparian fringing river red gum forest (*Eucalyptus camaldulensis*) and woodland. 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. For instance, the Great Cumbung Swamp that lies at the terminus of the Lachlan River system, west of Hay, NSW, supports one of the largest areas of common reed (*Phragmites australis*) and stands of river red gum in NSW (MDBA 2012a). The Great Cumbung Swamp supports or is capable of supporting a large number of water bird species, including species listed as threatened under Commonwealth and state legislation as well as species which are recognized in international migratory bird agreements (Maher 1990, MDBA 2012a). The central reedbeds of the Great Cumbung Swamp also provide an important drought refuge for birds (MDBA 2012a).

The past five years of monitoring (2014 – 2019) within the lower Lachlan river system has encompassed highly variable river hydrology and local rainfall conditions, and consequently a large variation in environmental conditions have been observed on the floodplains and wetlands of the Lachlan river. Rivers in semi-arid regions such as those of the lower Lachlan, exhibit extreme variability in flow and inundation of floodplains relies on rainfall during particularly wet years (Walker et al. 1995). The rainfall of the Lower Lachlan has a high degree of inter-annual variability (ranging from 101 mm to 820 mm annually at Hillston Airport, data from 1881 to 2018) (Bureau of Meteorology 2017). As such, the inter annual variability observed in the lower Lachlan system over this five-year period may not be considered unusual.

While floodplain inundation in semi-arid regions is temporally irregular, flooding is ecologically very important (Poff and Ward 1989, Reid et al. 2016). Important characteristics of the flooding regime on floodplains include flood frequency, flood duration, number of days between floods, and flood predictability (Poff and Ward 1989). As plants on floodplains are adapted to certain hydrological attributes (such as depth, duration and frequency of flooding), spatial variability in the flooding regime across floodplains influences their distribution and abundance, related to species specific requirements and tolerances for flooding and drying (Roberts et al. 2016).

The diversity, type and condition of riparian and wetland vegetation communities are strongly influenced by the frequency, duration and timing of inundation (Brock and Casanova 1997, Nilsson and Svedmark 2002). The alteration of flow regimes, because of the combined effects of flow regulation and abstraction, have had widespread and significant effects on riparian and wetland vegetation (Nilsson and Berggren 2000, Horner et al. 2009), particularly in arid and semi-arid environments (Busch and Smith 1995). To address these effects, environmental flows are often used to try to improve vegetation condition and diversity (Merritt et al. 2010).

The floodplain and wetland vegetation communities of the Lower Lachlan river system naturally display sequences of dry and wet phases depending on regional climatic conditions. However, during the Millennium drought (2001-2009), the health of the wetland vegetation declined rapidly with reductions in river red gum canopy cover recorded at a number of significant wetlands (Armstrong et al. 2009). Observations and measurements of the reedbeds and river red gums 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).

Monitoring of floodplain and wetland sites for the LTIM Project has been conducted since 2014 and has encompassed vastly different annual rainfall and hydrological conditions. These have ranged from very dry conditions in 2014-15 and 2018-19 to the fourth largest flood on record in 2016-17. The floodplain and wetland vegetation communities have continued to display dry and wet phases depending on the prevailing conditions (Dyer et al. 2017). The context in which the 2018-19 environmental watering actions were delivered was one in which the wetlands were dry and the flow in the Lachlan River was low. The floodplain of the lower Lachlan River had remained dry over 2018 and 2019 (Figure 75), with only one site (Nooran Lake) receiving environmental water during the 2018-19 watering season. The conditions dominated by local rainfall patterns more so than river hydrology.

Figure 75. Redgum woodland monitoring site at Whealbah on the 19th of June 2019. Photo: Yasmin Cross.

During the 2018-19 watering season, two watering actions targeted vegetation outcomes. These were a small watering action targeting riparian vegetation and habitat for aquatic species in Yarrabandai Lagoon (part of the mid Lachlan) that commenced on the 18th March 2019 (watering action 3) and a watering action targeting the Great Cumbung Swamp that aimed at wetting the central reedbeds of the Great Cumbung Swamp, with water reaching the swamp on 30th June 2019 (watering action 4). Neither of these sites were monitored as part of the LTIM project.

This technical report provides an evaluation of the outcomes for vegetation in the Lower Lachlan river system[1] and addresses the specific evaluation questions listed in the following sections. In doing so, the response of vegetation to the drying conditions within the catchment is described in relation to watering history. As this is the fifth year of the five-year LTIM Project, the results have been described in the context of the results gathered throughout the project and in relation to the response of the vegetation to all environmental watering actions which have occurred over the five years, as well as the historic hydrological and climatic conditions within the catchment.

9.1.1 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

Given the limited monitoring sites which had received Commonwealth environmental water in 2018-19, the selected area specific evaluation questions have been re-framed in the context of watering history.

1) What did Commonwealth environmental water, in the context of the watering history of sites, contribute to:
    a. vegetation species diversity?
    b. vegetation community diversity?
    c. the condition of floodplain and riparian trees?
    d. populations of long-lived plants?

9.2 METHODS

Vegetation monitoring sites were selected to provide a sample from the different vegetation communities distributed across wetlands and riparian zones with different environmental watering probabilities, see Dyer et al. (2014) and Table 26 on p. 159.

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 26) 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 26) 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 the number of seedlings and saplings <10cm dbh. In each 0.04 ha plot, the floristic survey recorded species abundance (of all species including trees) and cover.

All plants observed (including grasses) were identified to species either during field surveys or from field specimens which were preserved for later identification. Where plants were

[1] Vegetation responses to watering actions in the mid Lachlan river system are not evaluated as part of the LTIM project.

not able to be identified to species (because of a lack of suitable identifying features) they were recorded to the lowest taxonomic level possible and as distinct species based on morphological differences.

Table 26. 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. Zones are defined in Dyer et al. 2014 and shown in Figure 1 (page 19).

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	River red gum/black box/river cooba/lignum	2	0
		Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum/river cooba/black box	2	2
ZONE 3					
Lake Ita (LI)[2]	Open Lake fringed with black box and red gums	Lt2.1: Temporary floodplain lakes	Black box/river cooba	3	0
		Lt2.1: Temporary floodplain lakes	River red gum	2	0
Clear Lake (CL)	Lake (with reedbeds) fringed with red gum	Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	0

[2]Lake Ita had originally been established as an optional site for vegetation monitoring (Dyer et al., 2014). With the cessation of access to Murrumbidgil Swamp, Lake Ita is now being monitored each year. As this is likely to continue to the end of the monitoring, a new riparian plot was established at Lake Ita to provide replication for the red gum tree community plots.

Nooran Lake (NL)	Lake (with reedbeds) 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
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	Black box/river cooba/lignum	2	0
		Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
ZONE 5					
Booligal (BO)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	2

Table 27. Wetland sampling dates and observations 2018-19.
Watering categories correspond to the historical watering of the sites (see Table 28).

	OBSERVATION (inundation averaged across plots/transects at each site)				NOTES (plot and transect specific observations)		WATERING HISTORY (see Table 28)	
	Spring 2018		Autumn 2019					
SITE (CODE)	Transect	Plot	Transect	Plot	Transect	Plot	Transect	Plot
ZONE 1								
Hazelwood (HW)	dry	dry	dry	dry			B	A
Whealbah (WB)	dry	dry	dry	dry			B	A
Moon Moon (MM)	dry	dry	dry	dry			B	B
ZONE 2								
Lake Bullogal (LBU)	dry	dry	dry	dry			A	A
The Ville (TV): Mixed		dry		dry				A
The Ville (TV): RRG	dry	dry	dry	dry			B	B
ZONE 3								
Lake Ita (LI): BBX		dry		dry				A
Lake Ita (LI): RRG		dry		dry				A
Clear Lake (CL)		dry		dry				A
Nooran Lake (NL)	dry	dry	dry	dry			C	B
Lake Marrool (LM)	dry	dry	dry	dry			B	A
ZONE 4								
Tom's Lake (TL)		dry		dry				B
Lake Tarwong (LT): BBX		dry		dry				A
Lake Tarwong (LT): RRG	dry	dry	dry	dry			A	A
ZONE 5								
Booligal (BO)	dry	dry	dry	dry			B	B

9.2.1 EVALUATION APPROACH

9.2.1.1 Action specific evaluation

During 2018-19, Commonwealth environmental water was used to maintain and enhance the condition of the central reedbeds of the Great Cumbung Swamp in June 2019 (Figure 76). The reedbeds of the Great Cumbung Swamp are not monitored as part of the LTIM Project for logistical and financial reasons, and the 2018-19 watering action did not reach the Cumbung swamp until the 2019-20 monitoring year. This means it was not possible to evaluate the outcomes of the 2018-19 watering for the reedbeds or surrounding tree community which were inundated using Commonwealth environmental water. A site visit to the Great Cumbung Swamp was undertaken in July 2019 to observe and assess the extent of the inundation. While no quantitative data were collected, lower lying parts of the reedbed were inundated, and the soil moisture under the reeds surrounding these lower lying sections was high. The Commonwealth environmental watering action also inundated an area of intermittent river red gum floodplain swamp to the south of the Great Cumbung Swamp (Figure 77).

Figure 76. Photo of part of the central reedbed of the Great Cumbung Swamp taken 30 July 2019 following an environmental watering action in June/July 2019. Photo by Will Higgisson.

Figure 77. Photo of the intermittent river red gum floodplain swamp south of the Great Cumbung Swamp taken 29 July 2019 following an environmental watering action in June/July 2019. Photo by Will Higgisson.

9.2.1.2 Selected Area evaluation

To address the Selected Area evaluation questions, the 2018-19 vegetation data are combined with the data collected over the previous four years and considered in the context of annual weather patterns and watering history. To enable this, the five years of monitoring were characterised in terms of the context provided by the annual weather patterns: 2014-15 was dry, 2015-16 was moderately wet, 2016-17 was very wet, 2017-18 was drying and 2018-19 was dry. At each site, transects and plots were assigned a watering history based on the watering that has occurred since 2012-13 (Table 28 and Figure 78). These categories were used to structure the data analysis and interpret the response of the vegetation observed.

Table 28. Watering history used to structure analysis of vegetation data.

WATERING HISTORY	DESCRIPTION
A	Received water only with the large floods of 2012-13 and 2016-17
B	Received water in 2012-13, 2015-16 and 2016-17 2015-16 water was either translucent releases or environmental water or a combination
C	Received water in 2012-13, 2015-16, 2016-17, 2017-18, 2018-19 2015-16 water was either translucent releases or environmental water or a combination, 2017-18 water was Commonwealth environmental water.

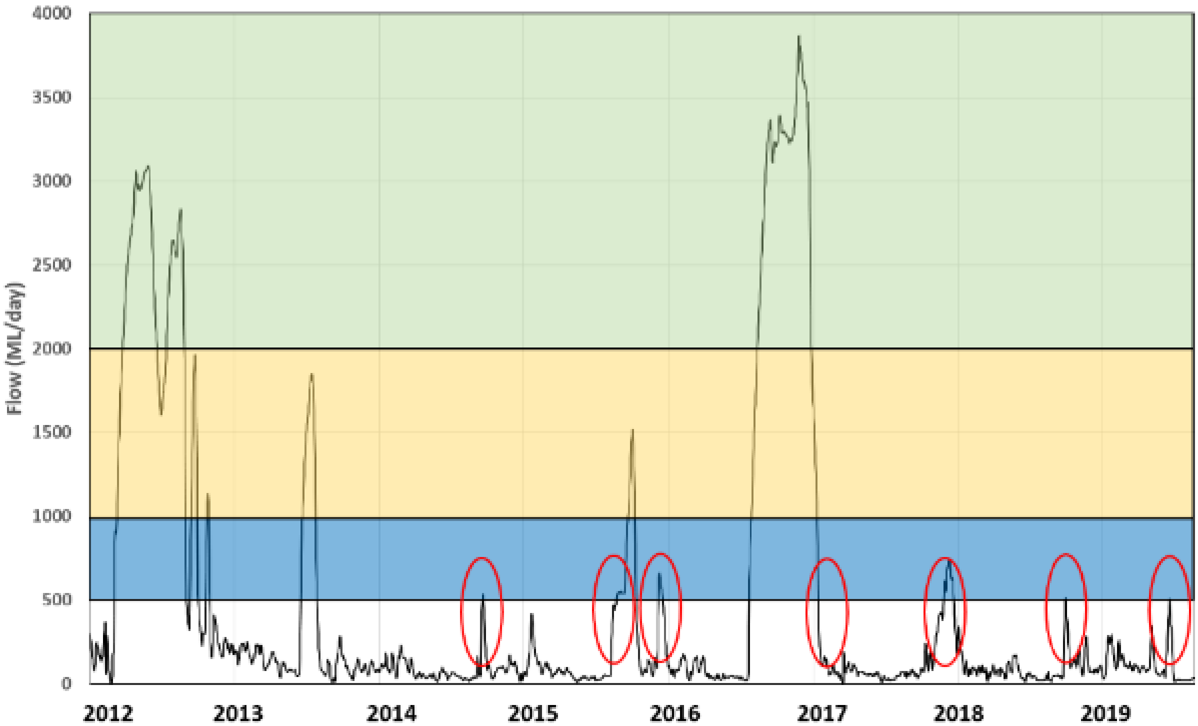


Figure 78. Conceptualisation of recent watering history categories (defined in Table 28).

Green shading represents watering category A, yellow shading represents watering category B and the blue shading represents watering category C.

Red circles show environmental watering actions resulting in inundation of at least one LTIM monitoring site. Black line indicates river flow (ML/day) taken from the Lachlan River at Booligal.

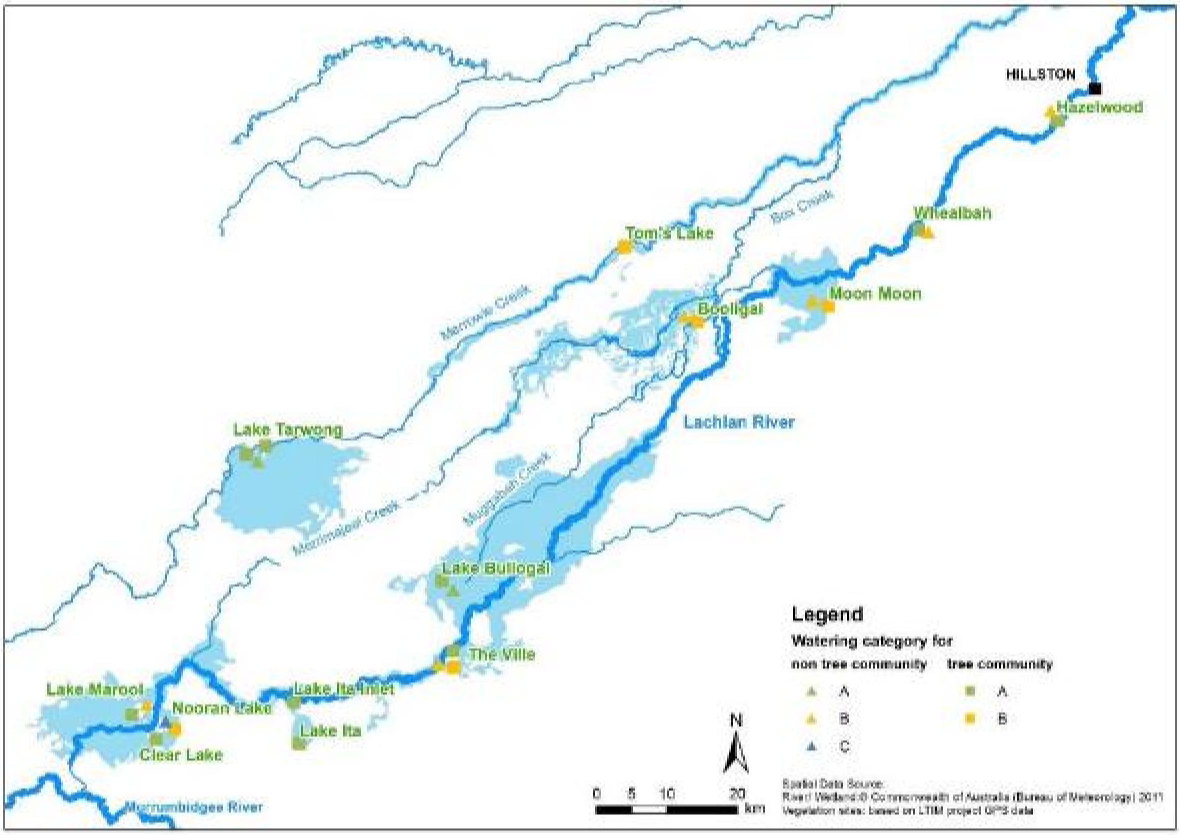


Figure 79. Map of the vegetation monitoring sites categorised according to watering history.

To evaluate vegetation outcomes the following approach was applied:

- Vegetation species diversity is defined as the number of groundcover species and the evenness of their abundance. Simpson's Diversity Index has been calculated for each site and compared across years for each watering history.
- 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 29) of Brock and Casanova (1997) and Casanova (2011). Plants were allocated to plant functional groups based on unpublished data from DoPIE. Species were also classified as native/non-native using information provided on PlantNET (http://plantnet.rbgsyd.nsw.gov.au/). A list of all species observed within non-tree and tree community sites, including their species name, family, functional grouping, and their native/non-native classification is presented as Appendix 1.
- Cumulative species richness curves were calculated for tree communities and non-tree communities within the amphibious plant functional group. The amphibious plant functional group was used, as these species are most likely to respond to watering.
- The condition of floodplain and riparian trees is defined as the canopy cover of the floodplain trees (river red gums and black box). The evaluation condition metrics (Table 29) 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). 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.
- The numbers of seedlings and saplings present in all plots per site were aggregated to give a combined count per time of sampling and facilitate comparison between monitoring dates.
- The mean (± 1 SE) numbers of seedlings and saplings present per site were grouped based on current land-use (nature conservancy or grazing) to evaluate the influence of land-use on seedling survivorship.

Table 29. Plant functional group classifications of Brock and Casanova (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.

9.2.2 DATA ANALYSIS

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

- Species richness was calculated as 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.
- Cumulative species richness of amphibious species was calculated as the total number of amphibious species that were observed within a site for each year of the five years.
- 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).

The observations relating to land-use 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.

9.3 RESULTS

In 2018-19, more than 95% of taxa were identified to species level.

9.3.1 VEGETATION SPECIES RICHNESS AND DIVERSITY

9.3.1.1 Non-tree community

A total of 98 species were identified across the non-tree community sites during the 2018-19 watering season, this was the second last lowest recorded number of species within the non-tree community plots of any year of the five-year monitoring program.

A total of 124 species were identified during 2017-2018, 96 in 2016-17, 154 in 2015-16 and 130 during the 2014-15 watering season.

The majority of species were recorded in autumn (84 species), while only 62 species were recorded during spring sampling. The greatest number of species per site during autumn sampling was at Hazelwood (26 species) and during spring sampling was at the Lachlan Valley State Conservation Area at Booligal (17 species).

In spring 2018 the plant community across all non-tree community sites was dominated by

- forb species (old man weed (*Centipeda cunninghamii*), trailing verbena (*Verbena supina*), and smooth heliotrope (*Heliotropium curassavicum*)),
- chenopods (mainly black roly-poly (*Sclerolaena muricata*), small crumbweed (*Dysphania pumilio*), nitre goosefoot (*Chenopodium nitrariaceum*), fat hen (*Chenopodium album*), and creeping saltbush (*Atriplex semibaccata*)), and
- grasses (blown-grass (*Lachnagrostis filiformis*), and common couch (*Cynodon dactylon*)).

Some species were locally common, observed in relatively high numbers at only a single site, including blue rod (*Stemodia florulenta*) at Lake Tarwong, mouse tail (*Myosurus australis*) at Booligal, and spiny sedge (*Cyperus gymnocaulos*) at Lake Marool.

In Autumn 2019 a range of annual species were present in greater numbers compared to spring 2018 including small crumbweed, and exotic species smooth mustard (*Sisymbrium erysimoides*), burr medic (*Medicago polymorpha*), turnip weed (*Rapistrum rugosum*), and New Zealand spinach (*Tetragonia eremaea*). These are all terrestrial dry species that grow in response to rainfall.

During the 2018-19 watering season sites The Ville, Lake Bullogal, and Nooran Lake were observed to have the lowest number of species that had been recorded at these sites over the 5-year monitoring program.

Patterns in site scale vegetation diversity (Simpson's diversity index) in 2018-19 appear to be related more strongly to the prevailing (dry) weather conditions than to watering history (Figure 80).The fact that species diversity in watering category C (Nooran Lake) has remained high compared to watering categories A and B, may be a result of the environmental watering action it received in late 2017 (Figure 80).

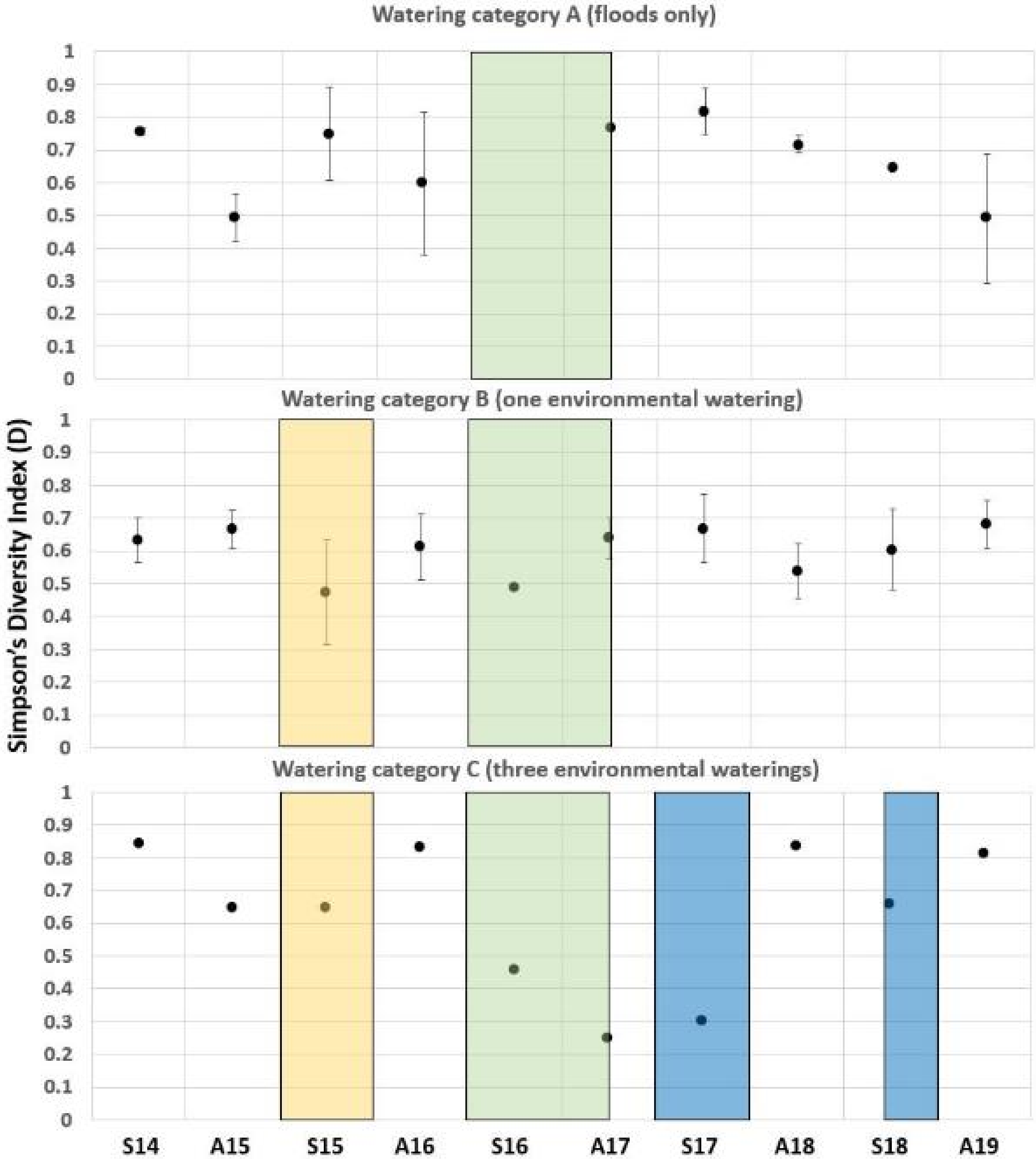


Figure 80. Comparison of groundcover vegetation diversity in the non-tree community between seasons and years using Simpson's diversity index (D).

The data points are the mean diversity index for each class of watering history (refer to Table 28, p. 163).

Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, A19: Autumn 2019.

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. The yellow shading represent the environmental watering that occurred in 2015 to sites in watering categories B and C, the green shading represents flooding during 2016-17 that flooded all sites (watering category A), and the blue shading represents the environmental watering events that flooded Nooran Lake (watering category C).

Note that data are not shown for the peak of the flood event in Spring 2016, because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

The cumulative species richness of amphibious species increased during and following flooding in 2016-17 at sites in all watering categories. Sites that received environmental water in spring 2015 had a greater number of amphibious species compared to sites in watering category A which did not receive environmental water. While all three watering categories showed an increase in cumulative species richness during and following the flood in 2016-17, the sites in watering category A had the largest increase in species richness of amphibious species.

