COMMONWEALTH ENVIRONMENTAL WATER OFFICE

MONITORING, EVALUATION AND RESEARCH PROGRAM: LACHLAN RIVER SYSTEM

2019-20 TECHNICAL REPORT: FINAL

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Lachlan river system 2019-20 Technical Report

Final February 2021

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Disclaimer

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Front cover photo: Environmental water under the redgums of the Great Cumbung Swamp, June 2020. Photo by Fiona Dyer

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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
DPIE	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
MER	Monitoring, Evaluation and Research
MDBA	Murray-Darling Basin Authority
MDFRC	Murray-Darling Freshwater Research Centre
OEH	Office of Environment and Heritage[1]
SRA	Sustainable Rivers Audit
WQA	Water quality allowance
WUM	Water Use Minute

[1] Note that the NSW Government Department that was the Office of Environment and Heritage is now a part of the Department of Planning, Industry and Environment. The acronym remains as documents published prior to 2019, still retain the OEH authorship.

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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. The Lachlan River flows through the lands of the Nari Nari, Ngiyampaa, Wiradjuri and Yita Yita Nations, and we acknowledge these people as the traditional owners of the land on which this publication is focused.

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1 INTRODUCTION

The dry conditions that prevailed in 2018-19 persisted through the remainder of 2019 and into the early months of 2020. These extreme conditions placed considerably pressure on the regions water resource which continued to decline rapidly. Environmental watering actions in such dry conditions focused on protecting important refuge habitat within an otherwise extremely dry landscape.

Four watering actions using Commonwealth environmental water were delivered to the Lachlan river system in 2019-20, three of which were delivered in combination with NSW environmental water. These watering actions targeted multiple objectives and sites within the Lachlan river system and used a total of 22 777 ML (22 026 ML Commonwealth environmental water and 751 ML NSW environmental water). The first watering action provided a spring pulse to the river and targeted multiple sites on its way to the Great Cumbung Swamp. This action commenced with releases from Wyangala Dam on the 16th September and reached the edge of the Great Cumbung Swamp in early November. A small portion of this watering action was held over in Brewster Weir Pool to provide refuge habitat for olive perchlet and was delivered to the river system in late autumn, capitalizing on natural inflows following rains. In combination, the multiple components of this watering action were designed to provide longitudinal connectivity and variability of flows, stimulate primary production, support native fish condition and protect the core reed beds and other non-woody vegetation communities of the Great Cumbung Swamp.

The remaining watering actions were small actions designed to protect refuge habitat. The second watering action provided water to Yarrabandai Lagoon in October to improve condition and provide refuge habitat in the mid Lachlan river system. This watering action built upon the use of environmental water in 2018-19 in Yarrabandai Lagoon, continuing to support refuge habitat during dry times. The third watering action provided a spring pulse to Booberoi Creek, also in the mid-Lachlan, with water delivered between October and November to maintain the health of the creek and provide off-river channel refuge habitat. The fourth watering action provided water to the Noonamah black box woodlands in spring to maintain the health of the black box communities and provide refuge habitat for native animals.

In combination, the four watering actions contribute to the watering priorities of the Murray-Darling Basin Authority of supporting lateral and longitudinal connectivity, supporting native fish, providing drought refuges in very dry catchments and maintaining the condition of species and habitat (MDBA 2019).

The Monitoring, Evaluation and Research program (MER program) is the primary means by which the Commonwealth Environmental Water Office (CEWO) undertakes monitoring and evaluation of the ecological outcomes of Commonwealth environmental watering. It follows the previous Long Term Intervention Monitoring project (LTIM project) which evaluated the ecological outcomes of Commonwealth environmental watering activities between 2014 and 2019. Monitoring activities implemented within the MER program to evaluate the outcomes of Commonwealth environmental watering actions in the Lower Lachlan river system in 2019-20 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.

This document provides the technical reports for the 2019-20 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. 2020).

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.

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 and MER programs is the western end of the Lachlan River, and extends from the outlet of Lake Brewster to the Great Cumbung Swamp (Figure 2-1.). 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 has historically been 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. 2020). The interaction of a number of factors such as these are considered key drivers in the 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) (Davies et al. 2008; MDBA 2012b). 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 a series of natural flow events (2012 and 2016), translucent flow events and targeted 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.

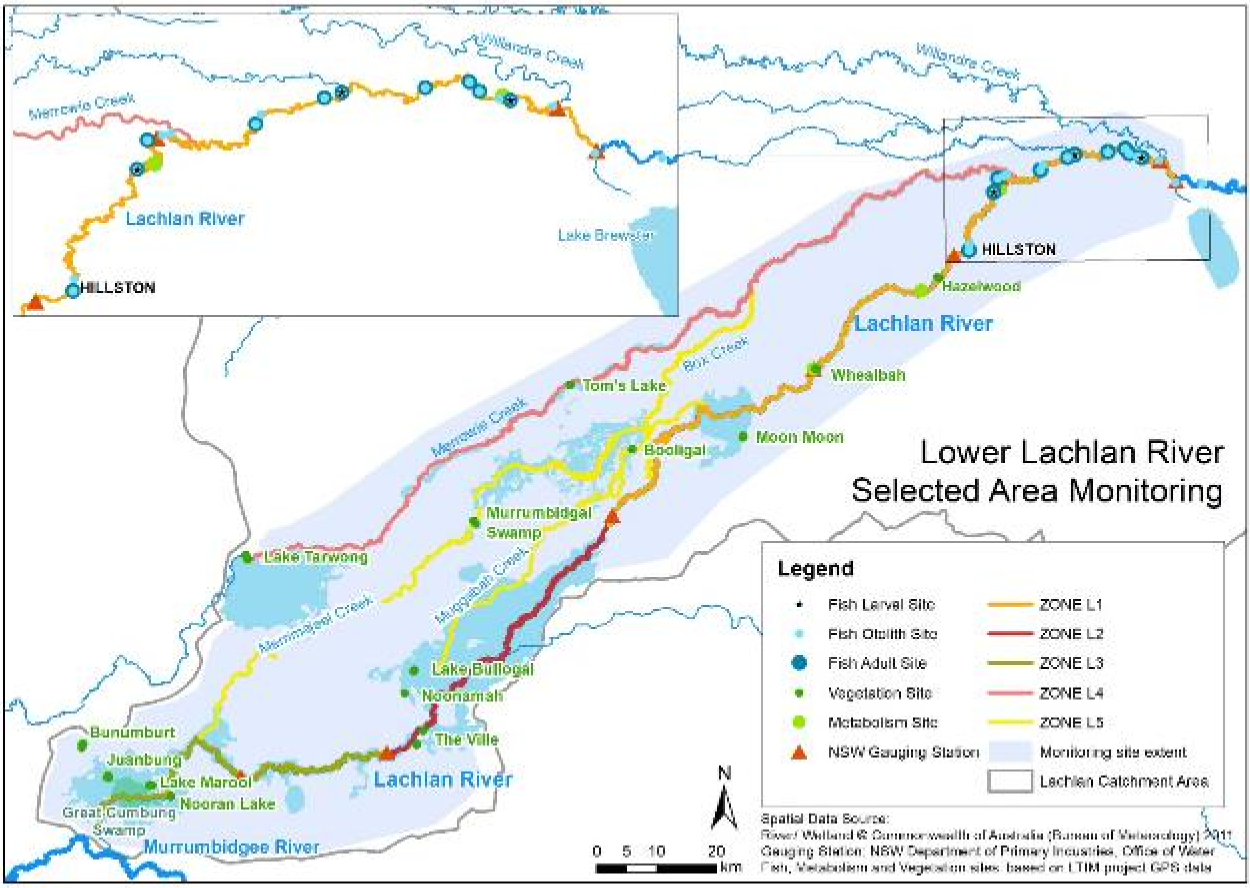

Figure 2-1. The Lower Lachlan river system showing the region for the LTIM project and MER program.

3 2019-20 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 Lachlan catchment had been dry since January 2017 with below average to very much below average rainfall in the two years to the end of June 2019 (Figure 3-1), see also (Dyer et al. 2019a; Dyer et al. 2018b).

These dry conditions persisted through to the end of 2019 with the three years to the end of December 2019 some of the lowest rainfall on record (Figure 3-1).

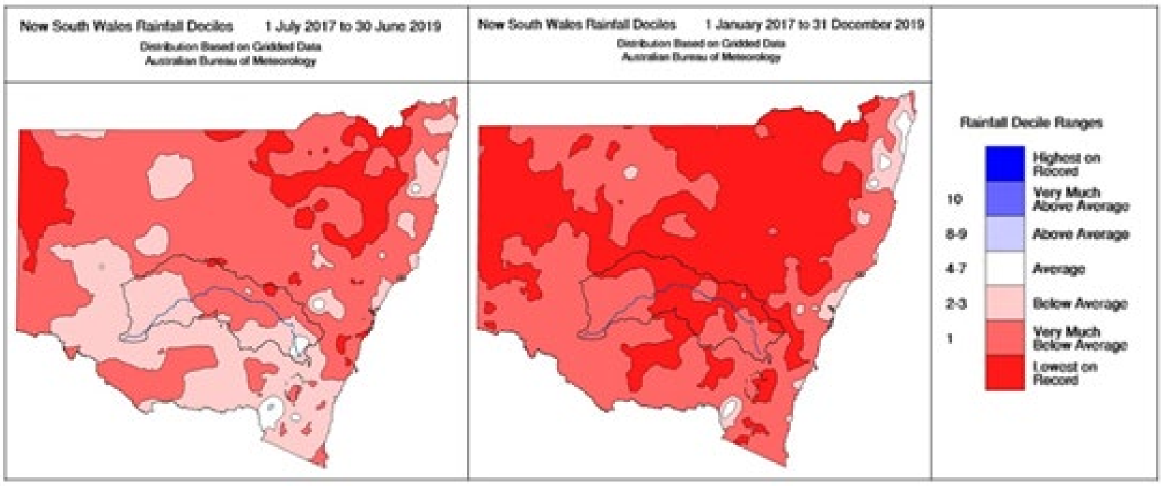

Figure 3-1. Rainfall deciles for New South Wales. Left: Data for the period 1st of July 2017 to 30th of June 2019 (2017-18 and 218-19 watering year) and right, data for the period 1st January 2017 to 31st December 2019. Images from the Bureau of Meteorology Rainfall Archive.

The start of 2020 saw a return to average rainfall conditions with significant events in April 2020 (Figure 3-3) for the mid Lachlan. With three months of high above rainfall in 2020, the lower Lachlan River records below mostly average rainfall for the watering year 2019-20 (Figure 3-2 and Figure 3-3).

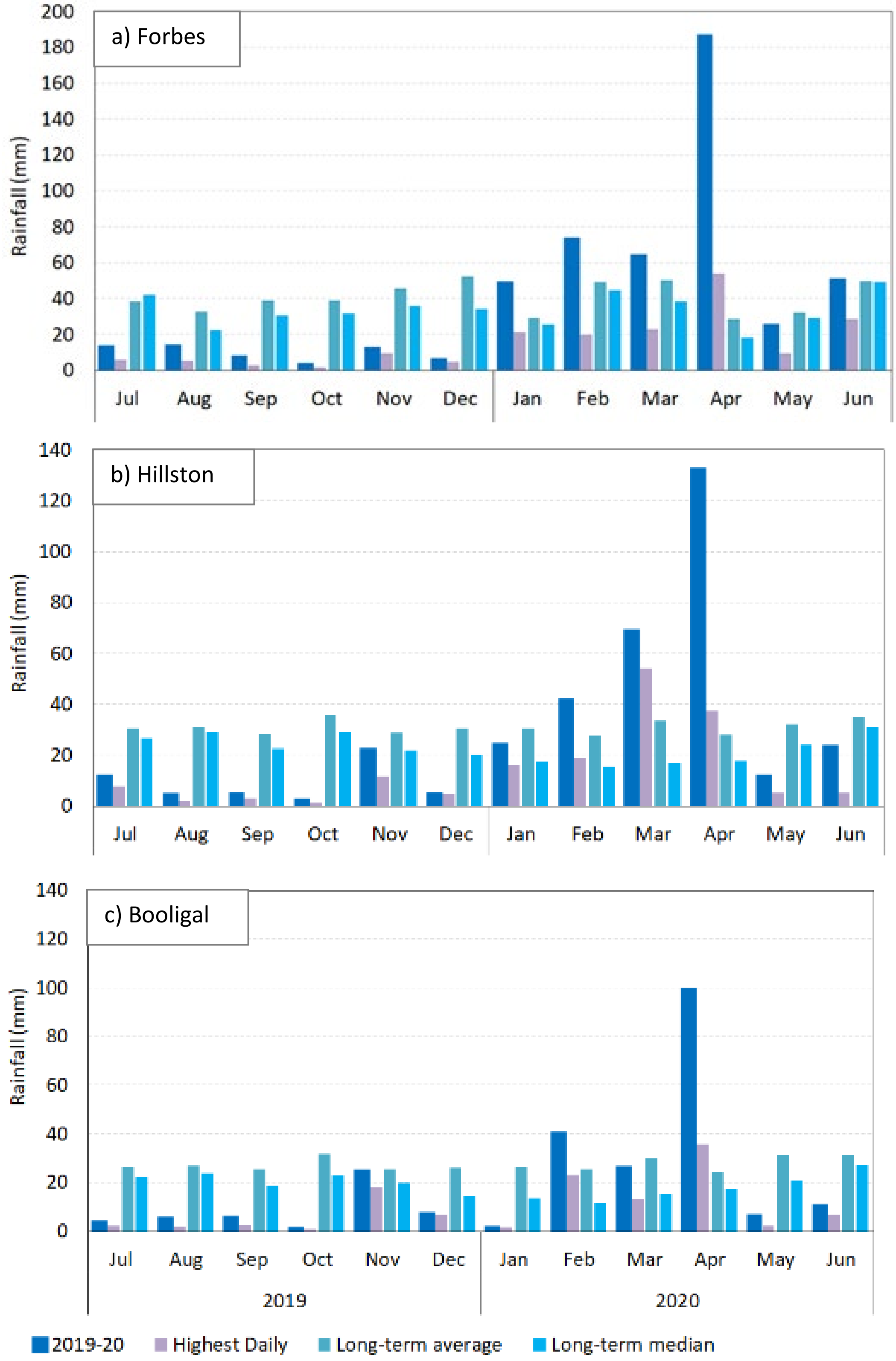

Figure 3-2. Monthly rainfall at a) Forbes Airport (065103), b) Hillston Airport (075032) and c) Booligal (075007) during 2019-20 compared with the mean and median rainfall for the entire period of record, and daily highest rainfall events per month.

Data sourced from Climate Data Online, Bureau of Meteorology. Note: a) Forbes on larger scale.

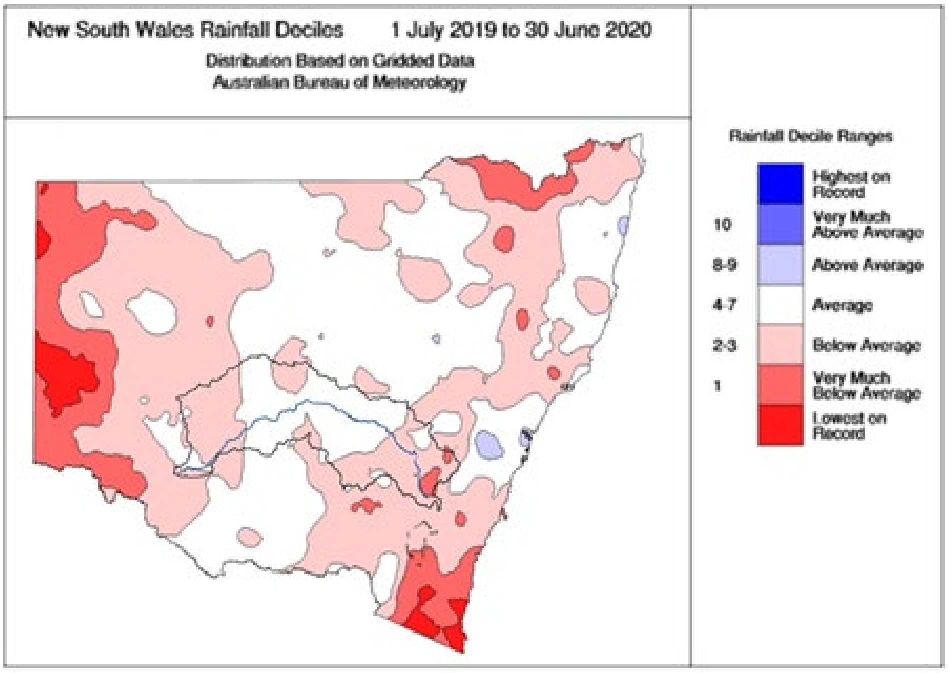

Figure 3-3. Rainfall deciles for New South Wales for the 2019-20 watering year. Images from the Bureau of Meteorology Rainfall Archive.

Temperature were generally above average across the catchment throughout 2019-20, with temperatures in December 2019 several degrees above average (Figure 3-4).

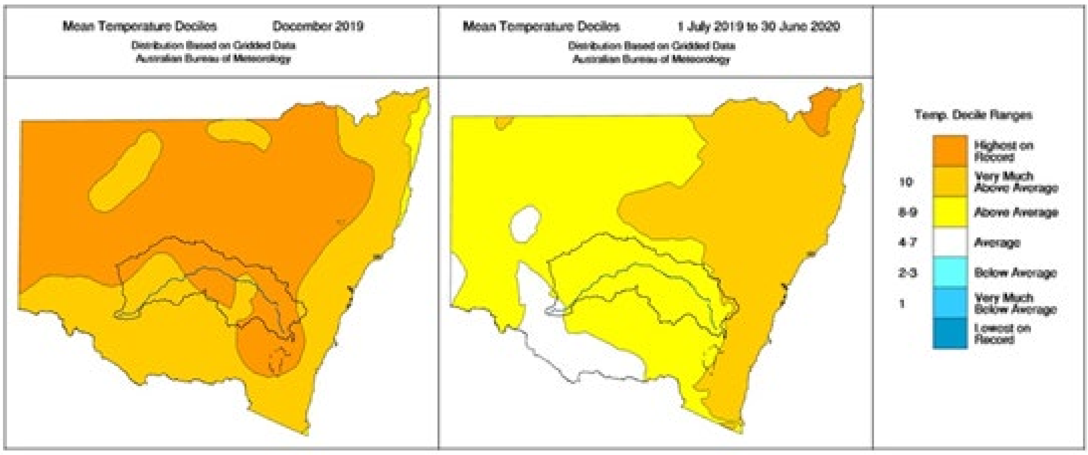

Figure 3-4. Mean temperature deciles for NSW for December 2019 (left) and the 2019-20 watering year (right). Images from the Bureau of Meteorology Temperature Archive.

3.2 Environmental 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 2019-20 water year, the Commonwealth government held a total of almost 87 856 ML in entitlement (Table 3-1).

Table 3-1. Environmental water held entitlements in the Lachlan River Valley as at 1 July 2019.

	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

At the 30th June 2019, the Commonwealth environmental water office held 37 219 ML of general security water in Wyangala Dam carried over from previous years. The implementation of drought rules meant that 16 004 (43%) of this held environmental water was transferred to the NSW drought account. An 87% allocation of high security entitlements meant that a further 811 ML was also available and the total water available for use by the Commonwealth Environmental Water Holder at 1 July 2019 was 22 026 ML.

3.3 Planned Water Use

Planning for environmental watering in 2019-20 was undertaken within the context of increasingly severe drought conditions. More than 40% of the environmental water held by the Commonwealth Environmental Water Holder had been transferred to the NSW drought account and water planners were facing the lowest 3-year sequence of inflows on record. Dry conditions were expected to persist and there was the possibility of further restrictions on accessing carryover volumes. Under such conditions, environmental water planning was focused on maintaining key refuges in the landscape and continuing to support the native fish populations remaining after the hypoxic conditions experienced in the mid-Lachlan in 2016-17.

The annual watering priorities of the Murray-Darling Basin Authority (MDBA 2019) were set in anticipation of dry to very dry conditions across the Basin. Consequently, their focus was on the needs of key sites (Barwon-Darling and Lower Darling river system, the Narran Lakes, Koondrook-Perricoota Forest and the Coorong, Lower Lake and Murray Mouth) as well as generic objectives for flow and connectivity, vegetation, waterbirds and native fish. There were not specific annual environmental watering priorities relevant to the Lachlan catchment and thus the Commonwealth Environmental Water Portfolio Management Plan: Lachlan River 2019-20 (Commonwealth of Australia 2019) suggests that the CEWO was aiming to contribute to the following 2019–20 Basin multi-year priorities relevant to the Lachlan River region:

- Support lateral and longitudinal connectivity along the river systems;
- Maintain the extent, improve the condition and promote recruitment of forests and woodlands;
- Maintain the extent and improve the condition of lignum shrublands;
- Improve the abundance and maintain the diversity of the Basin's waterbird populations;

- Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the southern connected Basin; and
- Support viable populations of threatened native fish, maximize opportunities for range expansion and establish new populations.

Over the past two watering seasons, priority had been given to supporting native fish recovery following a significant decline in fish numbers thought to have been caused by hypoxic events associated with the flooding in 2016-17. Watering actions planned in 2019-20 had a priority for maintaining refugia and protecting key assets along the river system.

3.4 Implemented watering actions

3.4.1 Commonwealth environmental water delivery

The total Commonwealth environmental water deliver to the Lachlan river system in 2019-20 was 22 026 ML and through a process of re-regulation, was used to target multiple locations and ecological objectives at different times of the year (Table 3-2 and Table 3-3). A number of these watering actions were supplemented with 448 ML of NSW environmental water (Table 3-3).

Releases for the first 2019-20 watering action targeting multiple objectives commenced at Wyangala Dam on the 16th September 2019. A small spring fresh (hereafter Watering Action 1d, Table 3-2) was modified as it passed through Brewster Weir to provide a small fresh in the lower river and maintain baseflows for an extended period of time. The small fresh passed through Hillston in the second half of October and baseflows continued through until early December. The small fresh reached the edge of the Great Cumbung Swamp in early November 2019. A portion of this spring fresh (2,000 ML, Watering Action 1a) was held over in Brewster Weir Pool and released in between 4th and 17th of May to coincide with natural inflows following rain, providing longitudinal connectivity and creating variability in river height in the lower Lachlan River. This volume was again managed as a 'run of river' flow reaching the edge of the Great Cumbung Swamp on the 4th June.

Attempts were made to use two further portions of the spring fresh en-route to the Great Cumbung Swamp. One (Watering Action 1b, Table 3-2) was directed at Lake Comayjong, which commenced to fill on the 7th November. Only a small volume of water was delivered to Lake Comayjong with channel delivery issues and very low delivery flow rates resulting in the action being abandoned and the water remained in the Great Cumbung Swamp system. The other was directed at Lake Bunumburt and its back lakes (Watering Action 1c, Table 3-2). While some water reached Bunumburt Lake, delivery arrangements and slowing flow rates meant that water was unable to reach the back lake areas and the water remained in the Great Cumbung Swamp system.

The main watering action was complemented by three small watering actions targeting First Nations values, refuge habitat and vegetation health. Booberoi Creek was the recipient of two of these (Watering Actions 2a and b, Table 3-3) with 2,900 ML delivered in October and November 2019 and a further 1,572 ML of Commonwealth environmental water and 528 ML of NSW environmental water delivered between the start of October 2019 and the end of February 2020. In combination, these actions targeted habitat for native fish and water plants, supporting First Nations cultural values.

A small watering action targeting refuge habitat for native frogs and waterbirds was delivered to Yarrabandai (formerly Burrawang West) Lagoon commencing on the 13th September (Watering Action 3, Table 3-3). This watering action comprised 400ML of Commonwealth environmental water and 148 ML of NSW environmental water. A further small watering action comprising 126 ML of Commonwealth environmental water, 94 ML of NSW environmental water and 40 ML of privately owned water was delivered to Noonamah in late October (Watering Action 4, Table 3-3). This watering actions targeted the health of Black box health and refuge habitat for native animals including Southern Bell Frogs.

The ecological outcomes from Watering actions 2 and 3 were not monitored under the MER program in 2019-20.

Table 3-2. The components of the main 2019-20 Commonwealth environmental watering action.

DESCRIPTION	DETAILS			
Action	1a	1b	1c	1d
Target Asset	Brewster Weir Pool	Lake Comayjong	Lake Bunumburt	Lachlan River channel; Lower Lachlan River, main channel below Lake Brewster, terminating in the Great Cumbung Swamp
Reference	Water Use Minute 10081 (2019-20)			
Accounting Location	Lachlan River at Forbes (Cotton's Weir)			
Flow component	Fresh flow	Wetland watering	Wetland watering	Fresh flow
Volume (CEW)	2,000 ML	1,000 ML	1,000 ML	13 028 ML
Volume (NSW)				
Re-use	The 2000 ML kept in Brewster Weir Pool was subsequently released to the lower Lachlan River channel in late Autumn			
Total Volume	17 028 ML			
Objectives	Primary: • Maintain refuge area for olive perchlet, a threatened native fish Secondary (on release from weir pool): • Provide hydrological variability • Maintain vegetation condition, particularly of the core reed bed areas of the Great Cumbung.	Primary: • Provide refuge for native animals including waterbirds Secondary: • Maintain floodplain connectivity	Primary: • Maintain the health of black box communities • Provide refuge for native animals including waterbirds Secondary: • Maintain floodplain connectivity	Primary: • Contribute to in-channel flows that maintain refuge areas for native fish, maintain native fish condition, maintain native fish communities, provide hydrological variability and connectivity, maintain aquatic vegetation condition. • Inundate the core reed bed areas of the Great Cumbung to maintain vegetation condition and provide drought refuge to native waterbirds. Secondary: • Maintain water quality
Basin Watering Priorities	Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the southern connected Basin. Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations.	Improve the abundance and maintain the diversity of the Basin's waterbird population.	Maintain the extent, improve the condition and promote recruitment of forests and woodlands.	Support lateral and longitudinal connectivity along the river systems. Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the southern connected Basin.

Table 3-3. The 2019-20 joint Commonwealth NSW environmental watering actions.

DESCRIPTION	DETAILS			
Action	2a	2b	3	4
Target Asset	Booberoi Creek		Yarrabandai Lagoon	Noonamah
Reference	Water Use Minute 10081 (2019-20)			
Accounting Location	Booberoi Weir off-take		Private meter	Private meter
Flow component				
Volume (CEW)	2,900 ML	1,572 ML	400 ML	126 ML
Volume (NSW)		507 ML	148 ML	94 ML
Total Volume	4,979 ML		548 ML	220 ML (plus 40 ML privately owned water)
Objectives	Primary: • Maintain refuge habitat for native fish, birds and frogs that are also of cultural importance • Maintain connectivity with the Lachlan River • Maintain riparian vegetation condition Secondary: • Maintain water quality		Primary: • Maintain refuge habitat for native birds and frogs • Maintain connectivity with the Lachlan River • Maintain riparian vegetation Secondary: • Maintain water quality	Primary: • Maintain vegetation condition • Maintain refuge habitat for native birds and frogs Secondary: • Maintain floodplain connectivity
Basin Watering Priorities	Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the southern connected Basin. Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations.		Improve the abundance and maintain the diversity of the Basin's waterbird population	Maintain the extent, improve the condition and promote recruitment of forests and woodlands

Table 3-4. The 2019-20 NSW environmental watering actions.

ACTION	TARGET ASSET	ACCOUNTING LOCATION	VOLUME (ML)	WATER SOURCE
LAC19/20-01	Kiagarthur		500	NSW licensed environmental water
LAC19/20-02	Merrowie to Murphy's Lake	Merrowie Creek off take	1,057	
LAC19/20-03	Booberoi	Booberoi Creek off take	956	
LAC19/20-04	Merrimajeel Creek to Murrumbidgil Swamp		6,273	
LAC19/20-08a	Noonamah Black Box Wetland	Private license and meter	370	

4 HYDROLOGY – THE WATERING ACTIONS

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 (Bunn and Arthington 2002; Nilsson and Berggren 2000). 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 (Gehrke et al. 1995; Kingsford 2000; Walker and Thoms 1993) 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 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 Monitoring, Evaluation and Research Plan for the Lachlan river system (Dyer et al. 2014b; Dyer et al. 2019c). 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 2019-20 environmental watering actions were delivered was one in which the river system was experiencing one of the worst sequences of dry conditions on record. While water from the 2016-17 floods had persisted across the landscape well into 2017, below average rainfall from the start of 2017 and 2018, accompanied by higher than average temperatures saw cumulative three-year inflows to Wyangala Dam that were some of the lowest ever recorded. Under such conditions, the focus for environmental water delivery in 2019-20 was on protecting important refuge habitat in an otherwise extremely dry landscape.

Four watering actions using Commonwealth environmental water were delivered to the Lachlan river system in 2019-20, three of which were delivered in combination with NSW environmental water (Table 3-2 to Table 3-4). Each of these watering actions were designed to either generate hydrological variability or support lateral connectivity. The first watering action targeted the hydrological variability in the main channel of the Lachlan River below Lake Brewster and the reed beds of the Great Cumbung Swamp at the end of the system. Water from this action was regulated and re-regulated to achieve environmental outcomes at multiple locations. The remaining actions targeted refuge habitat and riparian condition in Booberoi Creek, Yarrabandai Lagoon and Noonamah black box woodlands.

The first watering action was designed to deliver a spring fresh in the lower Lachlan River, providing refuge and supporting native fish en-route to the central reed beds of the Great Cumbung Swamp. This watering actions was modified as it passed through Brewster weir to provide both a small fresh and extended baseflows to the lower river. In addition, part of the water from this action held over in Brewster Weir pool for several months to maintain refuge for olive perchlet and later released to provide a small pulse in the lower Lachlan River channel in late autumn.

The second watering action was designed to provide spring and summer pulses to Booberoi Creek, providing lateral connectivity and maintaining refuge habitat.

The third watering action targeted Yarrabandai Lagoon and involved the delivery of 548 ML into the wetland to prevent it from drying out. In doing so, it aimed to generate lateral connectivity and provide refuge habitat for a range of species.

The fourth watering action targeted the Noonamah black box woodlands and involved the delivery of 220 ML of environmental water in combination with 40 ML of privately-owned water. This action provided longitudinal connectivity to support the health of black box communities, providing refuge for a range of species.

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 refuge habitat for a range of water dependent 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?

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 4-1) and from the mid Lachlan. 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 theEnvironment, Energy and Science (ESS) Group within the NSW Department of Planning, Industry and Environment (DPIE), formerly 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.