The watering event at Nooran Lake in spring 2017 did not result in any new amphibious species that had not been recorded previously. To note, Nooran Lake had the greatest number of amphibious species of all sites. All amphibious species except one at Nooran Lake (Common Bittercress, (*Cardamine hirsuta*)) were native. The amphibious species consisted of woody perennial species river cooba (four sites), tangled lignum (*Duma florulenta*) (four sites), river red gum (seven sites), and rhizomatous perennials common nardoo (*Marsilea drummondii*), and common spike-rush (*Eleocharis acuta*) (at four sites each) along with a range of annual herbaceous species. When these perennial species were present at a site, they were usually present in spring 2014 and the increase in cumulative species richness of amphibious species over the five years was primarily related to new flood respondent annual species. There has been no or very little change in the cumulative number of amphibious species at all non-tree sites over the 2018-19 watering season.

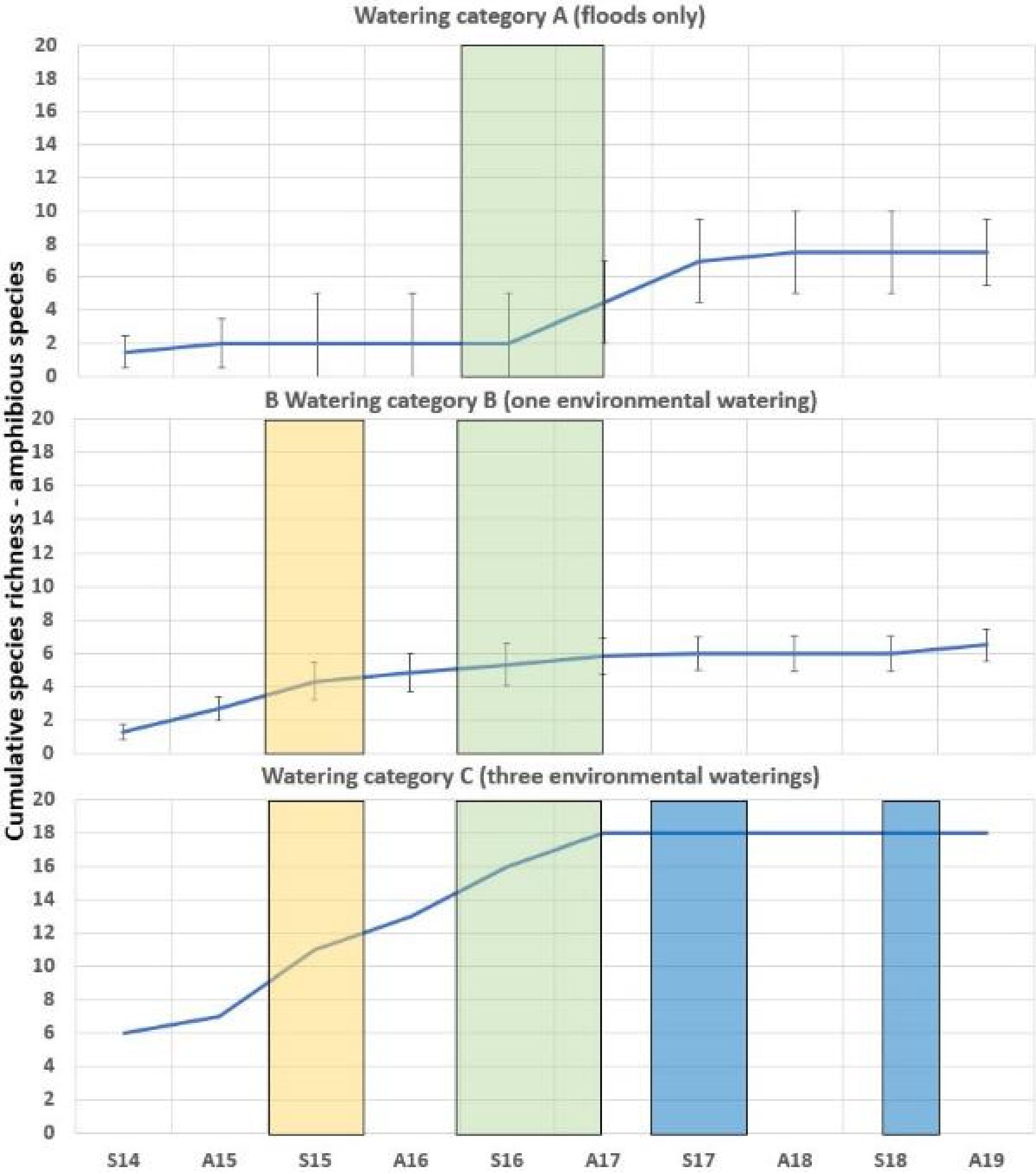


Figure 81. Comparison of cumulative species richness within the non-tree communities according to the site watering categories.

The yellow shading represent the environmental watering that occurred in 2015 to sites in watering categories B and C, the green shading represents flooding during 2016-17 that flooded all sites (watering category A), and the blue shading represents the environmental watering events that flooded Nooran Lake (watering category C).

Error bars represent ± 1 standard error of the mean.

9.3.1.2 Tree community

A total of 120 understorey species were identified across the tree community plots during 2018-19 watering season, this was the lowest recorded number of species within the tree community plots of any year of the five-year monitoring program.

A total of 156 species were identified in 2017-18, 181 species in 2016-17, 166[3] species in 2015-16 and 137 species identified during the 2014-15 watering season. There was a similar number of species identified in spring 2018 (93 species) to Autumn 2019 (92 species).

The greatest number of species were recorded at Whealbah and Lake Bullogal (23) in Spring 2018 and at Hazelwood (32) in Autumn 2019. Mossgiel daisy (*Brachyscome papillosa*) which is a species listed as vulnerable in NSW[4], was not recorded at Lake Ita Inlet this watering season despite being observed in 2016-17 (Autumn 2017) and 2017-18 (Spring 2017) watering seasons.

In Spring 2018 the groundcover in the tree community was dominated by

- perennial herbs (forest germander (*Teucrium racemosum*), Trailing Verbena (*Verbena supina*) and lippia (*Phyla canescens*)),
- a rhizomatous perennial rush (common spike-rush (*Eleocharis acuta*)),
- a grass species (blown-grass (*Lachnagrostis filiformis*)), and
- chenopods, mainly climbing saltbush (*Einadia nutans subsp. nutans*), ruby saltbush (*Enchylaena tomentosa*), creeping saltbush (*Atriplex semibaccata*), spiny saltbush (*Rhagodia spinescens*), black roly-poly, and nitre goosefoot (*Chenopodium nitrariaceum*).

Other species such as yellow twin-heads (*Eclipta platyglossa*), spreading goodenia (*Goodenia heteromera*), poison pratia (*Lobelia concolor*), tall groundsel (*Senecio runcinifolius*), common nardoo (*Marsilea drummondii*), river mint (*Mentha australis*), smooth heliotrope (*Heliotropium curassavicum*) and common couch were present although were in lower abundances. Other species were not reported here as they only occurred as few individuals and usually within a single site.

In Autumn 2019 a range of annual or short-lived perennial species became more numerically dominant including burr medic (*Medicago polymorpha*), small crumbweed (*Dysphania pumilio*), small bedstraw (*Galium murale*), smooth mustard (*Sisymbrium erysimoides*), river cress (*Rorippa eustylis*) and climbing fumitory (*Fumaria capreolata*).

Sites that have only received water from natural flooding in 2016-17 show reasonably consistent site scale groundcover vegetation diversity (Simpson's diversity index) across years with the exception being in autumn 2016 when the diversity was low (Figure 82) across both watering categories. The diversity of vegetation at sites that have received one environmental watering action (in 2015-16) over the four year period resulted in the lowest diversity in Spring 2016 when the sites were under water (Figure 82). The diversity at these

[3] Four species not identified in 2015-16 were identified in 2017 and are included here

[4] https://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10106

sites had increased by autumn 2017. The diversity at sites in watering category A increased between Autumn 2018 and Spring 2018. The diversity of vegetation has increased slightly within watering categories A and B between spring 2018 and Autumn 2019 (Figure 82).

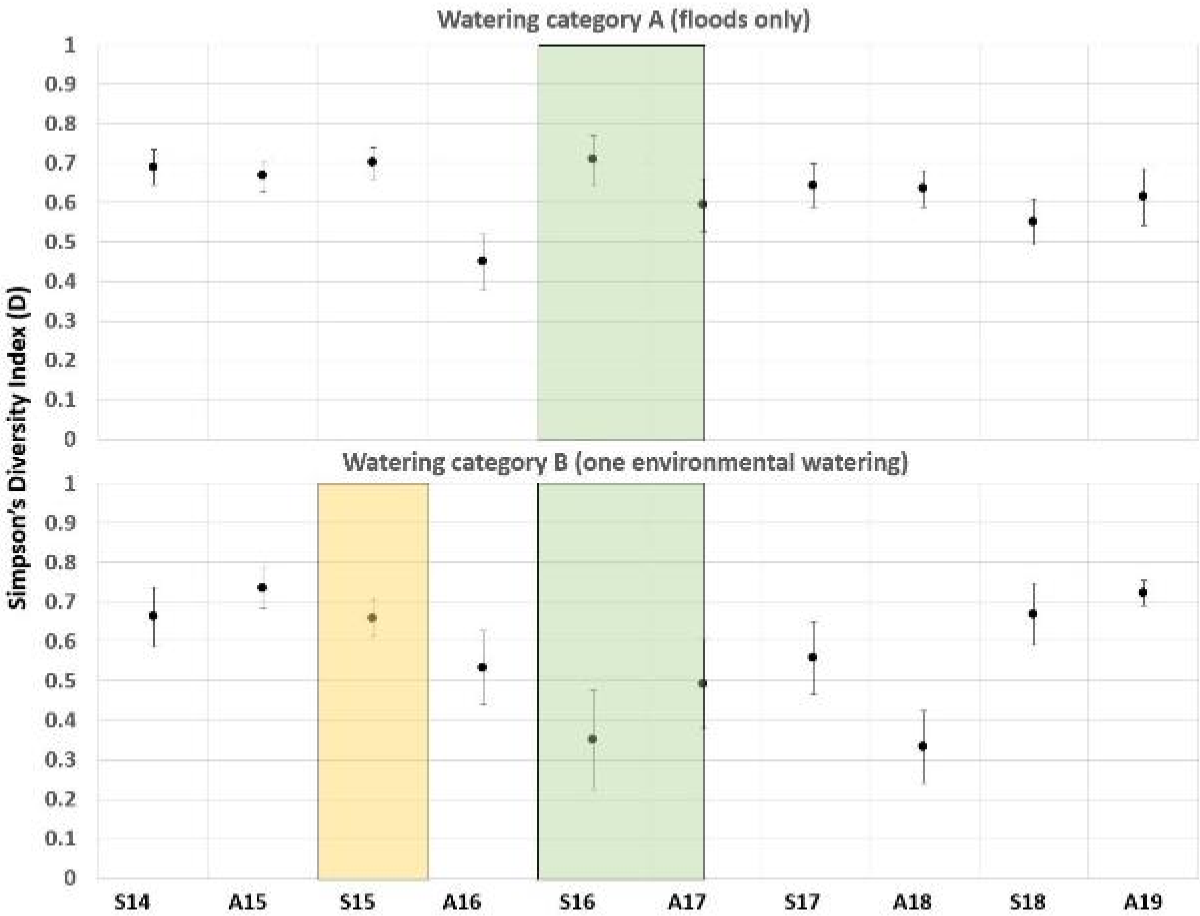


Figure 82. Comparison of groundcover vegetation diversity in the tree community between seasons and years using Simpson's diversity index (D).

The data points are the mean diversity index for each watering treatment (refer to Table 28, p. 163). Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, and A19 Autumn 2019. Yellow represents the period that environmental watering occurred at sites in watering category B, and the green represents the flooding event in 2016-17 that flooded all sites. Error bars represent ± 1 standard error of the mean.

The cumulative species richness of amphibious species in the tree communities increased in response to environmental watering and flooding (Figure *83*). Sites in watering category B that received one environmental watering in spring 2015 had an increased number of amphibious species in spring 2015.

Species richness of amphibious species increased at sites in both watering categories during the flood in 2016-17. All amphibious species at all tree community sites were native. The amphibious species within the tree communities consisted of woody perennial species river cooba (eight sites), tangled lignum (ten sites), river red gum (nine sites), and rhizomatous perennials common nardoo, and common spike-rush (at eight and nine sites respectively). When these species were present at a site they were usually present in spring 2014 and the increase in cumulative species richness over the five years was primarily related to new flood respondent annual species. There has been no or very little change in the number of additional amphibious species at all sites over the 2018-19 watering season (Figure 83).

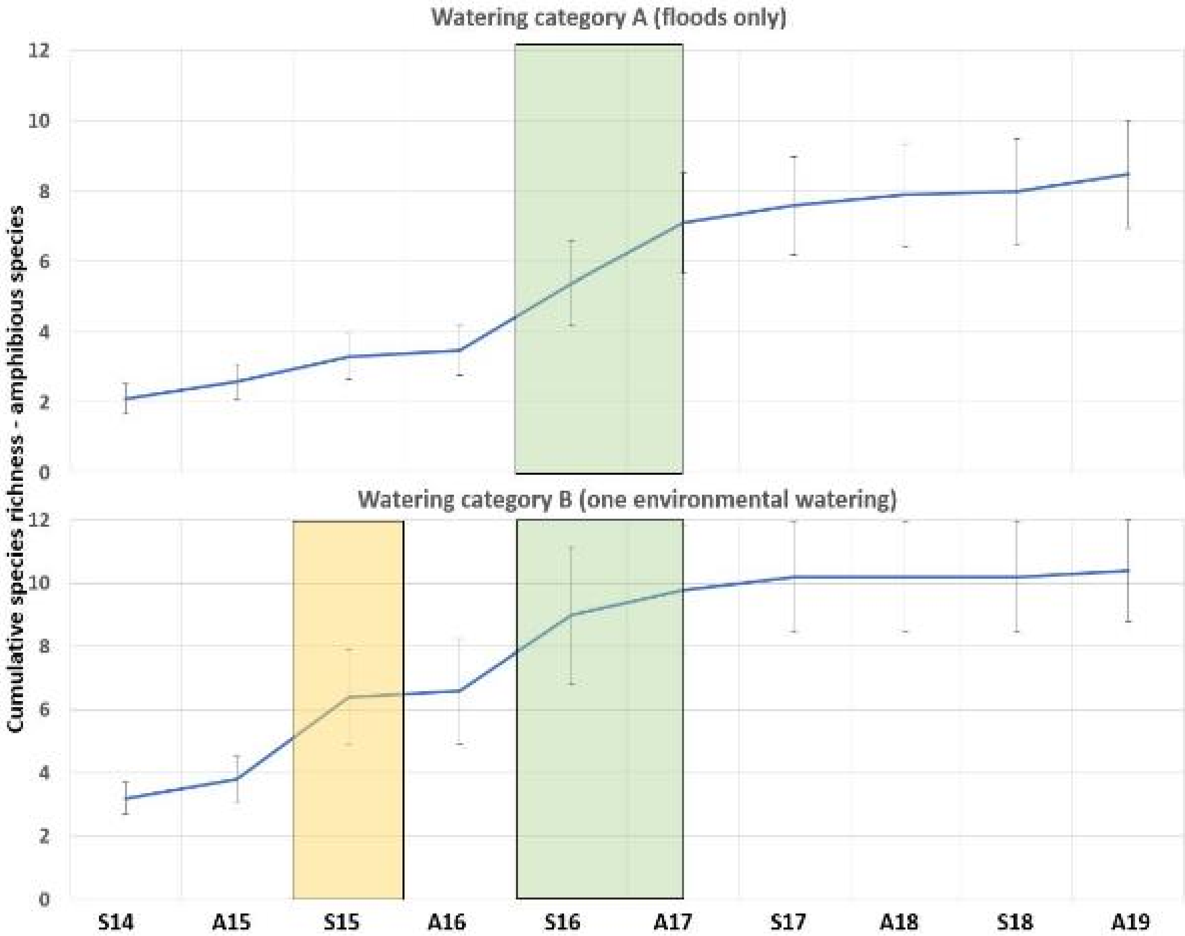


Figure 83. Cumulative species richness of amphibious species in the tree communities at sites within the watering category A (floods only) (top figure) and watering category B (one environmental watering) (bottom figure) across the five years of monitoring.

Yellow represents the period that environmental watering occurred at sites in watering category B, and the green represents the flooding event in 2016-17 that flooded all sites.

The error bars represent ± 1 standard error of the mean.

9.3.2 VEGETATION COMMUNITY DIVERSITY

9.3.2.1 Nativeness and functional types: non-tree community

Overall groundcover in the 2018-19 watering season was considerably lower than that observed in the previous four years of monitoring and resembled the Spring 2014 watering season (Figure 84). Groundcover was similar between spring 2018 and autumn 2019 at sites in watering categories A and C, and greater in spring than autumn at sites in watering category B (Figure 84). The groundcover in both spring 2018 and autumn 2019 was dominated by Terrestrial-dry species, with Amphibious species making up no or a very low proportion of the cover at sites in all three watering treatments.

The amphibious species group was dominated by woody perennial species tangled lignum *(Duma florulenta),* river red gum, and river cooba, with few annual amphibious species or those present making up a small proportion of the total cover. Nooran Lake (in watering category C) was dominated by terrestrial-dry species, nitre bush (*Nitraria billardierei*), ruby saltbush (*Enchylaena tomentosa*), black roly-poly, climbing saltbush (*Einadia nutans subsp. nutans*)*,* and fat hen (*Chenopodium album*). There was no obvious effect of the past four years of watering history on the response of the groundcover vegetation and the groundcover in the 2018-19 watering season appears to be responding to local rainfall conditions (Figure 3, p. 21) and this is what appears to be driving the cover and species assemblage on the floodplain. For instance, at sites Hazelwood, Whealbah and Moon Moon monitoring occurred after considerable rainfall (approximately 90 mm) over the preceding two months and cover was dominated by small (<5 cm) Terrestrial- dry annual species such as burr medic (*Medicago polymorpha*), small crumbweed (*Dysphania pumilio*), New Zealand spinach (*Tetragonia eremaea*) and smooth mustard (*Sisymbrium erysimoides*).

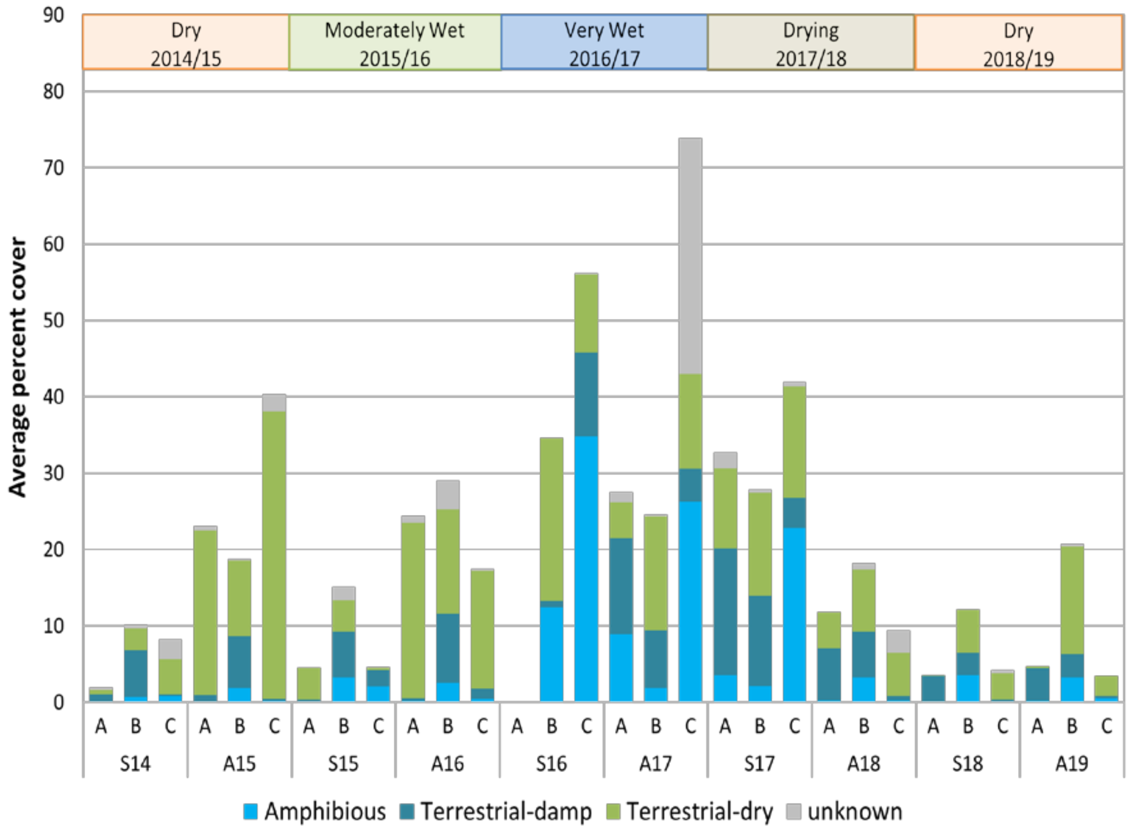


Figure 84. Average percent cover of terrestrial and amphibious species within the non-tree community for sites from each watering history over the sampling period.

Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, and A19: Autumn 2019.

Watering treatments are defined as A, B and C (refer to Table 28 for explanations, p. 163).

Unknown represents species that were unable to be identified to a suitable level for classification. Note that data are not shown for the peak of the flood event in Spring 2017. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

The vegetation cover at the non-tree community sites in 2018-19 varied between sites and between spring and autumn. More than 65% of the vegetation cover at monitoring sites in 2018 was native and this dropped to 41% native in 2019. There was no noticeable influence of the past four years of watering history on the proportion of native species present during the drying phase (Figure 85). The average percent cover of exotic plants increased from 5% in spring 2018 to 41% in Autumn 2019. This increase in the proportion of exotic cover occurred at sites Hazelwood (increase from 14% exotic cover in spring 2018 to 59% exotic cover in Autumn 2019), Moon Moon (increase from 0% cover of native and exotic cover in Spring 2018 to 48% exotic cover in Autumn 2019), and Whealbah Lagoon (increase from 8% exotic cover in spring 2018 to 54% in Autumn 2019).

Exotic species at these sites which increased in cover between Spring and Autumn were dominated by burr medic (*Medicago polymorpha*), Patterson's curse (*Echium plantagineum*), climbing fumitory, turnip weed, and smooth mustard (*Sisymbrium erysimoides*). These are all annual and Terrestrial (dry or damp) species. To note, is that the three sites that showed this increase in exotic plant cover were all monitored following a (2 month) period of higher than average rainfall. This increase in exotic plant cover was not observed at sites in the other two watering treatments.

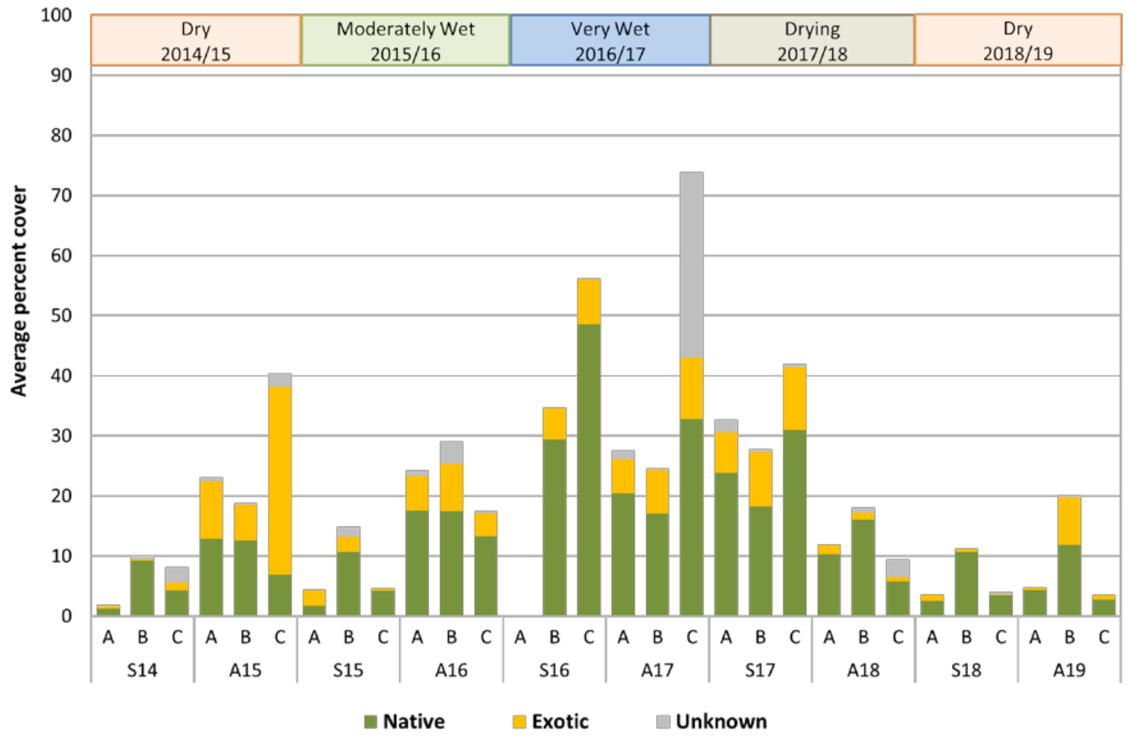


Figure 85. Average percent cover of native and exotic species for the non-tree communities for sites from each watering history over the sampling period.

Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, and A19: Autumn 2019.

Watering treatments are defined as A, B and C (refer to Table 28 for explanations, p. 163). Note that data are not shown for the peak of the flood event in Spring 2016 (Flood Peak), because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

Unknown species are those that were unable to be identified.

9.3.2.2 Nativeness and functional types: tree community

Within the tree community, the percent groundcover remained fairly consistent between spring 2018 and autumn 2019. Groundcover within the tree community in Spring 2018 and Autumn 2019 was the lowest recorded over the five years of monitoring within both watering treatments (Figure 86). Groundcover was dominated by Terrestrial species in both Spring 2018 and Autumn 2019. The few amphibious species which were present in the 2018-19 watering season primarily consisted of long-lived perennial species such tangled lignum and river cooba and the rhizomatous species common nardoo (*Marsilea drummondii*) and common spike-rush (*Eleocharis acuta*). All groundcover at sites in watering category B consisted of Terrestrial-dry species in Autumn 2019 (watering category A, Figure 86).

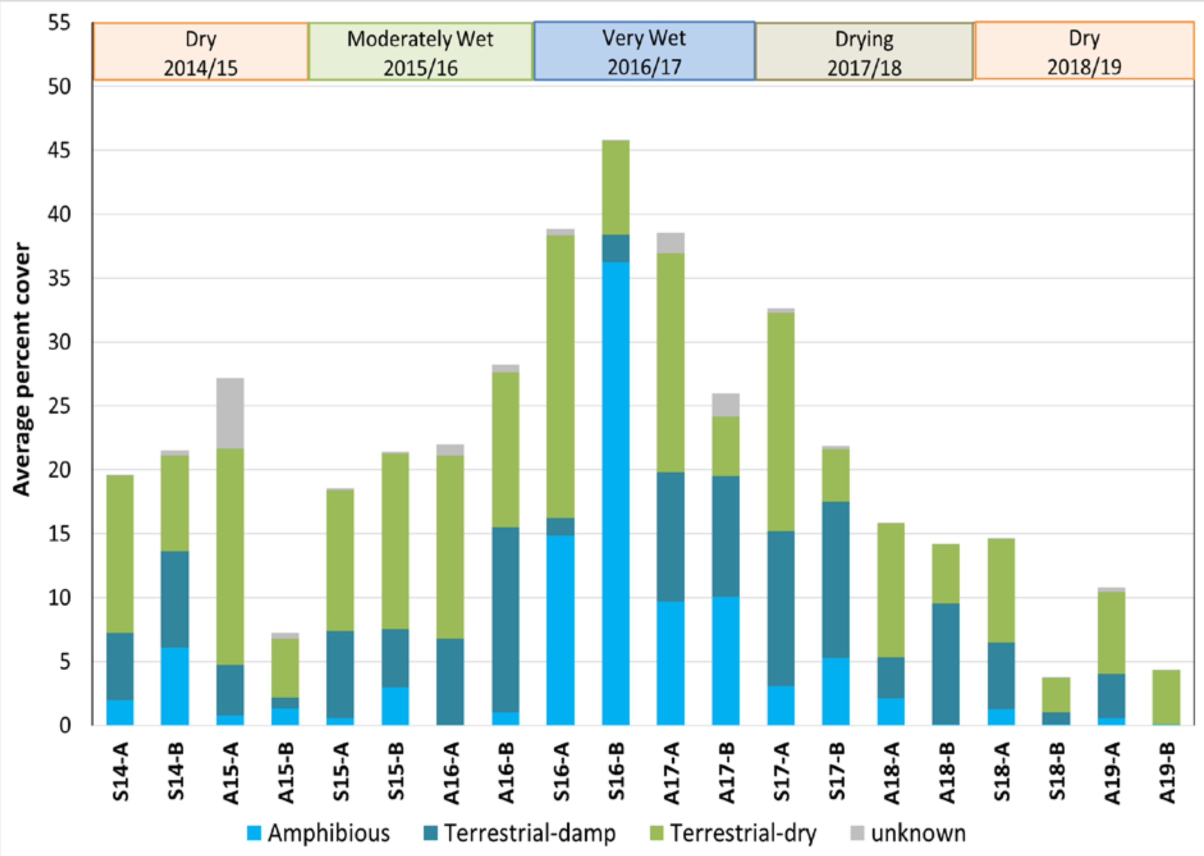


Figure 86. Average percent cover of terrestrial and amphibious species within the tree community for sites from each watering history over the sampling period.

Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, and A19: Autumn 2019.

Watering treatments are defined as A and B (refer to Table 28 for explanations, p. 163).

Unknown represents species that were unable to be identified to a suitable level for classification.

The degree of nativeness at sites remained high in Spring 2018 (at least 76% nativeness) and reduced in Autumn 2019, with the groundcover vegetation at two sites made up of less than 45% native species (Figure 87).

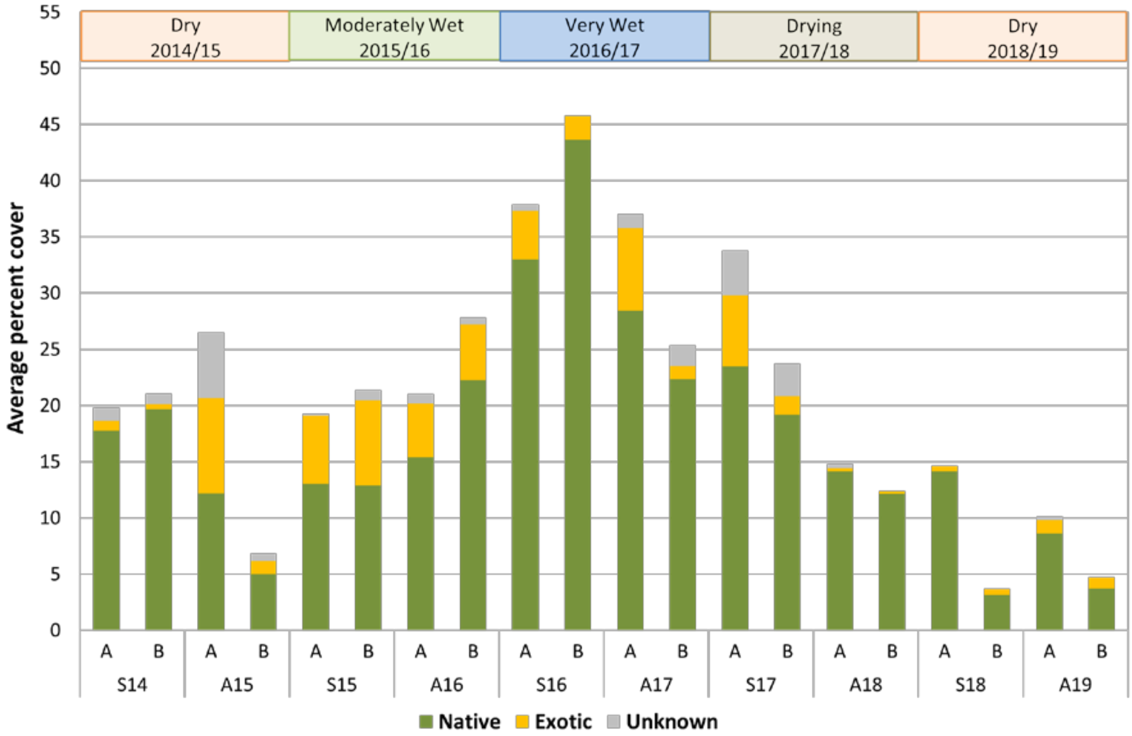


Figure 87. Average percent cover of native and exotic species for the tree communities for sites from each watering history over the sampling period.

Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, and A19: Autumn 2019.Watering treatments are defined as A and B (refer to Table 28 for explanations, p. 163).

9.3.3 CONDITION OF FLOODPLAIN AND RIPARIAN TREES

The percent foliage cover remained fairly consistent in 2018-19 at all sites, and remained fairly similar to that observed in 2017-18 (Figure 88). Sites that have only been watered with natural flood events display more marked changes in foliage cover which has reduced over the past three years in response to the prevailing (dry) catchment conditions. The foliage cover at sites that received environmental water have remained consistent over the past four watering seasons. The foliage cover at sites in watering category A have reduced slightly each year since 2016-17.

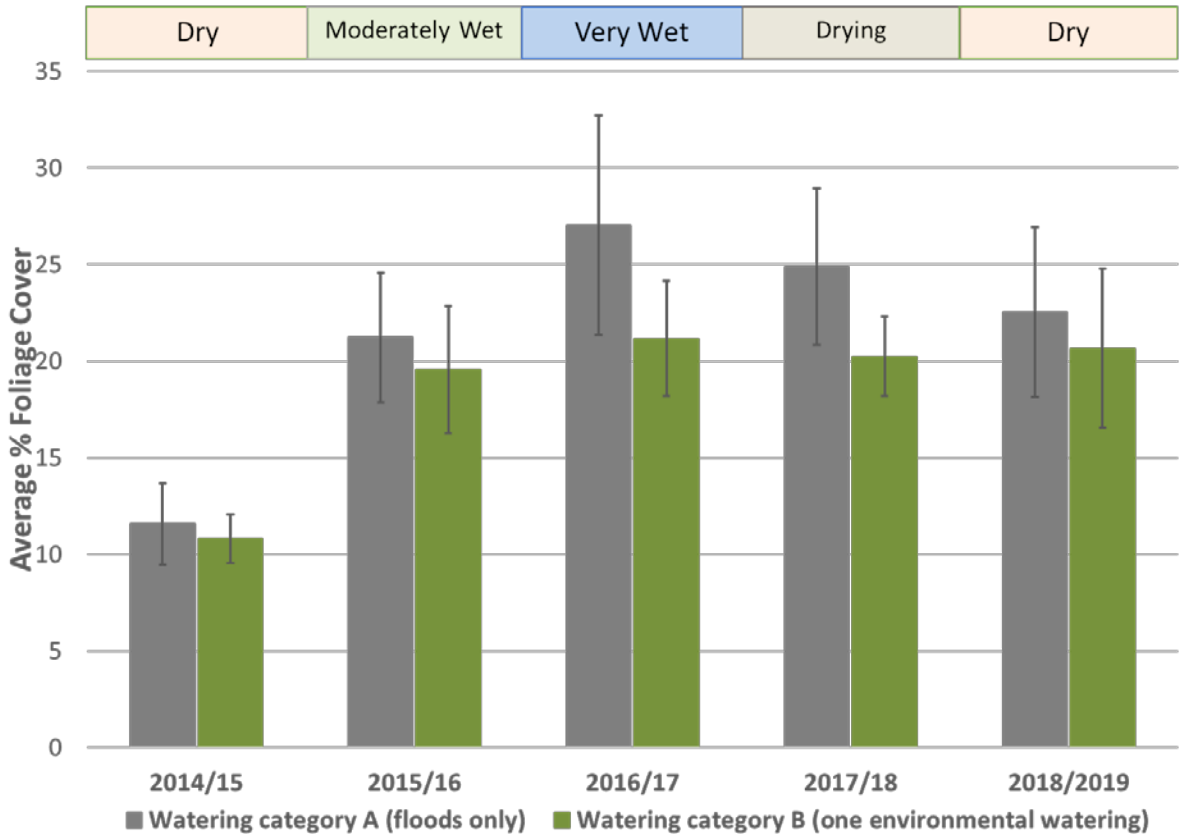


Figure 88. The percent foliage cover over the four monitoring seasons for the woodland vegetation community sites from the two different watering categories.
Watering treatments are defined as A and B (refer to Table 28 for explanations, p. 163).
Error bars represent ± 1 standard error of the mean.

The percent foliage cover at sites varied between years and watering treatments within river red gum sites and black box sites (Figure 89). Foliage cover at river red gum sites showed a similar pattern across the five years in watering categories A and B. Foliage cover was similar at river red gum sites in watering categories A and B in 2014. Foliage cover increased in both watering categories in 2015 and 2016, but to a greater extent at sites in watering category A. Foliage cover decreased at sites in both watering categories in 2017 and 2018 (Figure 89). At black box sites foliage cover varied between watering categories (Figure 89). At black box sites foliage cover was also similar at sites in watering categories A and B in 2014 and foliage cover increased to a similar extent in both watering categories in 2015. Foliage cover in watering category B stayed similar in 2016 and 2017 and increased slightly in 2018, while it has dropped at black box sites in watering category A in 2016 to approximately 10%, and it has remained around this point through 2017 and 2018.

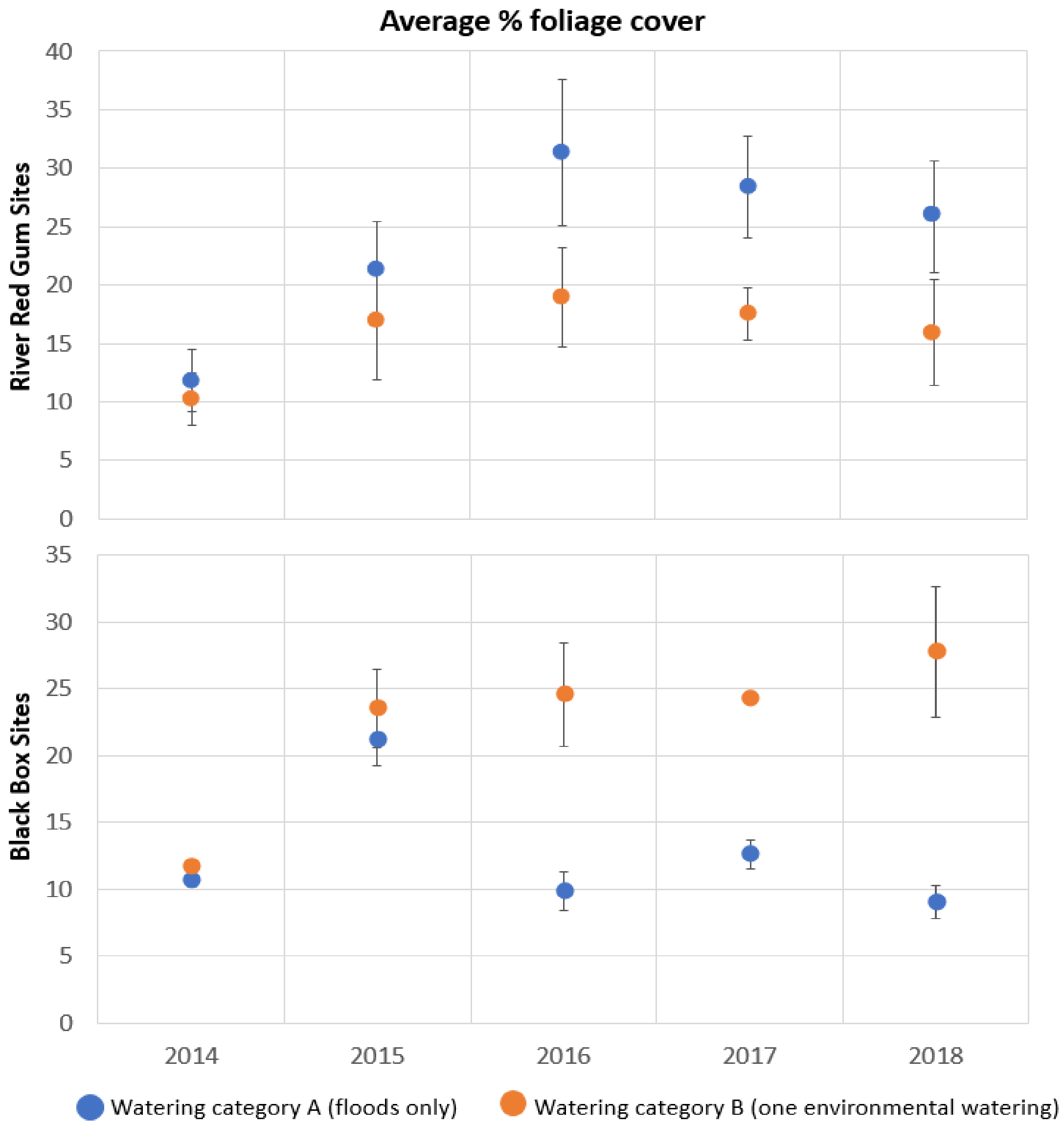


Figure 89. Average % foliage cover within river red gum sites (top figure) and black box sites (bottom figure).
Error bars represent ± 1 standard error from the mean.

9.3.4 CONTRIBUTIONS TO LONG LIVED PLANTS

There was a marked response of seedlings to flooding, particularly in river red gum communities with sites at which the floodwaters recently receded (particularly at Lake Ita and Lake Tarwong) recording large numbers of seedlings. Some of the seedlings had survived into Autumn 2019. The numbers of seedlings dropped considerably at some sites by Autumn 2019 (most notably Lake Tarwong), while some sites have remained fairly high (most notably at Lake Ita). The numbers of seedling recruits increased at all sites in watering category B in 2016 following environmental watering they received in 2015 (most notable at Moon Moon, Nooran Lake, and Tom's Lake). This increase in number of recruits was not observed at sites in watering category A in 2016 (Table 30).

Table 30. The average number of seedlings and saplings per site. All numbers reported are from Autumn sampling events.

SITE	FLOODPLAIN/ WETLAND COMPLEX	LAND USE	GRAZING INTENSITY	RECRUITMENT (<20 cm to >3 m)				
Trip				2015	2016	2017	2018	2019
Hydrological conditions				Dry	Mod-Wet	Very-Wet	Drying	Dry
Red gum community								
Lake Ita	Lachlan River Floodplain	Nature conservation	Low	0	3	124	1439	1021
Moon Moon Swamp	Booligal Wetlands	Grazing (cattle)	Recent and frequent	7	37	water-logged	12	2
Clear Lake	Cumbung Swamp	Grazing (cattle)	Recent and frequent	31	12	40	25	20
Nooran Lake	Great Cumbung Swamp	Grazing (cattle)	Recent and frequent	7	19	5	4	7
Hazelwood	Lachlan River Floodplain	Grazing (sheep)	Recent and frequent	18	21	15	18	15
Lake Bullogal	Lachlan Swamp	Grazing (sheep – large numbers)	Recent and frequent	0	0	34	4	1
Lake Tarwong	Merrowie/Box Creek	Grazing (sheep)	Recent and frequent	119	46	flooded	9485	33
Lake Marrool	Great Cumbung Swamp	Grazing	Recent and occasional	1	1	1	1	1
Whealbah	Lachlan River Floodplain	Grazing (sheep)	Recent and occasional	370	463	67	35	13
Black box community								
Booligal wetland	Booligal Wetlands	Nature conservation	Low	14	22	56	46	47
Lake Ita	Lachlan River Floodplain	Nature conservation	Recent and frequent	0	1	1	2	0
Tom's Lake	Booligal Wetlands	Grazing (cattle)	Recent and frequent	1	21	110	5	12
Lake Tarwong	Merrowie/Box Creek	Grazing (sheep)	Recent and frequent	0	1	80	17	4
Mixed Red Gum, River Cooba and Black Box								
The Ville	Lachlan Swamp	Nature conservation	Low	21	39	58	51	27

The numbers of recruits increased at many sites in 2017 and 2018 following the recession of flood waters in 2017. The numbers of seedlings had reduced at some sites over the 2018-19 watering season compared to the previous year. This was likely related to land use, with sites that are used for grazing (sheep or cattle) having considerably reduced numbers of recruits compared to the previous year. This pattern of seedling loss was not observed at some of the nature conservation sites (Figure 90).

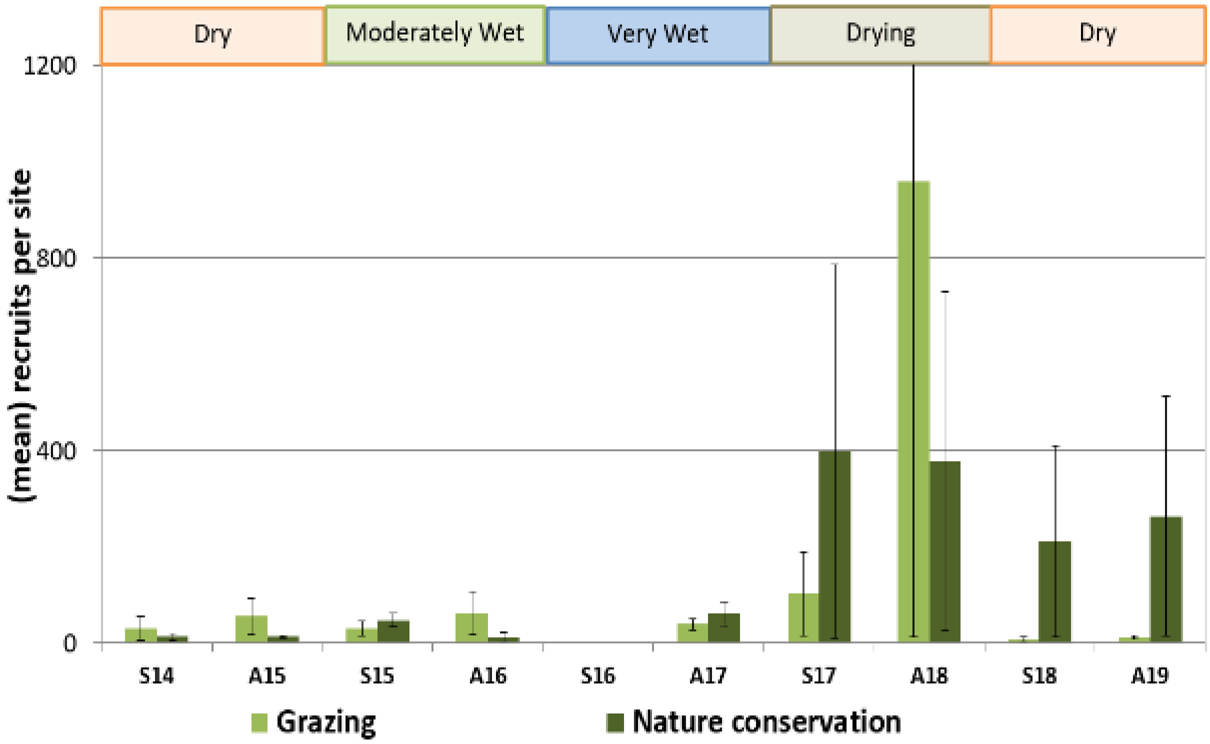


Figure 90. The mean number of recruits per site, within grazing and nature conservation land use categories. Error bars represent ±1 SE.

9.4 DISCUSSION

Over the five years of monitoring, the floodplain and wetland vegetation communities have continued to display dry and wet phases depending on the prevailing conditions. This has been particularly evident in the composition of species making up the groundcover vegetation, with different species being present under certain hydrological or climatic conditions related to species specific hydrological responses. Our assessment of the vegetation species richness and diversity within tree and non-tree communities demonstrate that many plants that occur on the floodplains of the lower Lachlan river germinate and establish under species/functional group specific hydrological conditions (as described by Casanova and Brock 2000, Capon 2003, Nicol et al. 2003). This means that the assemblage of species shifts depending on the prevailing conditions.

Flooding stimulates germination and growth responses in many aquatic and semi-aquatic species, resulting in these species re-establishing from the soil seed bank during flooding or following flood recession (Casanova and Brock 2000, Capon and Brock 2006). The results showed that under dry conditions, recent rainfall resulted in an increase in the cover and species richness of terrestrial often exotic annual species which made up the dominant groundcover. During and following flooding conditions, a diverse assemblage of amphibious species dominated, and interestingly in the lower Lachlan catchment these are primarily native. Flooding events provide an important opportunity for these annual or short-lived perennial amphibious species to germinate, grow and ultimately replenish the soil seed bank. As observed following flooding in 2016 (Dyer et al. 2017), while replenishing the soil seed bank of amphibious species, flooding may also reduce the seed bank of terrestrial exotic annual species, if flooding persists for an extended period of time. Exotic annual species had reduced at sites where flooding during 2016-17 persisted for a few months. These exotic terrestrial species may not have seeds adapted to anaerobic conditions and thus lose viability during flooding.

The fact that a range of amphibious species was observed in the wetter phases suggests some resilience of the floodplain and wetland plant communities in the lower Lachlan river system. While the seed of many amphibious floodplain species can remain viable for decades and over successive wetting and drying cycles (Brock and Rogers 1998, Brock 2011), prolonged drying has been observed to reduce species richness and number of individuals compared to sites more recently flooded (Brock et al. 2003, Nielsen et al. 2013). Nooran Lake was found to have the greatest number of amphibious species present of all sites. Nooran Lake was the most frequently flooded site, and this provides regular opportunity for replenishment of the soil seed bank via contribution of seed produced by extant vegetation and hydrochorous dispersal. In considering environmental watering for floodplain vegetation, one focus should be on maintaining/increasing the numbers of these amphibious species (as these are a) primarily native and b) require flooding), while reducing the numbers of exotic terrestrial species (by lowering the viable soil seed bank of terrestrial species).