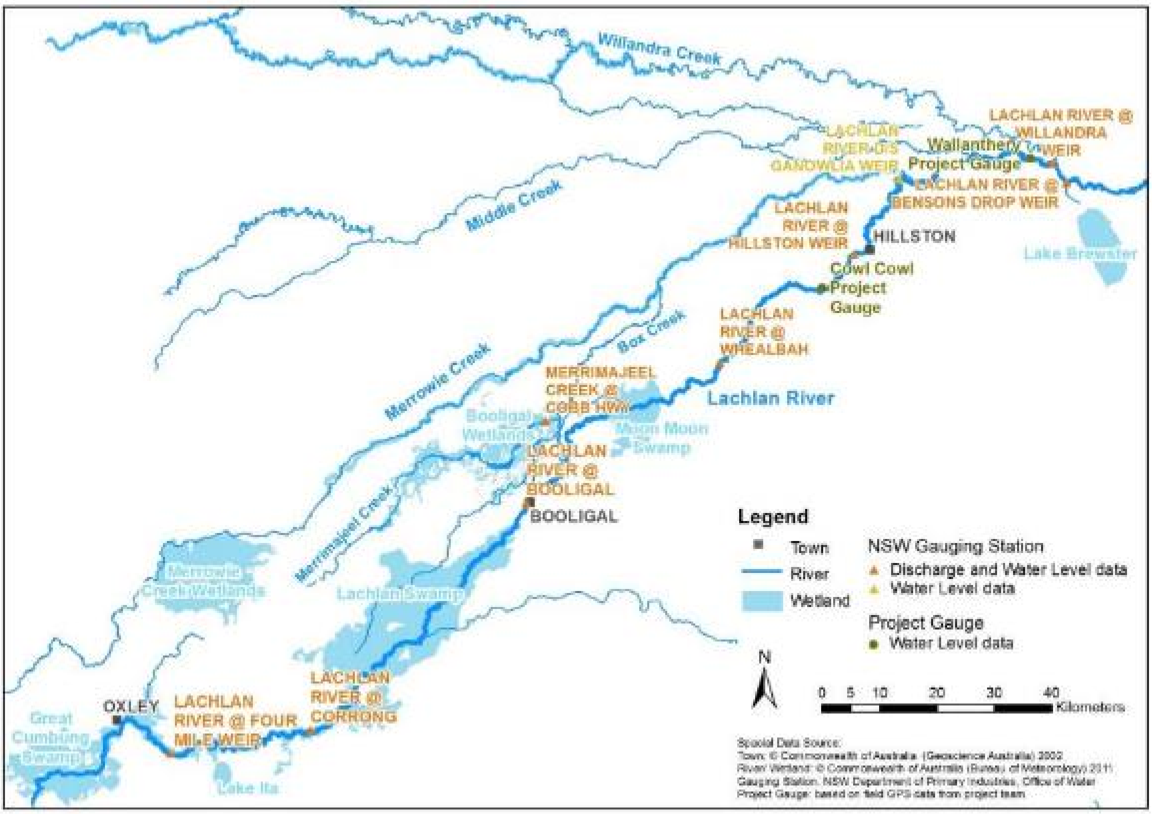

Figure 4-1. The location of relevant gauging stations in the lower Lachlan river system.

4.3 Results

A total of 22, 026 ML of Commonwealth environmental water was used in the Lachlan river system in 2019-20. This contributed approximately 8% of the flow in the river at Forbes, 23% at Hillston and 39% at Booligal (Table 4-1). The latter figure is likely an overestimate as very conservative losses have been applied to the reach between Hillston and Booligal.

Table 4-1. The 2019-20 accounted Commonwealth environmental water in the Lachlan river system.

	Total Annual Flow (ML)	Commonwealth environmental water (ML)
Forbes (Cotton's Weir)	276 166	22 026
Hillston Weir[1]	54 167	12 660
Booligal[2]	25 750	10,128

1 Based on advice from NSW Water; 2 Assumes a 20% loss rate 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 (8%), it was a significant proportion of the flow in the lower Lachlan River (around 40% of annual flow at Booligal). Commonwealth environmental water was strategically delivered to modify the flow regime to support several specific ecological objectives at a number of locations. The details of each of the watering actions are described in the following sections.

4.3.1 Watering Action 1: Supporting native fish and maintaining vegetation condition

The first watering action delivered flow components in the lower Lachlan River, providing refuge and supporting native fish en-route to the central reed beds of the Great Cumbung Swamp. This involved a small spring fresh designed to:

1. provide hydrological variability and connectivity through in-channel flows to maintain refuge areas for native fish and provide in-channel conditions that support native fish communities; and
2. inundate the core reed bed areas of the Great Cumbung to maintain vegetation condition and provide drought refuge to native waterbirds.

Part of the water from this action held in Brewster Weir pool for several months to maintain refuge for olive perchlet and later released to provide a small pulse in the lower Lachlan River channel in late autumn to:

1. provide hydrological variability; and
2. inundate part of the core reed bed areas of the Great Cumbung.

The water accounting position was set as Forbes (Cotton's Weir) and no flow targets were set for the lower Lachlan river system. The flows were managed to continue through the river system as a 'run of river'.

Releases for the first 2019-20 watering action commenced at Wyangala Dam on the 16th September 2019. The river rose rapidly, peaking at just under 2,000 ML/day on the 27th September. The peak was maintained until the 2nd October when the river dropped to under 500 ML/day over 5 days (Figure 4-2). As such, it provided a small fresh in the river (OEH 2018a)[2]. The small fresh was maintained along the river, arriving at Hillston Weir on the 9th October and peaking at just over 1,000 ML/day on the 15th October at the Weir. The fresh was modified as it passed through Brewster Weir to provide 37 days where environmental water was used to keep baseflows around 100 ML/day. Environmental water ceased at Hillston Weir on the 9th December (Figure 4-3). The spring fresh passed Booligal in late October arriving at Four Mile Weir on the edge of the Great Cumbung Swamp at the start of November 2019 (Figure 4-4 and Figure 4-5). The base flow support provided by Commonwealth environmental water continued at the gauge at Four Mile Weir until the 21st January.

The spring fresh inundated the central reed-beds and low lying areas of the Great Cumbung Swamp for approximately six weeks. The peak inundation occurred around the 27th November (Figure 4-6) and dried quite quickly with only remnant pools left by mid December. The baseflow support provided to the lower river did not translate to continued wetting of the Swamp post mid-December.

The portion of this watering action (2,000 ML), held over in Brewster Weir Pool, was released between 4th and 17th of May to coincide with natural inflows following rain, providing longitudinal

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[2] The Long Term Watering Plan (Part b OEH, 2018) describes small freshes at Forbes as flows of greater than 600 ML/day for a minimum of 10 days.

connectivity and creating variability in river height in the lower Lachlan River. This pulse passed Hillston Weir between the 9th and 24th May with peak flows at Hillston Weir of just under 290 ML/day placing it just into the flow range of a small fresh (OEH 2018a) (Figure 4-3). This small autumn fresh passed Booligal in late May (Figure 4-4) and arrived at the edge of the Great Cumbung Swamp on the 5th June (Figure 4-5).

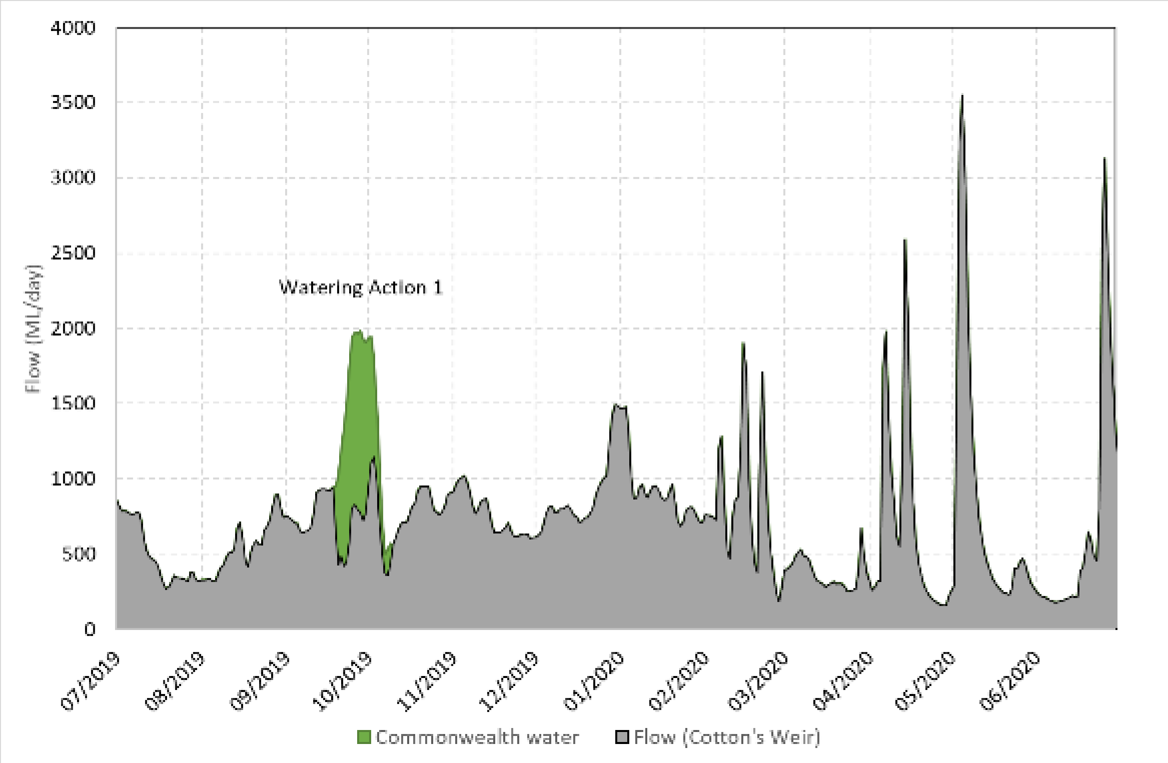


Figure 4-2. Flow at Cotton's Weir (Forbes) for the watering year 2019-20 showing Watering Action 1. Commonwealth (green) environmental water is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey.

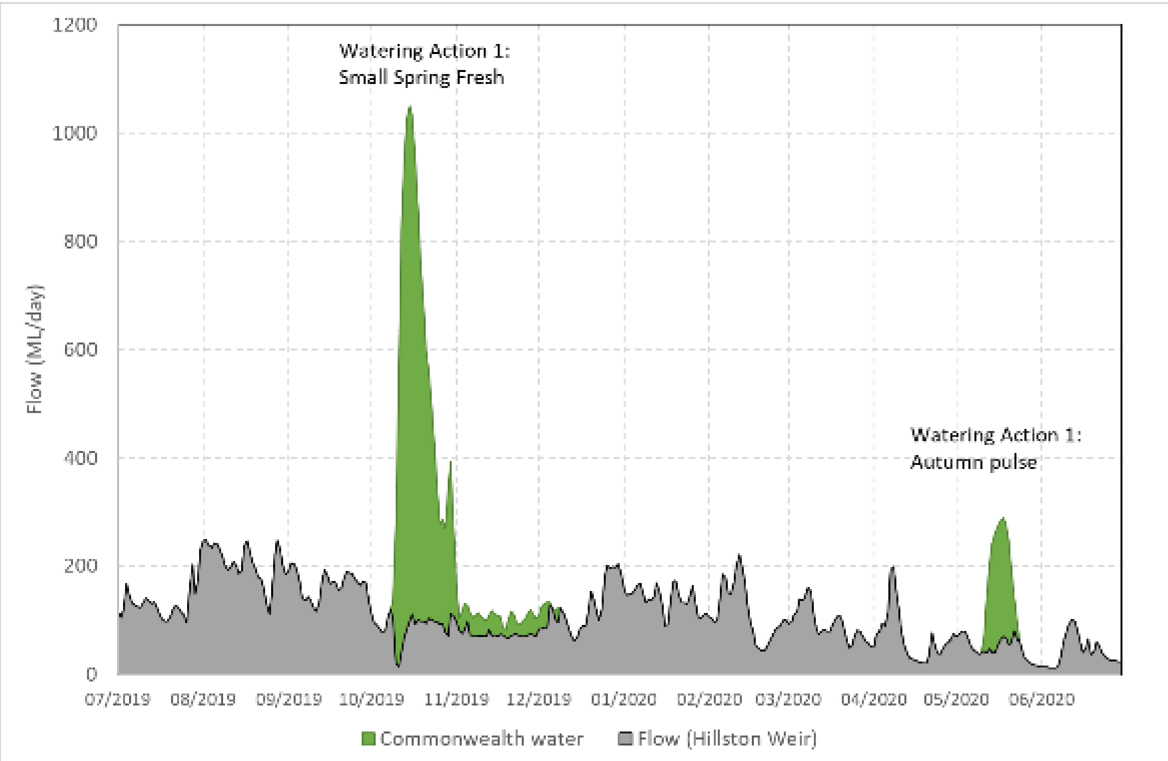


Figure 4-3. Flow at Hillston Weir for the watering year 2019-20 showing Watering Action 1. Commonwealth (green) environmental water is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey.

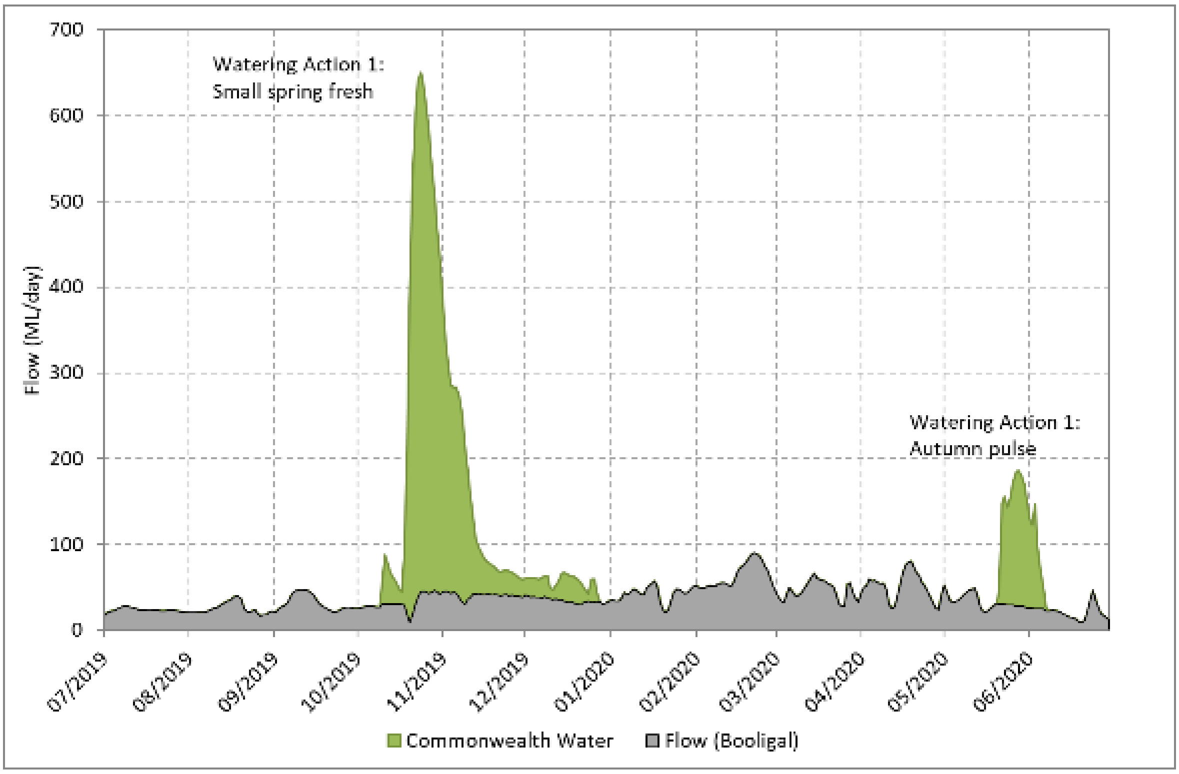


Figure 4-4. Flow at Booligal for the watering year 2019-20 showing Watering Action 1. Commonwealth (green) environmental water is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey.

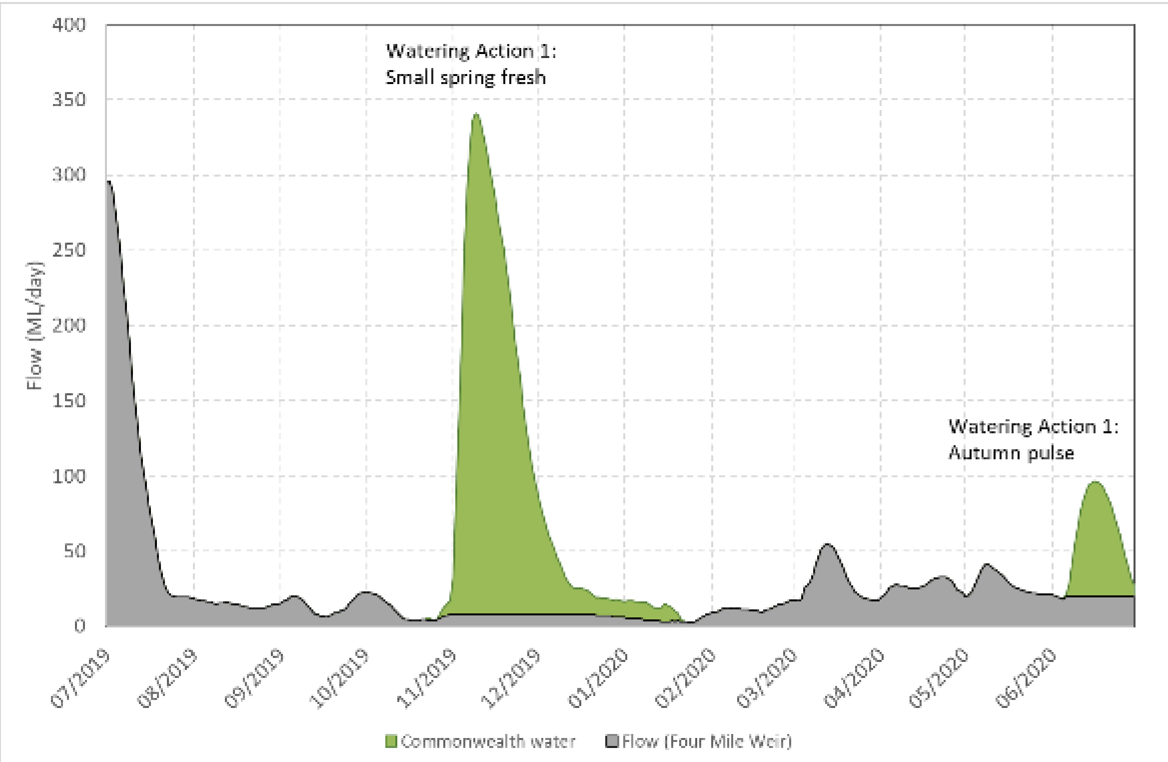


Figure 4-5. Flow at Four Mile Weir for the watering year 2019-20 showing Watering Action 1. Commonwealth (green) environmental water is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey.

The water level changes associated with the spring fresh ranged from 0.2 m at Cotton's Weir to almost 1 m at Four Mile Weir. The autumn pulse component of the watering action was considerably smaller and resulted in a change in water level of 0.2 m at Hillston Weir and just over 0.3 m at Four Mile Weir.

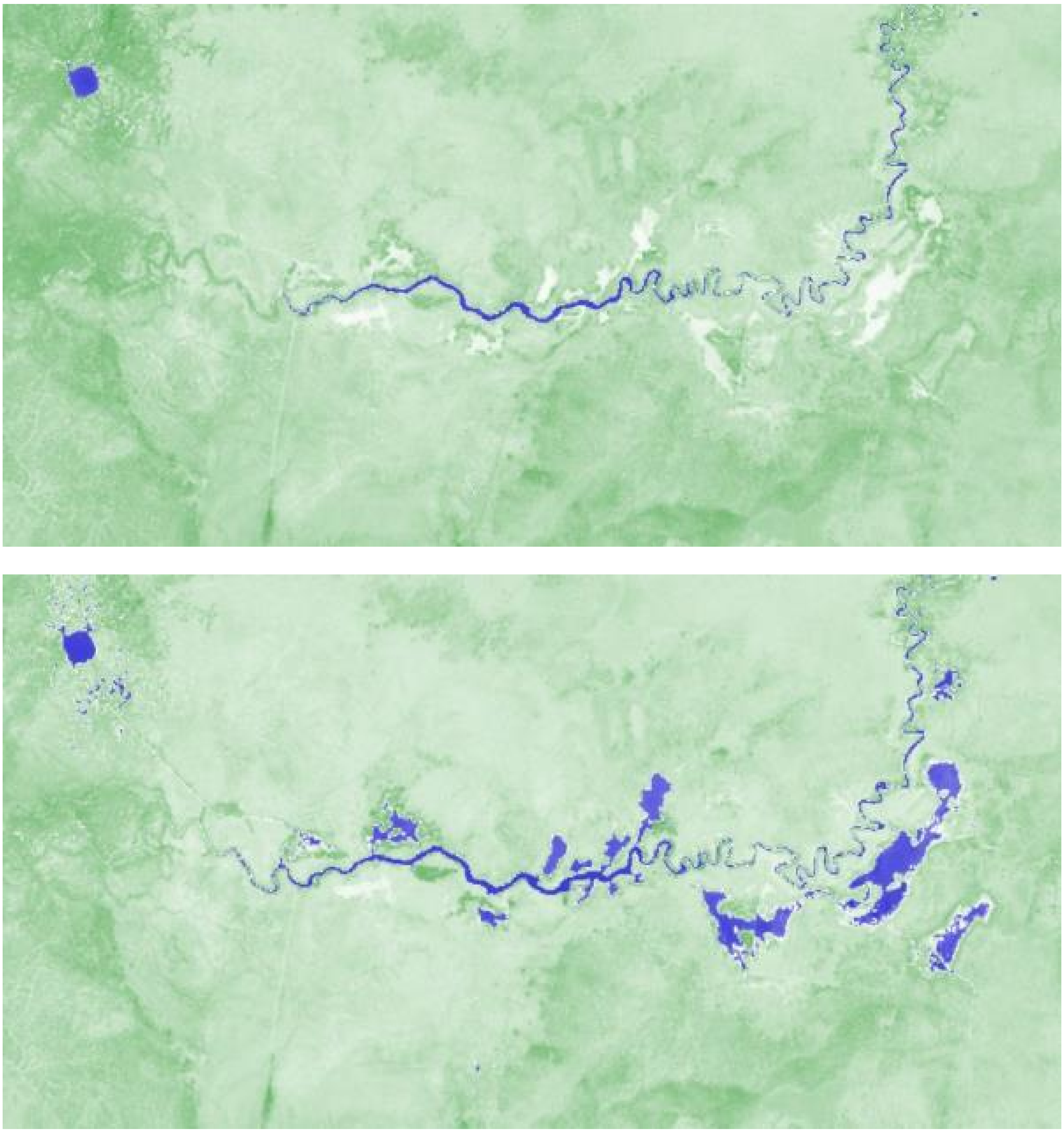


Figure 4-6. Sentinel imagery from the Great Cumbung Swamp prior to the arrival of environmental water (23rd October 2019, upper image), and at the peak of the spring/summer watering (27th November 2019, lower image).
Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground.

4.3.2 Watering Action 2: Supporting First Nations values, refuge habitat and vegetation health

The second watering action provided flow to Booberoi Creek to provide habitat for native fish and water plants, thus supporting First Nations values. Flow was delivered in two parts (Figure 4-7). The first commenced on the 4th October and delivered 2,900 ML over 57 days. The second commenced on the 17th December and delivered a further 1,572 ML of Commonwealth environmental water over 28 days. This action was not monitored under the MER program in 2019-20.

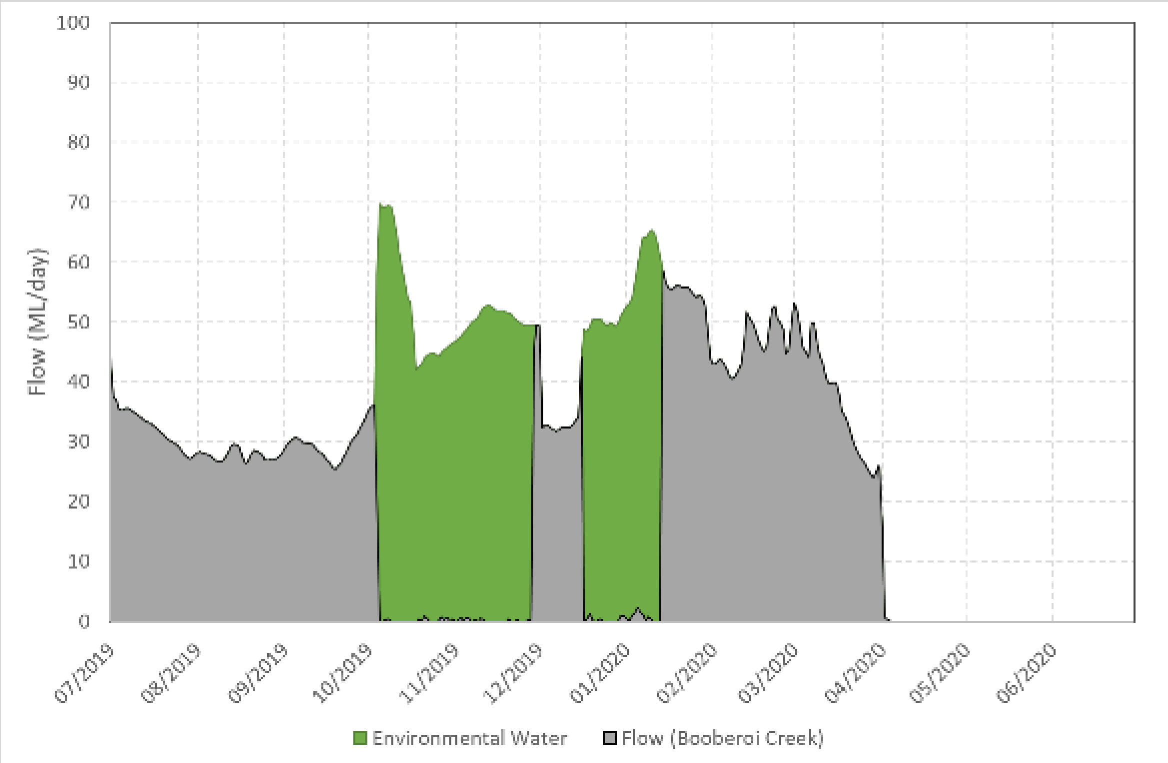


Figure 4-7. Flow at Booberoi Creek for the period 1 July 2019 to 30 June 2020 showing Watering Action 2. Commonwealth (green) environmental water is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey.

4.3.3 Watering Action 3 & 4: Yarrabandai Lagoon

A third Commonwealth environmental watering action targeted refuge habitat for native frogs and waterbirds as well as riparian vegetation in Yarrabandai Lagoon. A total of 548 ML, comprising 400 ML of Commonwealth environmental water and 148 ML of NSW environmental water, was delivered between the 13th September and the end of December 2019 to keep the lagoon inundated (Figure 4-8). Delivery rates were around 15 ML/day. This action was not monitored under the MER program in 2019-20.

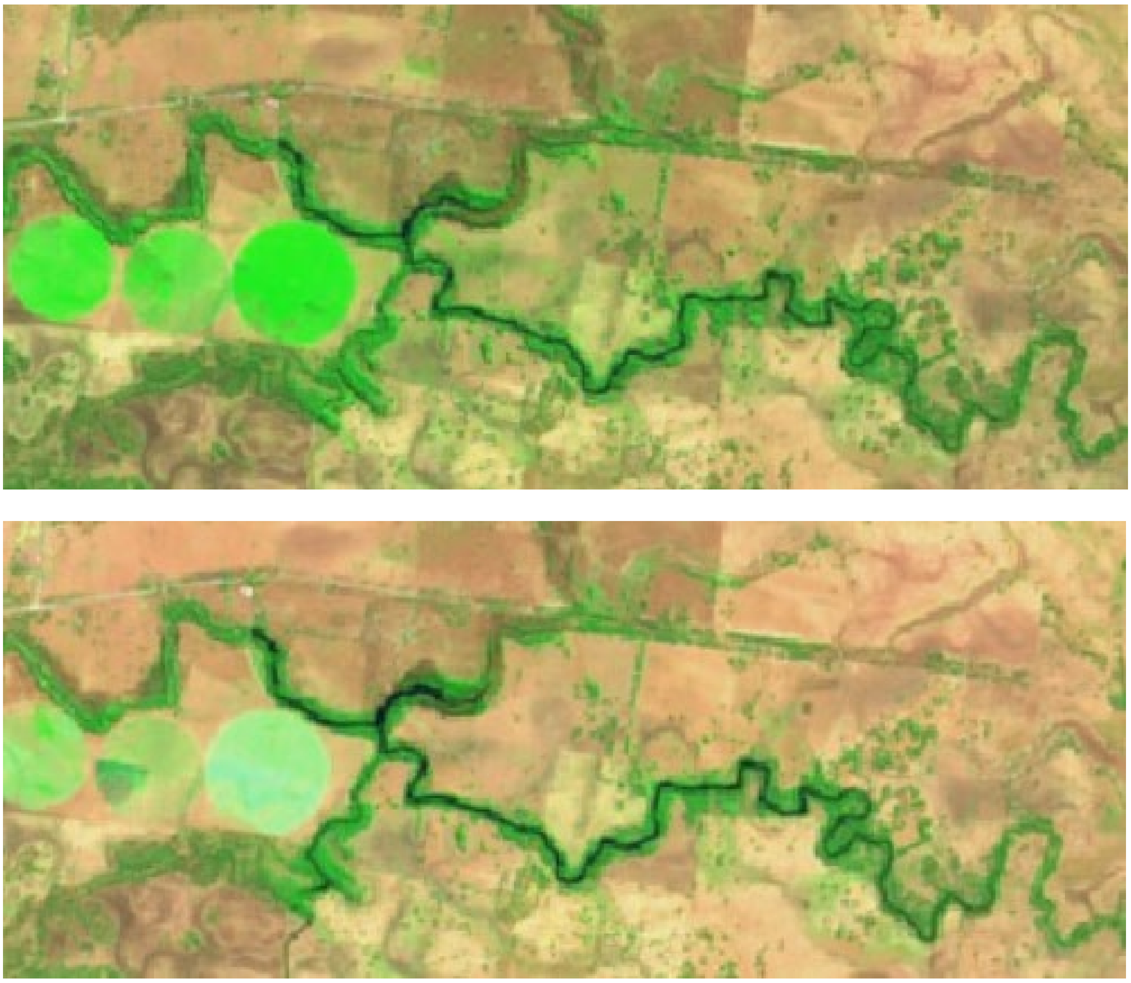


Figure 4-8. Sentinel imagery of Yarrabandai Lagoon area prior to the arrival of environmental water (5th September 2019, upper image), and towards the peak of the water (10th October 2019, lower image). Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground

4.3.4 Watering Action 4: Noonamah

The fourth Commonwealth environmental watering action targeted wetland vegetation (Black box health) and refuge habitat at Noonamah (Figure 4-9). A total of 260 ML was delivered to the wetland, comprising 126 ML of Commonwealth environmental water, 94 ML of NSW environmental water and 40 ML of privately owned water. This wetland is a new addition to the vegetation monitoring under the MER program, but the lack of pre-environmental flow data means that outcomes from this watering action will be difficult to infer.