Woody perennial plants on floodplains often require flooding for survival, growth and reproduction as rainfall alone is often insufficient (Roberts and Marston 2011). For example, flooding maintains tree condition in floodplain trees river red gum and black box (Holland et al. 2009). Percent foliage cover increased in river red gum and black box community sites following the 2016-17 floods. While the two black box sites (Tom’s Lake and Booligal) within watering category B (i.e. one environmental water) haven’t received additional environmental watering since 2014, their position on tributaries which are used for stock and domestic water delivery appears to have benefited the black box trees at these sites, with percent foliage cover much higher in 2017 and 2018 compared to the black box sites in watering category A (i.e. floods only).

The tree condition and tree condition metrics appear to change at a slower rate to the fast growing often annual groundcover species. Tree condition appears to respond to flooding by increasing foliage cover over the following year. Foliage cover then appears to remain high for at least the next two to three years. Many of the tree condition metrics (apart from foliage cover) didn’t relate strongly to changes in hydrological conditions and may require longer data sets to detect temporal variation. It is also likely that there is spatial variation between our sites in relation to floodplain topography resulting in variation in how long water sits in different parts of the landscape as well as depth of groundwater.

Woody perennial plants which occur on floodplains of the Murray Darling Basin are known to time reproduction around flooding (Doody et al. 2014, Catelotti et al. 2015, Higgisson et al. 2018, 2019a). As such, flooding provides the conditions vital for key life history stages (i.e., seed production, dispersal and germination). The numbers of seedlings of trees river red gum, black box, and river cooba were observed to be strongly related to the occurrence of flooding, with no increase in seedling abundance during dry conditions, and substantial increases at most sites following flooding (particularly evident following flooding in 2016-17). This result demonstrates the importance of flooding events in maintaining the tree communities within the floodplain landscape. The often-uncommon occurrence of flooding events on the fringing communities which occur on floodplains (particularly in intermittent black box floodplain swamps) means that when flooding does occur, it is vital that (at least some of) these seedlings survive. Comparisons in the numbers of seedlings between land use (livestock grazing and nature conservation) categories showed the negative effect that livestock have on seedling survivorship and suggests that watering actions should be coupled with other complementary management actions. This result also highlighted the important role of nature reserves in maintaining these communities in the landscape.

9.4.1 WHAT DID COMMONWEALTH ENVIRONMENTAL WATER CONTRIBUTE TO NATIVE RIPARIAN AND WETLAND VEGETATION COMMUNITIES?

Commonwealth environmental water reached the Great Cumbung Swamp in winter 2019. The water was persisting in parts of the Great Cumbung Swamp during a site visit from 29th July- 1st August 2019. Water had inundated parts of the central reedbeds (Figure 91). The water had also inundated the intermittent river red gum floodplain swamp south of the central reedbeds (Figure 92). While purely observational, new reed shoots were present in and surrounding the floodwater in the reedbeds and there was a diverse range of amphibious respondent species under the river red gums. The reedbeds of the Great Cumbung Swamp are mentioned in the Basin-wide environmental watering strategy, which specifies key objectives to maintain the current extent and increase periods of growth for stands of common reed and cumbungi (*Typha sp*.) in the Great Cumbung Swamp (MDBA 2014) and they have been targeted with environmental water over the past five years. For these reasons the central reedbeds of the Great Cumbung Swamp are likely to be monitored as part of the up-coming Monitoring, Evaluation and Research program.

Figure 91. Photo taken of the Great Cumbung Swamp, central reedbeds on 31st August. Photo by Will Higgisson.

Figure 92. Photo taken of the Great Cumbung Swamp, river red gum floodplain swamp on the 30th August. Photo by Damian McRae.

Commonwealth water inundated the non-tree community at Nooran Lake in December 2018 through January 2019, resulting from the Commonwealth environmental watering action which occurred from October through to December 2018 targeting fish and stream productivity outcomes. The non-tree community at Nooran Lake has the greatest number of amphibious species of all sites and this is (at least partially) related to the regular influence of environmental watering.

9.4.2 VEGETATION RESPONSES TO ANNUAL WEATHER AND HYDROLOGICAL CONDITIONS

Analysis of the five years of monitoring data from the LTIM in the lower Lachlan river system has provided valuable insight into the response of the vegetation which occurs on the floodplain to the hydrological and climatic conditions. The species assemblage of the groundcover shifts in response to recent changes in hydrology and climate. The cover and diversity are typically very low during very dry periods (such as Spring 2018), and terrestrial annual and mostly exotic species dominate in response to rainfall during these dry periods (as observed at some sites in Autumn 2019). During and following flooding a range of amphibious (mostly native) species establish. This is a time of great productivity on the floodplain with cover and diversity at the highest observed following recent flood recession.

Greater vegetation cover is present during wetter conditions and when there is residual water in the landscape (through the drying phase) than in years when the sites have been dry. There is also a greater number and cover of amphibious and terrestrial damp species during wetter conditions than in years when the sites have been dry. The catchment weather and hydrological conditions are strong drivers of vegetation cover and community composition in the floodplains and wetlands of the Lower Lachlan river system.

9.5 EVALUATION

The outcomes for vegetation in the Lower Lachlan river system are addressed in the answers to the specific evaluation questions (the questions for both short and long terms responses are the same) in the following sections.

Short-term (one year) and long-term (five year) evaluation questions:

1) What did Commonwealth environmental water, in the context of the recent watering history of the sites, contribute to vegetation species diversity?

In the absence of Commonwealth environmental water, fewer native amphibious plant species would have occurred in the lower Lachlan River system. The number of amphibious species observed increased at sites which received environmental water in 2014 while sites that did not receive environmental water in 2014 did not see this same increase in amphibious species. The site which has received the most frequent environmental watering in the five years of the LTIM Project (Nooran Lake – Watering Treatment C) displays the greatest number of amphibious species of all sites and this is likely to be at least partially related to the regular input of environmental water maintaining and replenishing the soil seed bank. The vast majority of amphibious species observed across the Lachlan river system were native.

Patterns in site scale vegetation diversity suggest that it is a combination of recent watering history and weather conditions that defines the response of site scale diversity to environmental water. This information is useful in defining expectations for watering actions.

2) What did Commonwealth environmental water, in the context of the watering history of sites, contribute to vegetation community diversity?

Some of the monitored sites reduced their degree of nativeness in 2018-19, with the cover of exotic species increasing in response to rainfall conditions. There were no or very few amphibious and terrestrial damp species in 2018-19 compared with the previous years. This reflects the dry conditions and a return to a dominance of terrestrial dry species. This was observed across all sites, irrespective of recent watering history illustrating the role of local weather conditions in driving the vegetation community.

Commonwealth environmental water has provided the hydrological conditions which have maintained amphibious flood respondent species in the lower Lachlan River system. In the absence of Commonwealth environmental water, native amphibious plant species would have occurred less frequently in the lower Lachlan River system. The site which has received the most frequent environmental watering in the five years of the LTIM Project (Nooran Lake – Watering Treatment C) displays the greatest number and cover of amphibious species of all sites and this is likely to be at least partially related to the regular input of environmental water maintaining and replenishing the soil seed bank.

3) What did Commonwealth environmental water, in the context of the watering history of the sites, contribute to the condition of floodplain and riparian trees?

It has not been possible to disentangle the role of Commonwealth environmental water in the condition of floodplain and riparian trees from the role of local weather conditions. This is, in part, attributed to monitoring few sites that regularly receive environmental water. The tree condition across all sites was observed to improve with wetter conditions and environmental water in 2015-16 and again (slightly) following flooding in 2016-17. Tree condition has remained fairly consistent subsequently. Watering history does not appear to have influenced the response of foliage cover when considered in the context of the response to annual weather conditions.

It is noted that the condition of black box trees at Booligal and Tom's Lake have maintained condition over 2018 and 2019, while black box trees at other sites have reduced in condition over this same period. The maintenance of condition at Booligal and Tom's Lake may be an environmental benefit from stock and domestic water passing near to these sites. While not environmental water, **the role of other sources of water such as stock and domestic appears to provide some benefit to condition of floodplain trees**.

4) What did Commonwealth environmental water, in the context of the watering history of the sites, contribute to populations of long-lived organisms following flooding?

Environmental water resulted in a large number of eucalypt seedlings germinating at sites which received environmental water in 2015 (most notably at Moon Moon, Nooran Lake, and Tom's Lake). This increase in the numbers of seedlings was not observed at sites that did not receive environmental water. This eucalypt germination response was dwarfed by the large natural flood in 2016-17, with large numbers of seedlings being observed across most sites following flood recession.

Monitoring has shown the negative effect that livestock have on seedling survivorship and suggests that watering actions should be coupled with other complementary management actions. This result also highlighted the important role of nature reserves in maintaining these communities in the landscape.

9.6 FURTHER COMMENTS AND RECOMMENDATIONS

In combination, the observations from five years of monitoring vegetation in the Lachlan catchment informs the use of environmental water for vegetation outcomes. The following provides further comments and specific recommendations relating to vegetation outcomes.

9.6.1.1 Recommendation 1: Develop specific objectives for vegetation outcomes

The nature of the benefit for vegetation expected within the Great Cumbung Swamp was not well described within relevant documentation and was simply described in terms of providing an end of system flow. The establishment of explicit, measurable objectives for wetland vegetation is a challenge faced by environmental water managers, in part because of the temporal variability in wetland vegetation. **It is recommended that specific objectives for vegetation sites be developed.** This can be incorporated into the existing 'river run' approach to annual hydrograph planning. Out of the results of this report, a specific objective could be on maintaining/increasing the numbers of amphibious plant species (as these are a) primarily native and b) require flooding), while reducing the numbers of exotic terrestrial species. There is a need to develop clear and measurable objectives around the timing, duration and depth of flows to achieve vegetation responses. Each watering action should test our ability to achieve the desired vegetation response or inform future us of Commonwealth Environmental Water.

9.6.1.2 Recommendation 2: Increase the number of sites monitored to include a greater number of sites that receive environmental water.

Monitoring a greater number of sites that receive or may receive environmental water would increase our ability to assess and analyze the response of the vegetation to environmental water. **The inclusion of extra sites that are likely to receive environmental water should be considered moving into the MER Program.** There are sites (especially some black box sites) which have been monitored in the lower Lachlan River Catchment over the past five years of the LTIM Project which have not and will not and very unlikely to receive environmental water. One option is to drop a few of these sites and add additional sites which are more likely to flood and thus will provide more useful data on the response of the vegetation to watering. Choosing sites which have some level of environmental protection and away from sites heavily influenced by sheep and cattle grazing will also improve our ability to detect a response to watering.

9.6.1.3 Recommendation 3: Monitor the growth and condition of lignum shrublands and their response to environmental watering

One of the 2018-19 annual watering priorities of the Murray Darling Basin was to enable growth and maintain the condition of lignum shrublands. While lignum occurs and forms part of the vegetation community at some of our monitoring sites, we do not explicitly monitor any lignum shrublands as part of the Lachlan catchment monitoring program. **It is recommended that sites within Lignum Shrublands which are targets for environmental watering as well as non-target sites for environmental watering be included as part of the monitoring program over the subsequent MER Program.** This will allow us to detect the response to and benefits of environmental watering as well as develop information on the requirements and tolerances to drying and wetting in tangled lignum. This should underpin the development of flow recommendations that include details on intended timing, duration and depth of inundation and how these elements are required for the vegetation outcomes being targeted.

9.6.1.4 Recommendation 4: Consider landscape vegetation diversity when setting objectives for vegetation outcomes

Landscape position influences the depth and duration of watering and the vegetation that occurs at them. The vegetation present within the sequences of dry and wet phases differs depending on the landscape position and the current approach to evaluating the changes has provided some valuable understanding to date but needs to be considered within a landscape diversity context for future watering actions. **It is recommended that landscape vegetation diversity be a consideration when setting objectives for vegetation outcomes and that a nested set of objectives may be appropriate.** This has not been well done elsewhere and would require investment in the development of an appropriate approach. It would require combining vegetation mapping data with potential inundation mapping and scenario testing to establish landscape priorities. Some analysis of historical data (refer Recommendation 5) would provide the framing for such a task.

9.6.1.5 Recommendation 5: Use a combination of current research and invest in an analysis of historical data sets to inform watering objectives

Research conducted by the University can be used to inform the establishment of objectives. Work by (former) PhD student Will Higgisson to better understand the vegetation communities of the floodplains and wetlands of the Lower Lachlan system (including seedbank studies and predictions of vegetation community patterns) will inform future decisions for watering of these sites. His work suggests that the open water wetlands within the catchment (those which would have been flooded frequently) are vulnerable to vegetation encroachment as they are watered less frequently. It is likely that some encroachment has already occurred, and an analysis of historical aerial imagery should give some insights to this. If this is the case, then thought should be given to maintaining open water areas with watering actions.

It is also noted that the establishment of objectives for wetland vegetation has been the subject of work by the Environmental Water Knowledge and Research team and a forthcoming publication provides a framework that may assist with the development of objectives. **It is therefore recommended that an analysis of historical imagery, historical reports and data sources be conducted and the information combined with current research to inform future watering actions.**

9.6.1.6 Recommendation 6: Consider exotic weeds when using environmental water

Flows may have the capacity to assist with managing invasive weed species at certain sites, through a combination of appropriate timing, duration and depth. Environmental water managers may want to consider the option of trialling some experiments that would enable the impact of flows to manage invasive weed species and the re-establishment of native plant species. This could be undertaken as a set of glass house trials (e.g. to test the field observation of flood duration for promoting/killing exotic plants such as African Boxthorn or Bathurst Burr) or in the field at monitoring sites (in particular, the open wetland and Billabong sites).

9.6.1.7 Recommendation 7: Review the monitoring approach to better detect vegetation outcomes

The reedbeds of the Great Cumbung Swamp are not monitored as part of the LTIM Project for logistical and financial reasons. This means it was not possible to evaluate the outcomes of the 2017-18 watering for the reedbeds, nor of previous years watering actions that have reached the reedbeds. **It is recommended that non-standard methods be developed to monitor the condition of the central reedbeds as part of the on-going MER program**. Drones for monitoring vegetation were trialled as part of the 2016-17 Lachlan LTIM, but the design was opportunistic and not well or strategically targeted. The development of drone based methods for monitoring the reedbeds would be a useful investment given the significance of the vegetation community in the Great Cumbung Swamp.

9.6.1.8 Recommendation 8: Manage herbivory for vegetation outcomes in association with environmental watering actions.

There are a number of factors other than the provision (or not) of environmental water, including herbivory, that can impact on the vegetation response observed at monitoring sites. Environmental water managers may want to consider the option of trialling an experimental design that would enable the impact of excluding herbivory (e.g. the use of herbivore exclusion fencing) to be examined in relation to the associated use of environmental water at monitoring sites.

9.7 APPENDIX 1: SPECIES LIST FROM NON-TREE AND TREE COMMUNITY SITES FROM THE 5 YEARS OF LTIM MONITORING ACROSS ALL SITES WITHIN THE LOWER LACHLAN RIVER SELECTED AREA.

Table 31. Species list from non-tree community sites over 5 years of LTIM monitoring across all sites within the lower Lachlan River (A-Z)

SPECIES LIST NON-TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Abutilon theophrasti	Malvaceae	Terrestrial-dry	non-native
Acacia stenophylla	Fabaceae (Mimosoideae)	Amphibious	native
Alopecurus geniculatus	Poaceae	Terrestrial-damp	non-native
Alternanthera	Amaranthaceae	Terrestrial-damp	native
Alternanthera denticulata	Amaranthaceae	Terrestrial-damp	native
Alternanthera nodiflora	Amaranthaceae	Terrestrial-damp	native
Arabidella nasturtium	Brassicaceae	Terrestrial-dry	native
Asperula gemella	Rubiaceae	Terrestrial-damp	native
Asteraceae	Asteraceae	unknown	unknown
Atriplex leptocarpa	Chenopodiaceae	Terrestrial-dry	native
Atriplex lindleyi	Chenopodiaceae	Terrestrial-dry	native
Atriplex nummularia	Chenopodiaceae	Terrestrial-dry	native
Atriplex semibaccata	Chenopodiaceae	Terrestrial-dry	native
Atriplex suberecta	Chenopodiaceae	Terrestrial-dry	native
Atriplex vesicaria	Chenopodiaceae	Terrestrial-dry	native
Austrostipa	Poaceae	Terrestrial-dry	native
Azolla filiculoides	Azollaceae	Amphibious	native
Bergia trimera	Elatinaceae	Amphibious	native
Boerhavia	Nyctaginaceae	Terrestrial-dry	native
Boerhavia dominii	Nyctaginaceae	Terrestrial-dry	native
Bolboschoenus fluviatilis	Cyperaceae	Amphibious	native
Brachyscome	Asteraceae	Terrestrial-damp	native
Brachyscome basaltica	Asteraceae	Terrestrial-damp	native
Brachyscome goniocarpa	Asteraceae	Terrestrial-damp	native
Brassica tournefortii	Brassicaceae	Terrestrial-dry	non-native
Brassicaceae	Brassicaceae	unknown	unknown
Bulbine	Asphodelaceae	Terrestrial-damp	native
Callitriche sonderi	Callitrichaceae	Amphibious	native
Calotis scabiosifolia	Asteraceae	Terrestrial-dry	native
Calotis scapigera	Asteraceae	Terrestrial-damp	native
Capsella bursa-pastoris	Brassicaceae	Terrestrial-dry	non-native
Cardamine hirsuta	Brassicaceae	Amphibious	non-native
Carrichtera annua	Brassicaceae	Terrestrial-dry	non-native
Centaurea melitensis	Asteraceae	Terrestrial-dry	non-native
Centipeda cunninghamii	Asteraceae	Terrestrial-damp	native
Chenopodium	Chenopodiaceae	Terrestrial-dry	native
Chenopodium album	Chenopodiaceae	Terrestrial-dry	non-native
Chenopodium melanocarpum	Chenopodiaceae	Terrestrial-dry	native
Chenopodium murale	Chenopodiaceae	Terrestrial-dry	native
Chenopodium nitrariaceum	Chenopodiaceae	Terrestrial-dry	native
Cirsium vulgare	Asteraceae	Terrestrial-dry	non-native
Convolvulus erubescens	Convolvulaceae	Terrestrial-damp	native

SPECIES LIST NON-TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Conyza	Asteraceae	Terrestrial-dry	non-native
Conyza bonariensis	Asteraceae	Terrestrial-dry	non-native
Conyza sumatrensis	Asteraceae	Terrestrial-dry	non-native
Coronidium rutidolepis	Asteraceae	Terrestrial-dry	native
Cucumis myriocarpus	Cucurbitaceae	Terrestrial-dry	non-native
Cynodon dactylon	Poaceae	Terrestrial-damp	native
Cyperus difformis	Cyperaceae	Amphibious	native
Cyperus gymnocaulos	Cyperaceae	Amphibious	native
Daucus glochidiatus	Apiaceae	Terrestrial-dry	native
Duma florulenta	Polygonaceae	Amphibious	native
Dysphania pumilio	Chenopodiaceae	Terrestrial-dry	native
Echium plantagineum	Boraginaceae	Terrestrial-dry	non-native
Eclipta platyglossa	Asteraceae	Terrestrial-damp	native
Einadia	Chenopodiaceae	Terrestrial-dry	native
Einadia nutans	Chenopodiaceae	Terrestrial-dry	native
Eleocharis	Cyperaceae	Amphibious	native
Eleocharis acuta	Cyperaceae	Amphibious	native
Eleocharis plana	Cyperaceae	Amphibious	native
Eleocharis pusilla	Cyperaceae	Amphibious	native
Enchylaena tomentosa	Chenopodiaceae	Terrestrial-dry	native
Epaltes australis	Asteraceae	Terrestrial-damp	native
Eragrostis	Poaceae	Terrestrial-dry	native
Eragrostis australasica	Poaceae	Amphibious	native
Erodium crinitum	Geraniaceae	Terrestrial-dry	native
Erodium malacoides	Geraniaceae	Terrestrial-damp	non-native
Eucalyptus camaldulensis	Myrtaceae	Amphibious	native
Eucalyptus largiflorens	Myrtaceae	Terrestrial-damp	native
Euchiton sphaericus	Asteraceae	Terrestrial-dry	native
Euphorbia drummondii	Euphorbiaceae	Terrestrial-dry	native
Euphorbia planiticola	Euphorbiaceae	Terrestrial-dry	native
Fabaceae	Fabaceae	unknown	unknown
Fumaria	Fumariaceae	Terrestrial-damp	non-native
Fumaria capreolata	Fumariaceae	Terrestrial-damp	non-native
Galium aparine	Rubiaceae	Terrestrial-dry	non-native
Galium gaudichaudii	Rubiaceae	Terrestrial-dry	native
Geococcus pusillus	Brassicaceae	Terrestrial-damp	native
Geraniaceae	Geraniaceae	Terrestrial-dry	native
Geranium solanderi	Geraniaceae	Terrestrial-dry	native
Glinus lotoides	Aizoaceae	Terrestrial-dry	native
Goodenia	Goodeniaceae	Terrestrial-dry	native
Goodenia cycloptera	Goodeniaceae	Terrestrial-dry	native
Goodenia fascicularis	Goodeniaceae	Terrestrial-dry	native
Goodenia heteromera	Goodeniaceae	Terrestrial-dry	native
Haloragis glauca	Haloragaceae	Terrestrial-damp	native

SPECIES LIST NON-TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Haloragis heterophylla	Haloragaceae	Terrestrial-damp	native
Heliotropium	Boraginaceae	Terrestrial-damp	non-native
Heliotropium curassavicum	Boraginaceae	Terrestrial-damp	non-native
Heliotropium europaeum	Boraginaceae	Terrestrial-dry	non-native
Heliotropium supinum	Boraginaceae	Terrestrial-damp	non-native
Hordeum leporinum	Poaceae	Terrestrial-dry	non-native
Hydrocotyle trachycarpa	Apiaceae	Terrestrial-damp	native
Isolepis	Cyperaceae	Amphibious	native
Isolepis australiensis	Cyperaceae	Amphibious	native
Juncaceae	Juncaceae	Amphibious	native
Juncus	Juncaceae	Amphibious	native
Juncus flavidus	Juncaceae	Amphibious	native
Lachnagrostis filiformis	Poaceae	Terrestrial-damp	native
Lactuca saligna	Asteraceae	Terrestrial-dry	non-native
Lactuca serriola	Asteraceae	Terrestrial-dry	non-native
Lemna	Lemnaceae	Amphibious	native
Lemna minor	Lemnaceae	Amphibious	native
Lepidium fasciculatum	Brassicaceae	Terrestrial-dry	native
Limosella australis	Scrophulariaceae	Amphibious	native
Lolium rigidum	Poaceae	Terrestrial-dry	non-native
Ludwigia peploides	Onagraceae	Amphibious	native
Lycium ferocissimum	Solanaceae	Terrestrial-dry	non-native
Lythrum hyssopifolia	Lythraceae	Terrestrial-damp	native
Maireana	Chenopodiaceae	Terrestrial-dry	native
Maireana brevifolia	Chenopodiaceae	Terrestrial-dry	native
Maireana decalvans	Chenopodiaceae	Terrestrial-dry	native
Malva	Malvaceae	Terrestrial-dry	non-native
Malva parviflora	Malvaceae	Terrestrial-dry	non-native
Malva preissiana	Malvaceae	Terrestrial-dry	native
Malvaceae	Malvaceae	Terrestrial-dry	non-native
Marrubium vulgare	Lamiaceae	Terrestrial-dry	non-native
Marsilea drummondii	Marsileaceae	Amphibious	native
Medicago	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Medicago polymorpha	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Medicago praecox	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Melilotus indicus	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Mentha australis	Lamiaceae	Terrestrial-damp	native
Modiola caroliniana	Malvaceae	Terrestrial-dry	non-native
Myosurus australis	Ranunculaceae	Terrestrial-damp	native
Myriophyllum verrucosum	Haloragaceae	Amphibious	native
Nitraria billardierei	Nitrariaceae	Terrestrial-dry	native
Onopordum acanthium	Asteraceae	Terrestrial-dry	non-native

SPECIES LIST NON-TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Oxalis	Oxalidaceae	Terrestrial-damp	native
Oxalis corniculata	Oxalidaceae	Terrestrial-dry	non-native
Paspalidium jubiflorum	Poaceae	Terrestrial-damp	native
Paspalum distichum	Poaceae	Amphibious	native
Persicaria decipiens	Polygonaceae	Amphibious	native
Persicaria lapathifolia	Polygonaceae	Amphibious	native
Persicaria prostrata	Polygonaceae	Terrestrial-damp	native
Phalaris paradoxa	Poaceae	Terrestrial-damp	non-native
Phyla nodiflora	Verbenaceae	Terrestrial-damp	non-native
Phyllanthus lacunarius	Phyllanthaceae	Terrestrial-dry	native
Poa fordeana	Poaceae	Terrestrial-dry	native
Poaceae	Poaceae	unknown	unknown
Polygonum	Polygonaceae	Terrestrial-damp	non-native
Polygonum arenastrum	Polygonaceae	Terrestrial-damp	non-native
Polygonum aviculare	Polygonaceae	Terrestrial-damp	non-native
Polygonum plebeium	Polygonaceae	Terrestrial-damp	native
Polypogon monspeliensis	Poaceae	Terrestrial-damp	non-native
Pratia concolor	Lobeliaceae	Terrestrial-dry	native
Pseudognaphalium luteoalbum	Asteraceae	Terrestrial-dry	native
Pseudoraphis spinescens	Poaceae	Amphibious	native
Radyera farragei	Malvaceae	Terrestrial-dry	native
Ranunculus pumilio	Ranunculaceae	Amphibious	native
Ranunculus undosus	Ranunculaceae	Amphibious	native
Raphanus raphanistrum	Ranunculaceae	Terrestrial-dry	non-native
Rapistrum rugosum	Brassicaceae	Terrestrial-damp	non-native
Rhagodia spinescens	Chenopodiaceae	Terrestrial-dry	native
Rhodanthe corymbiflora	Asteraceae	Terrestrial-dry	native
Rorippa	Brassicaceae	Terrestrial-damp	non-native
Rorippa eustylis	Brassicaceae	Terrestrial-dry	native
Rorippa palustris	Brassicaceae	Terrestrial-damp	non-native
Rumex	Polygonaceae	Terrestrial-damp	native
Rumex crystallinus	Polygonaceae	Amphibious	native
Rumex tenax	Polygonaceae	Terrestrial-damp	native
Salsola kali	Chenopodiaceae	Terrestrial-dry	native
Schenkia australis	Gentianaceae	Terrestrial-damp	native
Schismus barbatus	Poaceae	Terrestrial-dry	non-native
Scleroblitum atriplicinum	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena birchii	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena brachyptera	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena muricata	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena parviflora	Chenopodiaceae	Terrestrial-dry	native

SPECIES LIST NON-TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Sclerolaena stelligera	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena tricuspis	Chenopodiaceae	Terrestrial-dry	native
Senecio	Asteraceae	Terrestrial-dry	native
Senecio cunninghamii	Asteraceae	Terrestrial-dry	native
Senecio quadridentatus	Asteraceae	Terrestrial-dry	native
Senecio runcinifolius	Asteraceae	Terrestrial-dry	native
Sida	Malvaceae	Terrestrial-dry	native
Sida corrugata	Malvaceae	Terrestrial-dry	native
Sida fibulifera	Malvaceae	Terrestrial-dry	native
Sisymbrium	Brassicaceae	Terrestrial-dry	non-native
Sisymbrium erysimoides	Brassicaceae	Terrestrial-dry	non-native
Sisymbrium irio	Brassicaceae	Terrestrial-damp	non-native
Solanaceae	Solanaceae	unknown	unknown
Solanum	Solanaceae	Terrestrial-dry	native
Solanum esuriale	Solanaceae	Terrestrial-damp	native
Solanum nigrum	Solanaceae	Terrestrial-dry	non-native
Sonchus oleraceus	Asteraceae	Terrestrial-dry	non-native
Sporobolus mitchellii	Poaceae	Terrestrial-damp	native
Stellaria media	Caryophyllaceae	Terrestrial-dry	non-native
Stemodia florulenta	Scrophulariaceae	Terrestrial-damp	native
Tetragonia eremaea	Aizoaceae	Terrestrial-dry	native
Urtica urens	Urticaceae	Terrestrial-dry	non-native
Verbena	Verbenaceae	Terrestrial-dry	native
Verbena officinalis	Verbenaceae	Terrestrial-dry	non-native
Verbena supina	Verbenaceae	Terrestrial-damp	non-native
Vicia	Fabaceae	Terrestrial-dry	non-native
Vittadinia cuneata	Asteraceae	Terrestrial-dry	native
Vulpia bromoides	Poaceae	Terrestrial-dry	non-native
Wahlenbergia	Campanulaceae	Terrestrial-damp	native
Xanthium occidentale	Asteraceae	Terrestrial-dry	non-native
Xanthium spinosum	Asteraceae	Terrestrial-dry	non-native
Zygophyllum apiculatum	Zygophyllaceae	Terrestrial-dry	native

Table 32. Species list from tree community sites over 5 years of LTIM monitoring across all sites within the lower Lachlan River (A-Z)

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Abutilon theophrasti	Malvaceae	Terrestrial-dry	non-native
Acacia salicina	Fabaceae (Mimosoideae)	Terrestrial-damp	native
Acacia stenophylla	Fabaceae (Mimosoideae)	Amphibious	native
Agrostis parviflora	Poaceae	Terrestrial-damp	native
Alopecurus geniculatus	Poaceae	Terrestrial-damp	non-native
Alternanthera	Amaranthaceae	Terrestrial-damp	native
Alternanthera denticulata	Amaranthaceae	Terrestrial-damp	native
Alternanthera nodiflora	Amaranthaceae	Terrestrial-damp	native
Amaranthus macrocarpus	Amaranthaceae	Terrestrial-dry	native
Amphibromus nervosus	Poaceae	Terrestrial-damp	native
Asperula conferta	Rubiaceae	Terrestrial-dry	native
Asperula gemella	Rubiaceae	Terrestrial-damp	native
Asteraceae	Asteraceae	Terrestrial-dry	unknown
Atriplex	Chenopodiaceae	Terrestrial-dry	native
Atriplex leptocarpa	Chenopodiaceae	Terrestrial-dry	native
Atriplex lindleyi	Chenopodiaceae	Terrestrial-dry	native
Atriplex nummularia	Chenopodiaceae	Terrestrial-dry	native
Atriplex pseudocampanulata	Chenopodiaceae	Terrestrial-dry	native
Atriplex semibaccata	Chenopodiaceae	Terrestrial-dry	native
Atriplex suberecta	Chenopodiaceae	Terrestrial-dry	native
Atriplex vesicaria	Chenopodiaceae	Terrestrial-dry	native
Azoll	Azollaceae	Amphibious	native
Azolla filiculoides	Azollaceae	Amphibious	native
Bergia trimera	Elatinaceae	Amphibious	native
Bidens pilosa	Asteraceae	Terrestrial-dry	non-native
Boerhavia	Nyctaginaceae	Terrestrial-dry	native
Boerhavia dominii	Nyctaginaceae	Terrestrial-dry	native
Bolboschoenus fluviatilis	Cyperaceae	Amphibious	native
Brachyscome	Asteraceae	Terrestrial-damp	native
Brachyscome basaltica	Asteraceae	Terrestrial-damp	native
Brachyscome goniocarpa	Asteraceae	Terrestrial-damp	native
Brachyscome papillosa	Asteraceae	Terrestrial-dry	native
Brassicaceae	Brassicaceae	Terrestrial-dry	unknown
Bulbine	Asphodelaceae	Terrestrial-damp	native
Bulbine bulbosa	Asphodelaceae	Terrestrial-damp	native
Bulbine semibarbata	Asphodelaceae	Terrestrial-damp	native
Callitriche sonderi	Callitrichaceae	Amphibious	native
Calocephalus sonderi	Asteraceae	Terrestrial-dry	native
Calotis	Asteraceae	Terrestrial-damp	native
Calotis scabiosifolia	Asteraceae	Terrestrial-dry	native
Calotis scapigera	Asteraceae	Terrestrial-damp	native

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Camphibiousobrotus	Aizoaceae	Terrestrial-dry	native
Capsella bursa-pastoris	Brassicaceae	Terrestrial-dry	non-native
Carrichtera annua	Brassicaceae	Terrestrial-dry	non-native
Centaurea melitensis	Asteraceae	Terrestrial-dry	non-native
Centipeda cunninghamii	Asteraceae	Terrestrial-damp	native
Chenopodium	Chenopodiaceae	Terrestrial-dry	native
Chenopodium album	Chenopodiaceae	Terrestrial-dry	non-native
Chenopodium melanocarpa	Chenopodiaceae	Terrestrial-dry	native
Chenopodium murale	Chenopodiaceae	Terrestrial-dry	native
Chenopodium nitrariaceum	Chenopodiaceae	Terrestrial-dry	native
Chenopodium pumilio	Chenopodiaceae	Terrestrial-dry	native
Cirsium vulgare	Asteraceae	Terrestrial-dry	non-native
Convolvulus arvensis	Convolvulaceae	Terrestrial-dry	non-native
Convolvulus erubescens	Convolvulaceae	Terrestrial-damp	native
Conyza	Asteraceae	Terrestrial-dry	non-native
Conyza bonariensis	Asteraceae	Terrestrial-dry	non-native
Conyza sumatrensis	Asteraceae	Terrestrial-dry	non-native
Craspedia	Asteraceae	Terrestrial-damp	native
Cucumis	Cucurbitaceae	Terrestrial-dry	non-native
Cucumis myriocarpus	Cucurbitaceae	Terrestrial-dry	non-native
Cullen cinereum	Fabaceae (Faboideae)	Terrestrial-damp	native
Cynodon dactylon	Poaceae	Terrestrial-damp	native
Cynoglossum suaveolens	Boraginaceae	Terrestrial-damp	native
Cyperaceae	Cyperaceae	Amphibious	native
Cyperus	Cyperaceae	Amphibious	native
Cyperus bifax	Cyperaceae	Amphibious	native
Cyperus difformis	Cyperaceae	Amphibious	native
Cyperus gymnocaulos	Cyperaceae	Amphibious	native
Damasonium minus	Alismataceae	Amphibious	native
Daucus	Apiaceae	Terrestrial-dry	native
Dichondra	Convolvulaceae	Terrestrial-dry	native
Dissocamphibiousus paradoxus	Chenopodiaceae	Terrestrial-dry	native
Duma florulenta	Polygonaceae	Amphibious	native
Dysphania pumilio	Chenopodiaceae	Terrestrial-dry	native
Echium plantagineum	Boraginaceae	Terrestrial-dry	non-native
Eclipta platyglossa	Asteraceae	Terrestrial-damp	native
Einadia	Chenopodiaceae	Terrestrial-dry	native
Einadia nutans	Chenopodiaceae	Terrestrial-dry	native
Eleocharis	Cyperaceae	Amphibious	native
Eleocharis acuta	Cyperaceae	Amphibious	native
Eleocharis pusilla	Cyperaceae	Amphibious	native
Eleusine indica	Poaceae	unknown	non-native
Enchylaena	Chenopodiaceae	Terrestrial-dry	native

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Enchylaena tomentosa	Chenopodiaceae	Terrestrial-dry	native
Epaltes australis	Asteraceae	Terrestrial-damp	native
Eragrostis	Poaceae	Terrestrial-dry	native
Eragrostis australasica	Poaceae	Amphibious	native
Eragrostis setifolia	Poaceae	Terrestrial-dry	native
Erodium botrys	Geraniaceae	Terrestrial-damp	non-native
Erodium malacoides	Geraniaceae	Terrestrial-damp	non-native
Eucalyptus camaldulensis	Myrtaceae	Amphibious	native
Eucalyptus largiflorens	Myrtaceae	Terrestrial-damp	native
Euchiton sphaericus	Asteraceae	Terrestrial-dry	native
Euphorbia australis	Euphorbiaceae	unknown	native
Euphorbia drummondii	Euphorbiaceae	Terrestrial-dry	native
Euphorbia stevenii	Euphorbiaceae	Terrestrial-dry	native
Fabaceae	Fabaceae	unknown	unknown
Fumaria	Fumariaceae	Terrestrial-damp	non-native
Fumaria capreolata	Fumariaceae	Terrestrial-damp	non-native
Galium	Rubiaceae	Terrestrial-dry	native
Galium aparine	Rubiaceae	Terrestrial-dry	non-native
Galium gaudichaudii	Rubiaceae	Terrestrial-dry	native
Galium murale	Rubiaceae	Terrestrial-dry	non-native
Geococcus pusillus	Brassicaceae	Terrestrial-damp	native
Geranium solanderi	Geraniaceae	Terrestrial-dry	native
Glinus lotoides	Aizoaceae	Terrestrial-dry	native
Glycyrrhiza acanthocarpa	Fabaceae (Faboideae)	Terrestrial-damp	native
Gnaphalium	Asteraceae	Terrestrial-dry	native
Goodenia cycloptera	Goodeniaceae	Terrestrial-dry	native
Goodenia fascicularis	Goodeniaceae	Terrestrial-dry	native
Goodenia glauca	Goodeniaceae	Terrestrial-dry	native
Goodenia heteromera	Goodeniaceae	Terrestrial-dry	native
Haloragis	Haloragaceae	Terrestrial-damp	native
Haloragis aspera	Haloragaceae	Terrestrial-damp	native
Haloragis glauca	Haloragaceae	Terrestrial-damp	native
Haloragis heterophylla	Haloragaceae	Terrestrial-damp	native
Heliotropium	Boraginaceae	Terrestrial-damp	non-native
Heliotropium curassavicum	Boraginaceae	Terrestrial-damp	non-native
Heliotropium europaeum	Boraginaceae	Terrestrial-dry	non-native
Heliotropium supinum	Boraginaceae	Terrestrial-damp	non-native
Helminthotheca echioides	Asteraceae	Terrestrial-dry	non-native
Hibiscus sturtii	Malvaceae	Terrestrial-dry	native
Hordeum leporinum	Poaceae	Terrestrial-dry	non-native
Hydrocotyle trachycarpa	Apiaceae	unknown	native
Isolepis	Cyperaceae	Amphibious	native
Isolepis australiensis	Cyperaceae	Amphibious	native

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Juncaceae	Juncaceae	Amphibious	native
Juncus	Juncaceae	Amphibious	native
Juncus aridicola	Juncaceae	Amphibious	native
Juncus flavidus	Juncaceae	Amphibious	native
Juncus usitatus	Juncaceae	Amphibious	native
Lachnagrostis filiformis	Poaceae	Terrestrial-damp	native
Lactuca	Asteraceae	Terrestrial-dry	non-native
Lactuca saligna	Asteraceae	Terrestrial-dry	non-native
Lactuca serriola	Asteraceae	Terrestrial-dry	non-native
Lemna	Lemnaceae	Amphibious	native
Lemna minor	Lemnaceae	Amphibious	native
Lepidium	Brassicaceae	Terrestrial-dry	native
Lepidium hyssopifolium	Brassicaceae	Terrestrial-dry	native
Lepidium pseudohyssopifolium	Brassicaceae	Terrestrial-dry	native
Limosella australis	Scrophulariaceae	Amphibious	native
Lolium rigidum	Poaceae	Terrestrial-dry	non-native
Ludwigia peploides	Onagraceae	Amphibious	native
Lycium ferocissimum	Solanaceae	Terrestrial-dry	non-native
Lythrum hyssopifolia	Lythraceae	Terrestrial-damp	native
Lythrum salicaria	Lythraceae	Amphibious	native
Maireana	Chenopodiaceae	Terrestrial-dry	native
Maireana appressa	Chenopodiaceae	Terrestrial-dry	native
Maireana brevifolia	Chenopodiaceae	Terrestrial-dry	native
Maireana decalvans	Chenopodiaceae	Terrestrial-dry	native
Maireana pyramidata	Chenopodiaceae	Terrestrial-dry	native
Maireana trichoptera	Chenopodiaceae	Terrestrial-dry	native
Malva	Malvaceae	Terrestrial-dry	non-native
Malva parviflora	Malvaceae	Terrestrial-dry	non-native
Malva preissiana	Malvaceae	Terrestrial-dry	native
Malvaceae	Malvaceae	Terrestrial-dry	non-native
Marrubium vulgare	Lamiaceae	Terrestrial-dry	non-native
Marsilea drummondii	Marsileaceae	Amphibious	native
Medicago	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Medicago arabica	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Medicago polymorpha	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Medicago praecox	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Melilotus indicus	Fabaceae (Faboideae)	Terrestrial-dry	non-native
Mentha australis	Lamiaceae	Terrestrial-damp	native
Mimulus gracilis	Scrophulariaceae	Terrestrial-damp	native
Minuria denticulata	Asteraceae	Terrestrial-dry	native
Modiola caroliniana	Malvaceae	Terrestrial-dry	non-native
Myoporum montanum	Myoporaceae	Terrestrial-dry	native
Myosurus australis	Ranunculaceae	Terrestrial-damp	native

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Myriophyllum	Haloragaceae	Amphibious	native
Myriophyllum propinquum	Haloragaceae	Amphibious	native
Myriophyllum verrucosum	Haloragaceae	Amphibious	native
Nicotiana velutina	Solanaceae	Terrestrial-dry	native
Nitraria billardierei	Nitrariaceae	Terrestrial-dry	native
Onopordum acanthium	Asteraceae	Terrestrial-dry	non-native
Oxalis chnoodes	Oxalidaceae	Terrestrial-dry	native
Oxalis corniculata	Oxalidaceae	Terrestrial-dry	non-native
Panicum decompositum	Poaceae	Terrestrial-dry	native
Panicum effusum	Poaceae	Terrestrial-dry	native
Paspalidium	Poaceae	Terrestrial-damp	native
Paspalidium jubiflorum	Poaceae	Terrestrial-damp	native
Paspalum distichum	Poaceae	Amphibious	native
Persicaria	Polygonaceae	Amphibious	native
Persicaria orientalis	Polygonaceae	Amphibious	native
Persicaria prostrata	Polygonaceae	Terrestrial-damp	native
Phalaris	Poaceae	Terrestrial-damp	non-native
Phalaris aquatica	Poaceae	Terrestrial-damp	non-native
Phalaris minor	Poaceae	Terrestrial-dry	non-native
Phalaris paradoxa	Poaceae	Terrestrial-damp	non-native
Phyla nodiflora	Verbenaceae	Terrestrial-damp	non-native
Phyllanthus lacunarius	Phyllanthaceae	Terrestrial-dry	native
Physalis	Solanaceae	Terrestrial-dry	non-native
Physalis minima	Solanaceae	Terrestrial-damp	non-native
Picris angustifolia	Asteraceae	Terrestrial-dry	non-native
Plantago	Plantaginaceae	Terrestrial-dry	non-native
Plantago cunninghamii	Plantaginaceae	Terrestrial-damp	native
Poa	Poaceae	Terrestrial-dry	native
Poa fordeana	Poaceae	Terrestrial-dry	native
Poaceae	Poaceae	Terrestrial-dry	unknown
Polygonum aviculare	Polygonaceae	Terrestrial-damp	non-native
Polygonum plebeium	Polygonaceae	Terrestrial-damp	native
Polypogon monspeliensis	Poaceae	Terrestrial-damp	non-native
Portulaca oleracea	Portulacaceae	Terrestrial-dry	native
Potamogeton tricarinatus	Potamogetonaceae	Amphibious	native
Pratia	Lobeliaceae	unknown	unknown
Pratia concolor	Lobeliaceae	Terrestrial-dry	native
Pseudognaphalium luteoalbum	Asteraceae	Terrestrial-dry	native
Pseudoraphis spinescens	Poaceae	Amphibious	native
Psilocaulon tenue	Aizoaceae	Terrestrial-dry	native
Radyera farragei	Malvaceae	Terrestrial-dry	native
Ranunculus pumilio	Ranunculaceae	Amphibious	native
Ranunculus undosus	Ranunculaceae	Amphibious	native

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Raphanus raphanistrum	Ranunculaceae	Terrestrial-dry	non-native
Rapistrum rugosum	Brassicaceae	Terrestrial-damp	non-native
Rhagodia spinescens	Chenopodiaceae	Terrestrial-dry	native
Rhodanthe corymbiflora	Asteraceae	Terrestrial-dry	native
Rorippa	Brassicaceae	Terrestrial-damp	non-native
Rorippa eustylis	Brassicaceae	Terrestrial-dry	native
Rorippa laciniata	Brassicaceae	Terrestrial-dry	native
Rorippa palustris	Brassicaceae	Terrestrial-damp	non-native
Rumex	Polygonaceae	Terrestrial-damp	native
Rumex brownii	Polygonaceae	Terrestrial-damp	native
Rumex crystallinus	Polygonaceae	Amphibious	native
Rumex tenax	Polygonaceae	Terrestrial-damp	native
Salsola kali	Chenopodiaceae	Terrestrial-dry	native
Schenkia australis	Gentianaceae	unknown	native
Schismus barbatus	Poaceae	Terrestrial-dry	non-native
Scleroblitum atriplicinum	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena birchii	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena brachyptera	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena constricta	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena convexula	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena divaricata	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena intricata	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena muricata	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena parviflora	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena stelligera	Chenopodiaceae	Terrestrial-dry	native
Sclerolaena tricuspis	Chenopodiaceae	Terrestrial-dry	native
Senecio	Asteraceae	Terrestrial-dry	native
Senecio cunninghamii	Asteraceae	Terrestrial-dry	native
Senecio glossanthus	Asteraceae	Terrestrial-dry	native
Senecio pinnatifolius	Asteraceae	Terrestrial-dry	native
Senecio quadridentatus	Asteraceae	Terrestrial-dry	native
Senecio runcinifolius	Asteraceae	Terrestrial-dry	native
Sida	Malvaceae	Terrestrial-dry	native
Sida corrugata	Malvaceae	Terrestrial-dry	native
Sida fibulifera	Malvaceae	Terrestrial-dry	native
Sida intricata	Malvaceae	Terrestrial-dry	native
Sida rhombifolia	Malvaceae	Terrestrial-dry	native
Sisymbrium	Brassicaceae	Terrestrial-dry	non-native
Sisymbrium erysimoides	Brassicaceae	Terrestrial-dry	non-native
Sisymbrium irio	Brassicaceae	Terrestrial-damp	non-native
Solanaceae	Solanaceae	Terrestrial-dry	unknown
Solanum	Solanaceae	Terrestrial-dry	native

SPECIES LIST FROM TREE COMMUNITY SITES	FAMILY	FUNCTIONAL GROUP	NATIVE/ NON-NATIVE
Solanum esuriale	Solanaceae	Terrestrial-damp	native
Solanum nigrum	Solanaceae	Terrestrial-dry	non-native
Solanum simile	Solanaceae	Terrestrial-dry	native
Sonchus oleraceus	Asteraceae	Terrestrial-dry	non-native
Spergularia marina	Caryophyllaceae	Unknown	native
Sporobolus caroli	Poaceae	Terrestrial-dry	native
Sporobolus mitchellii	Poaceae	Terrestrial-damp	native
Stellaria angustifolia	Caryophyllaceae	Terrestrial-damp	native
Stellaria media	Caryophyllaceae	Terrestrial-dry	non-native
Stemodia florulenta	Scrophulariaceae	Terrestrial-damp	native
Taraxacum officinale	Asteraceae	Terrestrial-dry	non-native
Tetragonia	Aizoaceae	Terrestrial-dry	native
Tetragonia eremaea	Aizoaceae	Terrestrial-dry	native
Teucrium racemosum	Lamiaceae	Terrestrial-dry	native
Themeda triandra	Poaceae	Terrestrial-dry	native
Triglochin	Juncaginaceae	Amphibious	native
Triglochin dubia	Juncaginaceae	Amphibious	native
Typha	Typhaceae	Amphibious	native
Urtica incisa	Urticaceae	Terrestrial-damp	non-native
Urtica urens	Urticaceae	Terrestrial-dry	non-native
Verbascum thapsus	Scrophulariaceae	unknown	native
Verbena	Verbenaceae	Terrestrial-dry	native
Verbena officinalis	Verbenaceae	Terrestrial-dry	non-native
Verbena supina	Verbenaceae	Terrestrial-damp	non-native
Veronica camphibiousnata	Plantaginaceae	Terrestrial-damp	non-native
Veronica peregrina	Plantaginaceae	Terrestrial-damp	non-native
Vittadinia cuneata	Asteraceae	Terrestrial-dry	native
Wahlenbergia	Campanulaceae	Terrestrial-damp	native
Wahlenbergia fluminalis	Campanulaceae	Terrestrial-damp	native
Xanthium occidentale	Asteraceae	Terrestrial-dry	non-native
Xanthium spinosum	Asteraceae	Terrestrial-dry	non-native
Zygophyllum	Zygophyllaceae	Terrestrial-dry	native
Zygophyllum apiculatum	Zygophyllaceae	Terrestrial-dry	native

10 COMMUNICATION AND ENGAGEMENT

10.1 INTRODUCTION

Under the LTIM Project, the Lower Lachlan Selected Area has had resources dedicated to Communication and Engagement (C&E) that have supported two components of communication and engagement activities. The first has been internal project communication and has been associated with the delivery of the monitoring and evaluation activities. This involved the project team, the CEWO, key water delivery stakeholders and other operational stakeholders. The second has been external communication and engagement and involved stakeholder groups outside of the core operation of the LTIM Project including landholders, affected communities and the general public. Both are critical to the success of ongoing environmental watering programs.

This chapter of the technical report provides an overview of the C&E activities delivered in 2018-19 and summarises the learning over the past five years that informs the development of ongoing C&E activities.