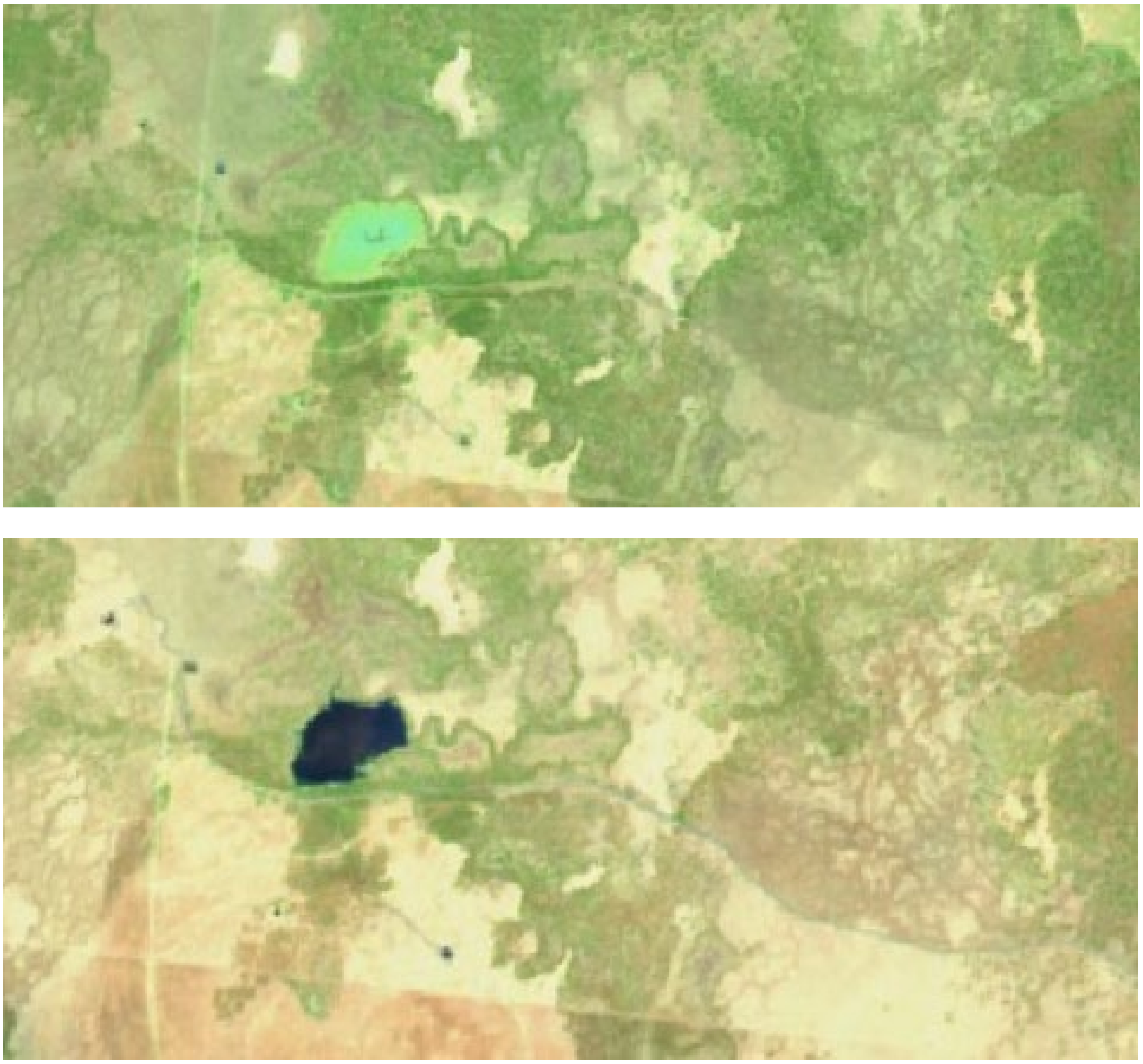


Figure 4-9. Sentinel imagery of Noonamah wetland area prior to the arrival of environmental water (28th September 2019, upper image), and towards the peak of the water (12th November 2019, lower image). Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground.

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 evaluate the efficacy of the watering actions for achieving ecological outcomes.

The four environmental watering actions delivered in 2019-20 were significant, using all of the Commonwealth's available volume in the Lachlan river system (not counting the volume held in the drought account). The use of the water attracted significant attention because of the dry conditions under which it was delivered. In combination, the volumes delivered contributed approximately 8% of the flow in the river at Forbes, 23% at Hillston and 39% at Booligal. The proportions are similar to those delivered in 2015-16 and in 2017-18 but were delivered in a much drier landscape context.

These watering actions were particularly significant for the lower reaches of the river, providing more than one third (39%) of the flow at Booligal.

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

1) What did Commonwealth environmental water contribute to refuge habitat for a range of water dependent species?

All four of the watering actions provided water to parts of the river system that would otherwise have been dry in 2019-20, thus contributing to the provision of aquatic habitat for water dependent species. The first watering action provided 2,000 ML to Brewster Weir pool for almost 8 months (October to May) to maintain refuge areas for olive perchlet as well as providing flow to the main channel and core reed beds of the Great Cumbung Swamp to provide refuge habitat. The conversion of part (just over 1200 ML) of the spring pulse (Watering action 1) into elevated baseflow downstream of Brewster Weir did not extend the duration that the reedbeds of the Great Cumbung Swamp were wet. It marginally increased the water level in the lower river channel (by between 5 and 10 cm).

The second watering action provided water to Booberoi Creek for 85 days ensuring that water remained in the creek during this time. The third and fourth watering actions provided water to Yarrabandai Lagoon and Noonamah wetland respectively providing refuge habitat for aquatic species in an otherwise dry landscape.

2) What did Commonwealth environmental water contribute to hydrological variability in the lower Lachlan River during periods of low flow?

The first watering action provided a small spring fresh in both the mid and lower Lachlan river system as well as a small autumn pulse in the lower Lachlan river system. In the mid reaches, the spring fresh provided at Forbes provided one of only five pulses to reach 2,000 ML/day in the watering year and the only one occurring in spring. In the lower reaches (downstream of Brewster Weir), this watering action provided the only small freshes in the river for the watering year; one in spring and one in autumn.

The spring fresh resulted in a change in water level of between 0.1 m and 2.0 m (depending on the position in the river), contributing to in-stream variability and providing an opportunity to boost productivity in the river channel. The conversion of a proportion of the spring pulse into baseflow downstream of Brewster Weir reduced the in-stream variability.

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

The watering actions delivered in 2019-20 connected in-channel habitats and provided flow to the end of the river system, when it would otherwise have continued to dry. Commonwealth environmental water achieved short periods of connectivity in channel, raising river levels between 0.1 and 1 m in height. As the water progressed downstream, environmental water became a greater proportion of the flow in the river, with around 40% 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/early summer. This generated opportunities for water birds to access habitat and provided water to the aquatic vegetation. The conversion of part of the spring pulse into baseflow did not extend the longitudinal connection, but continued to support flow in the river when conditions were rapidly drying.

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 spring fresh of watering action 1 passed down the river between October and December, which is known to be peak Murray cod spawning time. This introduces risks to nesting fish because of changes in flow velocities and sudden changes in river height which are not triggered by natural cues. This environmental watering action provided only a small change in water level in the majority of the river channel (between 0.1 m and 0.4 m). The consequences for larval Murray cod are addressed in Chapter 7.

The style of environmental water management employed in the Lachlan catchment for the past four years uses a single parcel of water to achieve multiple benefits throughout the river system. Such as approach is an efficient and effective use of water and in previous years it has presented substantial challenges for evaluating the watering actions, particularly with the timely provision of accounting data. Accounting of the spring watering action was provided early in 2019-20 which has been incredibly valuable for timely reporting, however these have been the only data received for the 2019-20 watering actions. It remains a recommendation that more regular accounts be prepared to support the reporting requirements.

The conversion of a portion of the spring pulse into elevated baseflow used around 1200 ML and appeared to provide an operational (water delivery) outcome rather than being ecologically driven. There is limited documentation of the rationale for this decision. Chapter 5 shows that the lower river would likely have ceased to flow at this time and it is not clear what ecological outcomes were sought by providing low flows at this time. It is recommended that such decisions be better documented to assist with reporting and, in times when water delivery is controversial, if environmental water is being used to support operational deliveries this needs to be clearly explained to the broader community.

CEWO Adaptive Management Response: The CEWO agrees that in the future, more specific environmental objectives should be set for the elevated baseflow component of similar watering actions. The CEWO considers that the elevated baseflow component of this watering action contributed to the broader objectives applied to all of the watering actions implemented in the

Lachlan catchment during 2019-20 – those objectives being based around maintaining refuge habitat across the river system.

In attempting to maximise the provision of refugia, environmental water was used to target nine locations in 2019–20, including the mid and lower-Lachlan river channel. Water was successfully provided to seven of these, with channel delivery issues and slowing flow rates at the end of the system affecting the ability to get water into Lake Comayjong and Lake Bunumburt. On-ground observations by water managers and local landholders identified the channel delivery issues and the watering actions were modified. Such delivery issues are likely to occur at end of system wetlands when conditions are very dry and careful thought should be given to targeting these types of locations under such conditions. There was a robustness in the watering attempt of Lake Comayjong and Lake Bunumburt, with watering actions able to be modified when it was decided that they would be unsuccessful and the water was diverted to other parts of the Great Cumbung Swamp, still providing refuge. There was no known validated information on commence to fill (CTF) and volumes to fill (VTF) and duration required to inundate these wetlands as neither had been specifically targeted with an environmental water order prior and there is no metering requirement. This was an important opportunity to observe and learn as part of the adaptive management cycle. In the case of Comayjong, the trial identified a structural constraint (collapsed road culvert) and temporary gauging by WaterNSW Hydrometrics provided valuable insights into the capacity of the gravity fed channel to assess against the cost–benefit of pumping. DPIE–ESS and the landholder were assisted by Balranald Shire Council (BSC) to improve the infrastructure and the Lachlan EWAG visited the site as engagement and capacity building exercise also supported by Flow-MER via engaging Drone contractor to monitor inundation extent (Mal Carnegie).

5 HYDROLOGY – WATER RESOURCE DEVELOPMENT AND ENVIRONMENTAL WATER

5.1.1 Introduction and methods

The flow regime of a river shapes the evolutionary and ecological processes which occur within the river and its floodplains. Critical flow components such as magnitude, frequency and duration of a specific flow condition (such as cease-to-flow, small and large fresh, and overbank flows) structure river ecosystems (Poff et al. 1997) and as such are often defined at locations along a river (for example the lower Lachlan River, OEH NSW 2018). These flow characteristics contribute to the hydrological regime on floodplains via lateral connection between the river and its floodplain (Junk et al. 1989). 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). Understanding how these flow components have changed under current flow conditions is vital in determining the impacts of flow regulation and how environmental water contributes to maintaining the natural flow regime.

This chapter provides the results of hydrological modeling over a short (1 year), medium (the 6 years of LTIM/MERP), and long (135 years) term, to improve our understanding of the impacts of flow regulation on in-channel flows and wetland inundation in the lower Lachlan River system. Further, we describe the contribution that environmental water has made to the regulated flow regime during this watering year (2019-20) and over the LTIM and MER Projects (2014-20) in the context of the natural flow regime.

Firstly, we describe the hydrological character of the Lachlan River over this watering year (2019-20) under current (actual) flow conditions and compare this to modeled natural (without development) flows from two river gauges along the lower Lachlan River (Whealbah and Booligal). We then compare current (actual) flow conditions with modeled natural (without development) flows over the last six years of LTIM and MER Projects. In these sections, we highlight how the hydrological conditions have changed related to river regulation and describe the contribution that environmental water has made. We have selected a range of wetlands in which we monitor vegetation condition and diversity, which have or would have (under natural flow conditions) been inundated over this period (either 1 or 6 years). Using commence to fill (CTF) values derived from Higgisson et al. (2020) and the modelled natural and actual current flow records we calculated eight connection metrics representing important components of the flow regime of intermittent streams (Olden and Poff 2003). The approximate volume (ML) of water that was likely to have inundated the floodplain was estimated as the total flow above the CTF value at each site. These volumes of water may have inundated other sites with similar positions on the floodplain. Modeling 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). The modeled natural (without development) flow conditions have water management infrastructure and water extraction activities removed.

Using long-term hydrological data sets under modeled flow scenarios, we then describe five key flow components and how they have changed under current flow conditions through comparing modeled natural (without development) flows to modeled current (with development) flow conditions using 135 years of modeled flow data at Booligal gauge. The use of long-term data sets such us this improves our ability to effectively describe the characteristics in river flow patterns (Poff et al. 1997). The key flow components we used in this analysis were small freshes, large freshes, small overbanks, and extreme high and low flow events. These components are characteristic of highly variable river systems such as the Lachlan River. We compared modeled flow scenarios (natural and current flow conditions) to account for changes in climatic conditions, land-use effects and water infrastructure which have occurred in the Lachlan Catchment over the past 100 years. The modeled natural (without development) flow conditions have water management infrastructure and water extraction activities removed, while the current flow conditions represent current water resource development conditions, including current water supply infrastructure and licensed extractions modeled over the 135 years of available (daily) flow data at Booligal.

A small fresh occurs when > 150 ML/day passes Booligal gauge for > 10 consecutive days, a large fresh occurs when > 650 ML/day passes Booligal gauge for > 5 consecutive days, and a small overbank occurs when > 2700 ML/day passes Booligal gauge for > 30 consecutive days (OEH 2018b). Here we report an extreme high flow event as the average maximum annual discharge (ML/day) (magnitude), over the 135 years of flow records, and the number of days per year that the daily flow exceeds the average maximum annual discharge, under natural flow conditions (frequency) and their interannual coefficient of variation (CV) (see Poff et al. 2007). The same procedure was undertaken to calculate extreme low flow events. We present the percentage change from natural flow conditions to current flow conditions for these five key flow components.

5.1.2 This watering year (2019-20)

The hydrological character of the Lachlan River during the 2019-20 watering year was markedly different under actual flow conditions compared to what would have happened under natural flow conditions (Figure 5-2). The flow of the Lachlan River is less variable and more stable under current flow conditions. The Lachlan River remained low and within channel, under natural flow conditions for the first half of the watering year and would have ceased to flow for 81 days at Whealbah and 82 days at Booligal over the watering year. This would have occurred between July 2019 and February 2020. Under actual flow conditions the river did not cease to flow during the 2019-20 watering year. The low-flow conditions of 2019 changed abruptly in early February 2020 under Natural flow conditions, with much more water in the river and much greater variability in flow conditions, with five (obvious) high flow events (one exceeding 2,500 ML/day at Whealbah), over the second half of the watering year (Figure 5-2). Over this same period, the actual river flow of the Lachlan River was much less variable, with much less water in the river. The one high-flow event which occurred over the 2019-20 watering year, was environmental watering action 1 (the peak in Late October and early November on Figure 5-1 and Figure 5-2). This environmental water event peaked at nearly 1,000 ML/day at Whealbah and 650 ML/day at Booligal. Apart from this event, the flow remained within channel and between approx. 20 and 230 ML/day at Whealbah throughout the year.

Seven of the wetlands in which we monitor vegetation diversity would have been inundated during the 2019-20 watering year under natural flow conditions (Table 5-1), Hazelwood not shown in the table would have briefly connected for 2 days in March 2020. All river-floodplain connection events would have occurred between February and June 2020 with no connection events occurring from July through December 2019. Lake Ita would have connected eight times for a total of 39 days (approx. 10 000 ML) and Lake Marool seven times for a total of 31 days (7,255 ML). Under actual flow conditions, The Great Cumbung Swamp and Nooran Lake were the only monitoring sites that connected to the river (Table 5-1) and this was attributed to environmental watering action 1. This environmental water action connected the Great Cumbung Swamp to the river for 10 days in November and resulted in 574 ML of water inundating the Swamp and surrounding temporary wetlands including Nooran Lake.

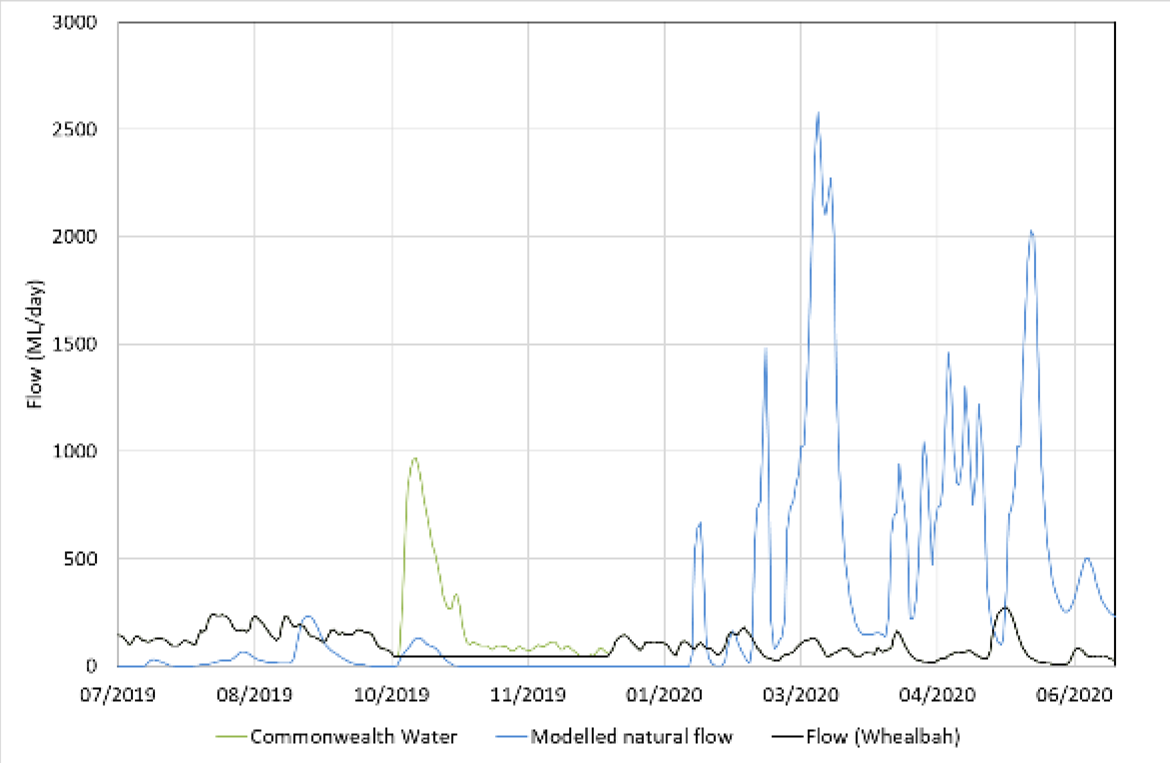


Figure 5-1. Modelled natural flow (ML/day) (blue hydrograph) and actual river flow (black hydrograph) of the Lachlan River at the Whealbah river gauge from 1 July 2019 to 30 June 2020. The green shows an estimate of the environmental water actions.

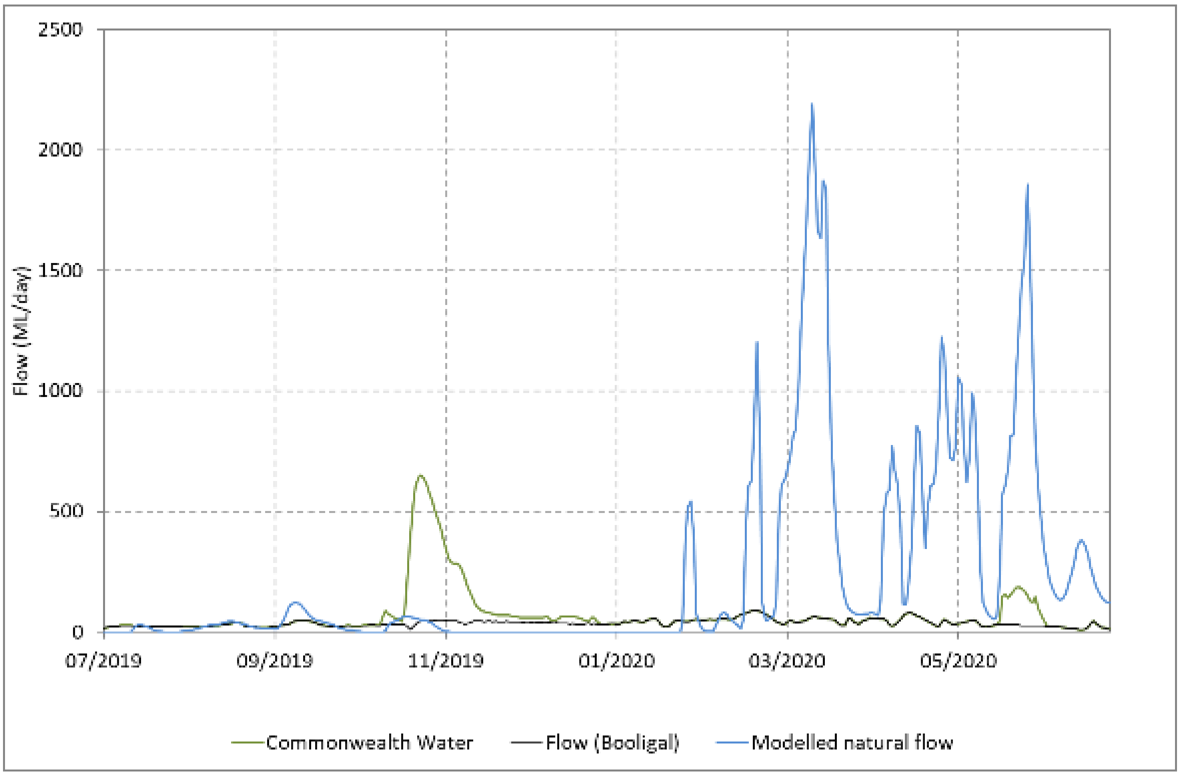


Figure 5-2. Modelled natural flow (ML/day) (blue hydrograph) and actual river flow (black hydrograph) of the Lachlan River at the Booligal river gauge from 1 July 2019 to 30 June 2020. The green shows the environmental water actions.

Table 5-1. River – floodplain connection metrics for six locations on the floodplain of the lower Lachlan River under modelled natural flow conditions (N) and current flow conditions (C) over the 2019-20 watering year.
** The Great Cumbung Swamp (GCS) includes Nooran Lake. They have the same CTF and are in close proximity.*

	The Ville CTF 950 ML/day (Corrong)		Moon Moon CTF 1600 ML/day (Whealbah)		Lignum Lake CTF 900 ML/day (Corrong)		Lake Marool CTF 730 ML/day (Corrong)		Lake Ita CTF 650 ML/day (Corrong)		GCS * CTF 350 ML/day (Corrong)	
	N	C	N	C	N	C	N	C	N	C	N	C
No. of connections	4	0	2	0	5	0	7	0	8	0	8	1
Days connected (total)	18	0	15	0	19	0	31	0	39	0	69	10
Mean days connected	5	0	8	0	4	0	4	0	5	0	9	10
Longest connection	9	0	10	0	9	0	10	0	13	0	19	10
No. of disconnections	5	365	3	365	6	365	8	365	9	365	9	2
Mean days disconnected	70	365	117	365	58	365	42	365	36	365	33	178
Longest disconnection	244	365	253	365	244	365	244	365	243	365	219	233
Total volume (ML)	2,195	0	6,973	0	3,140	0	7,255	0	9,927	0	25 327	574

5.1.3 Six years of river regulation and environmental water

Over the past six years (2014-20) the flow of the Lachlan River would have experienced a more variable flow regime under natural flow conditions (Figure 5-3). The Lachlan River would have ceased to flow over the last six years for 390 days at Whealbah and 201 days at Booligal under natural flow conditions. Larger flow events that connect the river to the floodplain would have been much more frequent and greater in magnitude. The reedbed within the Great Cumbung Swamp had the greatest number of connection events and days connected of all sites under natural flow conditions, with a total of 44 connection events and 30.4% of days connected. Under natural flow conditions, the longest disconnection ranged from 333 days at the Great Cumbung Swamp reedbed to approximately 1300 days at Whealbah RRG and Nooran Lake RRG over the six years.

Under current flow conditions the number of connection events was substantially less across all nine sites. Apart from the large flood event in 2016-17, most sites did not connect over the past six years. This resulted in less total days connected, greater number of days between connection events, and lower total volumes of water ending up on the floodplain (Figure 5-3). The total volume of water which inundated the floodplain of the lower Lachlan is approximately half (54%) of what would have occurred under natural flow conditions (Table 5-2). Lake Ita, Lake Marool and Moon Moon Swamp would have connected at least once a year, while under current flow conditions they remained dry for over three consecutive years.

Environmental water has increased the number of days the floodplain connected to the river and total volumes of water at Lake Ita, Lake Marool, Moon Moon and the Great Cumbung Swamp (including Nooran Lake) over the past six years. Environmental water provided five additional connection events (increase from 4 to 9) to the Great Cumbung Swamp that would not have happened under current flow conditions providing an additional 11 417 ML of water to the reedbed and surrounding temporary floodplain lakes (such as Nooran Lake). In the absence of environmental water, the flow of the Lachlan River over the past six years would have been far less variable and more homogenous, with fewer medium to high flow events (Figure 5-3).

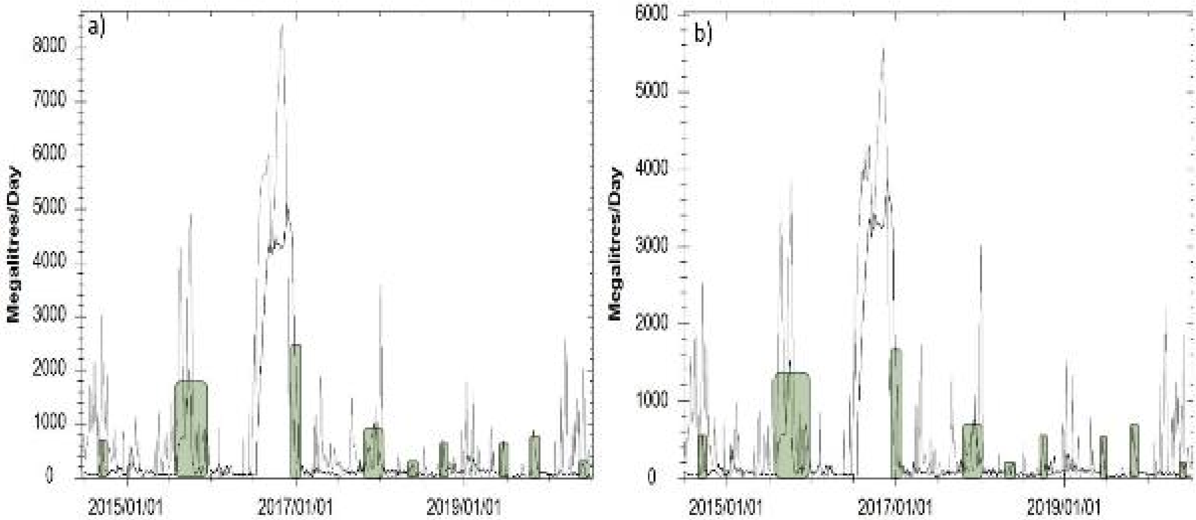


Figure 5-3. Modelled natural flow (ML/day) (grey hydrograph) and actual river flow (black hydrograph) of the Lachlan River at a) Whealbah river gauge and b) Booligal river gauge on the Lachlan River from 1 July 2014 to 30 June 2020.

Table 5-2. River – floodplain connection metrics for nine locations on the floodplain of the lower Lachlan River under modelled natural flow conditions (N), and current (actual) flow conditions including Environmental water (C/w), and without Environmental water (C/wo) from 1 July 2014 through 30 June 2020.

	No. of connections			% of days connected			Mean days connected			Longest connection			Mean days disconnected			Longest disconnection			Total volume (ML)		
	N	C/w	C/wo	N	C/w	C/wo	N	C/w	C/wo	N	C/w	C/wo	N	C/w	C/wo	N	C/w	C/wo	N	C/w	C/wo
Booligal Swamp	5	1	1	7.8	5.6	5.6	34	124	124	135	124	124	337	1,034	1,034	905	1,285	1,285	231 789	99 764	99 764
Hazel-wood Lagoon	8	1	1	8.1	6.1	6.1	22	133	133	75	133	133	224	1,028	1,028	795	1,283	1,283	471 014	203 860	203 860
Lake Ita	33	2	2	18.9	8.7	8.1	13	96	89	164	170	160	52	667	672	378	1,267	1,277	372 804	259 460	256 082
Lake Marool	29	2	2	17.4	8.4	7.9	13	93	87	160	167	158	60	669	673	379	1,268	1,277	341 195	244 346	242 021
Moon Moon	14	2	2	12.2	7.8	7.5	19	86	82.5	144	160	154	128	674	676	423	1,271	1,277	720 934	374 258	357 952
Whealbah	5	1	1	8.5	6.2	6.2	37	135	135	139	135	135	334	1,028	1,028	904	1,283	1,283	482 777	209 452	209 452
Whealbah RRG	3	1	1	7.2	5.4	5.4	52	119	119	132	119	119	509	1,034	1,034	1,310	1,286	1,286	326 823	95 188	95 188
Nooran Lake RRG	5	1	1	7.4	6.3	6.3	32	137	137	134	137	137	338	1,028	1,028	1,273	1,282	1,282	153 020	123 639	123 639
GCS Reedbed	44	9	4	30.4	13.3	10.3	15	32	56.3	199	177	164	34	190	393	333	326	923	532 179	326 358	314 941

5.1.4 Changes to key flow components under current conditions (using 135 years of modeled flow data)

5.1.4.1 Freshes and small overbank flows

Comparing 135 years of modelled natural and current flow conditions, under natural flow conditions, at Booligal, on average a small fresh would have occurred at least twice a year, a large fresh three times a year, and a small overbank flow once every two years. These key flow components would have experienced a high degree of interannual variability.

The frequency and interannual variability in the occurrence of small freshes, large freshes and small overbank flows have all been reduced under current flow conditions. The frequency of small freshes has not been changed considerably, occurring 8% less often. However, the frequency of large freshes and small overbank flows has been substantially reduced, and now occur approximately half as often as they would have under natural flow conditions (Table 5-3).

Over the past six years, environmental water has made a significant contribution to increasing the number of small freshes that have occurred in the lower Lachlan at Booligal. Without environmental water a total of eight small freshes would have occurred, while environmental water has contributed to an additional four small freshes, resulting in an average of two freshes each year compared with 1.3 without environmental water. Environmental water has not contributed to large freshes or small overbank flows.

Table 5-3. The frequency and interannual variability of small freshes, medium freshes, and small overbank flows at Booligal Gauge on the Lachlan River and the percentage change from natural conditions using 135 years of modelled Natural and Current flow conditions, and actual flow data with and without commonwealth environmental water over 2014-20.

Note: Small fresh: > 150 ML/day for > 10 consecutive days, large fresh: > 650 for > 5 consecutive days, and small overbank: > 2700 ML/day for > 30 consecutive days. Numbers in brackets are the total number of each flow component which occurred between 2014-20.

	Natural Flow Conditions	Current Flow Conditions	Percentage change	2014-20 WO/CEW	2014-20 W/CEW
Frequency of small freshes (per year)	2.73	2.52	-7.69	1.3 (8)	2 (12)
Interannual variability in Frequency of small freshes (CV)	1.48	1.26	-14.86		
Frequency of large freshes (per year)	3.18	1.32	-58.49	0.5 (3)	0.5 (3)
Interannual variability in Magnitude of large freshes (CV)	1.63	1.37	-15.95		
Frequency of Small overbank flows (per year)	0.54	0.28	-48.15	0.2 (1)	0.2 (1)
Interannual variability in Frequency of small overbank (CV)	0.68	0.55	-19.12		

5.1.4.2 Extreme high and low flow events

The Lachlan River naturally experiences a highly variable flow regime, ranging from an average maximum and minimum annual daily discharge of 3,646 ML and 16.2 ML respectively. The magnitude of extreme high flow events is 30% less under current flow conditions, and now occur half the time they would have under natural flow conditions (Table 5-4). The maximum annual flow in many years is now much lower than it would have been under natural flow conditions (Figure 5-4), and this has increased the interannual variability in magnitude of extreme high flows under current flow conditions (Table 5-4). The frequency of extreme low flow events and interannual variability in extreme low flow events have both been substantially reduced, occurring less often and now with little variation between years.

Table 5-4. The magnitude (the average maximum annual discharge (ML/day), frequency (the number of days per year that the daily flow exceeds the (natural) average maximum annual discharge), and interannual variability in magnitude and frequency (CV) of extreme high and low flows for modeled natural and current flow conditions at Booligal, and the proportional difference between modeled natural and current flow conditions.

	Natural Flow Conditions	Current Flow Conditions	Percentage change
Magnitude of High flows (ML/day)	3,646	2,545	-30.20
Interannual variability in Magnitude of high flows (CV)	1,428	1,752	22.69
Frequency of high flows (per year)	23.1	11.2	-51.52
Interannual variability in Frequency of high flows (CV)	39.6	30.9	-21.97
Magnitude of Low flows (ML/day)	16.2	5.1	-68.52
Interannual variability in Magnitude of low flows (CV)	43.9	9.6	-78.13
Frequency of Low flows (per year)	64.5	10.8	-83.26
Interannual variability in Frequency of low flows (CV)	63.5	10.1	-84.09

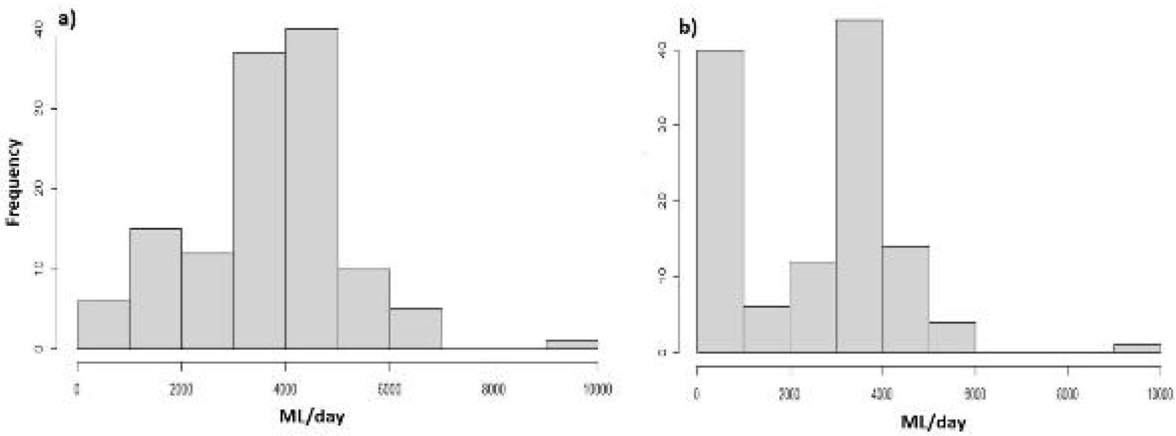


Figure 5-4. Histogram showing the maximum annual discharge (ML/day) at Booligal for each year (1895-2020) under a) natural flow conditions and b) current flow conditions.

5.1.5 Discussion

The Lachlan River naturally experiences a highly variable flow regime experiencing large differences in flow magnitude and interannual variability. A highly variable flow regime is a defining feature of Australia's dryland river systems (Walker et al. 1995). This variability in flow has resulted in a reliance on flow regulation to improve the reliability of water supply in the Lachlan Catchment. The flow of the Lachlan River has been extensively modified by flow regulation and water resource developments. The Lachlan River now experiences less flow variability and the high flows have been reduced in magnitude and frequency resulting in an overall more homogenous flow regime.

Over the past six years, environmental water has made an important contribution to replacing components of the natural flow regime which were removed under current flow conditions. Environmental water has provided a range of small to medium sized flow events (especially small freshes), which would not have occurred otherwise under current flow conditions. Environmental water has not contributed to increasing the number of larger flow events such as overbank flows. Despite this, environmental water has increased the duration of a large flood event (in early 2017), increasing the number of floodplain-river connection days and amount of water on the floodplain during this event.

The fact that environmental water contributes more so to smaller flows than larger ones, means that certain wetlands are more likely to be flooded using environmental water, and this is related to the type and location of the wetland. For example, the Great Cumbung Swamp and surrounding temporary floodplain lakes such as Nooran Lake, Clear Lake, and Lake Bunumburt are at the terminus of the Lachlan River. The low topography in this area, and terminal nature of the wetlands and lakes, means that it naturally floods with small freshes. As such, this part of the Lachlan is often targeted with environmental water. In contrast many of the wetland sites along the lower Lachlan river system require much higher flows to become inundated, and environmental water has not provided the higher flows that would enable these wetlands to be targeted. This means that these higher wetlands are likely to continue to decline in condition because they no longer receive the frequency of inundation required to support their ecosystems and functions.

6 STREAM METABOLISM AND WATER QUALITY

6.1 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 alter primary production and organic matter breakdown rates in several ways (Bernhardt et al. 2018). Flow can mobilize carbon and nutrients off in-channel benches, the floodplain or from upstream (Boulton and Lake 1992; MDFRC 2013; Stewardson et al. 2013), potentially increasing GPP (nutrients) and/or ER (organic matter). Environmental flows may also affect turbidity, which can act to reduce GPP, as a consequence of light limitation, alter water temperature (warmer temperatures tend to increase ER and to a lesser extent GPP). The direct physical effects of environmental flows can dilute water column primary producers and bacteria, and scour biofilms from in-channel substrate which can reduce GPP and ER.

In this section we evaluate the outcomes of providing Commonwealth environmental water to the lower Lachlan river system in terms of measured changes in water nutrients and GPP, ER, K and the GPP/ER ratio.

The 2019-20 Commonwealth environmental watering actions in the lower Lachlan river system are described in detail in Section 3 and 4 and Table 3-2 (on page 10).

<u>Watering Action 1</u> comprised a small spring fresh in the Mid and lower Lachlan river system and a later autumn fresh in the lower Lachlan river system (Section 4.3.1). These components were designed to provide hydrological variability in the river channel contributing to in-stream productivity to maintain native fish condition.

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

6.1.1 Selected Area Specific evaluation questions:

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

6.2 Methods

The evaluation of the stream metabolism and water quality outcomes used a combination of river height data (as described in Section 4), 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 River sites (Wallanthery (WAL), Lanes Bridge (LB), Cowl Cowl (CC) Whealbah (WB), see exact locations in Figure 6-1.

The water quality parameters dissolved oxygen and temperature were measured using the automatic stream loggers. Conductivity, pH and turbidity are manual point measures and were recorded using a handheld water quality meter. For nutrients and chlorophyll a water samples were taken two 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 sample were analyzed at University of Canberra.

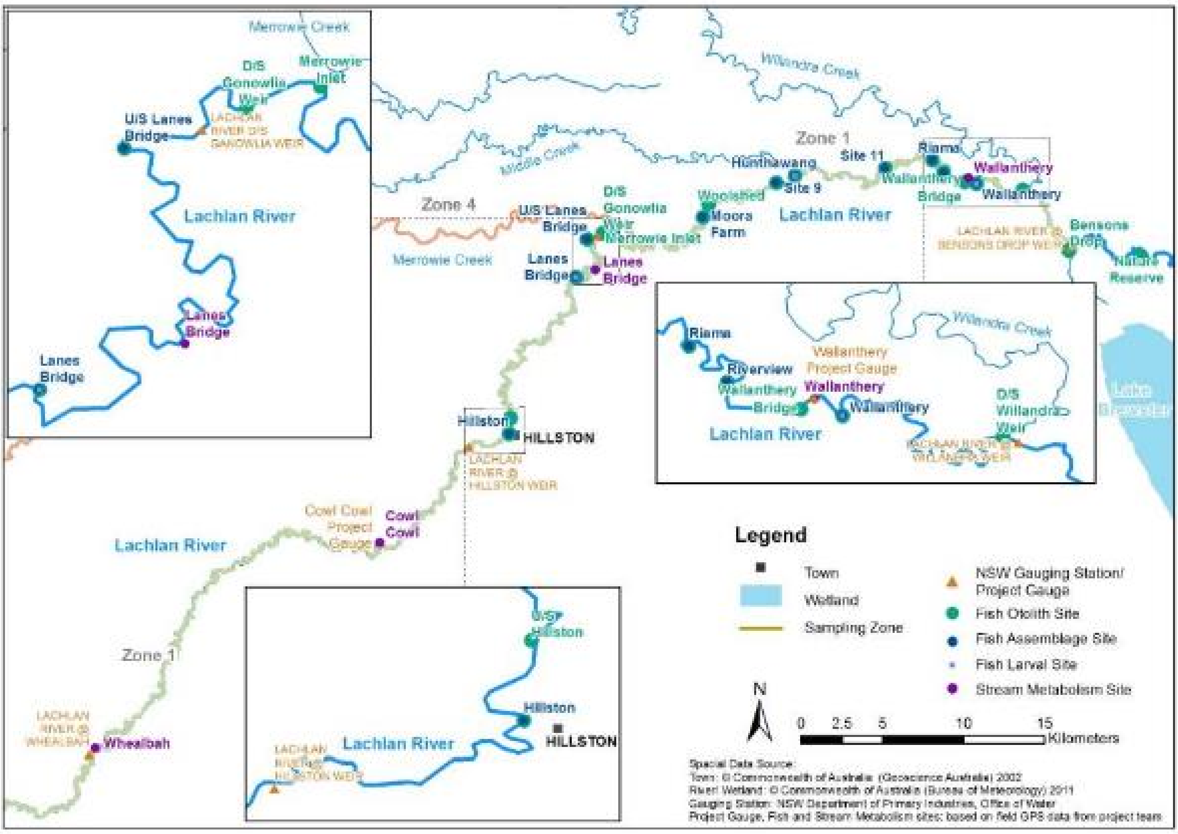


Figure 6-1. Map of monitoring sites for fish, larval fish and stream metabolism in the lower Lachlan river zone L1.

Stream metabolism was measured applying the standard methods for the MER program. An oxygen logger was installed in the water column at the edge of the stream (Figure 6-2).

Figure 6-2. Stream metabolism sites in the lower Lachlan River (top left to bottom: LB, WAL, WB (CC not shown but similar to LB).

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).

To reduce the loss of "incorrect" days via sudden dissolved oxygen drops down to values below 4 mg/L we interpolated the 10-minute-interval readings unless 12 consecutive readings occurred at the low level (suggest a true reduction in water column oxygen). In practice all sudden reductions were for very short periods (a single reading to 4 readings), indicating organic material such as leaf material temporarily lodging on the sensor.

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 reviewed. The version of the model used incorporated a series of updates which have been applied across the MER program and was current from the 18th of June 2018 (V2.3.3).

In the 2019-20 period we used miniDOT loggers at the four sites in the lower Lachlan River and installed two loggers at Lanes Bridge for a short period (Figure 6-1).

The five download dates for the reporting period 2019-20 are:

1. 4 - 6th of August 2019,
2. 5th of November 2019,
3. 3 or 18th of December 2019,
4. 6 and 7th of May 2020, and
5. 5th of June 2020.

As the latest download was only shortly before the reporting period finished in early June, a full calendar year of data is not available. During the year 4 days of data were not available due to data downloads, calibration of sensors and deployment of new equipment

6.3 Results

6.3.1 Water quality – 2019-20

Water temperature showed a typical seasonal pattern, ranging from 9.2 C in winter, to 30 C in summer, with no clear association with flow events (Figure 6-3). The same patterns were evident in the dissolved oxygen (DO) data (Figure 6-3 to Figure 6-5) with lower values in summer. We compared the logged dissolved oxygen data with the nearest NSW gauging station data, which we obtained from the WaterNSW site (https://realtimedata.waternsw.com.au/). Dissolved Oxygen data from NSW gauges are available only for Hillston and Willandra Weir, and only from the end of November 2019 onwards (Figure 6-4 and Figure 6-5). These data show when our project loggers are likely to have been exposed to the air by low river levels for a significant period (April) and on several days through the remainder of the year.

Environmental watering events did not have large effects on water quality in 2019-20 (Figure 6-4 to Figure 6-7). There was no evidence of an effect on dissolved oxygen concentrations from either watering action (Figure 6-4 and Figure 6-5 and also later, Figure-6-11). There was some evidence of reductions in turbidity and potentially salinity following the October fresh delivered from Lake Brewster as a component of Watering Action 1 (Figure 6-6), consistent with dilution of ions and fine sediment associated with the flow event. Total nitrogen was relatively consistent across sampling events, with low levels of nitrate/nitrite (Figure 6-7). 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. 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 the environmental flow in June 2020. This is consistent with mobilisation of organic matter into the channel and bank geomorphic processes. Ammonium values were highly variable and showed no relationship with environmental flow delivery.

There was no clear evidence for environmental flow deliver altering dissolved organic carbon (DOC) or chlorophyll (a measure of algal biomass) (Figure 6-7). This is largely due to the sparse nature of the data at key periods of environmental water delivery. There is some evidence of higher DOC values during delivery of environmental flows in October, consistent with mobilisation of organic matter. There was very high variability in measurements through the periods of environmental flow delivery suggestive of patchiness of these resources.

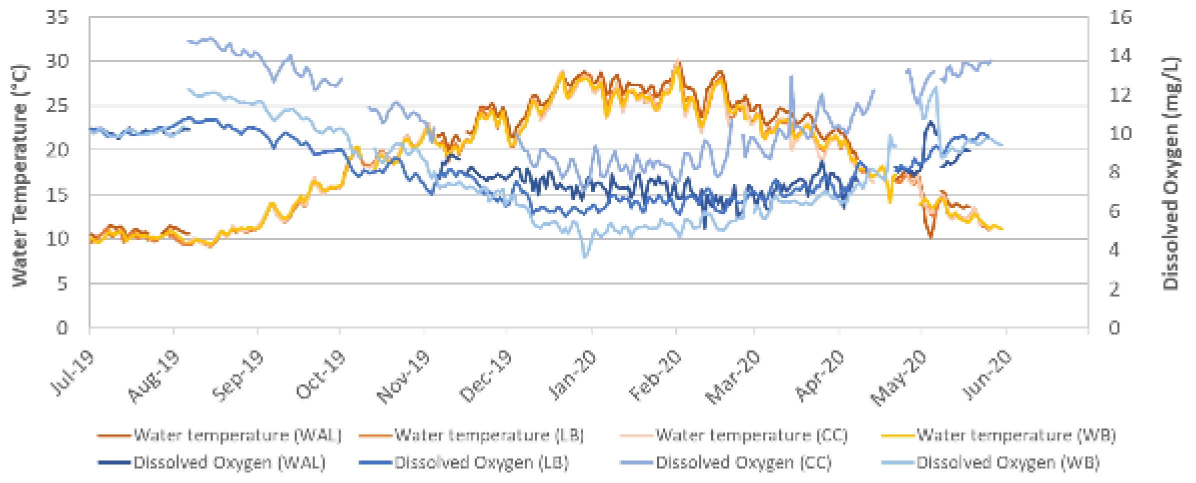


Figure 6-3. Water temperature and dissolved oxygen for the four lower Lachlan river sites (Wallanthery, Lane's Bridge, Cowl Cowl, and Whealbah) over the sampling period 2019-20.

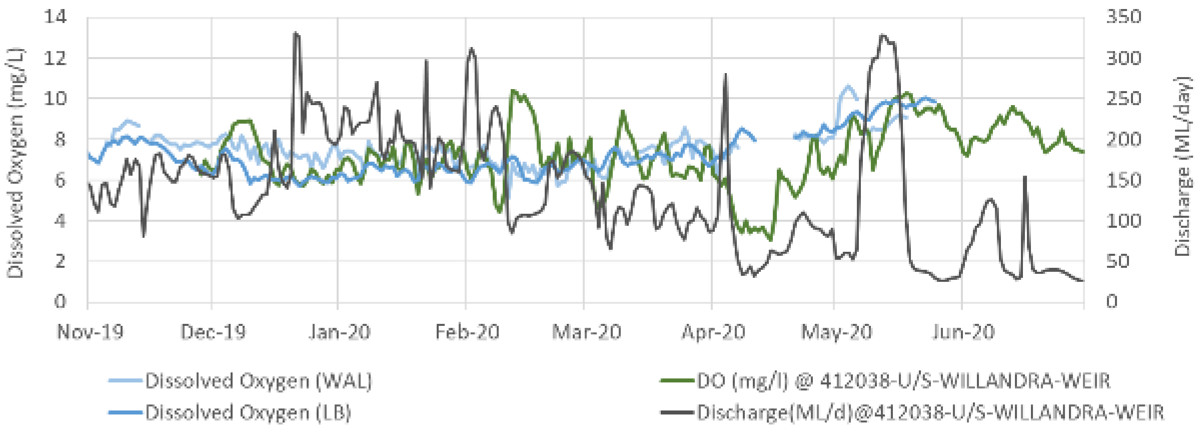


Figure 6-4. Dissolved oxygen for the two Lower Lachlan sites (Wallanthery and Lane's Bridge) compared to the NSW gauging station at Willandra Weir with their discharge, from November 2019 – July 2020.
Data from project loggers are missing in April and in the latter part of the year because the river level dropped below the position of the loggers.

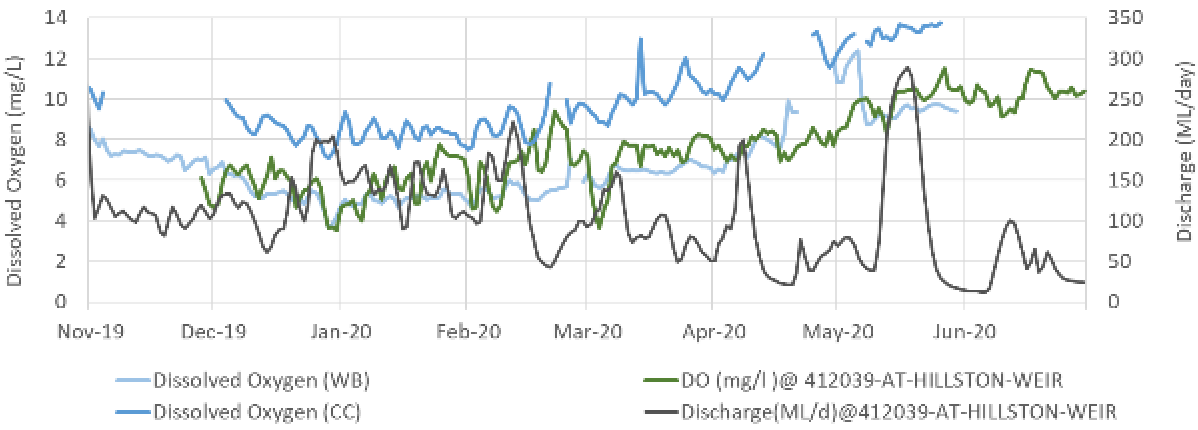


Figure 6-5. Dissolved oxygen for two lower Lachlan river sites (Cowl Cowl and Whealbah) compared to the NSW gauging station Hillston Weir with their discharge, from November 2019 – July 2020.
Data from project loggers is missing in April and in the latter part of the year because the river level dropped below the position of the loggers.

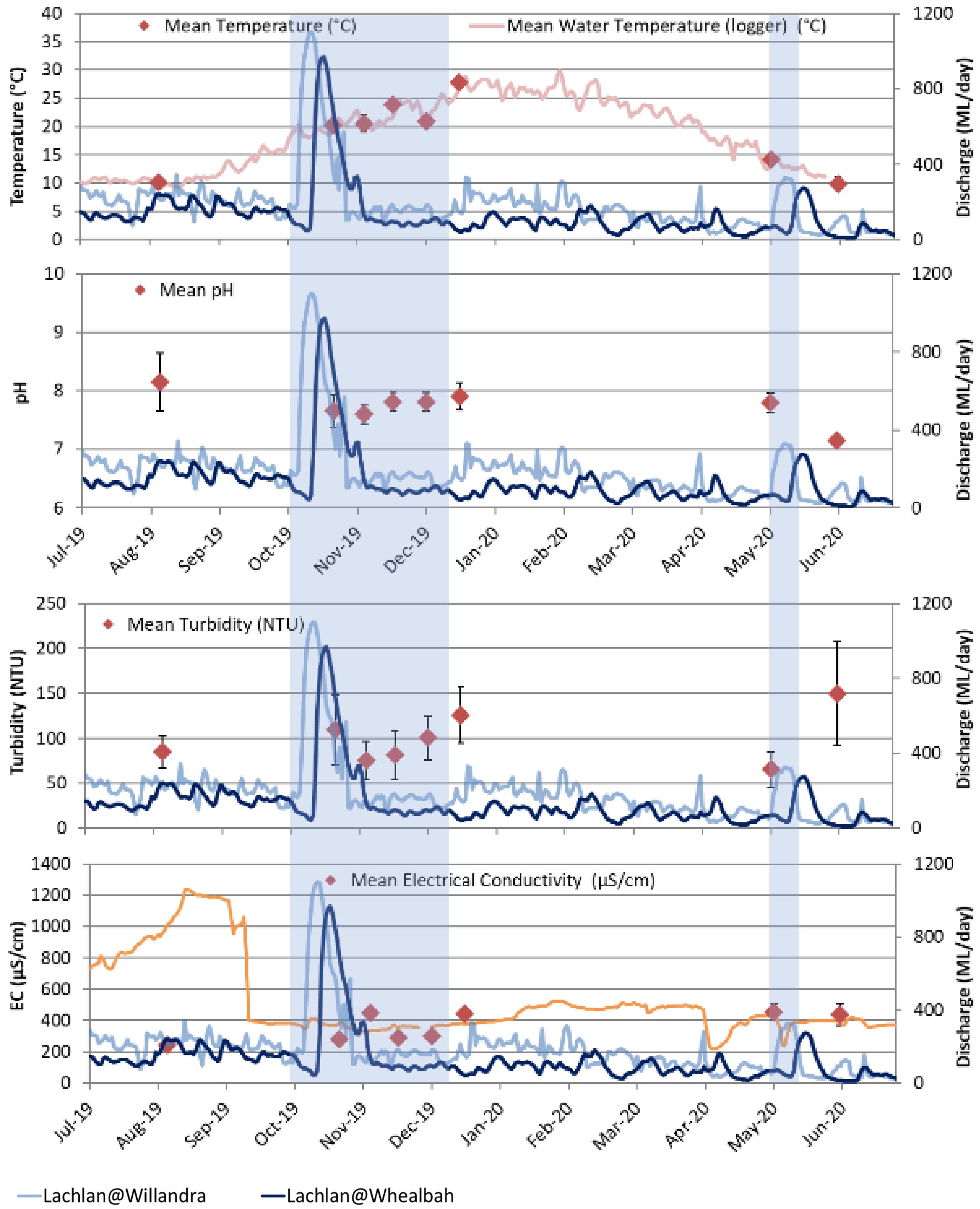


Figure 6-6. Mean water quality measurements (± standard error) for the four lower Lachlan river sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2019-20: physico chemical attributes.

Blue shaded vertical bars indicate watering actions based on Willandra discharge.

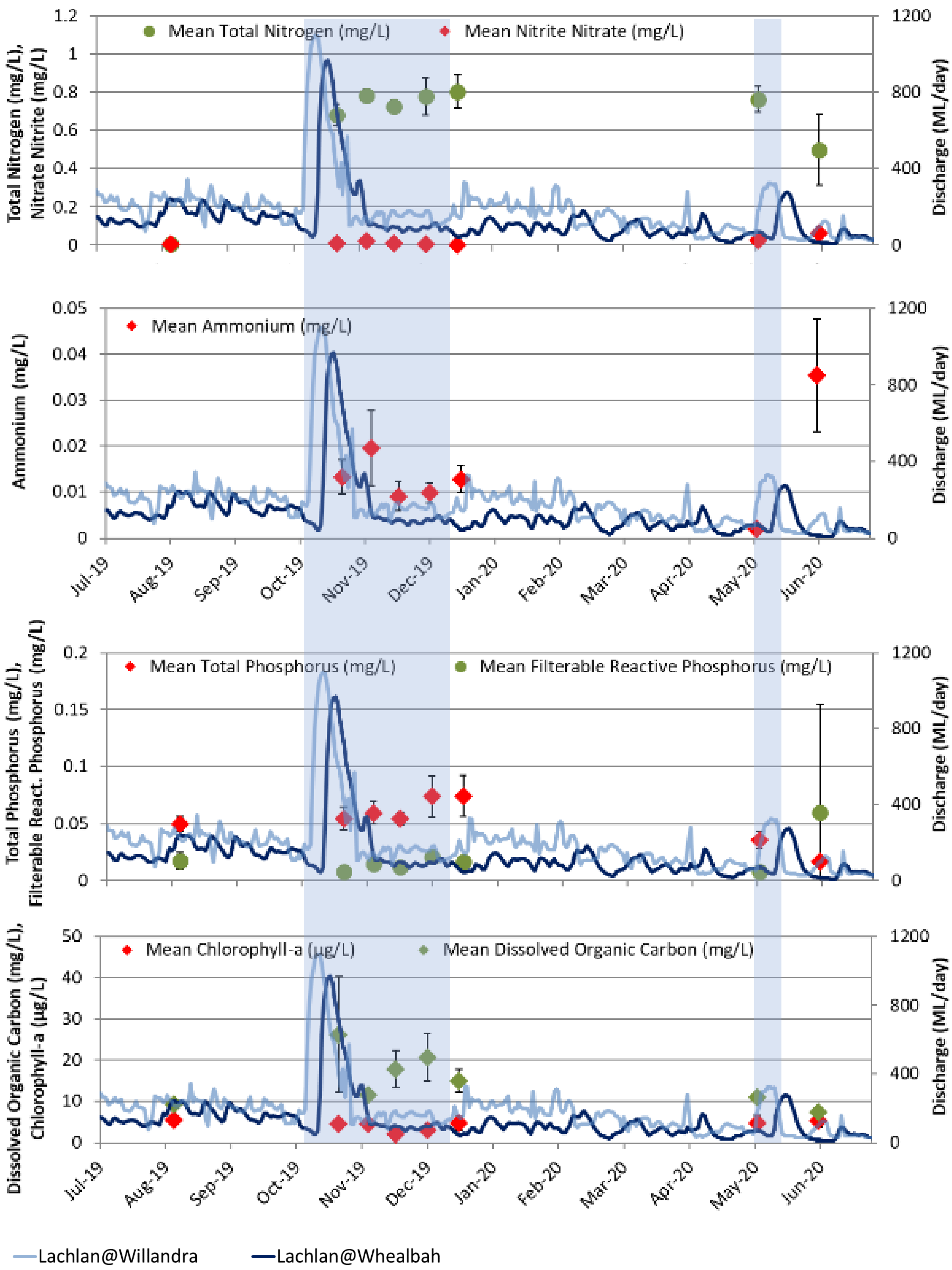


Figure 6-7. Mean water quality measurements (± standard error) for the four lower Lachlan river sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2019-20: nutrients and chlorophyll a.

Blue shaded vertical bars indicate watering actions based on Willandra discharge.

6.3.2 Water quality – 2014-20

The consolidated water quality data set from the lower Lachlan River 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 showed a strong typical seasonal pattern (Figure 6-8). Years with lower or higher inflows did not show any deviation from this general pattern.

Turbidity, pH and conductivity were relatively variable (Figure 6-9), 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 6-10) 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, billabongs or flows returning to the river from flooded agricultural land (CEWO 2017). 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 flows.

Concentrations of key basal resources were variable, particularly in the case of DOC (Figure 6-10) 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 6-10) There is a limited amount of data available for making clear conclusions on the effects of environmental water in the lower Lachlan River, and interpretation is made more complex by the high year to year variability in inflows.

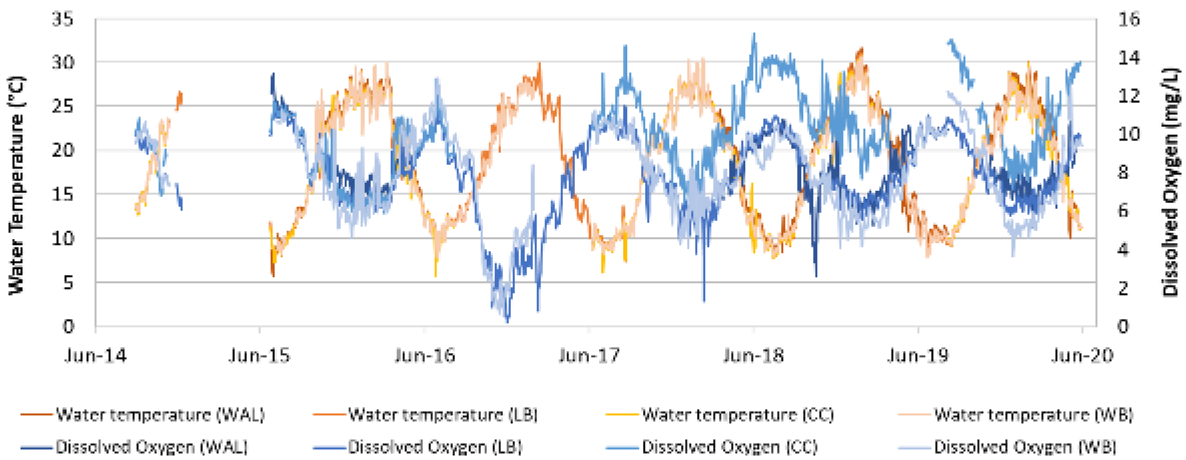


Figure 6-8. Water temperature and dissolved oxygen for the four study sites from the lower Lachlan river sites (Wallanthery, Lane's Bridge, Cowl Cowl, and Whealbah) over the sampling period June 2014- June 2020.

Note: 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.

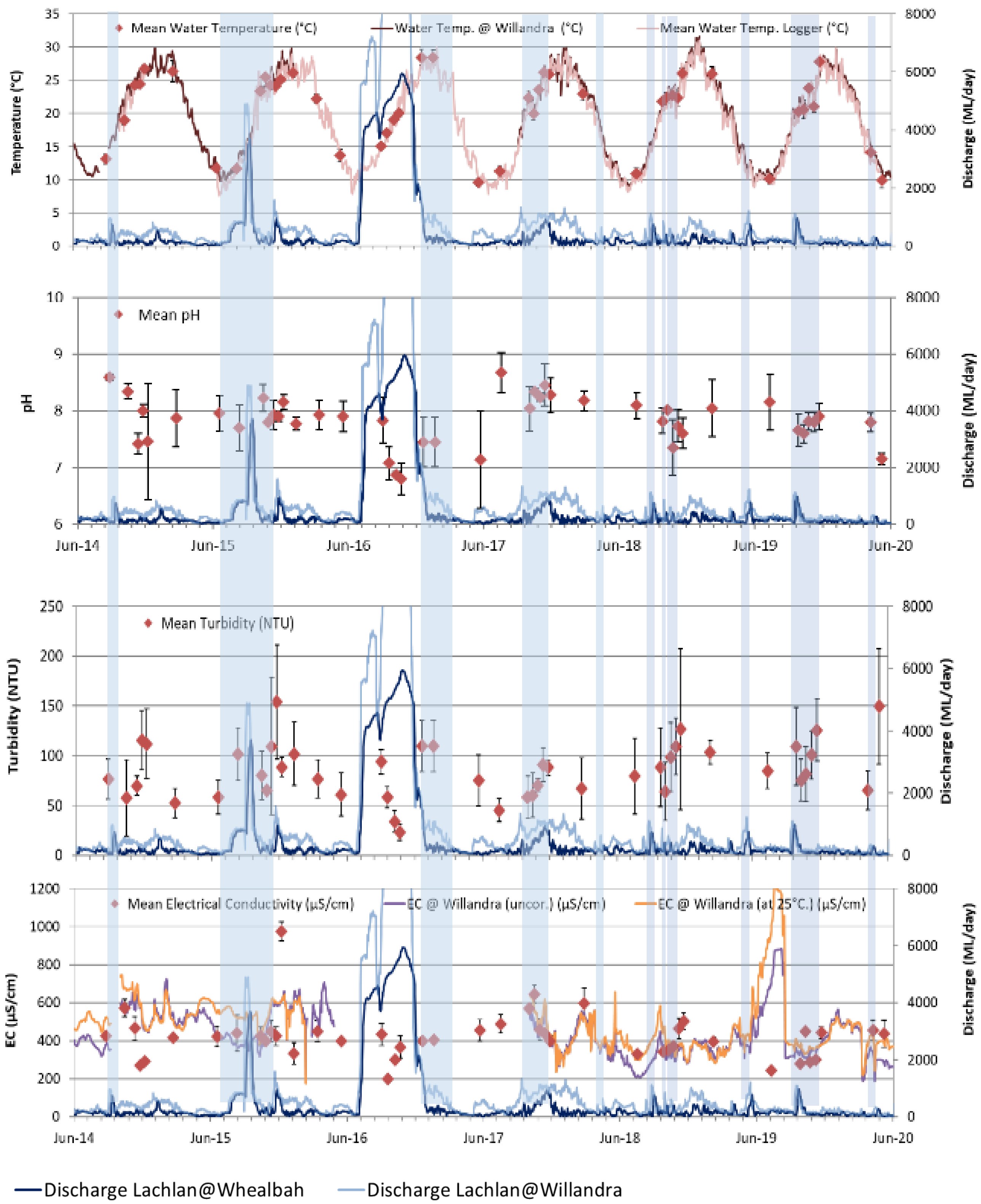


Figure 6-9. Mean water quality measurements (± standard error) for four lower Lachlan river sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2014-2020: physico chemical attributes. Note: Blue shaded vertical bars indicate watering actions.