10.1.1 INTERNAL PROJECT COMMUNICATION

Internal project communication has been associated with the delivery of the monitoring and evaluation activities. This involved the project team, the CEWO, key water delivery stakeholders and other operational stakeholders. The activities that have been undertaken in relation to internal project communication include communication with:

1. Operational stakeholders, these include the CEWO Lachlan Delivery Team, the NSW OEH Lachlan environmental water manager, members of the Lachlan Environmental Watering Advisory Group (EWAG) and key members of other state agencies including the NSW OEH Science Team, DoI Water and Water NSW.
2. Landholders who provide access to monitoring sites.

10.1.1.1 Internal communication: operational stakeholders

Internal communication activities in 2018-19 included:

- Nine monthly face to face meetings with the CEWO Delivery team
- Two EWAGs in Forbes
- Seven Technical Advisory Group (TAG) teleconferences
- Four quarterly project management reports
- Four quarterly observations reports which are now published at: https://www.environment.gov.au/water/cewo/catchment/lachlan/monitoring
- One annual technical report (this document)
- One annual synthesis report

In addition to these activities, there have been numerous phone calls among the project team and operational stakeholders to communicate findings, observations and operational matters.

10.1.1.2 Internal communication: landholders

The project is reliant on landholders along the river enabling access to monitoring sites. These include private landholders as well as NSW National Parks. This requires phone calls to arrange site access and the provision of data (e.g. species lists), photos and observations where the landholders are interested in receiving such information. In 2018-19 we have liaised with 19 landholders to access sites in the lower Lachlan river system and a further 7 within the mid Lachlan river system.

10.1.2 EXTERNAL PROJECT COMMUNICATION

External communication products in the Lachlan Selected Area LTIM C&E Theme focus on informing key stakeholders of watering events and monitoring activities, and then reporting back on LTIM Project observations and outcomes. In addition, there are science based communication activities which convey findings to the broader scientific community. External engagement activities have been more opportunistic in nature, based on the C&E Theme Leaders existing communication and relationship networks across the Lachlan Catchment, and involved participation in, and support of, community events.

The objectives of the external LTIM C&E activities are to:

- Inform and provide opportunity for feedback (involve) from stakeholders to inform environmental water events at all phases (planning, implementation, MER). The underlying message is your local knowledge and history with the landscape is valued.
- Maintain ongoing access to long term monitoring sites through respectful landholder interactions and land access protocols, and by sharing results and information.
- Develop and consolidate a network of diverse stakeholder groups and local influencers with trust-based relationships; which allows for a productive exchange of local knowledge and discussion of how informs Basin-scale objectives.
- Highlight the value of LTIM for informing decision making when planning watering events (e.g. raise awareness around the processes for environmental water planning such as Technical Advisory Groups (TAGs) and use of expert opinion and observational data).
- Establish a reputation as a program which also supports local community events and priorities (i.e. invests in communities as well as their local environment where possible).

The ultimate goal of the external C&E activities under the LTIM Project has been to influence attitudes towards use of environmental water in the Lachlan, leading to more collaborative environmental management or delivery, as well as opportunities to improve environmental water outcomes via complementary land management activities.

The 2018-19 external C&E activities can be grouped into 6 types:

1. Local media products
2. Community updates
3. Social media
4. Reporting and scientific outputs
5. Community events and demonstration
6. Relationship management

10.1.2.1 Local media products

The LTIM Project have supported two community activities in 2018-19 that have resulted in mention in the Lake News (Figure 93 and Figure 94).

The secrets of Booberoi Creek

LANDHOLDERS, traditional owners, scientists and others with an interest in Booberoi Creek converged on the property Mt Boorithumble recently.

The Booberoi Water Users Group took a weekend off on February 23 and 24 to come together and share their interest in (and local knowledge of) the creek.

The aim of the weekend was to provide an opportunity for Booberoi Creek landholders, community members, researchers and government representatives to get together and discuss the many values of Booberoi Creek, and its importance as an off-river floodplain habitat and biodiversity hotspot.

Representatives from both State and Federal government agencies attended, as did Keith Bell, a commercial carp fisherman who shared his expertise on carp control.

The day kicked off on the creek bank where local ecologist Dr Adam Kerezsy retrieved some fish sampling equipment he had set the night before.

A fish species called flathead gudgeon was added to the growing list that rely on the habitat and food resources Booberoi Creek provides year round.

Following many questions and discussions on the riverbank, the group moved into the old shearers quarters to learn about the local bird fauna from Warren Chad, a Condobolin local and enthusiastic photographer and birdwatcher.

All commented that a major highlight of the day was the catering provided by the Down the Track crew from Lake Cargelligo.

After lunch several people took the opportunity to canoe down the creek and stop to appreciate some magnificent Morton Bay Fig trees - just one example of the rich local heritage that has survived.

Booberoi Creek is mentioned many times in the Ngiyampaa Nation consultation report, a component of water resource plans (WRPs) in NSW. Peter Harris contributed to the Ngiyampaa report, has helped facilitated the delivery of environmental water for Booberoi Creek through his membership of the Lachlan Environmental Water Advisory Group (EWAG), and attended the weekend to share his cultural connection and vision for Booberoi.

The conversations and discussions continued well into the afternoon and all attendees agreed the day was a great success.

They are now looking forward to their next chance to meet up by an iconic Booberoi Creek waterhole. The organisers thank the Kearines family who hosted the event.

A similar weekend is planned for the Island in the middle of the Lake on April 6 and 7. For more information contact Peter Skipworth from Cargelligo Wetlands and Lakes Council on 0428 981 749.

Flathead gudgeon were recorded in Booberoi Creek for the first time.

The Down The Track catering crew from Lake were on hand at Mt Boorithumble.

Discussing a river sample from Mt Boorithumble.

Right: Warren Chad talks birds over the weekend.

4 Lake News, Wednesday, March 20, 2019

Figure 93. Lake News newspaper article from the 29th of March 2019

Don't let the waterbugs bite

WaterWatch workshop reveals some odd specimens in local water samples

INTRODUCING Murrin Bridge and Lake Cargelligo's new Waterwatch and Waterbug Team, where quality is just as important as quantity!

Cecil Ellis, aquatic ecologist from Nature Navigation and the Waterbug Shop, led another two-day workshop last month at Murrin Bridge with the Community Development Program (CDP) Team and interested locals. Keen participants included Debra and Harry Clarke, Rachel Kennedy, Sinelle Thorpe, Shirylae Kirby, Charmaine Johnson, Brian Griffiths, Peter Harris, Ed Vagg, Mary Flaskas and Belinda McFadyen.

Lake's Local Landcare Coordinator, Nicole O'Neill, will assist the CDP Team and landholders put their training into action over the next year, regularly collecting and entering water quality data into the NSW WaterWatch database. The Team monitor turbidity, salinity, pH, temperature and dissolved oxygen, and take photos and observations. The Team have specialised equipment to obtain representative water samples and obtain waterbug samples from a range of habitats.

Cecil from Nature Navigation remarked it was one of the best run workshops he has had the pleasure to be involved in, with the canoe run at Fantasy Island to end the second day a fantastic experience! The Team was also lucky enough to have Down the Track cater a great morning tea and picnic lunch both days, led by Roy.

"On the day we found several waterbug curiosities from our samples at Lake Cowal, Lake Cargelligo and the Lachlan River at Fantasy Island near Murrin Bridge" said Cecil.

The Lachlan River sample revealed several types of freshwater crustaceans, including yabbies, freshwater shrimp and freshwater prawns or Macrobrachium. Macrobrachium look like a larger freshwater shrimp, but with a very long pair of front pincers.

We also found a mayfly larvae in the Lachlan River, mayflies are indicators of good waterway health. With only one mayfly, it is probably not worth getting too excited, until we return in Spring to complete another sample".

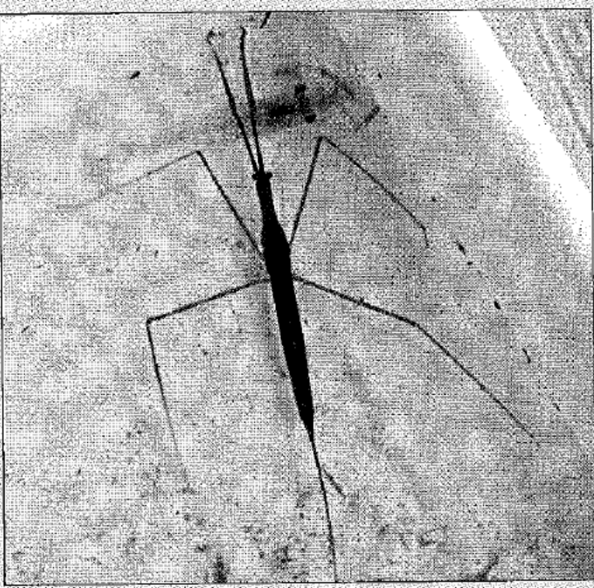
Other waterbugs found across the sites, included snails, predatory dragonfly larvae and a slender water scorpion (Ranatra).

Nicole O'Neill, who was being trained by Cecil to lead the group commented, "Ranatra had everyone captivated as it had been sitting camouflaged in the tray for 20 minutes before to Rachel's and Charmaine's surprise, it 'came alive' and wandered out of the sample tray and across the classroom floor!"

And while winter isn't the ideal time for waterbug sampling, the Team will use the time to train in preparation for the Waterbug Blitz in Spring. All the waterbugs where identified using the free Waterbug App available for Google and Apple devices.

Dr Jo Lenehan, from the Office of Environment and Heritage (OEH) has been working with the Murrin Bridge community on a wetland restoration project over the past two years and coordinates this workshop series component of the CDP work plan. The data will contribute to OEH and the Commonwealth's Long Term Intervention Monitoring (LTIM) Project routine water quality monitoring and stream productivity research in the mid and lower Lachlan, which has been conducted by the University of Canberra for the past 5 years. The LTIM Project also includes fish monitoring, with highlights to date the capture of eel-tailed catfish larvae from one site upstream of Lake Cargelligo near Kiacatoo in late November 2018. During the same sampling period, Murray cod were the most abundant species captured at all sites with good numbers of larval flat-headed gudgeon and Australian smelt, with only a handful of the alien species, gambusia and no larval carp detected!

To find out more about the LTIM Project or the Waterwatch/bug Citizen Science project contact Jo Lenehan on 043 793 8365 or email Nicole O'Neill at lakec@lachlandcare.org.au. Or visit sites below https://www.waterbugblitz.org.au/ and www.environment.gov.au/water/cewo/catchment/lachlan/monitoring.



Pictured: a slender water scorpion and fresh water shrimp from local water samples.

8 Lake News, Wednesday, June 12, 2019

Figure 94. Lake News newspaper article from the 12th of June 2019.

10.1.2.2 Community updates

The NSW Lachlan environmental water manager has provided two detailed operational updates to a local distribution list. These updates provide information about environmental water events to interested parties in the region and include information about Commonwealth environmental water delivery as well as NSW environmental water delivery.

10.1.2.3 Social media

The social media activities associated with the LTIM Project have been confined to Twitter in 2018-19. They have included direct tweets by members of the monitoring team (see Figure 95 for examples) or the provision of imagery that have enabled the CEWH to tweet (see Figure 96 for an example).

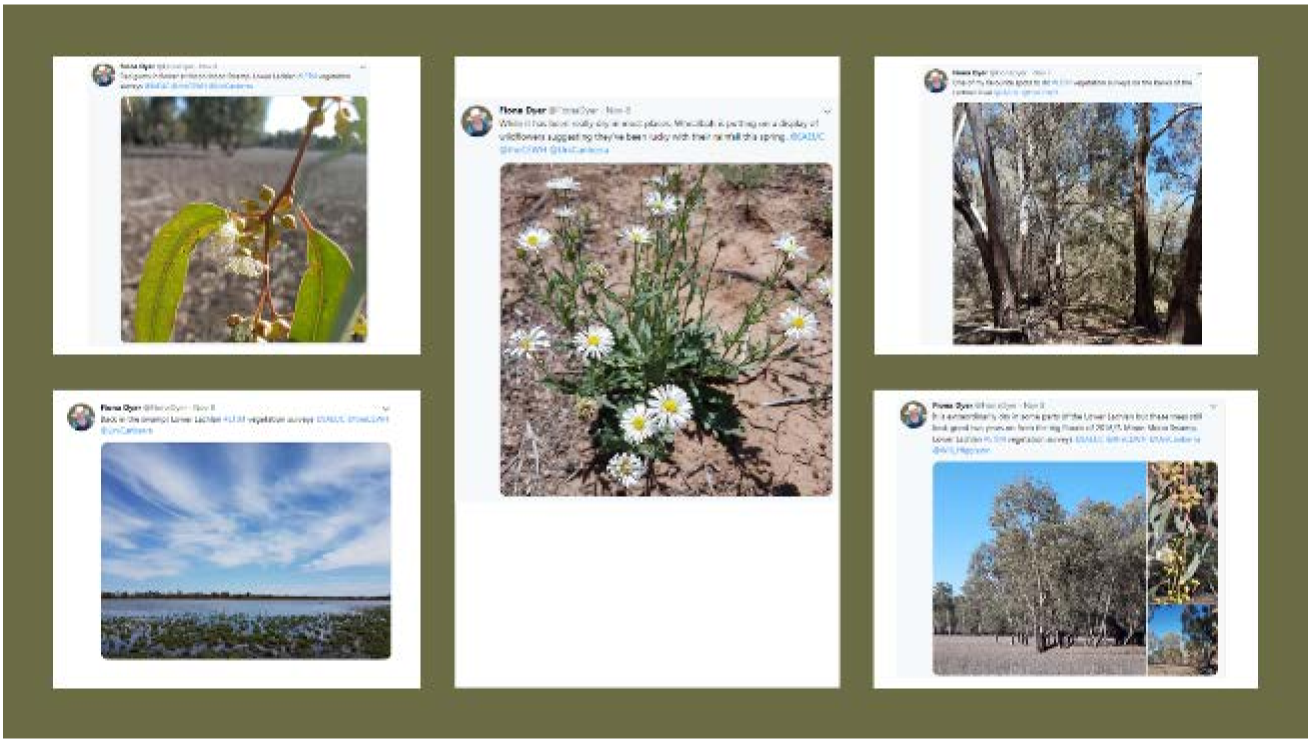


Figure 95. Dr Fiona Dyer's LTIM Vegetation Tweets during November 2018 promoting the Lachlan LTIM Project.

Figure 96. Tweet from @theCEWH noting the capture of the threatened silver perch at one of the LTIM sites

10.1.2.4 Reporting and scientific outputs

Five presentations on work associated with LTIM activities were presented at two conferences on behalf of the LTIM team in 2018-19 (Table 33)[5]. A further 3 scientific papers were published that were related to research which has been undertaken in association with monitoring that was undertaken in the Lachlan Selected Area (

[5] It should be noted that while the research has been conducted in association with the monitoring activities, none of the conference attendance was paid for by the LTIM project.

Table 34).

Table 33. Scientific presentations from 2018-19 for the LTIM Project and associated research.

Presenter	Conference	Title
Fiona Dyer **(Alica Tschierschke, Will Higgisson, Sharon Bowen, Patrick Driver, Jane Roberts)**	The International Society for Ecohydraulics Conference, Tokyo, Japan August 2018	Wetland vegetation responses to environmental water and flooding: the lower Lachlan river system, Australia
Will Higgisson **(Brian Higgisson, Fiona Dyer)**	The International Society for Ecohydraulics Conference, Tokyo, Japan August 2018	Hydrological impacts of water resource development on floodplain vegetation communities of a boom and bust system.
Fiona Dyer	The Australian Freshwater Sciences Society Conference, Adelaide, December 2019	Learning from Commonwealth environmental flows in the lower Lachlan: when no two years are the same
Will Higgisson	The Australian Freshwater Sciences Society Conference, Adelaide, December 2019	Genetic variation and gene-flow patterns in *Duma florulenta* (tangled lignum) and *Acacia stenophylla* (river cooba) across a large inland floodplain
Foyez Shams	The Australian Freshwater Sciences Society Conference, Adelaide, December 2019	Population genetic structure and effectiveness of stocking of hatchery born golden perch; a case study from Lachlan river catchment

Table 34. Publications arising from the LTIM Project and associated research

Publications
T Datry, A Foulquier, R Corti, D Schiller, K Tockner, C Mendoza-Lera, JC Clément, MO Gessner, M Moleón, R Stubbington, B Gücker, R Albariño, DC Allen, F Altermatt, MI Arce, S Arnon, D Banas, A Banegas-Medina, E Beller, ML Blanchette, JF Blanco-Libreros, JJ Blessing, IG Boëchat, KS Boersma, MT Bogan, N Bonada, NR Bond, KC Brintrup Barría, A Bruder, RM Burrows, T Cancellario, C Canhoto, SM Carlson, S Cauvy-Fraunié, N Cid, M Danger, Bianca Freitas Terra, AM Girolamo, Evans La Barra, R Campo, VD Diaz-Villanueva, **F Dyer**, A Elosegi, E Faye, C Febria, B Four, S Gafny, SD Ghate, R Gómez, L Gómez-Gener, MAS Graça, S Guareschi, F Hoppeler, JL Hwan, JI Jones, S Kubheka, A Laini, SD Langhans, C Leigh, CJ Little, S Lorenz, JC Marshall, E Martín, AR McIntosh, EI Meyer, M Miliša, MC Mlambo, M Morais, N Moya, PM Negus, DK Niyogi, A Papatheodoulou, I Pardo, P Pařil, SU Pauls, V Pešić, M Polášek, CT Robinson, P Rodríguez-Lozano, RJ Rolls, MM Sánchez-Montoya, A Savić, O Shumilova, KR Sridhar, AL Steward, R Storey, A Taleb, A Uzan, Ross Vander Vorste, NJ Waltham, C Woelfle-Erskine, D Zak, C Zarfl, A Zoppini (2018) A global analysis of terrestrial plant litter dynamics in non-perennial waterways. *Nature Geoscience* 1.
Higgisson, W., Briggs, S., Dyer, F. (2018) Seed germination of tangled lignum (*Duma florulenta*) and nitre goosefoot (*Chenopdoium nitrariaceum)* under experimental hydrological regimes. *Marine and Freshwater Research* DOI: 10.1071/MF17357
Higgisson W., Briggs S., Dyer F. (2018) Responses of nitre goosefoot (Chenopodium nitrariaceum) to simulated rainfall and depth and duration of experimental flooding. *Marine and Freshwater Research* 69(8) 1268-1278

10.1.2.5 Community events and demonstrations

The LTIM Project was associated with 7 community events in 2018-19. These included:

NAIDOC day celebrations

The LTIM Project funded activities and presenters at the NAIDOC day celebrations at St joseph's Primary School in Hillston. At this event the LTIM &E officer also ran a session on the parallels between traditional ecological knowledge and western science, and how they relate to the management of waterways for fish outcomes using examples from the LTIM Project.

The LTIM Project then worked with the Orange Cowra Cabonne Science Hub and Inspiring Australia to produce a 4 min Vodcast from the NAIDOC Day event which was well-received when shown during National Science Week community screenings of SCINEMA International Film Festival and on St Joseph's Facebook p. [https://vimeo.com/287378111] and [https://www.facebook.com/246801345763940/videos/ 225906861422636/].

Twenty five years celebration of the Hillston Hook, Line and Sinker Fishing Festival

As the majority of LTIM fish sampling sites were also within the fishing festivals geographical range, it was a great opportunity to highlight native fish values around Hillston, and how water for the environment (which is monitored by LTIM) has been used to support those values. Tanks displaying live native fish, such as freshwater catfish and olive perchlet, were very popular and had people asking lots of good questions (Figure 97). Larval catfish were caught by the LTIM team at Wallanthery and Hunthawang in November 2015.

Figure 97. Hillston Hook, Line and Sinker fishing festival with threatened species display, which featured species such as the olive perchlet (Ambassis agassizii) as the Hillston region has the only known population in the Lachlan, as well as freshwater catfish, which LTIM confirmed breed in the area (Photo: Jo Lenehan).

Condobolin & Districts Primary Schools Environment Day

More than 240 students took part in Environment Day from 12 schools across the district including Tullamore, Tullibigeal, Bogan Gate, Trundle, Bedgerabong, Condobolin Primary and Condobolin MET School. Being asked to run an activity entitled 'Waterbirds, A Glorious and Gregarious Group' provided another opportunity to engage primary school students in waterbird research and management using the LTIM's monitoring of the largest straw-necked ibis breeding event recorded in the Lachlan (>100,000 nests) as a case study. https://www.facebook.com/stjosephscondobolin/photos /pcb.2342413589132409/ 2342413269132441/?type=3&theatre.

Booberoi Creek cultural-environmental flows

The LTIM's support of the Booberoi Creek cultural–environmental flow has also continued to provide further opportunities for Ngiyaampaa Elders to reconnect with their country as they are the traditional owners of Booberoi Creek country. The project has enabled family members of former owners to return to their family properties.

The engagement highlight during this period was the larval fish monitoring demonstration and insightful discussion between LTIM researchers and NSW DPI Fisheries Engaged Angler representative, Graeme May, local Lachlan River landholder, Andre Cashmere, and several staff from Western and Central Tablelands Local Land Services (LLS) (Figure 98). Mr May has been advocating for screens on irrigation pumps to prevent larval fish entrapment while LLS is developing a pilot project with a trial site ear-marked for the Hillston area. This engagement event and the data that the LTIM Project has generated on 'larval drift hotspots' for varying species (e.g. threatened species of freshwater catfish) will inform and improve Mr May and

Local Land Services efforts to demonstrate the benefits of such technology to local irrigators and recreational fishing community.

Figure 98. Engaged Angler Graeme May in foreground inspecting a larval sample with Ben Broadhurst and Casey Proctor (Central Tablelands LLS) in the background; and right is Tweet associated with event. (Photo: Mal Carnegie, Lake Cowal Foundation).

The LTIM Project continued to support the Booberoi Creek cultural–environmental flow has also continued to provide further opportunities for Ngiyaampaa Elders to reconnect with their country as they are the traditional owners of Booberoi Creek country. Several Ngiyampaa community representatives assisted Community & Engagement Theme Leader Jo Lenehan download data and change the batteries on the supplementary stream metabolism station on Booberoi Creek in early December 2018. Dr Adam Kerezsy (Dr Fish Consulting) and Jo Lenehan also engaged several Booberoi Creek landholders and their family and friends (‘Doone’, ‘Hyandra’ and ‘Booberoi Station’) on the LTIM Project and watering events by having them assist with the fyke net directional monitoring. Dr Kerezsy commented that this form of engagement (combining data collection with landholder interaction) is simple but highly effective as it provides a visual demonstration, and opportunity for landholders to ask lots of questions about what they have observed – and put that local observational knowledge into a broader monitoring context. Photographic images captured by Mal Carnegie from Lake Cowal Conservation Centre during these landholder engagement events and monitoring have proven invaluable for several CEWO Tweets (Figure 98).

Collaborative carp management

A small proportion of the Commonwealth Environmental Water Office (CEWO) licenced water was diverted into Lake Brewster in 2017 to support aquatic plant growth and pelican breeding. The LTIM Project took the opportunity in late October to video and drone Keith Bell from K & C Fisheries Global Pty Ltd removing tonnes of large carp from the Brewster main cell and outlet channel (Figure 99 – Note this is a commercial fisheries operation and not funded by environmental water holders). There is further opportunity to develop a case study into collaborative management of carp in conjunction with environmental watering in known ‘carp biomass and breeding hotspots’, such as Lake Brewster and Lake Cargelligo

Figure 99. Commercial carp removal from Lake Brewster with Keith Bell Fisheries and Feral fisherman (Photo: Mal Carnegie, Lake Cowal Foundation).

Mt Boorithumble weekend

Landholders, traditional owners, scientists, environmental water managers and others with an interest in Booberoi Creek converged on the property Mt Boorithumble on Saturday the 23th of February to share their interest in, and local knowledge of, their creek.

Preliminary observations from the additional mid-Lachlan LTIM larval fish monitoring (October to December 2018) in the Lachlan River close by (Euabalong and Condobolin sites) were shared with landholders and the community – including the eel-tailed catfish larvae as catfish is an iconic and cultural species for Booberoi Creek. The local Lake News newspaper featured the engagement weekend (Figure 93) – and as there is great demand from all who attended (and those who wished they could have!) – the LTIM Communication and Engagement Team and OEH have discussed with landholders the option to do a similar event in future years.

Waterwatch workshop

A two-day Waterwatch workshop was held in Murrin Bridge to introduce the community to the new WaterWatch and Waterbug team. Lake Cargelligo Local Landcare Coordinator Nicole O’Neill will assist the Community Development team for the area as well as Landholders to put their training into action over the next year. The workshop was very popular with all who attended. Data from the program will be available to contribute to the Commonwealth Environmental Water LTIM Lachlan River project.

10.2 INFORMING FUTURE COMMUNICATION AND ENGAGEMENT ACTIVITIES

10.2.1 REFLECTIONS FROM 2018-19

The internal project communications are an essential part of delivering the monitoring project. In 2019, some additional investment was required in establishing sites within the mid-Lachlan. In many instances, new relationships have been commenced with landholders and these have enabled the team to not only deliver the monitoring activities, but talk with landholders about environmental water and the CEWO.