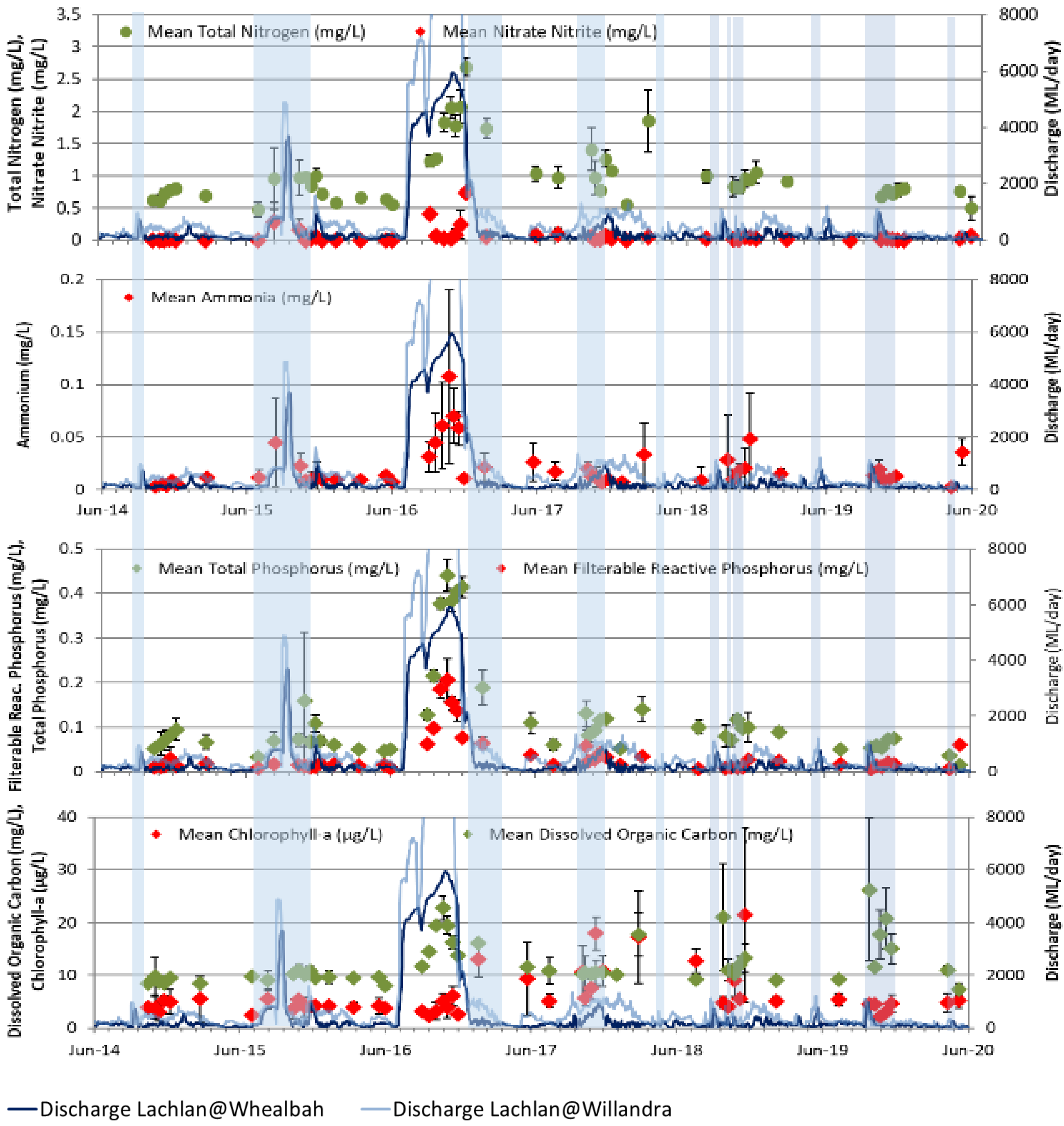


Figure 6-10. Mean water quality measurements (± standard error) for the four lower Lachlan river sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2014-2020: nutrients and chlorophyll a.

Note: Blue shaded vertical bars indicate watering actions.

6.3.3 Stream Metabolism – 2019-20

The availability of stream gauge data for the site in 2019-20 allowed us to ascertain when loggers may have been exposed to the air due to very low river levels. This happened throughout the reporting period over an interval of several days, and in total we excluded 106 days due to air exposure. Two thirds of these measurements occurred in April 2020 for a duration of 8 to 13 days per site and a month later from mid-May until the last logger download. Other short periods of logger exposure occurred at the Lane's Bridge and Cowl Cowl sites only in February for 2 days and at the start of October for 4 days but only the two lowest sites. Highly variable temperature data in April was likely a consequence of intense rainfall. The unusual high amplitude of daily water temperature and disorderly dissolved oxygen measurements in April could be caused likewise by the extreme rainfalls of 147 mm during the month. In addition to these explainable extreme data periods, two short periods (2 respectively 4 days) of data were excluded from the data analysis at the end of July and mid-November for Wallanthery. In these cases, the oxygen data suggests air exposure of the sensors, but there is no associated low flow event.

Table 6-1 shows the percentage of data days for which a GPP, ER and K estimate could be modelled under the standard acceptance criteria are shown for the reporting period. Stream metabolism data was able to be used from a total of 52% days (ranging from Wallanthery with 19% to Lanes Bridge with 83%, see Table 6-1. As in previous years the Cowl Cowl and Wallanthery sites had the lowest proportions of days which could be modelled (Dyer et al. 2018a).

In order to allow more days to be modelled for the analysis we lowered the R^2 value from 0.9 to 0.75. This allow an addition 185 days of data to be included (an average of 36% of the otherwise rejected data days) (Table 6-1).

In order to model stream metabolism in some critical periods (e.g. at low flows) K values of up to 20 were accepted in order to allow estimates to be extracted. It should be noted that high K values can lead to potential over-estimation of ER. For further information relate to Figure-6-11, plus Section 6.7 to Appendix 1: Stream metabolism plots for additional sites in the lower Lachlan River 2019-20.

After applying the standard acceptance and modified (lowered R^2 values) criteria, we visually inspected plotted GPP, ER, and K values as well as the GPP/ER ratios and rejected 49 additional data days because of unrealistically high GPP values and GPP/ER ratios. With exception of 3 days from Wallantherey. These values were associated with low flows in spring 2019 and April 2020, and likely reflect full or partial exposure of the data loggers.

Table 6-1. Stream metabolism data obtained from the four sites in the lower Lachlan river system during the sampling period 2019-20.
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 and modified (lowered R^2 in brackets) acceptance criteria.

SITE	TIME PERIOD	# LOGGED DAYS	Y	%	(Y)	(%)	NOTES (GAPS IN LOGGING DUE TO BATTERIE ISSUE AND AIR EXPOSURE)
WALLANTHERY (WAL)	1/07/2019 – 04/06/2020	213	40	19	54	31	No data for 3 months (between 07/08 and 05/11/19), Air exposure for 36 days
LANES BRIDGE (LB)	1/07/2019 – 04/06/2020	321	266	83	37	67	Air exposure for 19 days
COWL COWL (CC)	06/08/2019 – 04/06/2020	242	73	30	32	19	No data before 06/08/19, Air exposure for 32 days
WHEALBAH (WB)	1/07/2019 - 04/06/2020	320	184	58	62	46	Air exposure for 19 days
OVERALL		1096	563	51	185	35	

Time series plots of logged temperature, dissolved oxygen (DO) are shown in Figure 6-3 to Figure 6-5, page 39. 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 River are shown in Figure-6-11. Plots from the three remaining sites are in Section 6.7: Appendix 1: Stream metabolism plots for additional sites in the lower Lachlan River 2019-20.

The watering actions undertaken in the lower Lachlan River in 2019-20 took the form of relatively defined flow pulses (e.g. Figure 4-3, page 17). There is not strong evidence for an effect of watering actions on GPP or ER *per litre* see Figure-6-11, as well Figure 6-16 and Figure 6-17 in Appendix 1: Stream metabolism plots for additional sites in the lower Lachlan River 2019-20. Interpretation of impacts is complicated by a lack of data at Wallanthery and sparse data at Cowl Cowl. There is an observed increase in GPP and ER *per litre* in the months after the environmental flow in October 2019 (Figure-6-11, as well Figure 6-16 and Figure 6-17), but it is not possible to attribute that to the effects of the environmental flow, as other factors (particularly increasing water temperatures and further small flows) are likely to also be affecting metabolism. There is some evidence of a small peak in ER *per litre* at Whealbah immediately after the June 2020 environmental flow (Figure 6-17).

While there were not observable effects in primary production and respiration *per litre* in the river, the total carbon produced by the environmental flow events is notable (Figure 6-12), rising to almost 400 kg per day at the peak of the Spring pulse.

The ER rates are generally significantly higher than the corresponding GPP rates, meaning that the sites are predominantly heterotrophic (GPP/ ER<1) (Figure-6-11 and Figure 6-19). Heterotrophic conditions indicate that metabolism is mainly driven by external sources of organic carbon rather than from photosynthesis within the site. The increases in GPP and ER are highly correlated (Figure-6-11, as well Figure 6-16 and Figure 6-17), suggesting 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.

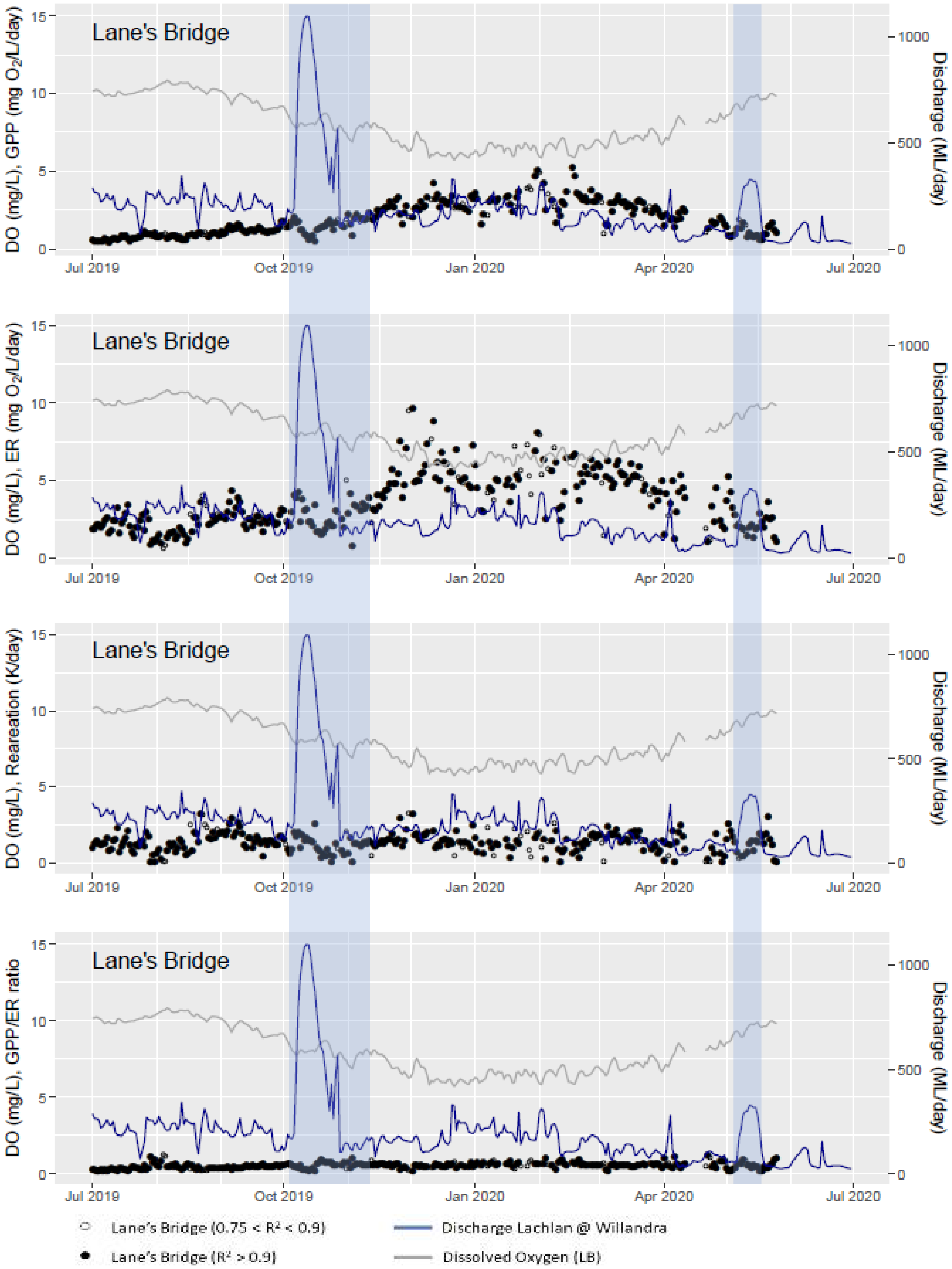


Figure-6-11. Gross primary production (GPP), Ecosystem respiration (ER), Reaeration (K) and the GPP/ ER ratio from Lane's Bridge in the lower Lachlan River, July 2019 - June 2020. Blue shaded vertical bars indicate watering actions.

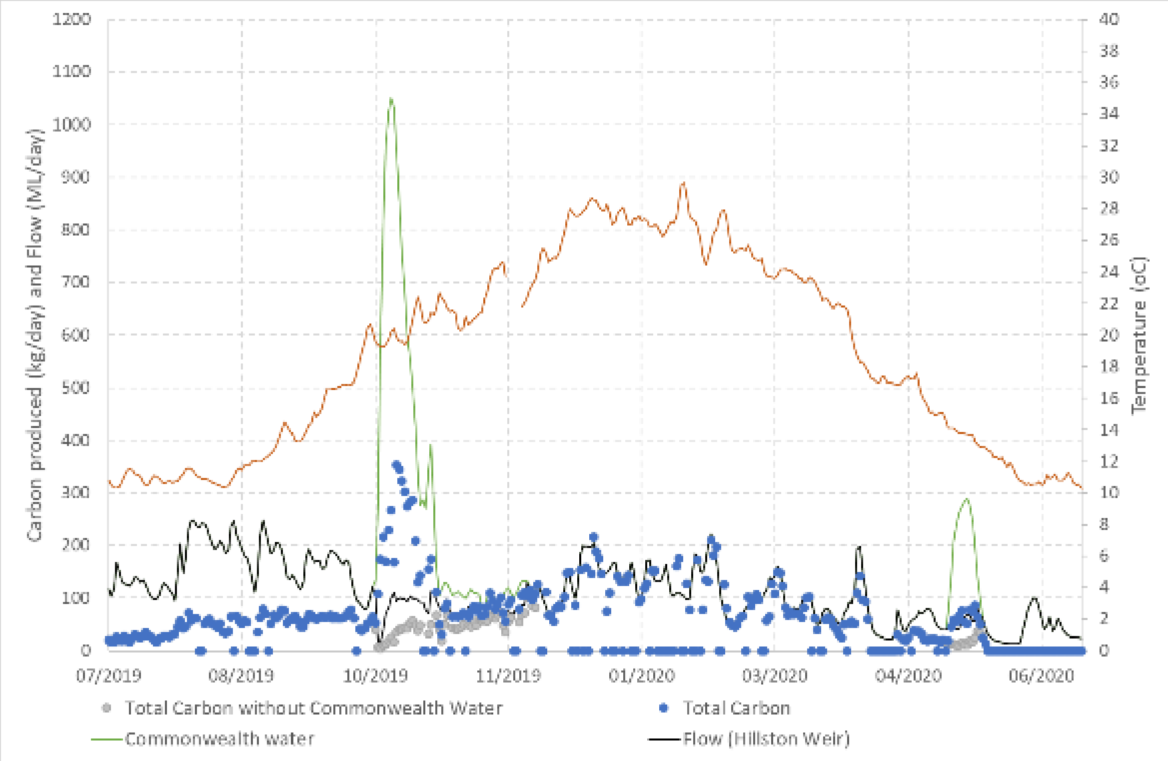


Figure 6-12. Total carbon produced (kg C/day) at Lane's Bridge for the watering year 2019-20. Commonwealth environmental water (green) is shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in black. Estimated total carbon production in the absence of Commonwealth environmental water is shown in grey and river temperatures are shown in orange.

6.3.4 Stream metabolism – 2014-20

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

- 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.
- 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.
- 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. A positive effect on ER after a winter environmental flow is apparent in the most recent (June 2020) data.

GPP and ER showed a seasonal pattern (Figure 6-14 and in Appendix 2: Stream metabolism plots for additional sites in the lower Lachlan River 2014-20), which are strongly correlated with seasonal variation in temperature (Figure 6-8 and Figure 6-9, in Section 6.3.2: Water quality – 2014-20). This pattern was particularly marked for GPP (Figure 6-14 and Figure 6-20). However environmental flows in warmer months were also associated with increased GPP, generally lagged by a short period after the flow delivery commenced.

While total production in the river shows a similar seasonal pattern (Figure 6-15), there is a very strong relationship with flow. Even small increases in flow result in an increase in total carbon produced.

ER responses were also seasonal, but the pattern was less marked and there were also intermittent very high values 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 6-14 and Figure 6-21).

Very high variation in reaeration (Table 6-3, page 51) 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 6-14 and Figure 6-22). 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 6-13. In-stream structures at Whealbah.

In particular fluctuations in ER 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 6-14 and Figure 6-23). There is a limited amount of data available for making clear conclusions on the effects of environmental water in the lower Lachlan River, and interpretation is made more complex by the high year to year variability in inflows (Table 6-2).

Table 6-2. 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 6-3. Stream metabolism data averages for all four variables and all four lower Lachlan river sites over the sampling period 2014-2020 under the standard acceptance criteria.

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
2019-20	5.6	1.8	3.6	3.5	3.6
AVERAGE	*3.3*	*2.0*	*2.9*	*2.8*	*2.7*
	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	5.9		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
2019-20	4.2	3.5	6.0	9.3	5.8
AVERAGE	*3.1*	*4.0*	*5.6*	*5.2*	*4.5*
	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
2019-20	3.0	1.3	2.5	2.7	2.4
AVERAGE	*2.1*	*1.5*	*3.0*	*1.5*	*1.9*
	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
2019-20	1.9	0.5	0.8	0.5	1.0
AVERAGE	*2.7*	*0.6*	*0.7*	*0.7*	*1.2*

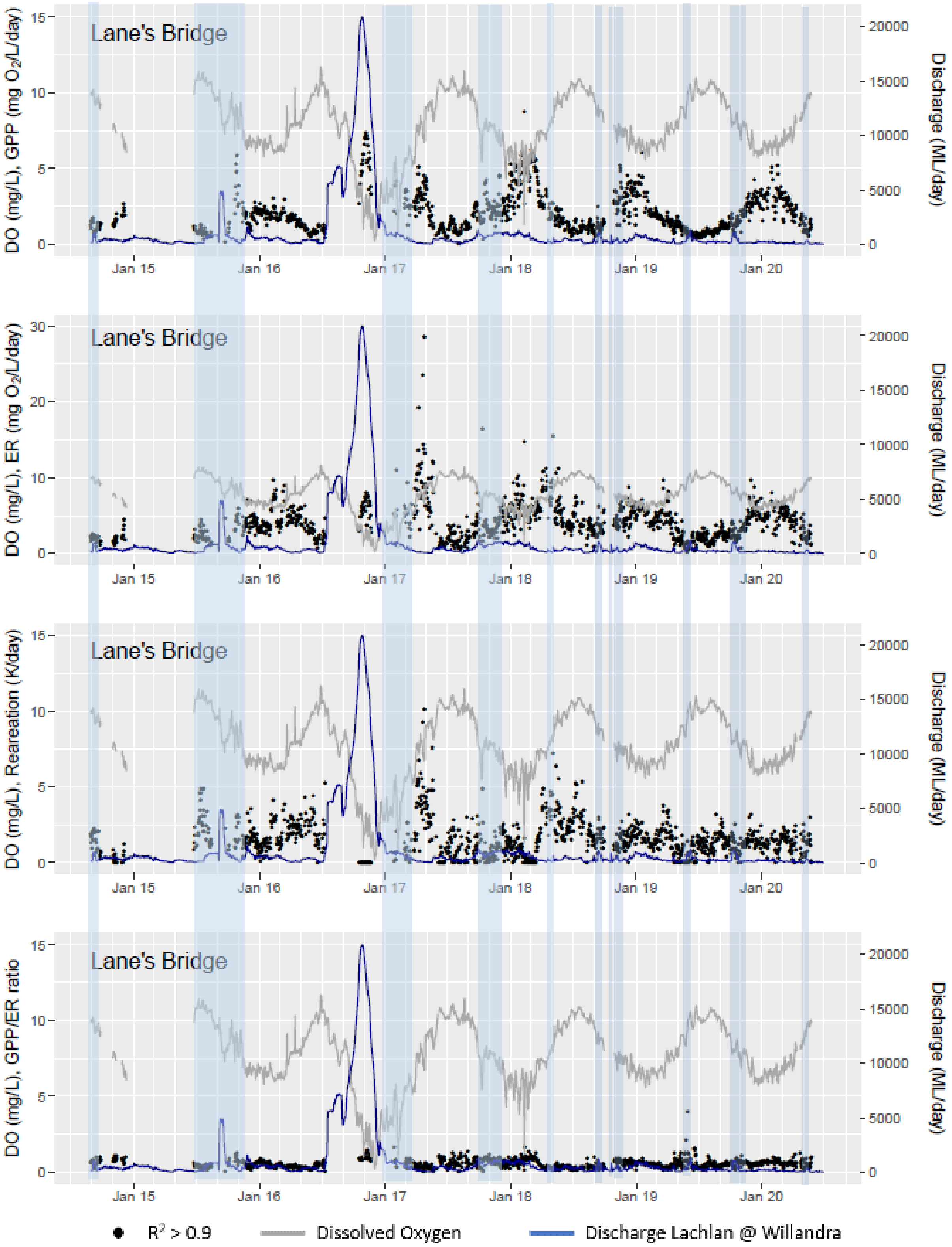


Figure 6-14. Gross primary production (GPP), Ecosystem respiration (ER), Reaeration (K) and the GPP/ ER ratio from Lane's Bridge in the lower Lachlan River, August 2014 - June 2020.

Blue shaded vertical bars indicate watering actions. Note: Ecosystem respiration (ER) on higher scale.

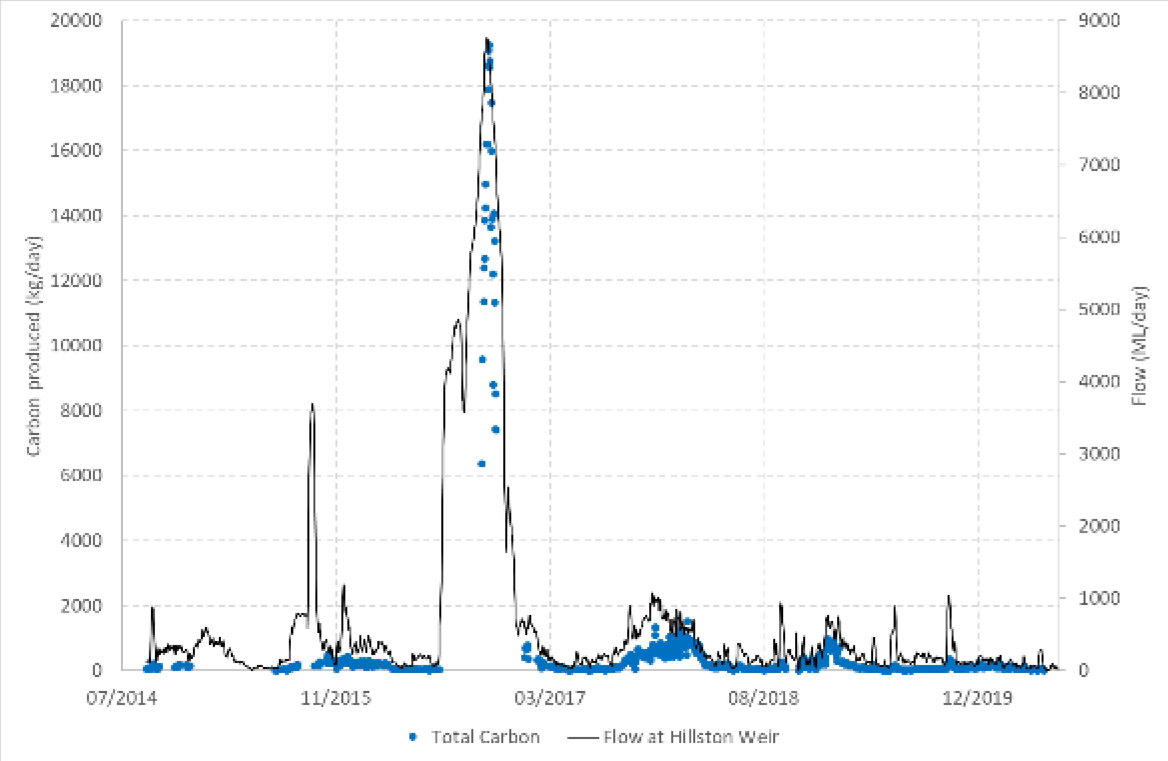


Figure 6-15. Total carbon produced (kg C/day) at Lane's Bridge for the entire monitoring period 2014-20. Flow at Hillston Weir is also shown

6.4 Discussion

The sampling period featured one environmental watering action in the lower Lachlan River, delivering freshes in early summer (October 2019) and autumn/ winter (June 2020). Water quality data suggested that the summer events mobilised nutrients and carbon, but it was not possible to clearly attribute a response in productivity to the flow. 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). However environmental flows may also reduce GPP through increased turbidity, reducing water temperature and physically disturbing primary producers (Bernhardt et al. 2018).

6.4.1 Watering Action 1

The first part of Watering Action 1, the spring fresh in October 2019 targeted native fish and productivity outcomes in the mid and lower reaches of the Lachlan River. The watering action was designed to stimulate primary productivity to support improvements in fish condition.

This event appeared to mobilise nutrients and carbon in channel but did not result in increases in algal biomass or measurable increases in GPP or ER. Interpretation of this is made more complex by the lack of data from Wallanthery and sparse data from Cowl Cowl. However, it is possible the relatively large steep peak of the small fresh increased turbidity and prevented light reaching productive surfaces in deeper water, but was not prolonged enough to allow biofilms to colonise newly inundated surfaces in shallower water.

The latter part of Watering Action 1, the autumn/ winter fresh in May and June 2020 sought to maintain water quality and provide a small pulse of productivity in the late autumn/early winter months.

This event appeared to mobilise nutrients and carbon in channel, resulting in a small increase in ER. Consistent with previous flows provided during cooler times of year, there was not a clear effect on GPP, and it seems likely that the response is largely due to mobilisation and processing of organic material from in-channel benches and the banks.

6.4.2 Watering over the period 2014-20

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 and winter 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 potentially 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.

6.5 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 2019-20 year was also characterised by progressive drying through summer then significant rainfall in autumn and early winter.

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. The two flows provided in 2019 both appeared to mobilise small amounts of nutrients and caused slight increases in pH and reductions in salinity.

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. In the most recent watering year a spring fresh in October 2019 did not generate an identifiable productivity response, while a smaller event in winter (June 2020) did appear to generate a small increase in ecosystem respiration.

6.6 Final comments and recommendations

Commonwealth environmental water was used strategically in 2019-20 for a range of outcomes did not appear to have generated clear productivity pulses. 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) There is some evidence from the 2019-20 watering year that the shape and magnitude of the flow event may affect the degree to which a productivity response is seen. This is consistent with a flow pulse which generates light limitation on existing biofilms, but is of insufficient length to allow new biofilms to develop.

e) 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 at warmer times of the year may not produce large responses in productivity if the length of the flow period is short. This requires consideration in coming year, and likely further analysis when data from more flow events becomes available.

III. 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.

6.7 Appendix 1: Stream metabolism plots for additional sites in the lower Lachlan River 2019-20

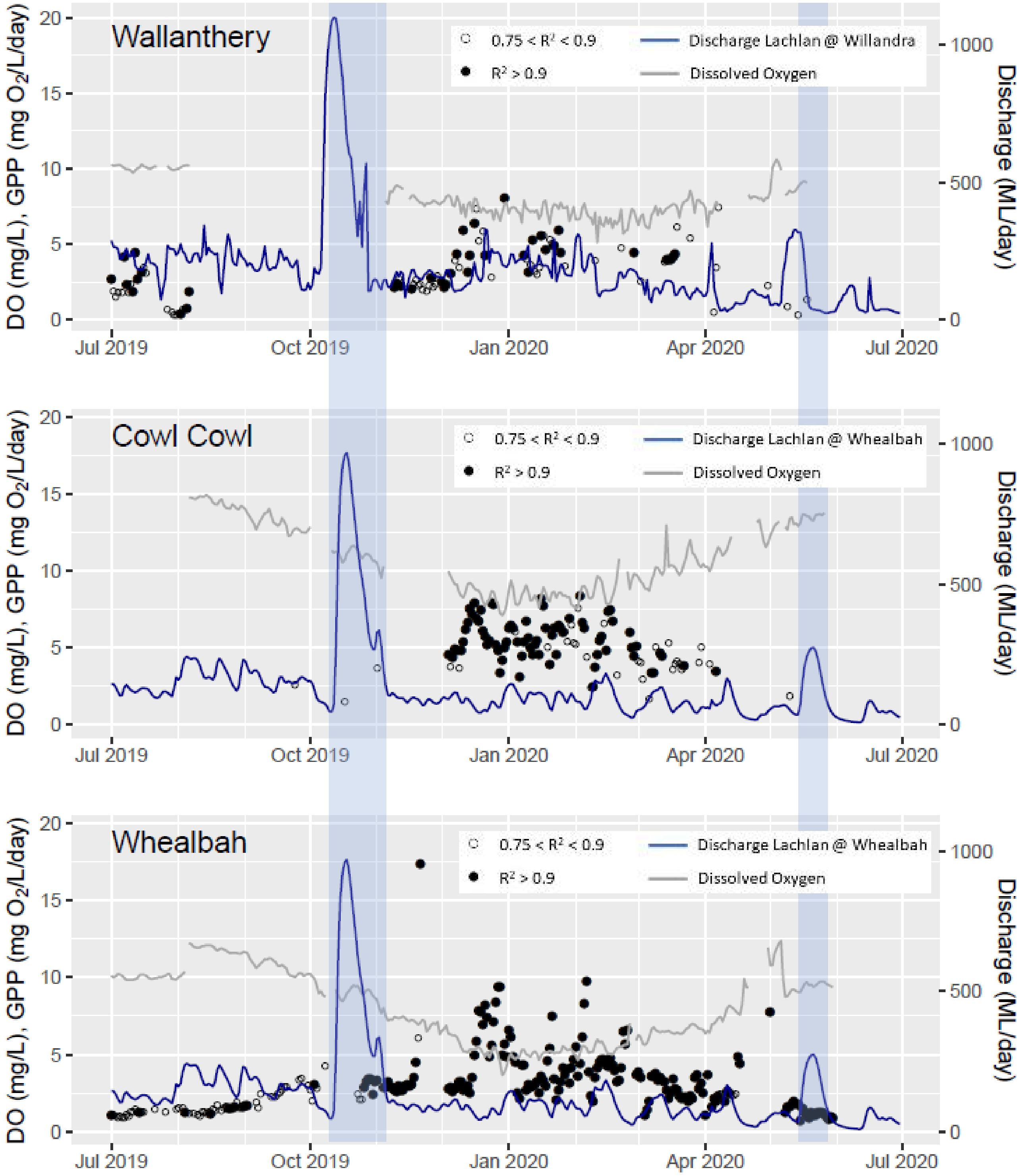


Figure 6-16. Gross primary production (GPP) from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, July 2019 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

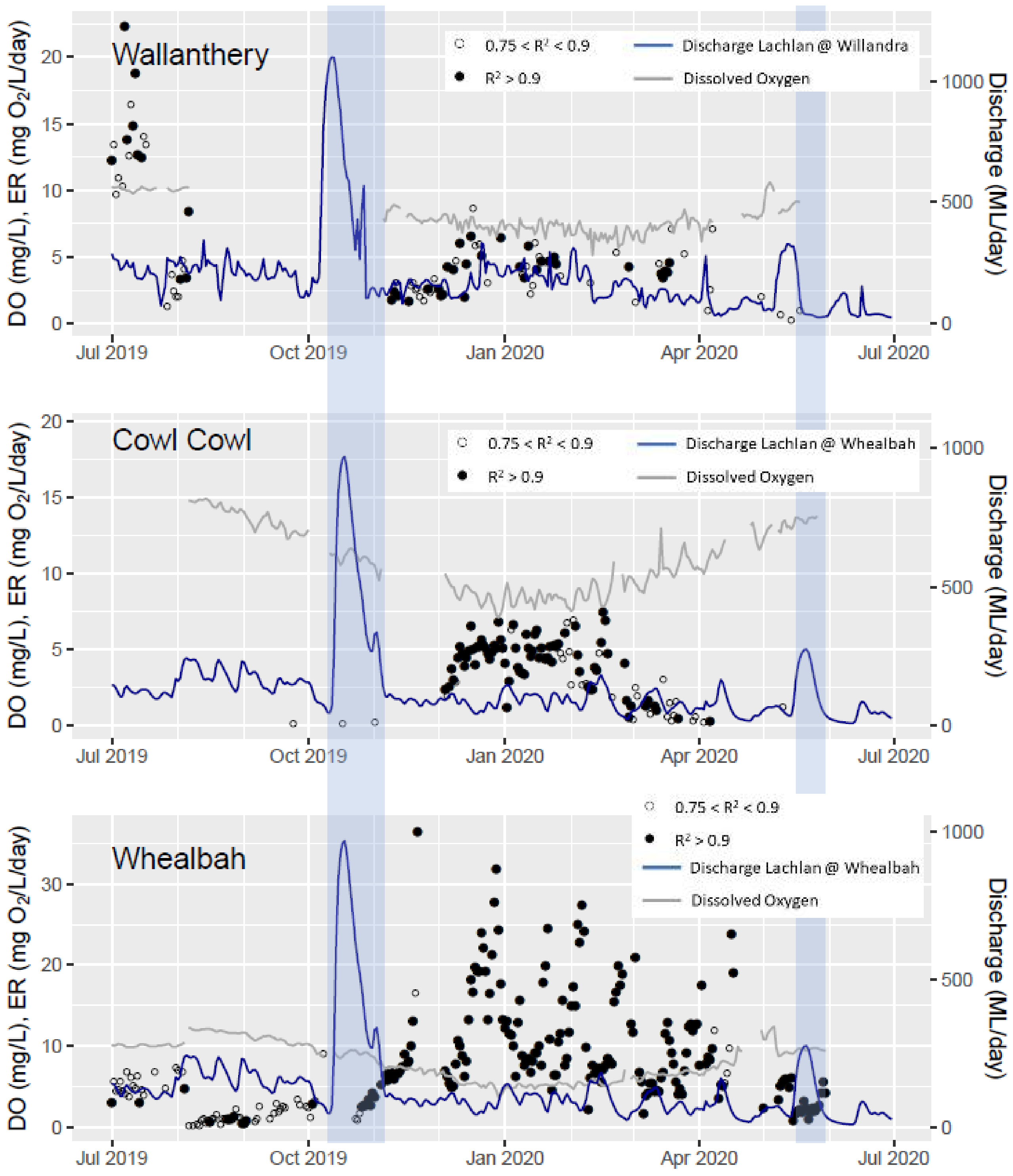


Figure 6-17. Ecosystem respiration (ER) from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, July 2019 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

Note: Whealbah on a higher scale for dissolved oxygen (DO) and ecosystem respiration (ER).

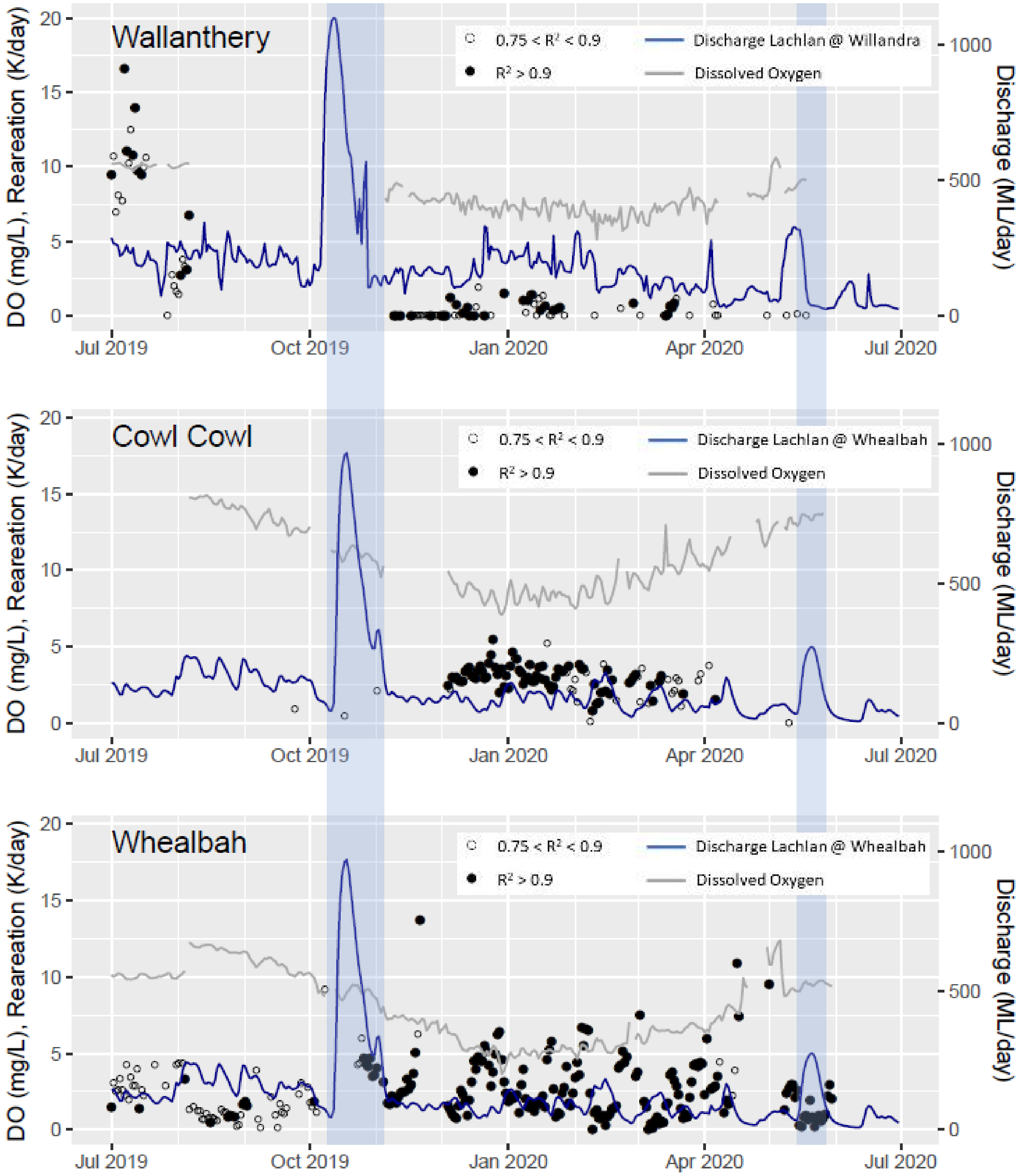


Figure 6-18. Reaeration (K) from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, July 2019 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

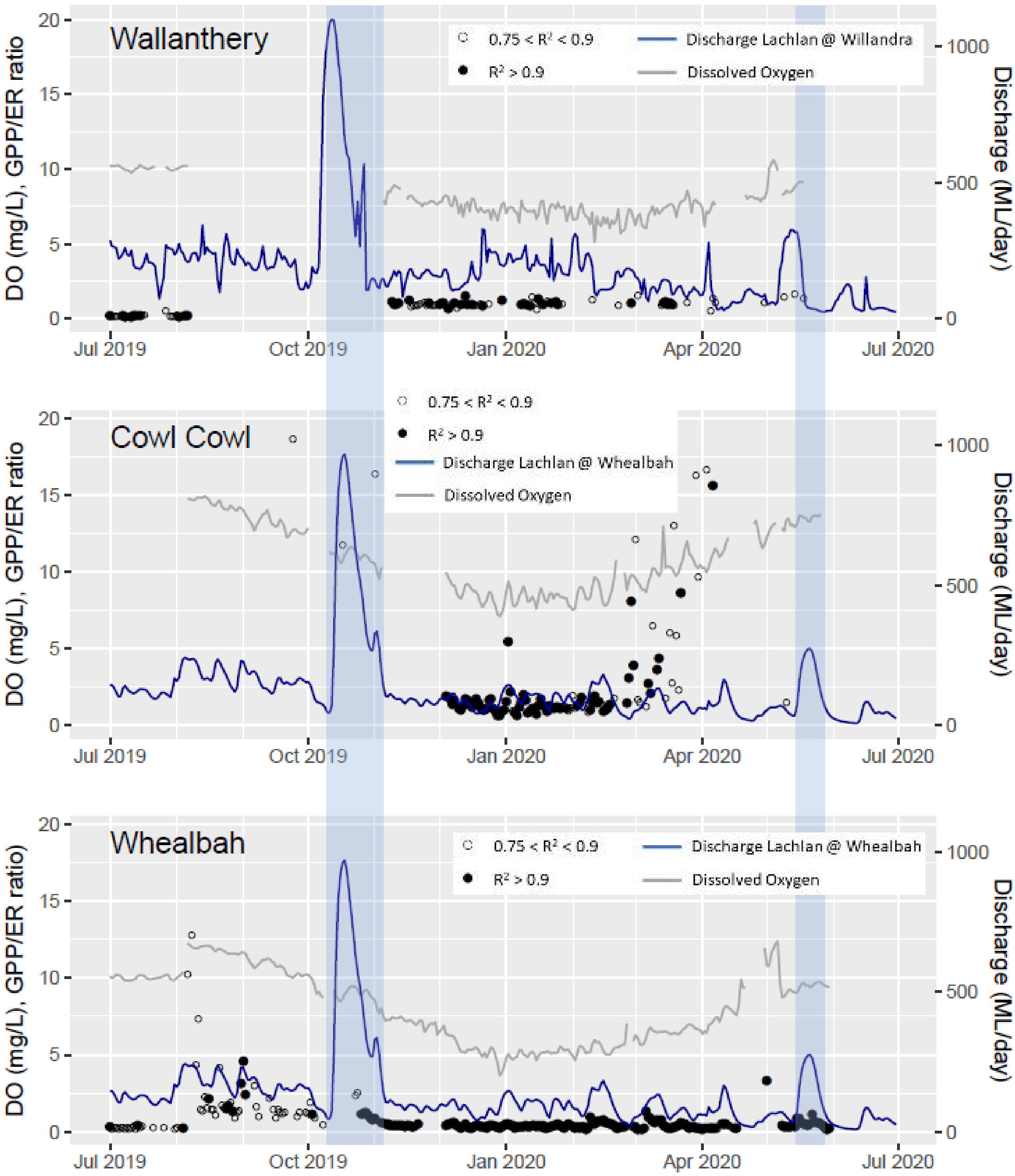


Figure 6-19. GPP/ ER ratio from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, July 2019-June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

6.8 Appendix 2: Stream metabolism plots for additional sites in the lower Lachlan River 2014-20

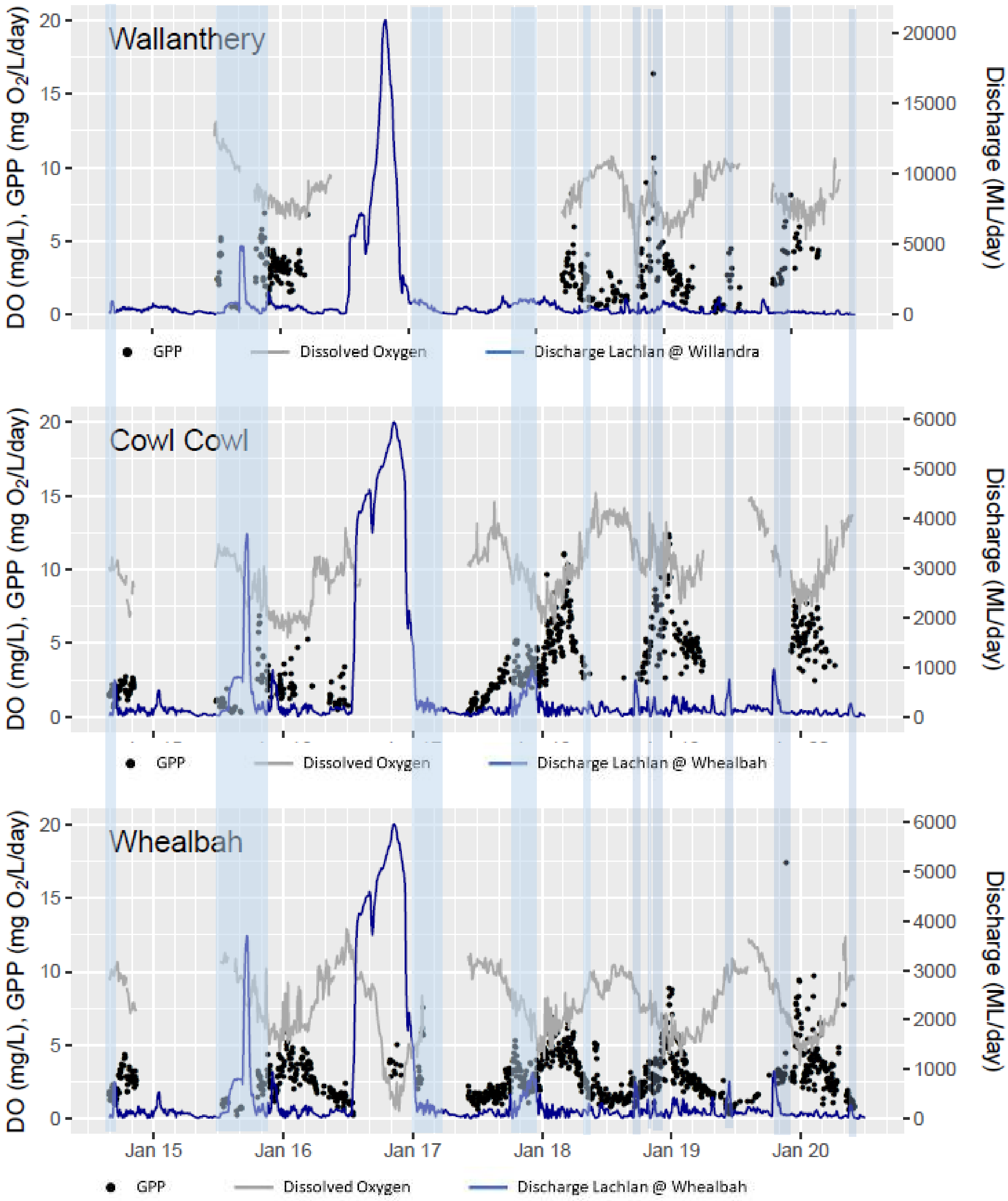


Figure 6-20. Gross primary production (GPP) from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, August 2014 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

Note: Wallanthery on a higher scale for discharge.

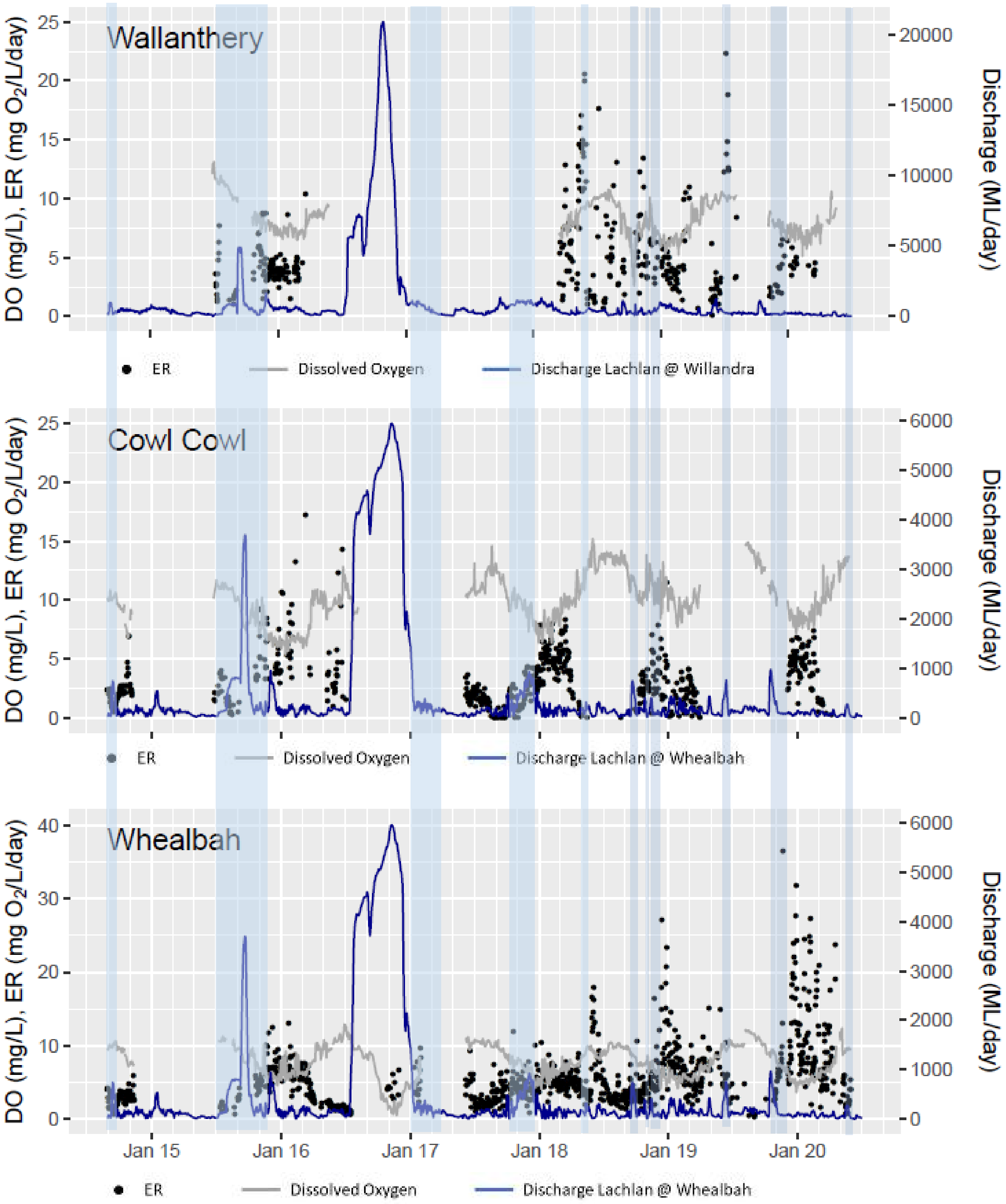


Figure 6-21. Ecosystem respiration (ER) from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, August 2014 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

Note: Whealbah on a higher scale for dissolved oxygen (DO) and ER. Wallanthery on a higher scale for discharge.

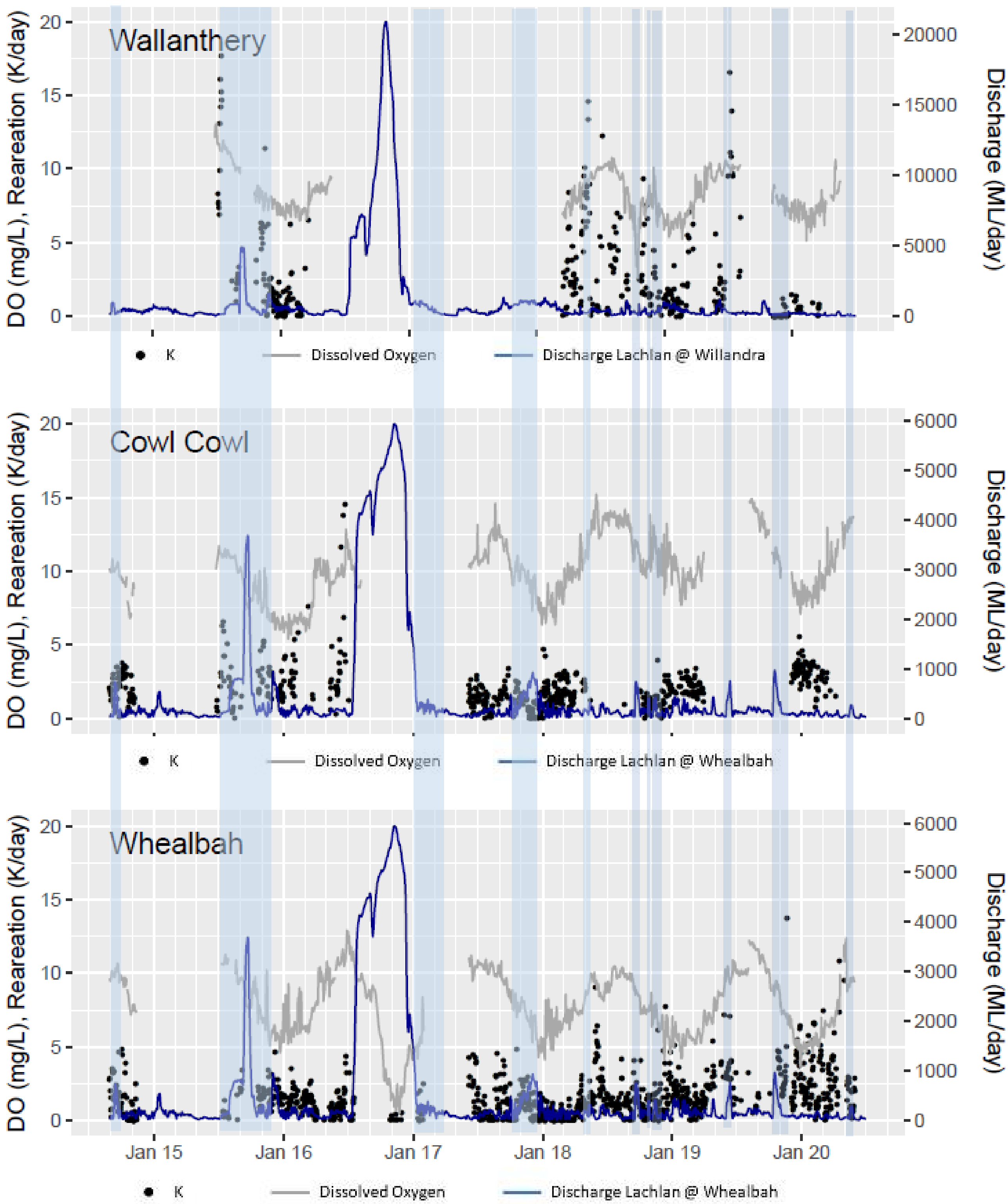


Figure 6-22. Reaeration (K) from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, August 2014 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

Note: Wallanthery on a higher scale for discharge.

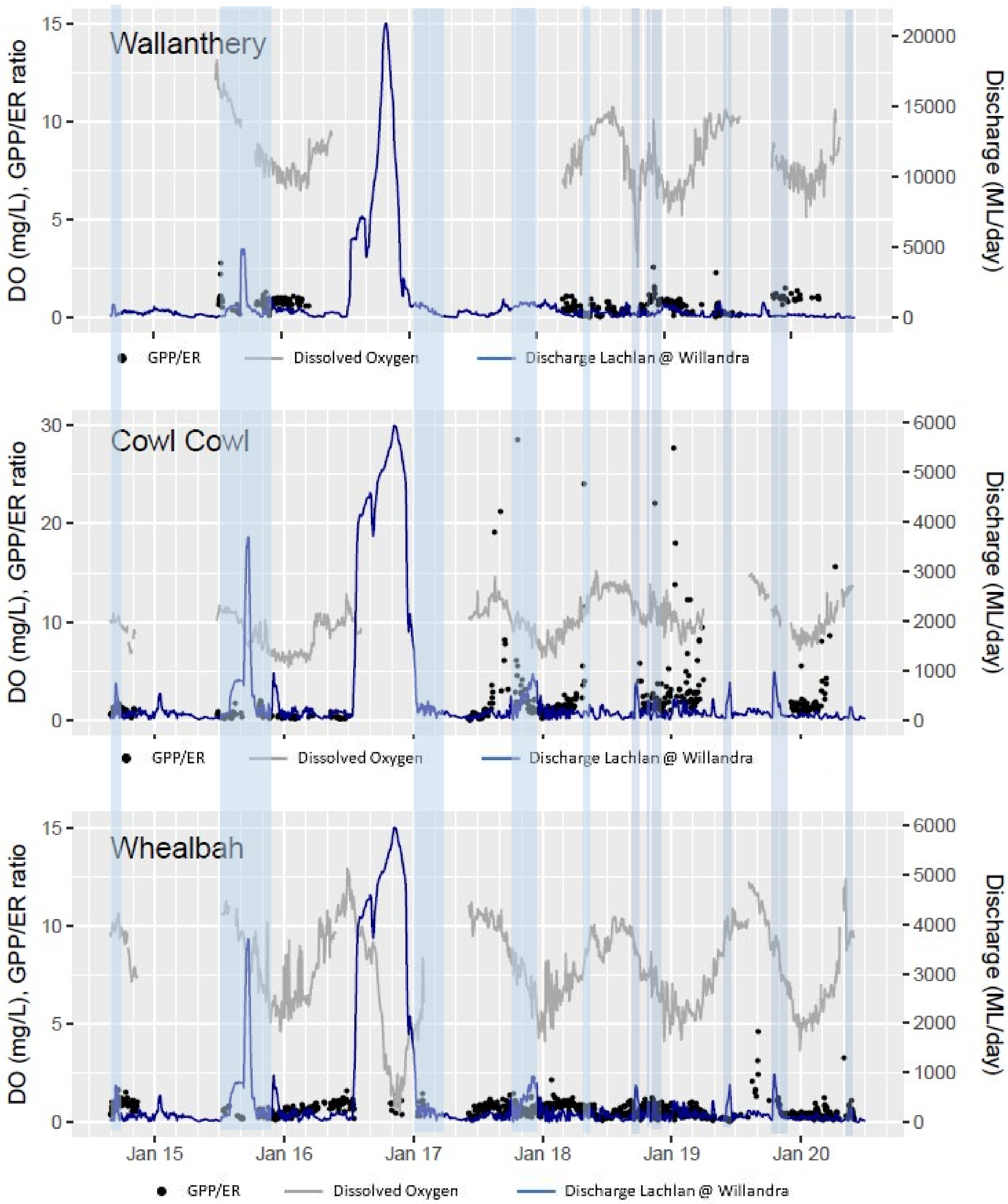


Figure 6-23. GPP/ ER ratio from Wallanthery, Cowl Cowl and Whealbah in the lower Lachlan River, August 2014 - June 2020.

Blue shaded vertical bars indicate watering actions based on Whealbah discharge.

Note: Cowl Cowl on a higher scale for dissolved oxygen and the GPP/ ER ratio. Not shown 20 outlier for Cowl Cowl for the GPP/ ER ratio above 30. Wallanthery on a higher scale for discharge.

7 FISH COMMUNITY

7.1 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 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.

From 2014-2015 to 2018-2019 the CEWH conducted a Long Term Intervention Monitoring project (LTIM project) across the lower Lachlan river system to quantify changes in ecosystem health in response to Commonwealth environmental water delivery, including fish community responses. This continues under a Monitoring Evaluation and Research (MER) program set up by the CEWO, and we report on data from 2019-2020 compared to previous years.

A number of Commonwealth environmental watering actions relevant to riverine native fish communities were delivered in 2019-20, including flows for refuge habitat of olive perchlet (Action 1a) and the maintenance of native fish health and habitats (Actions 1d, 2a, 2b) (Dyer et al. 2018a). To assess the contributions of Commonwealth environmental water to the fish community, the relevant short term and long-term questions evaluated are:

7.1.1 Short-term questions:

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

7.1.2 Long-term questions:

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

In 2019-20, the aim of this component of the Lachlan River MER program 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 current study reports on the first year of the three-year MER program in the lower Lachlan River.

7.2 Methods

Fish community data was collected from 10 in-channel sites from the lower Lachlan river system Selected Area, from Wallanthery to Hillston (Figure 6-1, page 36). 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; Davies et al. 2012). Sampling was undertaken in March 2020, 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', Figure 7-5, page 82), unbaited bait traps (n=10) and small fyke nets (n=10) (Hale et al. 2014). Decapods were also surveyed 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. For fyke netting, sub-sampling involved measuring all individuals for body size in each operation per gear type until 10 of a species, and remaining individuals were counted. For boat electrofishing, the first 50 individuals of a species across operations were measured body size, and the first 20 individuals per operation were also measured, with remaining fish 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). Data from large fyke nets which were previously used at lower Lachlan river sites to increase detection of freshwater catfish were removed, as this method was not used in the current sampling year. To determine differences between years in the lower Lachlan river selected area (2015, 2016, 2017, 2018, 2019 and 2020) 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 the 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 the minimum of that for 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 the average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 7-1). Eight fish metrics were calculated using the methods described by Robinson (2012).

Nativeness metrics determine the proportion of native compared to alien fishes. Specifically, these calculate the proportion of native fish contributing to total species richness (PropNS), total abundance (PropNAbund) and total biomass (PropNBiomass) (Robinson 2012).

Three Recruitment metrics examine the recent reproductive activity of the native fish community. These examine the proportion of recruiting vs total native fish species (PropRTaxa), the average proportion that recruiting vs. total abundances across native fish species (PropRAbund), and the average proportion of sites that native fish species were recruiting at vs. that which was expected (PropRSites) (Robinson 2012).