The external C&E activities undertaken in 2018-19 have capitalized on relationships that have been built up over many years in the catchment. They have been delivered in collaboration with NSW OEH, with the LTIM funding enabling community-based activities to go ahead.

10.2.2 LEARNING FROM THE 5 YEARS OF THE LTIM PROJECT

Communication products in the Lachlan Selected Area LTIM C&E Theme focused on informing key stakeholders of commencing watering events and monitoring activities. Outcomes observed or key results from the LTIM Project were reported to key stakeholders. Communication products were tailored for stakeholder audiences, with a focus on operational information (hydrograph) for those who may be directly impacted by changing river levels (e.g. move pump, order on top of flow to improve pumping efficiency, or move stock if risk of bogging or loss of access track, land inundated).

A focus on monitoring activities and results was provided for those who expressed an interest in the ecology and adaptive management of environmental water based on LTIM and other research and monitoring programs. For example, articles on waterbird breeding and aquatic vegetation have appeared in Lower Lachlan landholder newsletters.

The LTIM Project was also mentioned in numerous local media articles, and directly engaged with more than 30 recreational fishers and two clubs when enlisting the assistance of individual members of the public to collect fin clips and otoliths for a LTIM related PhD Project.

Engagement activities were more often opportunistic in nature, based on the C&E Theme Leaders existing communication and relationship networks across the Lachlan Catchment. The majority of events were by either by invitation (guest speaker at conference or meeting), display or activity as part of established event (Hillston Hook Line and Sinker and Condobolin Schools Enviro Day) or supported Indigenous involvement in environmental water management (Booberoi Creek and Hillston NAIDOC Day). It is therefore important to have the capacity to undertake activities when the opportunity arises.

In combination, these activities have resulted in more collaborative environmental water management with the Booberoi Water Users Group, Lower Lachlan Landcare, Torriganny, Muggabah and Merrimajeel Trust, Ngiyampaa nation, mid-Lachlan irrigators, and the lower Lachlan Great Cumbung Swamp landholders via State and Commonwealth environmental water management liaison.

Many of the LTIM C&E activities over the past 5 years have been made possible because of the relationship the C&E lead has with the local community and because of synergies between the role of the C&E lead within NSW Government and the funding able to be provided by LTIM. While such a collaborative arrangement has enabled a far greater number of activities to be supported than would be delivered in the absence of this arrangement, there are challenges associated with this model that include:

1) A lack of clear delineation of roles
2) A lack of transparency about what the C&E funding has paid for and what NSW have paid for and a perception of ‘double dipping’
3) The lack of control of CEWH communication and engagement activities
4) The inability for the current C&E lead to continue to devote the time to the LTIM Project.

Thus while there is opportunity from the CEWO and DoPIE network collaboration to continue evolving, the way in which it is delivered will have to be re-thought. This has been done as part of the development of ongoing MER activities (Dyer et al. 2019).

11 FIVE YEARS OF COMMONWEALTH ENVIRONMENTAL WATER

Commonwealth environmental water has been delivered in the Lachlan catchment since 2010 and to date more than 205 GL of Commonwealth environmental water has been delivered to achieve a wide range of outcomes. Watering actions have been set within the context of the MDBA's long term environmental objectives, as well as antecedent watering conditions, seasonal, operational and local management considerations.

11.1 CLIMATE AND WATER CONTEXT

The Lower Lachlan river catchment experiences alternating periods of wet and dry conditions (Figure 100). The recent Millennium drought (2001- 2010) was the longest extended dry period on record during which the river ceased to flow. While water has been more abundant since the drought, with floods in 2010, 2012 and 2016, each progressively longer and greater in discharge, the floods have been interspersed with periods of dry to very dry conditions. The past two years have seen very dry conditions prevail across the catchment with lower than average rainfall and higher temperatures, particularly in summer. This has led to rapidly declining water resource availability.

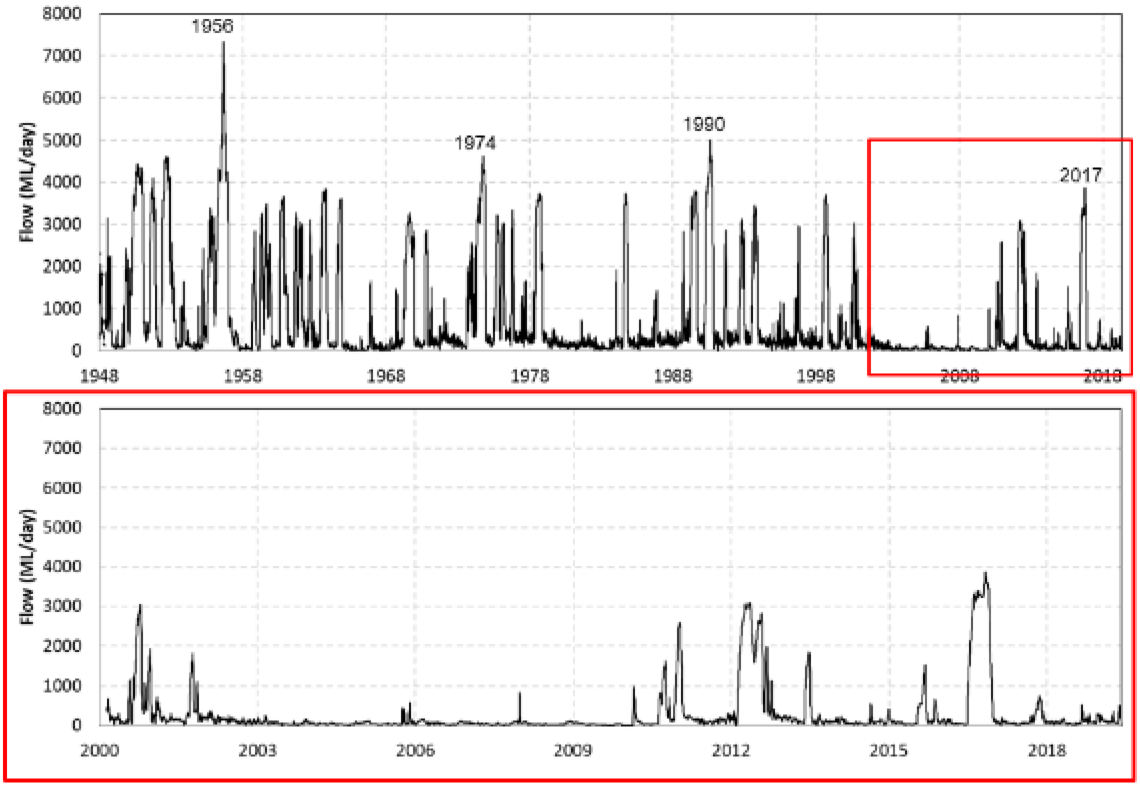


Figure 100. Hydrographs for the Lachlan River at Booligal illustrating the variability in flow in the river.
The long-term continuous flow record is shown at the top, the period from 2000 to present is shown at the bottom illustrating the Millennium drought and most recent flood events.

11.2 FIVE YEARS OF WATERING ACTIONS

This sequence of wet and dry conditions means that the past five years of the LTIM Project has seen the Lachlan catchment experience vastly different hydrological conditions ranging from the fourth largest flood on record (2016-17) to the recent very dry conditions of 2018 (Figure 101). Environmental watering actions have reflected water availability and have sought to build on the outcomes and learning from previous years watering actions. Where possible, the CEWO have sought to achieve multiple benefits from watering events to maximise the outcomes.

A total of 122 208 ML of Commonwealth environmental water has been used strategically within the context of water availability and catchment conditions. Annual volumes delivered have been as low as 5,000 ML in 2014-15 when conditions were dry and in years of greater water availability (2015 – 2018), the volumes used have been between 30 000 ML and 36 000 ML (Table 35).

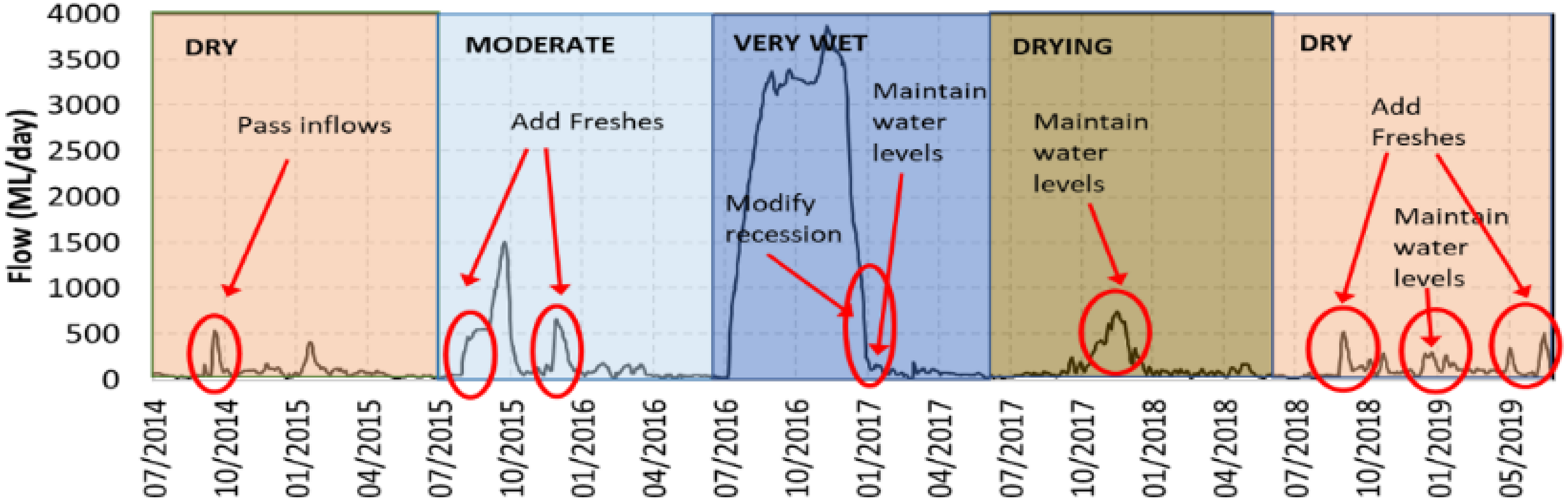
The volumes of Commonwealth environmental water used have been a very small proportion (typically less than 5%) of the annual flow at Forbes, but has been a far more significant proportion of the flow at Booligal, with more than 40% of the annual flow in the river at Booligal in 2015-16 and 2017-18 provided by Commonwealth environmental water. This illustrates the relative importance of Commonwealth environmental water for flow in the lower reaches of the Lachlan river system compared with the almost negligible contribution in the mid Lachlan.

Commonwealth environmental water has typically been used in spring and has native fish outcomes and improvements to habitat quality and access. Water has also been used opportunistically to support bird breeding and to mitigate adverse water quality outcomes during the floods of 2016-17. In 2017-18 and 2018-19, small winter freshes have been delivered to the lower river system to provide flow variability and habitat access during the winter months when flows are operationally low.

Within the main channel environmental flows have sought outcomes ranging from hydrological connectivity and variability, improvements in dissolved oxygen concentrations, providing cues for native fish spawning and providing refuge habitat. A number of significant wetlands have also received environmental flows including Booligal Swamp, Lake Tarwong and the Great Cumbung Swamp. These wetland flows have sought to support waterbird breeding, vegetation condition and fish dispersal outcomes.

Table 35. Summary of the environmental water use in the Lachlan River system during the 5 years of the LTIM Project.

Year	2014-15	2015-16	2016-17	2017-18	2018-19
Conditions	Dry	Moderately Wet	Very Wet	Drying	Dry
# Watering Actions	1	3	2	2	4
Volume (CEW)	5 000	36 020	29 492	33 523	18 173
Volume (NSW)	821	12 089	6 250 +7 571 (EWA[1]) + 15 000 (WQA[2])	9 205	
Total	**5 821**	**48 027**	**58 313**	**41 723**	**18 173**
Volume (other)		72 000 (Translucent flow)	350 000 (Translucent flow)		
Estimated CEW contribution to annual flow	Forbes: N/A Hillston: 6% Booligal: 18%	Forbes: N/A Hillston: 20% Booligal: 41%	Forbes: 1.5% Hillston: 3% Booligal: 6%	Forbes: 7% Hillston: 19% Booligal: 44%	Forbes: 4% Hillston: 11% Booligal: 24%
Flow component	Fresh flow	Fresh flow Baseflow Wetland inundation	Fresh flow	Fresh flow Base flow	Fresh flow Base flow Wetland inundation
Timing	Winter/Spring	Spring	Summer	Spring Autumn/Winter	Winter/Spring Autumn/winter
Target Asset	Lachlan main channel	Lachlan main channel (lower) Booligal wetlands Great Cumbung Swamp	Lachlan main channel (mid) Booligal wetlands	Lachlan main channel (mid and lower) Great Cumbung Swamp	Lachlan main channel (mid and lower) Yarrabandai Lagoon Great Cumbung Swamp
Target outcome	Native fish Habitat access	Native fish Habitat quality Wetland vegetation	Water quality Water birds	Native fish Habitat access and quality Wetland vegetation	Native fish & productivity Habitat access and quality Wetland vegetation
Approach	Protect tributary inflows	Add fresh	Modify recession of hydrograph Prevent water level drops in wetlands	Prevent water level drops Add fresh	Prevent water level drops Add fresh



eWater	5,821 ML	48,027 ML + 72,000 ML	34,219 ML + 350,000 ML	33,523 ML	18,173 ML
Objectives	Native fish	Native fish Vegetation	Water quality Bird breeding	Native fish	Native fish, Vegetation

Figure 101. Hydrological conditions in the Lachlan river system between 2014 and 2019 combined with the corresponding volumes of environmental water and generalised objectives.

11.3 FIVE YEARS OF RIVER REGULATION

The hydrological character of the Lachlan river system has been extensively modified by river regulation which has resulted in significant changes to in-channel flows and wetland inundation in the lower Lachlan river system (Driver et al. 2004; Higgisson et al. 2019b). To understand the nature of these changes over the past five years, we compared the observed flow in the river with modelled flow data for the river in the absence of regulation.

Modelled daily flow data under natural (pre-development) flow conditions for the Lachlan River were obtained from the NSW Department of Primary Industry and Environment (DPIE Water) for five river gauges on the lower Lachlan River. Modelling was undertaken using the Integrated Quantity and quality Model (IQQM) designed to examine long-term flow behavior under different management regimes (Hameed and Podger 2001). These data sets were compared to the actual current flow conditions of the Lachlan River over the past five years (which includes environmental water) using river flow data acquired from WaterNSW (https://realtimedata.waternsw.com.au).

Using commence to fill (CTF) values derived from Higgisson et al. (2019b) and the modelled natural and (actual) current flow records for Booligal Swamp and Nooran Lake we calculated eight connection metrics representing important components of the flow regime of intermittent streams (Olden and Poff 2003). The CTF value for Nooran Lake was revised following Higgisson et al. (2019b) resulting from improved estimates. Booligal Swamp (Figure 102, Table 36) and Nooran Lake (Figure 103, Table 37) were selected as they are or are part of wetlands considered assets in the Basin Plan Floodplains are likely to retain water for longer than the duration of connection related to floodplain topography. However, the effects of river regulation and environmental flow allocation are likely to be directly related to differences in river-floodplain connection. The approximate volume (ML) of water that is likely to have inundated the floodplain was estimated as the total flow above the CTF value at Booligal and Nooran Lake. These volumes of water may have inundated other sites with similar positions on the floodplain.

The current hydrological character of the Lachlan River over the past five years of LTIM is markedly different to that which would have occurred under natural flow conditions (Figures 90 and 91). The flow of the Lachlan River is more consistent and stable under current flow conditions with much less variability in flow. The high flow events have either been completely removed from the hydrograph or substantially reduced in duration and magnitude. Periods of no flow which occurred approximately 16% of the time under natural flow conditions, have not occurred over the past 5 years.

These changes to the flow of the Lachlan River have altered the connection regime between the floodplain and river. Small and medium connection events now in most instances do not occur while the large events have been reduced in magnitude and duration. While the frequency and magnitude of connection events has been reduced in each of the last five years, these reductions are more apparent during dry years (2014-15, 2017-18, and 2018-19) compared to the wet (2016-17) and moderately wet (2015-16) years. Under natural flow conditions, the Booligal Swamp would have received water briefly (one day) in 2014, twice in 2015, and 2018 yet under the current regulated conditions, these connection events did not occur. The large flood event in 2016-2017 was 11 days shorter (approx. 9%) in the Booligal Swamp (Figure 90 and Table 28). While the connection event in 2016-2017 to

Booligal Swamp was only 11 days shorter under current flow conditions, it received less than half the total amount of floodwater under current conditions (99764 ML) compared to natural flow conditions (212651 ML). In 2015-16, under natural conditions, Booligal Swamp would have received 18390 ML and 841 ML in 2017-2018 while connection did not occur in these years (Table 28).

Nooran Lake which is a lower lying (open) temporary wetland would have been flooded under natural flow conditions 12 times (total of 144 days) in 2014-15 which would have provided 48831 ML of floodwater on to Nooran Lake and the surrounding temporary wetlands. During 2015-16 the number of days Nooran Lake connected to the river (73 days) was half that which would have occurred under natural flow conditions (144 days), reducing the total volume of water on the floodplain by 80%. During the particularly wet 2016-17 year the number of days Nooran Lake connected to the river (180 days) was 20 % less than the number of days it would have connected to the river under natural flow conditions (224 days) reducing the total volume of water on the floodplain by 43% (Table 29). During 2017-18 and 2018-19, the number of days Nooran Lake connected to the river by floodwater was reduced from 58 to 30 days in 2017-18 and 31 to 6 days in 2018-19 resulting in a considerable reduction in the total volume of water on the floodplain and increasing the duration of disconnection. The connection regimes described for Nooran Lake under natural and current flow conditions are similar to those on other lower lying parts of the floodplain of the Lachlan River including the central reed beds of the Great Cumbung Swamp which has a similar CTF.

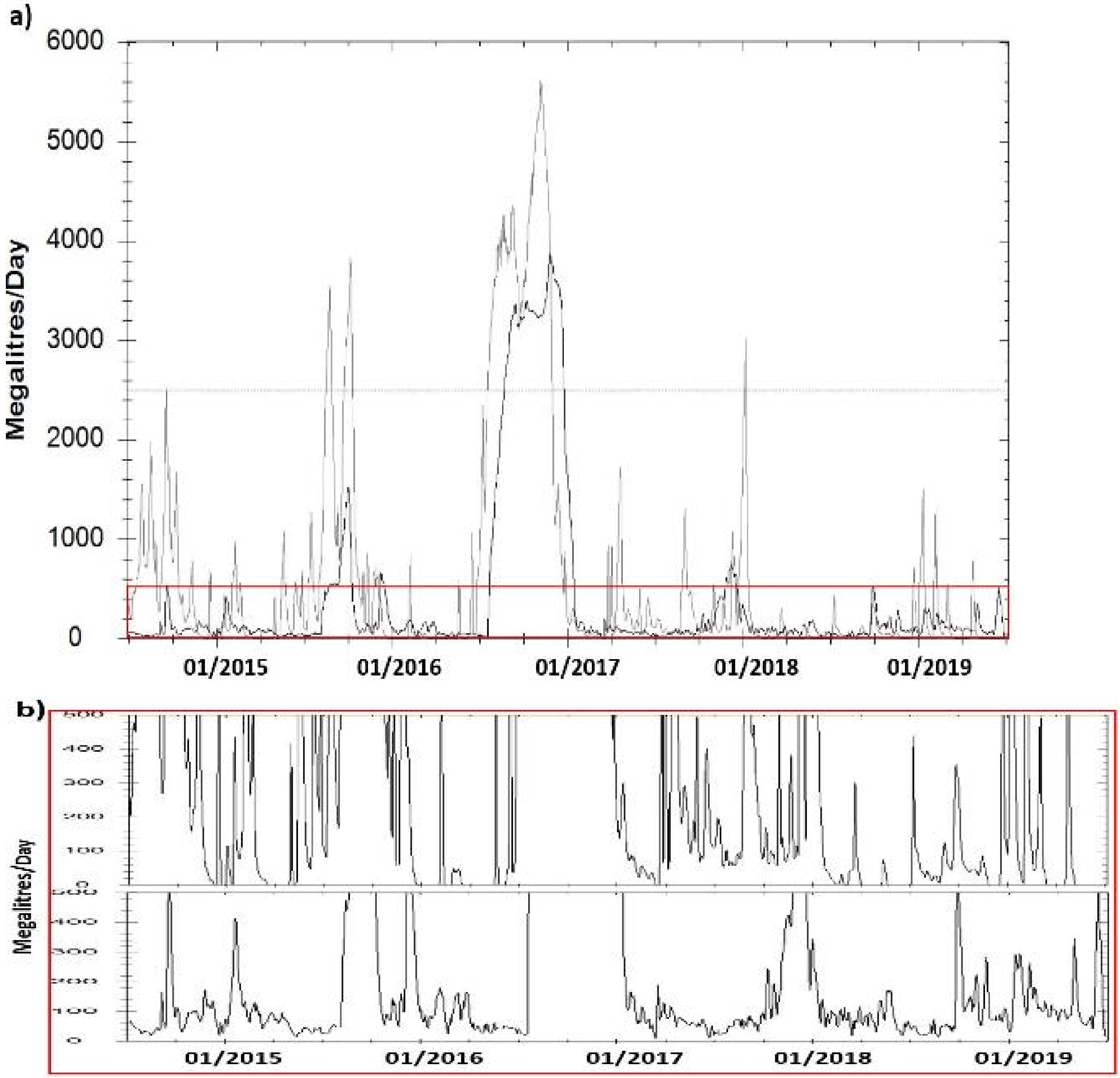


Figure 102. a) Modelled natural flow (ML/day) (grey hydrograph) and actual river flow (black hydrograph) of the Lachlan River at Booligal river gauge from 1 July 2014 to 30 June 2019. The dashed horizontal line represents the CTF value (2500 ML/day) required to connect the Booligal Swamp to the river by flooding. b) shows the modelled natural flow (top figure) and actual river flow (bottom) under low flow conditions (i.e. <500 ML/day).

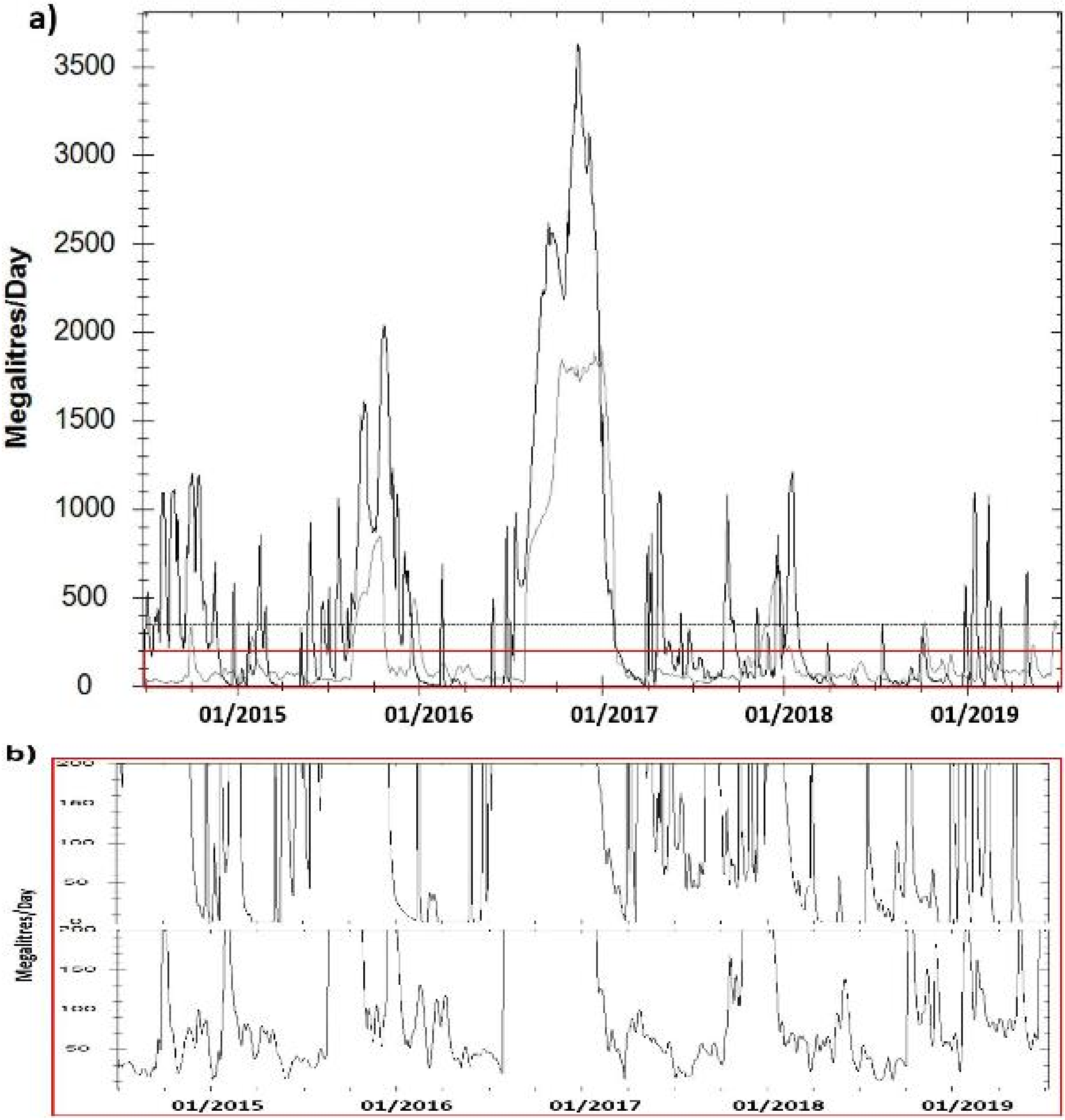


Figure 103. a) Modelled natural flow (ML/day) (grey hydrograph) and actual river flow (black hydrograph) of the Lachlan River at Corrong river gauge from 1 July 2014 to 30 June 2019. The dashed horizontal line represents the CTF value (350 ML/day) required to connect Nooran Lake to the river by flooding. b) shows the modelled natural flow (top figure) and actual river flow (bottom) under low flow conditions (i.e. <200 ML/day).