Two expectedness metrics assess the proportion of native fish species found within the relevant catchment and altitudinal zone, compared to a historical reference condition. These assess the proportion of observed vs. expected native fish species at each site (OE or Observed/Expected), and in each zone (OP or Observed/Predicted) (note that all lower Lachlan river sites fall within a single zone) (Robinson 2012).

Table 7-1. Size limits used to distinguish new recruits for each fish 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 (Llewellyn 2007; Pusey et al. 2004)
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)

7.3 Results

7.3.1 Watering year 2019-20

A total of 4,915 fish comprising seven native and three alien species were captured at the 10 in-channel sampling sites along the lower Lachlan River in autumn 2020 (Table 7-2). In order, carp gudgeon, eastern gambusia (*Gambusia holbrooki*), bony herring and common carp were the most abundant species (Table 7-2, Figure 7-1). In order, common carp, golden perch, Murray cod and bony herring contributed the greatest overall biomass in 2019-20 (Figure 7-2).

New recruits (juveniles) were detected in two native longer-lived species (bony herring at 6 of 10 sites and Murray cod at 9 of 10 sites (Figure 7-1 and Figure 7-3), and two native short-lived species (flatheaded gudgeon at 5 of 10 sites and carp gudgeon at 10 of 10 sites. No golden perch or Australian smelt new recruits were captured (Figure 7-1 and Figure 7-3). New recruits of three alien species were captured (common carp (*Cyprinus carpio*) at 9 of 10 sites, goldfish (*Carassius auratus*) at 4 of 10 sites, and eastern gambusia at 2 of 10 sites, Figure 7-1 and Figure 7-3.

No turtles were captured during fish community monitoring. Freshwater prawns (n=10331) were the most abundant taxa in small mesh fyke nets, bait traps and opera house traps Freshwater shrimp (n=479) and a small number of yabbies (n=32) were also captured (Table 7-2).

Table 7-2. Total (non-standardised) catch from the lower Lachlan river system target reach. Sampling was undertaken in autumn 2020 using a combination of five sampling gear types

	SAMPLING METHOD				
COMMON NAME	BOAT ELECTRO-FISHING	SMALL FYKE NET	BAIT TRAP	OPERA HOUSE TRAP	TOTAL
Fish (Native species)					
Australian smelt	8				**8**
bony herring	346				**346**
carp gudgeon complex		2824	34		**2858**
flatheaded gudgeon	2	13			**15**
golden perch	128				**128**
Murray cod	95				**95**
un-specked hardyhead	1	1			**2**
Fish (Alien species)					
common carp	228	1			**229**
Eastern gambusia	11	1181			**1192**
goldfish	39	3			**42**
redfin perch					**0**
Turtles					
long-necked turtle					**0**
Murray River turtle					**0**
Decapods					
freshwater prawn		9656	538	137	**10331**
freshwater shrimp		464	15		**479**
freshwater yabby		31		1	**32**

7.3.2 2019-20 vs Previous years

Sustainable Rivers Audit metric values in 2020 were generally comparable or better than those previously measured in 2015-2019. Nativeness metrics, which reached their lowest levels 2017 after flooding, remain at similar levels to non-flood years. An exception was the Nativeness metric PropNAbund, which was slightly lower than other non-flood years, indicating a measurable increase in alien fish abundance. Recruitment metric values in 2020 were also within the ranges of values previously observed in 2015-2019. PropRSites was at its highest level in 2020, signifying recruitment of native fishes was occurring at a high proportion of sites compared to other years. Expectedness metrics OE and OP were at their equal highest levels in 2020 compared to 2015-2019, illustrating proportions of native fish species relative to reference conditions were elevated relative to other years (Table 7-3, Figure 7-4).

Table 7-3. Summary of SRA fish indices over the six LTIM project sampling years in the lower Lachlan River.

	EXPECTEDNESS		NATIVENESS			RECRUITMENT		
	OE	OP	PROP NS	PROP NABUND	PROP NBIOMASS	PROP RTAXA	PROP RABUND	PROP RSITES
2015	0.42 ± 0.04	0.43	0.63 ± 0.05	0.88 ± 0.02	0.56 ± 0.06	0.50	0.13	0.36
2016	0.46 ± 0.02	0.43	0.73 ± 0.02	0.94 ± 0.02	0.72 ± 0.07	0.67	0.46	0.41
2017	0.44 ± 0.04	0.50	0.57 ± 0.03	0.36 ± 0.05	0.20 ± 0.05	0.71	0.49	0.44
2018	0.54 ± 0.04	0.43	0.71 ± 0.03	0.90 ± 0.03	0.49 ± 0.06	0.67	0.36	0.48
2019	0.44 ± 0.04	0.36	0.69 ± 0.02	0.90 ± 0.02	0.58 ± 0.10	0.80	0.27	0.42
2020	0.54 ± 0.04	0.50	0.71 ± 0.03	0.75 ± 0.06	0.56 ± 0.10	0.57	0.31	0.49

There were significant differences in the abundance ($Pseudo\text{-}F_{5,\,54}$ = 11.351, P < 0.001) of the fish community among years. Pair-wise comparisons indicated that abundances differed between all combinations of years, except between 2015-2016 (t = 1.759, P = 0.148). Differences were primarily driven by a higher abundance of alien common carp in 2017, and more native carp gudgeon in 2018, 2019 and 2020 (Table 7-4).

Similarly, differences in biomass occurred among years ($Pseudo\text{-}F_{5,\,54}$ = 5.221, P < 0.001), with these differences between all combinations of years except between 2015-2016 (t = 1.371, P = 0.253), 2016-2019 (t = 2.451, P = 0.052) and 2019-2020 (t = 1.979, P = 0.103). Differences in biomass were mainly attributed to 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 7-5).

Table 7-4. 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 2015-2016 are not included as no significant differences were found. Analysis results may differ from those reported in previous years due to reanalysis of the multi-year dataset after exclusion of large fyke nets which were not used in 2020 fish surveys.

INDICATOR	YEAR COMPARISON	SPECIES	CONTRIBUTION TO DIFFERENCE (%)	YEAR WITH GREATER VALUE	
ABUNDANCE	2015-2017	common carp	27		2017
		Eastern gambusia	13		2017
		carp gudgeon	13		2017
	2015-2018	carp gudgeon	28		2018
		Australian smelt	17		2018
		bony herring	13		2018
	2015-2019	carp gudgeon	14		2019
		Murray cod	14	2015	
		goldfish	13		2019
	2015-2020	carp gudgeon	27		2020
		bony herring	16	2015	
		Eastern gambusia	13		2020
	2016-2017	common carp	28		2017
		carp gudgeon	13		2017
		goldfish	10		2017
	2016-2018	carp gudgeon	26		2018
		Australian smelt	18		2018
		bony herring	12		2018
	2016-2019	Eastern gambusia	15	2016	
		carp gudgeon	15		2019
		bony herring	14	2016	
	2016-2020	carp gudgeon	26		2020
		bony herring	21	2016	
		Eastern gambusia	11		2020
	2017-2018	common carp	23	2017	
		Australian smelt	15		2018
		carp gudgeon	15		2018
	2017-2019	common carp	29	2017	
		Eastern gambusia	16	2017	
		goldfish	10	2017	
	2017-2020	common carp	26	2017	
		bony herring	15	2017	
		carp gudgeon	10		2020
	2018-2019	carp gudgeon	24	2018	
		Australian smelt	23	2018	
		bony herring	15	2018	
	2018-2020	bony herring	26	2018	
		Australian smelt	20	2018	
		carp gudgeon	14	2018	
	2019-2020	carp gudgeon	22		2020
		bony herring	21	2019	
		Eastern gambusia	17		2020

Table 7-5. 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 2015-2016, 2016-2019 and 2019-2020 are not included as no significant differences were found. Analysis results may differ from those reported in previous years due to reanalysis of the multi-year dataset after exclusion of large fyke nets which were not used in 2020 fish surveys.

INDICATOR	YEAR COMPARISON	SPECIES	CONTRIBUTION TO DIFFERENCE (%)	YEAR WITH GREATER VALUE	
BIOMASS	2015-2017	Murray cod	33	2015	
		common carp	22		2017
		golden perch	12	2015	
	2015-2018	Murray cod	23	2015	
		goldfish	13		2018
		common carp	13		2018
	2015-2019	Murray cod	28	2015	
		golden perch	15		2019
		common carp	14	2015	
	2015-2020	Murray cod	25	2015	
		goldfish	16		2020
		golden perch	13		2020
	2016-2017	common carp	28		2017
		Murray cod	26	2016	
		golden perch	11	2016	
	2016-2018	Murray cod	20	2016	
		common carp	16		2018
		bony herring	14		2018
	2016-2020	Murray cod	23	2016	
		goldfish	15		2020
		common carp	14		2020
	2017-2018	Murray cod	24		2018
		common carp	22	2017	
		goldfish	13	2017	
	2017-2019	common carp	25	2017	
		Murray cod	23		2019
		bony herring	13	2017	
	2017-2020	common carp	23	2017	
		Murray cod	22		2020
		golden perch	13		2020
	2018-2019	bony herring	19	2018	
		goldfish	14	2018	
		common carp	14	2018	
	2018-2020	bony herring	19	2018	
		goldfish	17		2020
		golden perch	13		2020

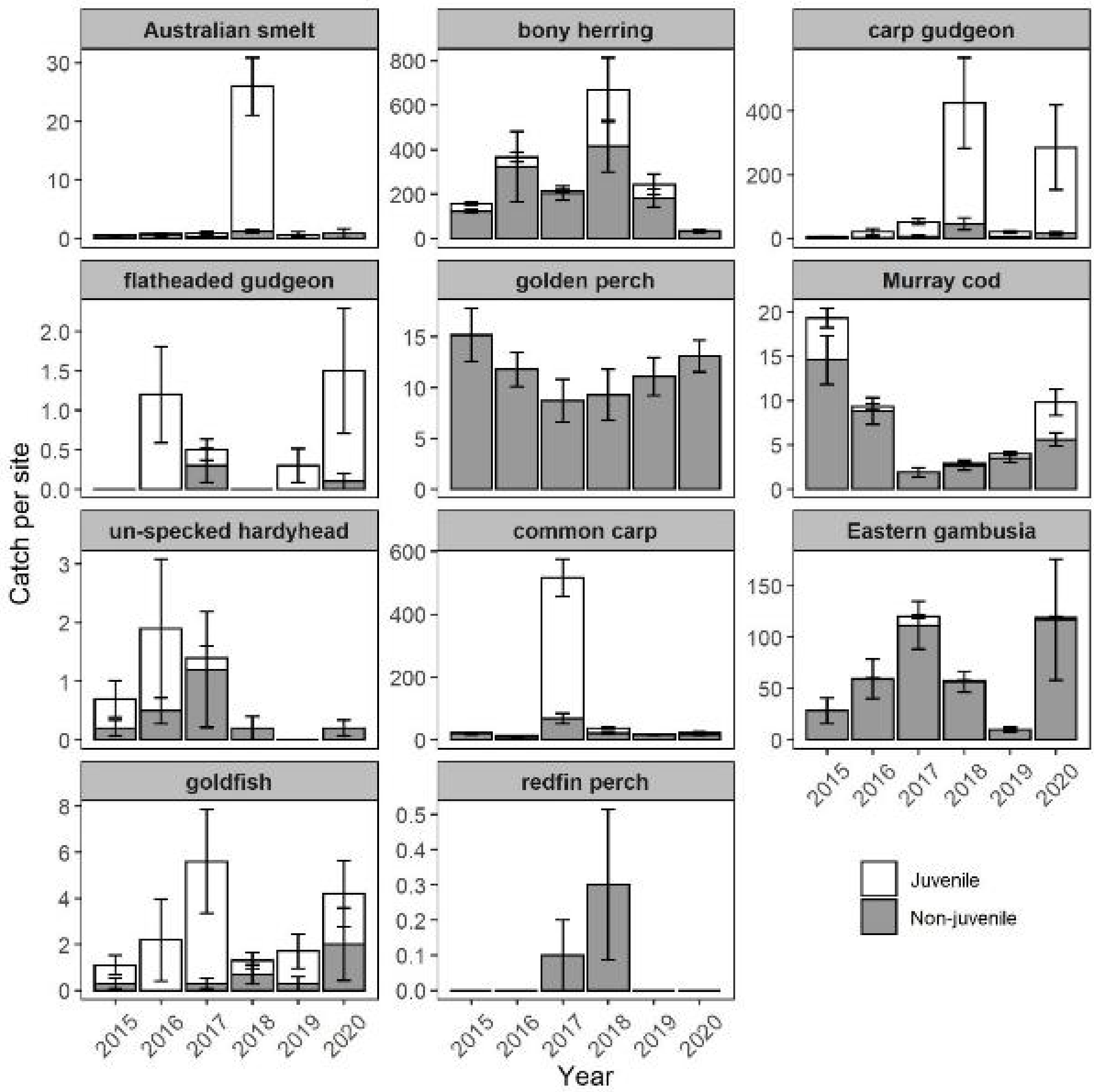


Figure 7-1. Catch per site (number of fish; mean ± SE) for each fish species within the lower Lachlan river system target reach, sampled from 2015-2020.

Cumulative stacked bars separate the catch of juveniles (white bars) and non-juveniles (grey bars).

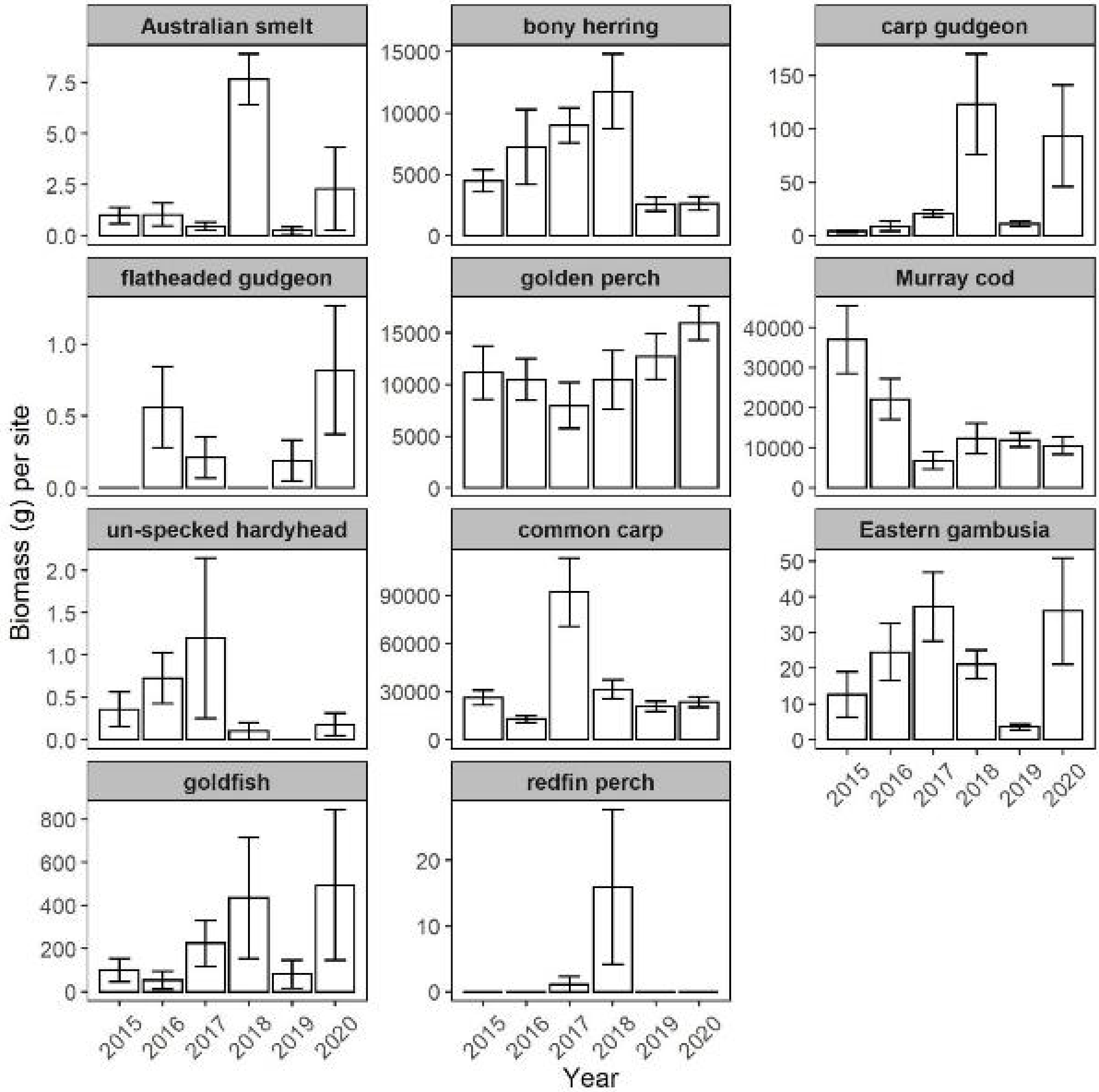


Figure 7-2. Biomass per site (g; mean ± SE) of each fish species within the lower Lachlan river system target reach, sampled from 2015-2020.

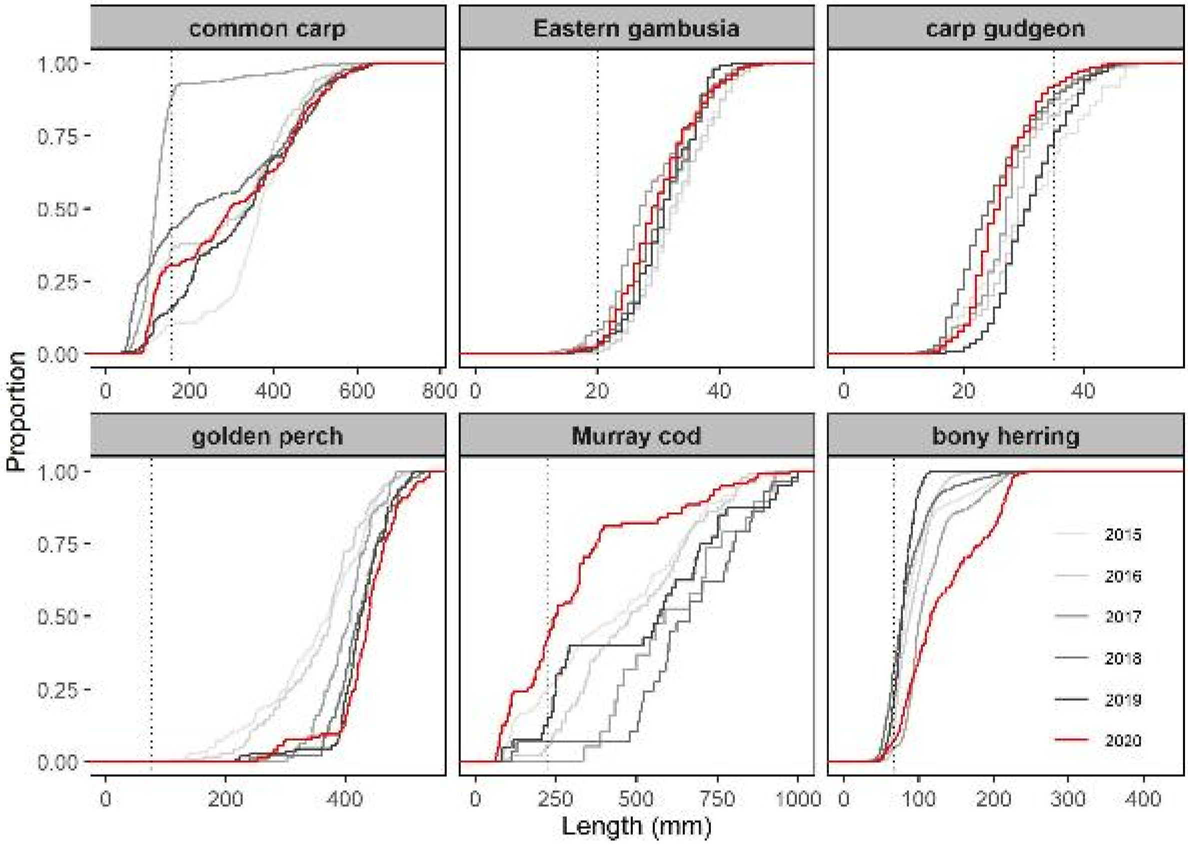


Figure 7-3. Proportionate length-frequencies of the six most abundant species captured in the Lachlan River from 2015–2020 (red line for current year, and grey lines for previous years of darker shades over time). The dashed lines indicate approximate size limits used to distinguish new recruits for each species (see Table 7-1).

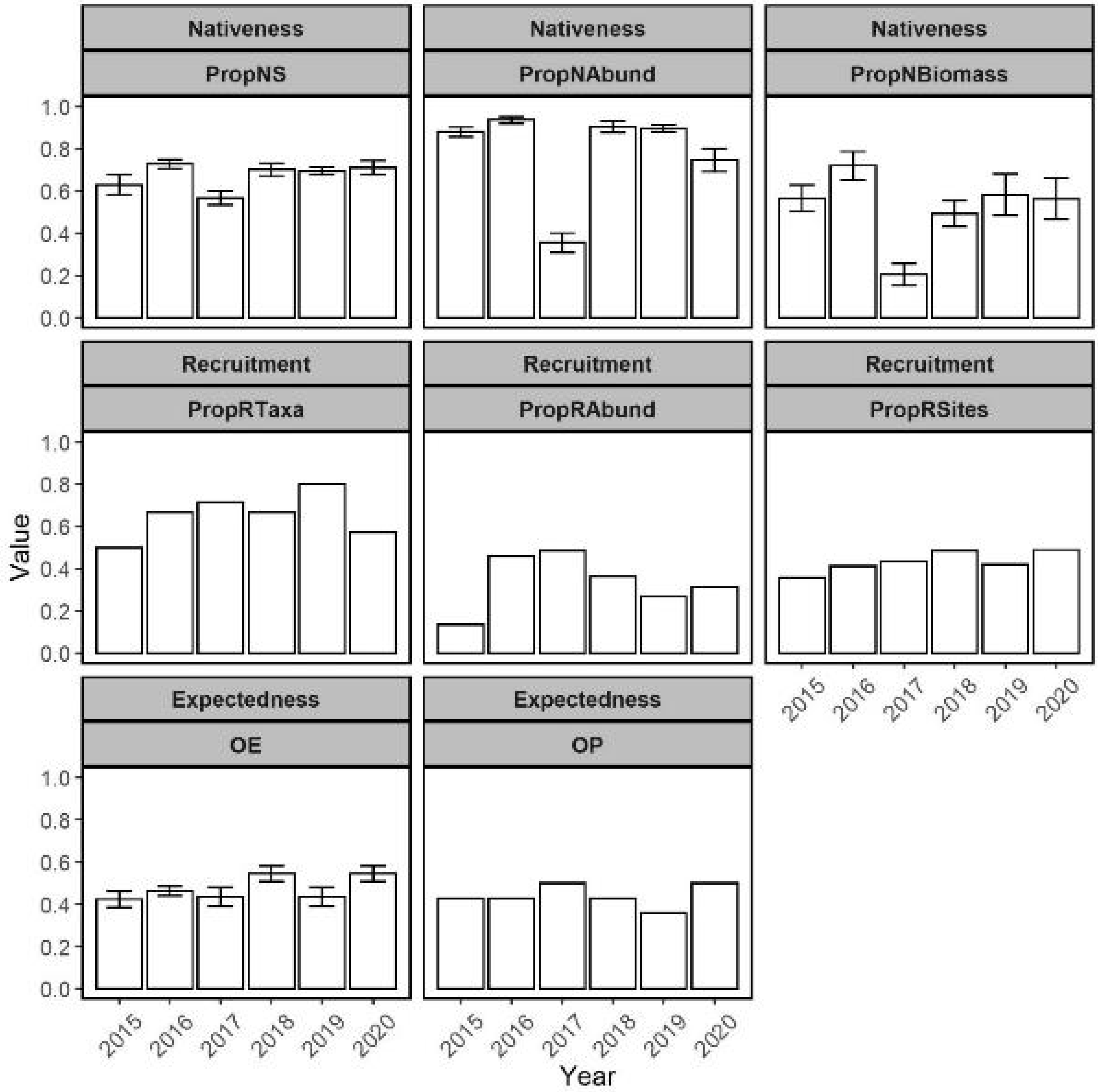


Figure 7-4. SRA metrics (mean ± SE) for the lower Lachlan River from 2015–2020.
Note that Recruitment metrics and the Expectedness metric OP are given single zone-level values, rather than values for many sites like other metrics, so standard errors could not be calculated. OE and OP refer to Observed/Expected and Observed/Predicted, respectively.

7.4 Discussion

In autumn 2020, seven native species of freshwater fish were captured in the lower Lachlan River. Based on bait trap, boat electrofishing and small fyke netting catches, all native fish species previously detected in 2015-2019 were recorded in the current year. Freshwater catfish were detected in 2015 (using fyke nets - large and small, (Dyer et al. 2015). While large fyke nets were used between 2015-2019, they were not deployed in 2020, which may have contributed to the absence of freshwater catfish in this year. Murray-Darling rainbowfish and silver perch are two native fish species presumed to be historically common in lowland sections of the Lachlan River. However, they are rarely found in the target reach and yet to be detected in this monitoring program (see Table 7-6, page 82). Flathead galaxias, olive perchlet, southern purple spotted gudgeon and southern pygmy perch are another four native fish species historically present in lowland regions of the Lachlan. Although olive perchlet is the only one recently detected at this location (Wallace and Bindokas 2011, DPI Fisheries, unpublished data). Despite numerous species absences, native fish species richness in the lower Lachlan River is generally higher than in other parts of the catchment. Furthermore, the data presented indicates that the level of native fish species richness has been maintained over the monitoring period.

SRA metric values in 2020 were higher or within the ranges of those recorded in previous years. The Recruitment metric PropRSites was at its highest level. Increases in the number of sites that native fish species were recruiting at, including Murray cod, were evident. Recruitment metric values for PropRTaxa and PropRAbund have been variable between 2015–2020, but did not significantly diverge in 2020, suggesting that similar numbers of native species were recruiting and to a comparable degree. Expectedness metric values for OE and OP (or Observed/Expected and Observed/Predicted) were equal to previous maximums and confirmed the maintenance of native fish species richness between 2015–2020. A concerning observation was that the Nativeness metric PropNAbund in 2020 was at its lowest level since 2017 when fish assemblages became dominated by alien fish species after a major flood event. More gambusia and goldfish were to blame for decreased native relative to alien fish abundance. Other Nativeness metrics PropNS and PropNBiomass were at normal levels in 2020 compared to other years. In general, SRA metric values suggested that the overall condition of the native fish community in the lower Lachlan River has been sustained or improved over the course of the monitoring program.

In response to hydrological conditions in 2019–2020, including Commonwealth watering actions, native bony herring abundance decreased in 2020 compared previous years. Greater winter die-off due to low temperature tolerance thresholds, pathogens or predation pressure along with reduced spawning and recruitment from poor phyto/ microzooplankton resources are possible explanations for this decline (Pusey et al. 2004). Adults currently present in the population may support future spawning and recruitment of this highly fecund species (Puckridge and Walker 1990)which can rebound substantially within 12–18 months following a major disturbance (Pusey et al. 2004). In contrast, most other native fish species (Murray cod, golden perch, carp gudgeon, flathead gudgeon, unspecked hardyhead) increased in abundance in 2020 compared to 2019, linked to the 2019–2020 Commonwealth watering actions. Longer-lived Murray cod and golden perch had previously declined in abundance following poor water quality associated with the 2016–2017 floods but in 2020 both were at similar abundances to 2015 and 2016 surveys before flooding. Although Murray cod adults remain at a lower abundance compared to 2015 and 2016. Resurgence in Murray cod new recruits at an abundance similar to their highest level in 2015 prior to flooding suggests that the hydrological conditions, supplemented by Commonwealth watering actions, is allowing recovery of this long-lived species in the system. Increased foraging opportunities from in-channel flows are thought to translate to better Murray cod growth (Stoffels et al. 2019), and potentially improve the success of larvae developing into juvenile and adult stages. Little change in abundance was observed for native Australian smelt in 2020 compared to 2019.

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). Annual stocking of Murray cod in the lower Lachlan River (DPI Fisheries, *unpublished data*) potentially confounds the interpretation of new recruits, but ongoing work is being undertaken to disentangle and appropriately attribute the correct management intervention for this species. 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. An acknowledgement that flow-recruitment relationships for Murray cod are specific to individual river systems also appears wise (Tonkin et al. 2021).

As in 2015–2019, golden perch recruits were not captured in 2020. 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 2020 has increased to levels observed in 2015–2016. Stocking of golden perch has been undertaken in the Lachlan River since the 1970’s, including on numerous occasions within the Selected Area in the past 10 years (DPI Fisheries, *unpublished data*). (Shams et al. 2020) recently reported that both natural recruitment and stocking contribute to riverine golden perch populations in the Lachlan River based on otolith microchemistry and genetic analyses, but that stocking is the dominant source. 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 opportunities for spawning and subsequent recruitment for this species.

7.5 Evaluation

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 2020, resilience and survival of the lower Lachlan River native fish community was maintained or improved compared to previous years as a result of hydrological conditions, including Commonwealth environmental water. The targeted watering actions appeared to benefit native fish spawning and recruitment in 2020, including Murray cod. SRA recruitment metrics were at their highest level or within normal ranges in 2020.

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

The lower Lachlan River native fish population was most affected by flooding/hypoxia and potential fish kills (anecdotal reports) in 2016–2017 during LTIM project 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 masked 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.

The lower Lachlan River native fish diversity has been restored to 7 native species in 2020, which was previously observed in 2015–2017 but had declined to 6 species in 2018–2019. SRA expectedness metrics were at equal highest levels in 2020 compared to previous years. The temporary decline in native fish diversity over the sampling period may relate to flooding/hypoxia linked to potential fish kills in 2016–2017 and the opportunistic detection of rare species. The role of Commonwealth environmental water in the restoration of native fish diversity in the lower Lachlan River is again difficult to ascertain.

7.6 Recommendations

- Future water delivery, focussing on native fish outcomes, should utilise natural triggers such as tributary inflows.

> **CEWO Adaptive Management Response**: The use of Commonwealth environmental water will continue to use tributary inflows as natural triggers for fish and other outcomes whenever possible.

- 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.

> **CEWO Adaptive Management Response**: The 2019-20 watering year was an example of how a single watering action, like the spring pulse, can be used to achieve multiple objectives. This included maintaining and providing refuge habitat under NSW Stage 3 drought conditions where it was also possible that all remaining environmental water could be quarantined for critical human needs only.

- Ongoing assessment of the source of new recruits for stocked species (Murray cod and golden perch) is required to tease out the effects of different management interventions such as fish stocking and flow management, and subsequently attribute the outcome to the correct intervention.

> **CEWO Adaptive Management Response**: The NSW Hatchery Quality Assurance Scheme (NSW DPI Fisheries 2019) notes that although four fish marking methods are available, none are currently mandatory under the Scheme. A requirement for the mandatory use of fish marking (e.g. via a user pays system) may assist is understanding the role of fish stocking programs in NSW.

- Watering actions to support golden perch are likely only possible during years of above average water availability. Given that the 5 years of the LTIM project have identified a range of conditions that do not 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/MER (e.g. Goulburn River) would further refine these releases for golden perch spawning outcomes.

> **CEWO Adaptive Management Response**: As noted in the spawning and larval fish chapter, the CEWO agrees that this is a priority for native fish in the Lachlan River system and other systems. While understanding spawning in Golden perch is essential, it is integrally linked to recruitment outcomes. Given the large volumes of water that are likely to be required to trigger Golden perch spawning, the CEWO is interested in exploring water use options, possibly over consecutive years, that would also seek to obtain young of year Golden perch following from a successful spawning event.