Table 36. River – floodplain connection metrics for Booligal Swamp under modelled natural flow conditions (N) and current flow conditions (C). CTF value for Booligal Swamp is 2500 ML/day at Booligal river gauge.

	2014 - 2015		2015 - 2016		2016 - 2017		2017 - 2018		2018- 2019	
	N	C	N	C	N	C	N	C	N	C
No. of connections	1	0	2	0	1	1	1	0	0	0
Days connected (total)	1	0	31	0	135	124	3	0	0	0
Mean days connected	1	0	16	0	135	124	3	0	0	0
Longest connection	1	0	19	0	135	124	3	0	0	0
No. of disconnections	2	1	3	1	2	2	2	1	1	1
Mean days disconnected	182	365	112	365	115	121	181	365	365	365
Longest disconnection	285	365	262	365	212	188	188	365	365	365
Total volume (ML)	29	0	18 390	0	212,651	99 764	841	0	0	0

Table 37. River – floodplain connection metrics for Nooran Lake under modelled natural flow conditions (N) and current flow conditions (C). CTF value for Nooran Lake is 350 ML/day at Corrong river gauge.

	2014- 2015		2015-2016		2016-2017		2017-2018		2018-2019	
	N	C	N	C	N	C	N	C	N	C
No. of connections	12	0	8	2	6	1	5	1	5	2
Days connected (total)	140	0	144	73	224	180	58	30	31	6
Mean days connected	12	0	18	37	37	180	12	30	6	3
Longest connection	42	0	97	59	199	180	24	30	10	4
No. of disconnections	13	1	9	3	7	2	6	2	6	2
Mean days disconnected	17	365	25	97	20	92	51	167	56	179
Longest disconnection	83	365	99	183	65	153	152	180	180	257
Total volume (ML)	48831	0	90155	17319	338859	193729	19004	5727	8956	69

In the context of river regulation over the past five years, environmental water has made a small but significant contribution to the inundation of Nooran Lake and the central reed beds of the Great Cumbung Swamp, but is a fraction of what has been removed from the system by regulation (Figure 102, Figure 103). The connection events described in 2017-18 and 2018-19 in Nooran Lake occurred as a result of environmental watering actions and would not have occurred otherwise. The two connection events in 2018-19 while short (mean 3 days) provided water and ground water recharge during an extended period of drought.

11.4 LEARNING FROM THE PAST FIVE YEARS

The delivery of water within an adaptive management framework during the 5 years of the LTIM Project has resulted in changes to the way in which environmental water is both planned and used. This has resulted in significant advances in the practise of environmental flow management. This has been complemented by learning about species and community responses to water which has seen refinement in the design of watering actions. In the

Lachlan River system, there has also been investment in trialling novel approaches to monitoring which offer some insight to future monitoring programs. The key learnings from the five years of the program are highlighted in the following sections, as well as some of the knowledge gaps that have been identified throughout the program.

11.4.1 DELIVERING WATER FOR NATIVE FISH

Supporting native fish in the Lachlan river system has been a major focus of environmental water delivery over the past five years. Water has been delivered to support fish outcomes, either directly (through the provision of spawning flows) or indirectly (through improvements to water quality or habitat access) in every year of the program.

11.4.1.1 Golden Perch

A specific objective of the 2015-16 watering actions was to trial the augmentation of flows in the expectation that this would trigger a golden perch movement and spawning response. There was no evidence of golden perch spawning between September and December 2015 in response to the targeted flow releases, and no young-of-year sampled in the LTIM fish community surveys in 2015–16. This was despite observations by researchers from the University of Canberra that golden perch captured within the t

arget reach in mid-October were primed for spawning.

It is suggested that the lack of golden perch spawning may be a result of the timing of the watering action in relation to water temperatures and a series of recommendations were provided in relation to subsequent efforts to support golden perch spawning in the catchment. These included:

- Make use of translucent flows to prime the fish to move and spawn (based on observations of ripe golden perch at the end of the 2015 translucent flows). Depending on the duration of the translucent flows, provide subsequent releases to give a second peak of the hydrograph expected to result in spawning.
- Where possible, use a combination of tributary inflow triggers and temperature triggers to define the timing of the spawning flows. This would require a more responsive approach to delivering Commonwealth environmental water than was possible in 2015-16.

Water has not been used in subsequent years to support golden perch spawning, however, collaborative, proactive processes have been put in place to enable a far more responsive approach to delivering watering actions that would enable more effective delivery of water in the future.

11.4.1.2 Murray cod

Over the last two years of the LTIM Project there have been watering actions targeted at supporting the spawning and recruitment of Murray cod and providing increased instream productivity that would support native fish communities. While the adult fish community remains in poor condition, the watering actions have provided conditions that have been suitable for increases in spawning and subsequent recruitment of Murray cod in both 2017-18 and 2018-19. In 2017-18, Commonwealth environmental water was used in the lower Lachlan to maintain water levels at 1400 ML/day in the mid Lachlan and 450 ML/day in the lower Lachlan. This was part of a strategy of minimising water level fluctuations during the key Murray cod breeding season to prevent nest abandonment or possible exposure of nests. This strategy was successful in preventing sudden decreases in water levels but was costly in water use (total use 31, 500 ML). While there was some evidence that the water management strategy may have influenced spawning and larval survival, the limited data (no data were collected from the mid Lachlan) meant it was difficult to attribute outcomes to water use. In 2018-19, the watering strategy was refined. Commonwealth environmental water was used to prevent water levels dropping below 800 ML/day in the mid Lachlan and were re-regulated to provide flow variability in the lower Lachlan. The strategy employed in 2018-19 (a hydrological 'floor') is far less water intensive (using only 2,032 ML) than the strategy employed in 2017-19 (a hydrological 'roof'). Both strategies have supported Murray cod spawning and recruitment to juveniles.

While there are several confounding factors that prevent direct comparison of the approaches in the mid Lachlan, it would appear that spawning in the lower Lachlan was not adversely affected by the series of small freshes in 2018-19 compared with the more stable water levels in 2017-18. The additional productivity benefit from the small freshes in the lower Lachlan would suggest that providing small freshes benefits more than Murray cod and is therefore a better use of environmental water than keeping the water level more constant. These small freshes may also have provided opportunities for movement prior to spawning. Given the improvements in Murray cod populations over the past 2 years, these watering actions should be considered exemplars for facilitating the movement of pre-spawning fish and maintaining spawning habitat during nesting periods to prevent rapid water level drops and nest abandonment or desiccation in the lower Lachlan.

While the small freshes that were delivered in the lower Lachlan appear to have been beneficial for Murray cod spawning and recruitment, caution should be exercised in directly translating the regime to the mid Lachlan. The water level changes that occur because of operational deliveries in the mid Lachlan are often considerably more rapid than would have occurred under natural conditions. Thus, there is sound conceptual basis for preventing rapid water level drops to prevent nest abandonment or desiccation. However, it is unlikely that the small water level drops (between 0.08 and 0.25 m) prevented by the 800 ML/day 'floor' in 2018-19 would have made any difference to spawning in the mid Lachlan and we lack data for 2017-18 to be able to compare outcomes. Future strategies for managing water levels in the mid Lachlan should revisit the concept of a fixed floor in light of understanding critical nesting habitat in relation to water level and consider modifying rates of change rather than fixed water levels. These would need to be informed by additional data from the mid Lachlan River.

11.4.1.3 Carp

The delivery of environmental water in warmer months to support native fish species runs the risk of promoting a common carp spawning event. To mitigate this risk, the use of Commonwealth environmental water for native fish outcomes has been confined to in-channel flows and has not inundated wetlands. This was a successful approach in 2014-15, 2017-18 and 2018-19 with low levels of common carp spawning detected in these years and minimising connections with wetlands during warmer months remains a strategy that continues to be used within the catchment.

Environmental watering was complicated in 2015-16 with the release of translucent flows under the NSW Water Sharing Plan. These releases resulted in short term connections between wetlands and the main channel. While carp spawning was observed in the connected wetlands 2015-16, carp spawning in the monitored reach remained low suggesting that the response within the wetlands did not translate to the main channel. This supported the strategy of minimising connections with the wetlands to prevent environmental water from generating carp.

11.4.1.4 Addressing questions of growth and survival

The project team's capacity to determine growth and survival of larval native fish is limited by only having estimates of age:length ratios for the target species based on limited published studies. Daily aging of at least a subset of species was 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. To include learning here from doing this in 2018-19 but the data are currently being revisited following QA/QC.

11.4.2 DELIVERING WATER FOR STREAM PRODUCTIVITY

Stream productivity responses have been either an implied or an explicit objective of providing freshes into the lower Lachlan river system over the past five years.

Our data have shown that while natural flow variability is the dominant driver of patterns of water quality and stream metabolism in the Lachlan River, environmental water can generate smaller, but ecologically meaningful responses. The effects of environmental water are likely to be more important in dryer years (e.g. 2014-15), where carbon has accumulated on banks and in flood runners. In relatively wet years, such as occurred in 2016-17, metabolism responses to environmental flows are likely to be small relative to natural variability.

The greatest productivity responses have been observed when freshes have been provided when associated with warmer water conditions. Pulses in productivity have been observed from both environmental water and from variable water levels associated with meeting other demands for water. The use of Commonwealth environmental water in 2017-18 and 2018-19 during cooler months generated a spatially variable, transient pulse of in-stream productivity that is likely to have benefited higher consumers. While providing environmental flows during cooler periods does not produce a large productivity response, providing resources at this time may 'prime' ecosystems and contribute to fish condition, allowing for more rapid and larger responses to spring flows in the subsequent year.

While these patterns in stream metabolism have emerged, the responses tend to be spatially and temporally variable. It has been recommended that high-resolution habitat mapping would provide an opportunity to examine the water level rises in relation to the inundation of channel features and may inform future flows targeting ecosystem responses through inundation of these features.

Our data indicates that the strategy of providing flows to generate productivity responses to support fish larvae and to improve food availability is realistic. In 2018-19, the watering actions contributed to pulses of instream productivity at the same time that small bodied native fish and Murray cod were spawning. Flatheaded gudgeon appear to have responded well to these conditions in the lower river suggesting that the strategy of managing

Commonwealth environmental water to generate a number of small freshes has had benefit and should be considered in future years to continue to support in-stream production and native fish recruitment.

11.4.3 DELIVERING WATER FOR VEGETATION

Wetland vegetation outcomes have been the target of environmental water in three of the five years of the LTIM Project. Objectives have not been specific, and water has been delivered as end of system flows to ‘provide water’ to the Great Cumbung Swamp and to Booligal wetlands.

The floodplain and wetland vegetation communities of the Lower Lachlan river system naturally display sequences of dry and wet phases depending on the prevailing weather conditions. Our monitoring data indicates that one of the stronger drivers of the species assemblages over the past 5 years has been the annual weather conditions. Inundation contributes to the species assemblages, and we have shown that Commonwealth environmental water can be used to produce native amphibious plants in the river system.

The greatest challenge in delivering water for vegetation outcomes is the lack of specific objectives for vegetation outcomes within the catchment. It has been recommended that specific outcomes for flows provided to vegetation sites be developed that include details on intended timing, duration and depth of inundation and how these elements are required for the vegetation outcomes being targeted.

11.4.4 DELIVERING WATER FOR WATER DEPENDENT VERTEBRATES

Environmental water has been delivered to provide access to habitat for water dependent vertebrates. Water has been provided specifically to target waterbirds in one of the five years of the LTIM Project.

The experiences of waterbird breeding in the Lachlan catchment in 2015-16 and 2016-17 highlight the importance of regional weather patterns, and the value of extensive flooding to provide foraging areas and habitat for food resources to thrive in a successful breeding event. The strategy of using Commonwealth environmental water to support breeding events once they have established (rather than trying to trigger a breeding event) is therefore sound and continues to be the approach of the CEWO.

11.4.5 INFORMING WATER DELIVERY

11.4.5.1 Natural cues

The approach taken to delivering environmental water in 2014-15 was to rely on passing tributary inflows through the system. This resulted in a small watering action being delivered (only 5 821 ML) in late August which was not suited to encouraging spawning of flow cued fish species. While natural cues are considered to be optimal for supporting ecological outcomes they are not predictable enough to be used to support specific species. The 2014-15 experience indicated that the targeting of specific species would likely require releases from storage to generate the flow regime required by those species. The management of Commonwealth environmental water over subsequent years has relied more heavily on releases from storage, rather than waiting for tributary inflows.

11.4.5.2 Responsive water delivery

In 2015-16, translucent flows provided important late winter/spring freshes in the system, that are likely to have primed the ecological responses observed in the rivers and wetlands. While it was difficult to disentangle the relative effects of Commonwealth environmental water and the translucent releases, the responses observed were considered unlikely to have occurred with either of them on their own. Translucent releases provide advantage in being linked to natural inflows and are of sufficient magnitude to inundate and connect wetlands to the main channel. As such they provide flows that are unlikely to be able to be delivered through Commonwealth environmental watering. The use of Commonwealth water to capitalise on the opportunities provided by translucent flows was recommended, but the opportunity to do so has not yet arisen.

11.4.5.3 Delivering environmental water during a flood year

In 2016-17 the Lower Lachlan river system was in flood. This meant that the approach to delivering Commonwealth environmental water changed from the traditional approach of adding missing elements of the hydrological regime to achieve environmental outcomes. Instead the management of Commonwealth water was in response to conditions in the river and the ecological responses observed. The aim was to capitalise on the natural flood event and protect vulnerable ecosystem attributes from the effects of a flood under highly managed conditions. This meant that environmental water was used to modify the outcome of the operation of Wyangala Dam once flood operations ceased. The positive outcomes achieved with the management of environmental water in 2016-17 provided evidence of the success of this approach when the system is in flood.

While the benefits of the first 2016-17 watering action for dissolved oxygen concentrations in the monitored reach are not clear, the improvements in the target reach (mid Lachlan) mean that the provision of environmental water to manage dissolved oxygen on the receding limb of natural flow events, particularly where they occur in summer, is a valid management option with potential benefits.

The provision of water to support the Blockbank waterbird colony was successful in achieving the goals of supporting a breeding event. Commonwealth environmental water contributed to the completion of nesting (prevented abandonment due to falling water levels) and provided suitable habitat in which chicks could be raised and successfully fledged. This 'event' demonstrates the value of cleverly managing water within the constraints of the system with a long lead time for delivering water. The combination of managing infrastructure, redirecting environmental water and delivering water generated successful outcomes.

A number of logistical challenges associated with a responsive style of environmental water management were identified during 2016-17 that affect the capacity for closing the adaptive management loop and institutional learning. These included the fact that the standard processes for documenting objectives for the watering actions (Water Use minutes) does not fit the rapid and responsive style of water management. While the approach adopted is agile and effective, it was recommended that better documentation of the actions, rationale and water use would facilitate future evaluation and learning. In response to this recommendation, the CEWH have implemented an internal documentation process that enables the water use decisions, actions and rationale to be logged, providing opportunities to better learn from their actions.

11.4.6 ACCOUNTING FOR THE USE OF ENVIRONMENTAL WATER

The style of environmental water management employed in the Lachlan catchment for the past three years is responsive and uses a single parcel of water to achieve multiple benefits throughout the river system. While such as approach is an efficient and effective use of water it has presented substantial challenges for evaluating the watering actions. Documentation of the watering actions improved considerably in 2018-19, and when combined with the 'log' of watering decisions implemented by the CEWH the opportunities to learn have improved considerably. However, there remain some difficulties, particularly with the timely provision of accounting data. There are differences in the operational accounting and the accounting using quality controlled publicly available hydrographic data which also causes problems. It remains a recommendation that that more regular accounts be prepared to support the reporting requirements.

11.4.7 INFORMING FUTURE MONITORING

11.4.7.1 Linking monitoring to target assets

The current LTIM Project for the Lower Lachlan river system (and the future MER Program) only monitors the river system below Lake Brewster, yet numerous watering actions during the LTIM Project have targeted the mid-Lachlan reach. Many of these watering actions in the mid-Lachlan were unable to be evaluated and it was recommended in a number of instances that the mid-Lachlan be monitored. In 2018-19, the CEWH invested in Short Term Intervention Monitoring (STIM) of fish and stream metabolic responses to environmental water in the mid-Lachlan. The data collected demonstrated that while the fish community in the mid and lower Lachlan contain the same species, the relative abundances differ significantly as do the responses to watering actions. There was some commonality of stream metabolic responses between the mid and lower Lachlan, but generally the productivity pulses were more spatially variable in the mid Lachlan and less predictable than in the lower Lachlan. This has implications for the expected outcomes for watering actions in the mid-Lachlan and highlights the need for more regular monitoring of that reach if it remains the target for watering actions.

Watering actions in the Lachlan across the five years of the LTIM Project have delivered water to the central reed beds and nearby open water areas of the Great Cumbung Swamp. Vegetation monitoring has not been set up to capture the outcomes of these actions. Access is difficult and costly. While initial forays into the use of drone technology to monitor vegetation outcomes as part of this project have been piecemeal and not particularly effective (Dyer et al. 2017) it was recommended that drone based methods be developed in a systematic and rigorous fashion to assist in future monitoring. This is being implemented in the MER Program.

11.4.7.2 Temporally relevant monitoring

One of the challenges with delivering water to improve dissolved oxygen concentrations is that typically by the time dissolved oxygen concentrations drop below 4 mg/L, it is too late to respond to achieve a benefit for fish. In the mid Lachlan, early warning of poor water quality in 2016-17 was hampered by a paucity of data (and particularly a paucity of continuous data) that could be used to trigger a response. It would have been particularly valuable to have had water quality monitoring equipment in the reach from Wyangala Dam to Lake Brewster to inform water management decisions. A recommendation to this effect was made in the 2016-17 reporting and has provided the impetus for a conversation with NSW agencies regarding monitoring infrastructure.

The management of environmental water for the Blockbank waterbird colony in 2016-17 demonstrated the value of tailoring observations to the conditions within the catchment. The establishment of the second colony was observed during a reconnaissance plane flight taken to gain an understanding of the extent of the flooding. Without this flight, the colony may have remained undetected for sufficient time that the water levels would have dropped and the colony put at risk.

11.4.7.3 Monitoring to detect fish spawning

There were some concerns early in the program that detecting spawning responses in the lower Lachlan river system for flow-cued fish may have be limited by the timing of the sampling program (fortnightly sampling). Increased monitoring intensity (sampling weekly at a minimum) was thought to have been required to monitor spawning response of any events specifically targeted at golden perch or other flow cued spawning species. The monitoring program in 2015-16 was augmented by an in-kind contribution from by DPI fisheries in an attempt to detect golden perch spawning. Weekly monitoring of larval fish failed to detect golden perch spawning and subsequent fish community sampling did not detect any juvenile golden perch. The combined monitoring dataset suggested that golden perch did not spawn in 2015-16 and the additional monitoring provided a far greater degree of confidence around such a conclusion than if only the LTIM monitoring were implemented. It is recommended that such targeted monitoring could be implemented in response to such watering actions in the future.

11.4.8 UNDERSTANDING FLOW ECOLOGY RELATIONSHIPS

The design of watering actions and our capacity to understand observed responses in the catchment is reliant on our knowledge of fundamental flow ecology relationships. Such knowledge is often imperfect. There have been several research students associated with the lower Lachlan LTIM Project whose research has (and is) generated (ing) strategic understanding.

11.4.8.1 Generating knowledge

Three post-graduate research students from the University of Canberra have worked alongside the monitoring team in the lower Lachlan catchment to address targeted knowledge gaps. The studies undertaken are listed below along with strategic excerpts from the abstracts of their theses.

1. Emily Belton – Honours May 2015 - The diet and prey selectivity of larval Murray cod in an upland and lowland river.

Emily's study examined the diet and prey selectivity of Murray cod larvae in a lowland river (lower Lachlan River) and an upland river (the upper Murrumbidgee River) in the Murray-Darling Basin. Gut content analysis was used to examine diet composition of larvae collected using drift nets and light traps. Prey availability was determined by sampling the pelagic and epibenthic microinvertebrate community and then comparing these findings to the diet composition of larval Murray cod to calculate prey selectivity.

A copy of Emily's thesis can be found at:
http://www.canberra.edu.au/researchrepository/items/41ccf84a-0110-4c36-9084-7c911115e9fb/1/

Her research demonstrated that while prey availability and diet composition differed between the lower Lachlan River and upper Murrumbidgee River, Murray cod were found to exhibit selective feeding for large copepods in both study areas. She also found that abundances of suitable prey items were found to be adequate in both systems despite no large overbank flows in the period leading up to the field sampling. These findings support the notion that low summer flows in the main channel provide suitable conditions for the survival and recruitment of some larval fish species.

2. Will Higgisson – PhD 2019 – The influence of flooding on the vegetation of the semi-arid floodplain of the lower Lachlan River

Will's study addressed some of the gaps in our understanding of floodplain plants and their responses to water, on the semi-arid floodplain of the lower Lachlan River, Australia. It characterised spatial and temporal differences in seed bank characteristics relative to hydrological gradients, investigated the life-history responses of two floodplain shrub species (tangled lignum (*Duma florulenta* (Meisn.), and nitre goosefoot (*Chenopodium nitrariaceum* (F.Muell.)) to watering, and investigated gene-flow and population genetic structure in tangled lignum and river cooba (*Acacia stenophylla* (A. Cunn. ex Benth.)). His study was framed within the context of the changes in river floodplain connectivity caused by water resource development.

Numerous publications have arisen from his thesis and can be found at:

Higgisson W., Briggs S., Dyer F. (2018) Responses of nitre goosefoot (Chenopodium nitrariaceum) to simulated rainfall and depth and duration of experimental flooding. *Marine and Freshwater Research* 69(8) 1268-1278

Higgisson, W., Briggs, S., Dyer, F. (2018) Seed germination of tangled lignum (Duma florulenta) and nitre goosefoot (Chenopdoium nitrariaceum) under experimental hydrological regimes. *Marine and Freshwater Research* 70(4) 493-503 DOI: 10.1071/MF17357

Higgisson, W., Higgisson, B., Powell, M., Driver, P., & Dyer, F. Impacts of water resource development on hydrological connectivity of different floodplain habitats in a highly variable system. *River Research and Applications*.

Will's study concluded that semi-arid floodplains such as the floodplain of the lower Lachlan River are temporally and spatially dynamic and complex. The organisation of vegetation on the floodplain is strongly related to the hydrological regime and the requirements and tolerances of each species. The dependency of floodplain vegetation on flooding means hydrological changes are likely to affect floodplain vegetation by reducing opportunities for life history processes such as growth, dispersal, seed production, and seed germination. The results suggest changes to the flow regime will influence the distribution and abundance of species, genetic diversity and genetic structure, and the distribution of populations and communities across floodplains. To maintain the diversity of vegetation and habitat types on the floodplain, environmental flows must consider the life-history strategies of the plants.

3. Foyez Shams – PhD continuing – Population Genetic Structure and Breeding Activity of Two Native Fish (Golden Perch and Murray Cod) From a Managed Catchment: A Case Study from Lachlan River

Foyez is currently completing his PhD which is investigating the population genetic structure and breeding activity of golden perch and Murray cod from the Lachlan river using genetic tools and otolith microchemistry analysis. This research will help to address gaps in our understanding of stocked and wild spawning of golden perch in the Lachlan river system and the population genetic structure of the two species. He expects to complete in early 2020.

To date, he has one publication from his PhD thesis:

> Shams, F., Dyer, F., Thompson, R., Duncan, R.P., Thiem, J.D., Majtanova, Z., Ezaz, T. (2019) Karyotypes and sex chromosomes in two Australian native freshwater fishes, golden perch (*Macquaria ambigua*) and Murray cod (*Maccullochella peelii*) (Percichthyidae). *International Journal of Molecular Sciences* 20 (17) 4244

11.4.8.2 Identifying knowledge gaps

Specific gaps in our understanding that limit both the design of watering actions as well as our capacity to understand observed responses have been identified throughout the LTIM Project. These have provided the foundation for the development of the research for the Monitoring, Evaluation and Research Program and a summary can be found in the Monitoring, Evaluation and Research Plan (Dyer et al. 2019).

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