- 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.

CEWO Adaptive Management Response: The use of Commonwealth environmental water, in partnership with operational flows, is a critical way to annually maintain Murray cod spawning habitat. The 2019-20 spring pulse showed that providing additional variability (providing a rise in water level and receding back to nesting flow level), during the spawning period poses little risk to Murray cod spawning outcomes (see spawning and larval fish chapter).

- 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.

CEWO Adaptive Management Response: A project to understand the movement patterns of key native fish species in the Lachlan catchment would need to a) demonstrate how it could be designed to answer evaluation questions without being compromised by the presence of barriers (such as weirs) which, without fishways installed on them, prevent fish movement in the first place; and b) demonstrate how we would obtain new knowledge that has not already been obtained for these key species in other Basin catchments (e.g. that fish prefer to move on higher flows/pulses).

7.7 Appendix

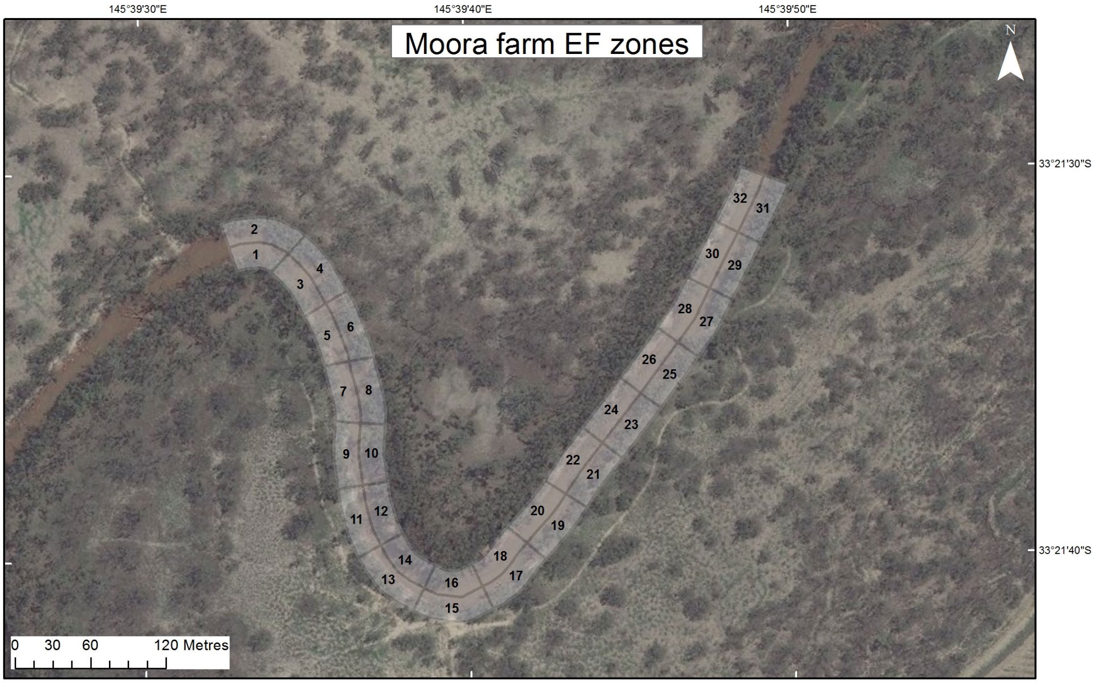


Figure 7-5. Example of mapped boat electrofishing units used for Category 1 fish community sampling in the Lachlan River. Each unit was sampled using 90 seconds of 'on-time'.

Table 7-6. Pre-European (PERCH = Pre-European Reference Condition for fisH) list of the expected native fish species present in the lowland Lachlan river basin, their associated rarity and subsequent detection during the LTIM 2015 and 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		

8 SPAWNING AND LARVAL FISH

8.1 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 behavior, and larval and juvenile survival (Balcombe et al. 2006; Humphries et al. 1999; Junk et al. 1989; King et al. 2003). Since the strength of recruitment to adulthood is largely driven by spawning success, and growth and survival of young, understanding how the flow regime influences the early life history of fishes is critical to managing fish populations (King et al. 2010).

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:

8.1.1 Short-term (one year) evaluation questions:

- What did Commonwealth environmental water contribute to native fish reproduction in the lower Lachlan river catchment?
- What did Commonwealth environmental water contribute to native larval fish growth and survival in the lower Lachlan river catchment?

8.1.2 Long-term (five year) evaluation questions:

- What did Commonwealth environmental water contribute to native fish populations in the lower Lachlan river catchment?
- What did Commonwealth environmental water contribute to native fish species diversity in the lower Lachlan river catchment?

The larval fish monitoring implemented within the lower Lachlan river system is directed at Basin scale evaluation and is confined to a single zone within the lower Lachlan river system Selected Area. There are likely to be strong differences in the fish community and habitats between zones within the Selected Area resulting in the evaluation of outcomes for the Selected Area being confined to the target reach (i.e. Zone 1) (Dyer et al. 2014b). 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, the second aims to address the short-term and long-term evaluation questions.

8.2 Methods

8.2.1 Field sampling

Larval fish were sampled at three sites (Dyer et al. 2014b) on the lower Lachlan river system Selected Area (Wallanthery, Hunthawang and Lanes Bridge, see Figure 6-1, page 36. To capture larval fish, three drift nets and 10 light traps were set overnight at each site (for more detail see Dyer et al. 2014a). 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 21st October 2019 and 17th December 2019:

The timing of sampling will be targeted around watering actions with expected outcomes for native fish spawning, with considerations for seasonal requirements of target species. The target species include representative from each of the three representative guilds:

- Equilibrium: Murray cod (*Maccullochella peeli*) and freshwater catfish (*Tandanus tandanus*)
- Periodic: Golden perch (*Macquaria ambigua*) and bony herring (*Nematalosa erebi*)
- Opportunistic: Australian smelt (*Retropinna semoni*) and flathead gudgeon (*Philypnodon grandiceps*).

8.2.2 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.

8.2.3 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 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 Section 8.8: Appendix 2: Results of Similarity percentage analysis (SIMPER) of annual differences in the larval fish community in the lower Lachlan river selected area).

8.3 Results

8.3.1 Watering year 2019-20

A total of 1248 larval fish were captured across the five sampling events of spring-summer 2019 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 8-1). Drift nets captured the majority of larval fish, though this was mostly driven by high abundances of Murray cod (Table 8-1). Numbers of larval fish were variable between sampling events, with trips 1 and 2 capturing the majority of fish (87% of all trips) comprising 17% and 70%, respectively. Murray cod were by far the most numerous species caught, comprising 93% of the total number of larval fish captured in 2019 (Table 8-1). Australian smelt were the next most dominant species, comprising nearly 4% of the total number of fish captured (Table 8-1).

Three of the six target species of larval fish species were captured in 2019: one Equilibrium species, Murray Cod, and two Opportunistic species, Australian smelt and flat headed gudgeon (Table 8-1). No Periodic representative species (golden perch or bony herring) were collected during larval sampling in 2019 (Table 8-1). Murray cod were captured in all trips, with the majority (53%) of individuals captured from a single site during sampling event 2 (Wallanthery) (Figure 8-1). Larval Murray cod ranged in length from 5.626 – 17.445 mm, corresponding to ages of 6 – 18 days (Figure 8-2). Estimated spawning window for Murray cod in 2019 was between 22/9/19 – 30/11/19, with two peaks between 26/9/19 – 1/10/19 and 13/10/19 – 19/10/19 (see Figure 8-7, in Section 8.7: Appendix 1: Estimating fish spawning dates 2019). Length of Murray cod decreased from trip 1 to trip 2 indicating that a second spawning event had occurred and the individuals in trip 2 were younger than those captured in trip 1 (Figure 8-2).

Table 8-1. Capture summary of larval fish from sampling conducted between mid-October to mid December 2019 in the lower Lachlan river system Selected Area.

SPECIES	DRIFT NETS	LIGHT TRAPS	TOTAL
Murray cod	743	418	**1161**
flat headed gudgeon	2	7	**9**
Australian smelt		48	**48**
carp gudgeon	1	3	**4**
freshwater catfish			**0**
golden perch			**0**
eastern gambusia		6	**6**
common carp	2	18	**20**
TOTAL	**748**	**500**	**1248**

Three opportunistic species were collected during larval sampling in 2019, these were Australian smelt, flat headed gudgeons and 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 most abundant on sampling event 2 (69% of larvae captured during this trip) (Table 8-1 and Figure 8-1). Australian smelt were captured at each site and were most numerous at Wallanthery. Australian smelt captured ranged in size from 3.67 – 19.77 mm (Figure 8-2) and ranged in estimated age from 5 – 25 days. Length frequency distribution and associated back calculation of estimated spawning dates indicate that Australian smelt had a spawning window spanning mid-September to mid-November in 2019 (seeFigure 8-7, Section 8.7). Peak spawning activity occurred around mid/late October 2019, when water temperatures were around 19 – 21 °C (see Figure 8-7, Section 8.7). Mean length of Australian smelt decreased between sampling trip 1 and 2, likely indicating a second spawning event happening in between sampling trips (Figure 8-2).

Flat headed gudgeon were captured in all sampling events except for sampling event 4 (early December). The majority (seven of nine) of flat headed gudgeon were captured in light traps. Flat headed gudgeon ranged in length from 7.45 – 17.71 mm (Figure 8-2), with an estimated age of 22 –

75 days. This corresponds to an estimated spawning window from late-August to early-October, when water temperatures were ~12 - 20 degree (see Figure 8-7, Section 8.7). Low numbers of flat headed gudgeon captured in 2019 made it difficult to analyse length frequency to attribute growth patterns between sampling trips (Figure 8-2).

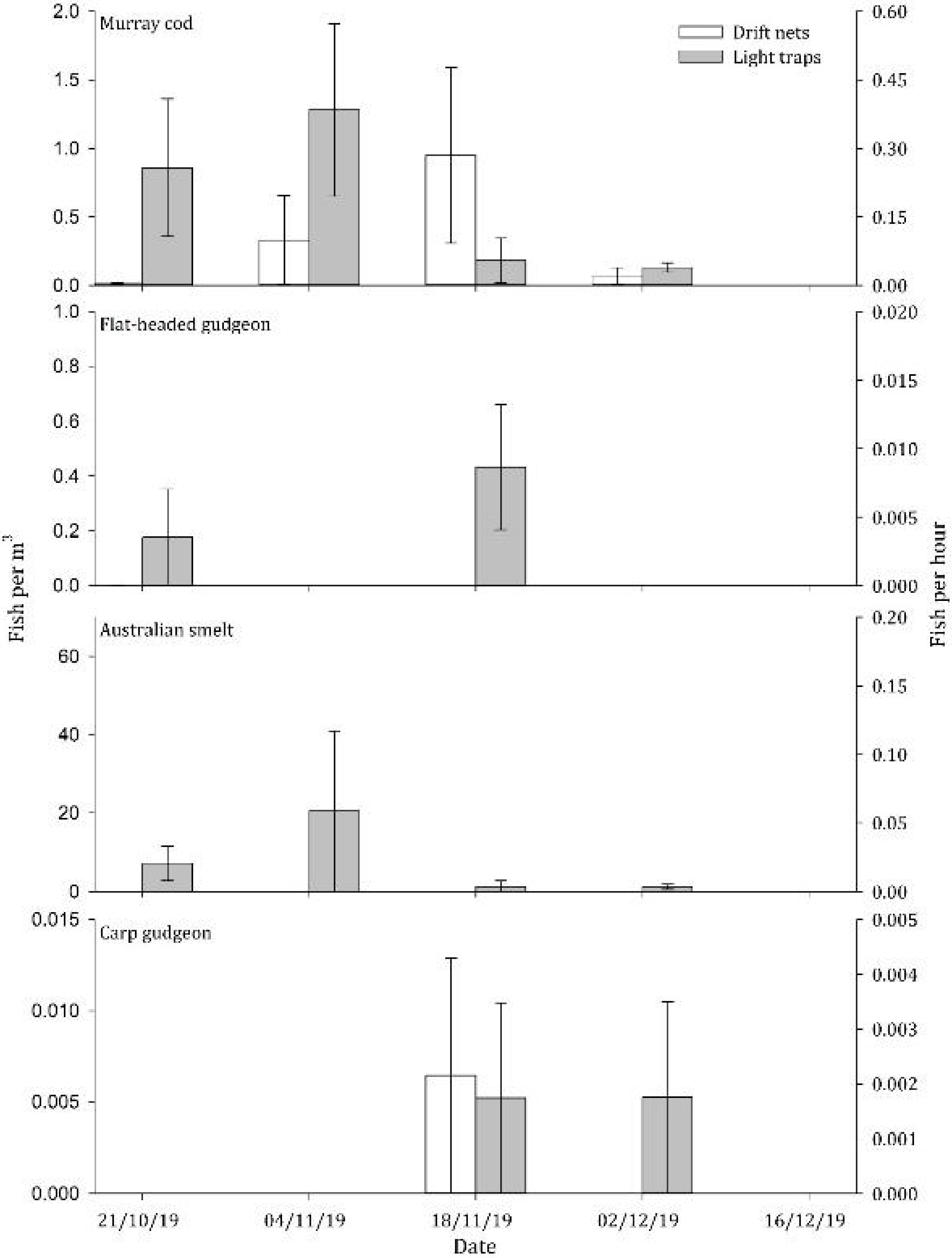


Figure 8-1. Mean catch per unit effort (± standard error) of the commonly caught larval native fish for drift nets (left axis, white bars) and light traps (right axis, grey bars) per sampling event in spring summer 2019.

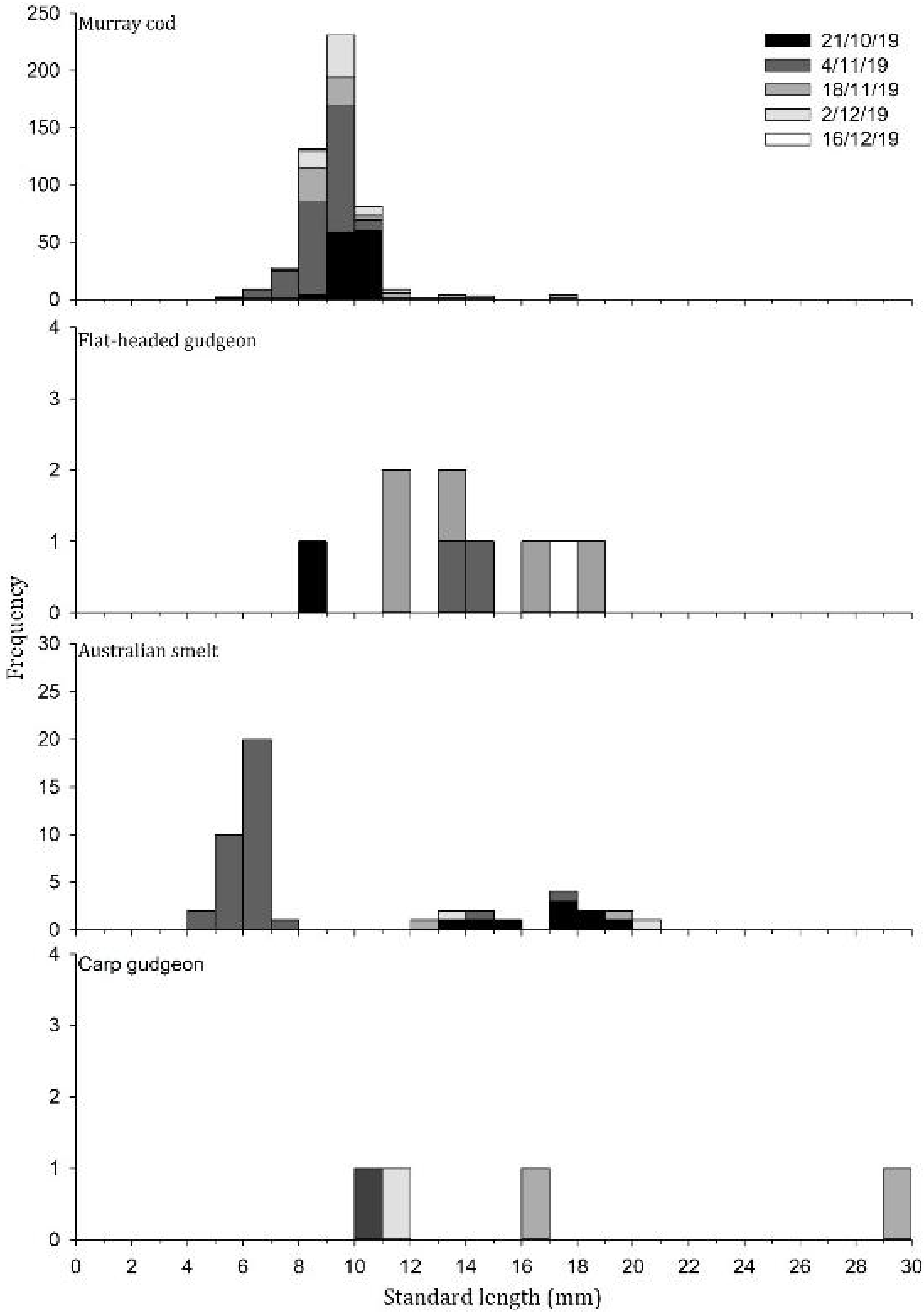


Figure 8-2. Length frequency histograms for each sampling event of commonly captured larval native fish species with site (n = 3) and sampling technique (n = 2) combined for 2019.

A total of 26 alien fish larvae were captured in 2019 comprising 20 common carp and six eastern gambusia (Table 8-1). The vast majority (95%) of common carp were captured during trips 1 and 3 from a single site (Wallanthery). Common carp ranged in length from 5.14 – 18.29 mm and estimated ages from 1 – 35 days old. The estimated spawning window of common carp spanned early-October – mid-November when water temperature was 18 – 20 °C (see Figure 8-7, Section 8.7). Eastern gambusia were captured in sampling events 1 and 3. Eastern gambusia ranged in size from 9 – 11 mm and were between 25 and 32 days old (based on estimated length vs age estimate equations presented in Humphries et al. (2008).

8.3.2 2019-20 vs Previous years

There was a significant difference in the larval fish community between years in the lower Lachlan river selected area (Table 8-2). Pairwise tests revealed that the larval fish community of 2019 was not statistically different to any other year, and was most similar to 2014 in being dominated by Murray cod larvae and very few individuals from other species. The large abundance of common carp was the discriminating factor between 2016 and all other years. The larval fish community in 2017 and 2018 was typified by far higher abundances of Australian smelt and flat headed gudgeon than other years (Figure 8-3 to Figure 8-5, and Table 8-3 in Section 8.7: Appendix 1: Estimating fish spawning dates 2019).

Table 8-2. 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 – 2019.

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Year	**5**	**23.116**	**4623.3**	**15.534**	**0.0001**	**9927**
Site (Year)	12	3571.4	297.62	No test		
Total	17	26688				

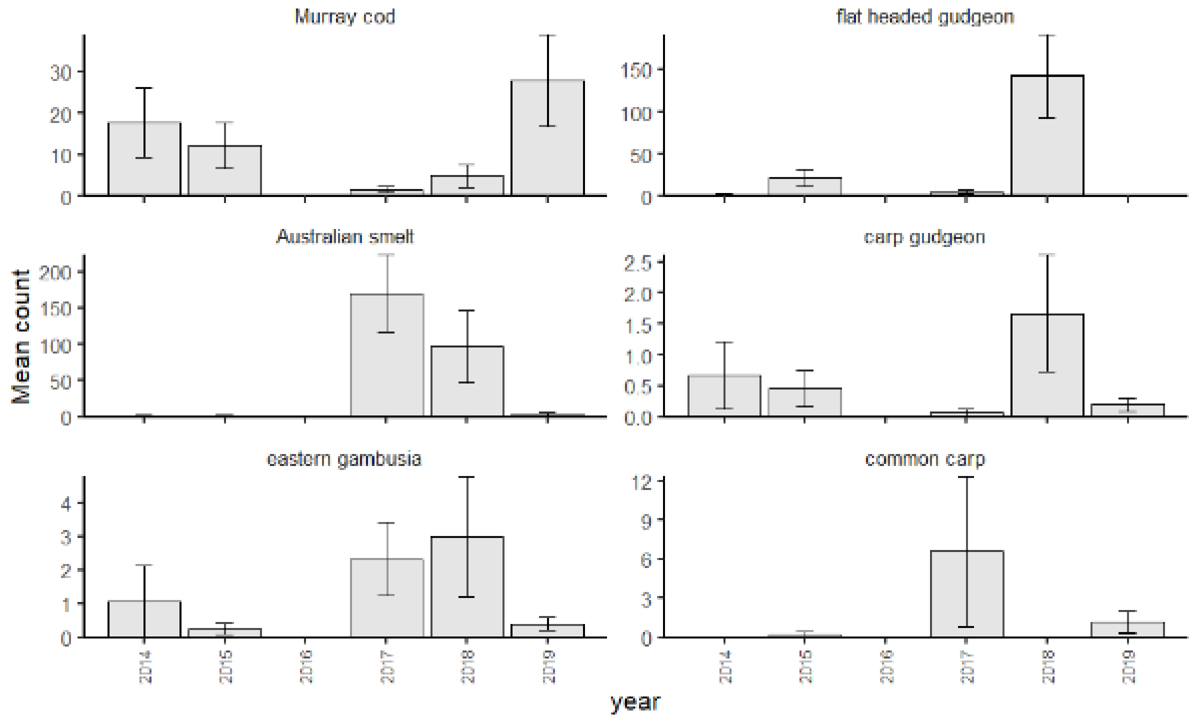


Figure 8-3. Mean raw abundances of larval fish species captured in light traps from spring – summer 2014 – 2019. Note: light traps were not set in 2016 due to river being in flood.

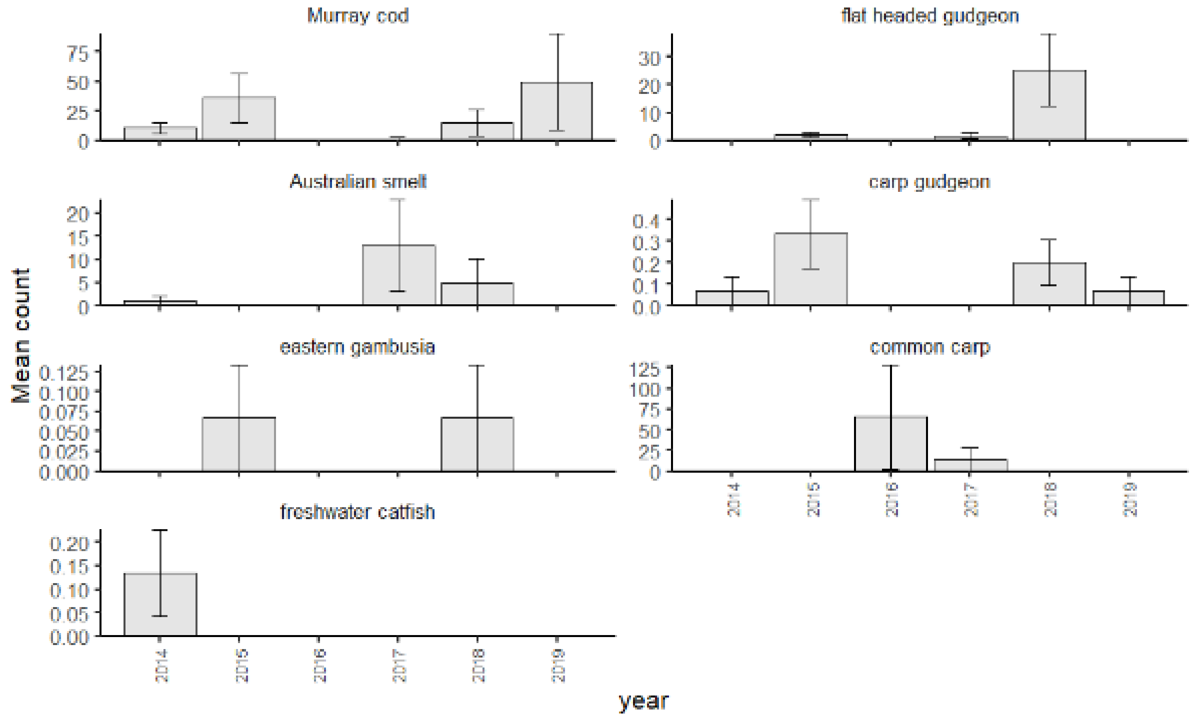


Figure 8-4. Mean raw abundances of larval fish species captured in drift nets from spring – summer 2014 – 2019.

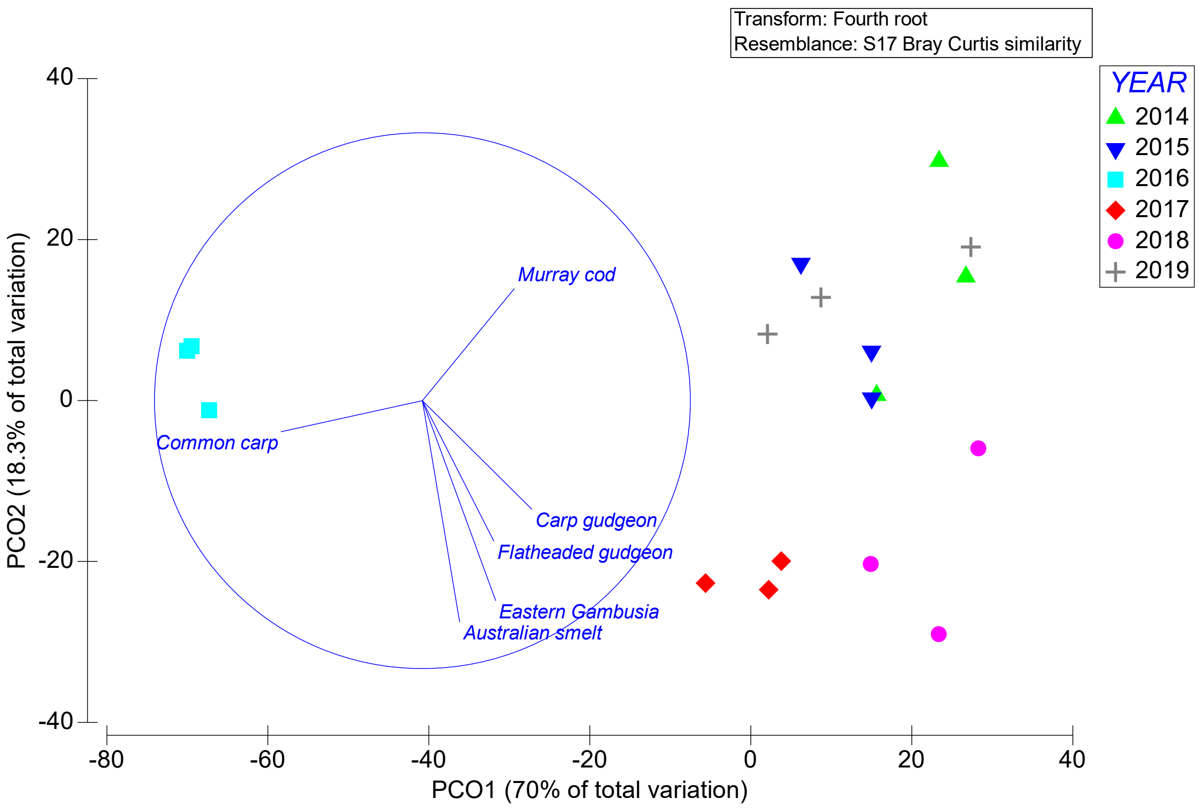


Figure 8-5. Annual larval fish community composition per site (plotted in multidimensional space via principal component analysis ordination) captured from the lower Lachlan river selected area using drift nets and light traps from spring/summer 2014 – 2019.

8.4 Discussion

A spring fresh flow pulse was released down the main Lachlan River channel which aimed to maintain health of fish communities and support fish population recovery by reinstating flow components that promote key ecological processes. This spring fresh passed through the sites monitored for larval fish in October 2019, when water temperatures were at 20 ^{o}C. The highest peaks in estimates spawning activity for both Murray cod and Australian smelt occurred on the recession of the spring fresh. Although neither species are recognised at being flow dependent spawners, the spring fresh in 2019 may have facilitated spawning processes by increasing connectivity and access to mates and spawning habitats, and created ideal conditions for early development by contributing to stream productivity (see Section 6: Stream metabolism and water quality).

In general, best practice water delivery to support successful Murray cod nesting has been based around maintaining relatively stable water levels during cod nesting period (Late September through to mid-November Harrington (2006) also (Koehn and Harrington 2006; Sharpe 2019). The spring fresh delivered in 2019 resulted in a river rise and fall of approximately 1.5 m, by far the largest variation during the watering year of 2019-20 (Figure 8-6). It may have been expected that the large variation right in the middle of the Murray cod nesting period may have resulted in stranded nests as the water level receded. Our data suggests that spawning activity decreased as the peak of the fresh arrived, then increased to its peak as the water level receded (Figure 8-7 and Section 8.7: Appendix 1: Estimating fish spawning dates 2019), and that larval fish abundances were the highest recorded since monitoring began in 2014. This result suggests that spawning and nesting of Murray cod populations in the lower Lachlan River are somewhat robust against the sharp rise and fall of the released spring fresh. This may have been achieved by selection of nesting sites low in the river channel during minimum operational flows, which may have reduced the risk of nest desiccation. Furthermore, it is likely that stream production was bolstered by the spring fresh, which would have increased food resources for larval and early juvenile Murray cod (and other larval fish species).

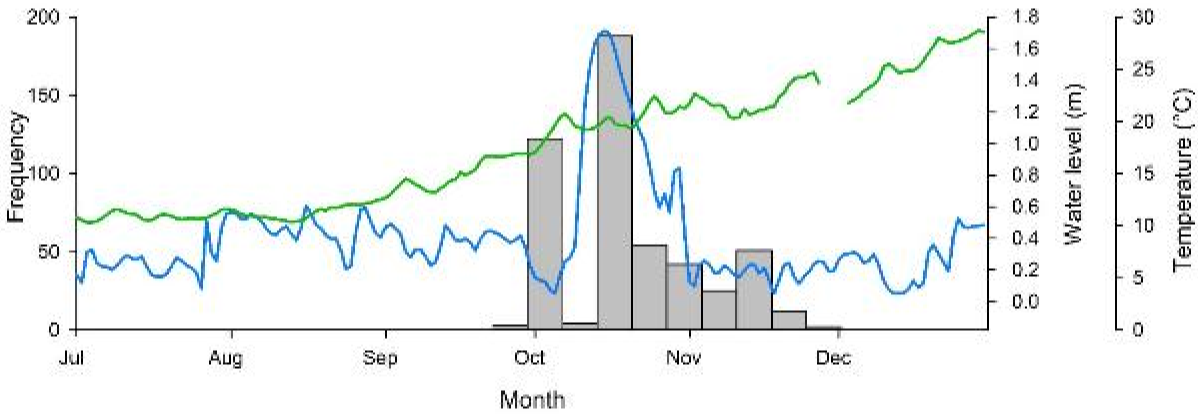


Figure 8-6. Frequency histogram of estimated spawning date of larval Murray cod captured in 2019 (all sites and trips combined – grey bars) with water level (from gauge downstream of Ganowlia weir – blue line) and temperature (from gauge Willandra Weir – green line).

As for the first five years of monitoring, there was no evidence of natural recruitment of golden perch in the selected area in 2019 (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 and temperatures of 23 °C are often quoted as optimal for spawning associated with an increase in discharge (Lake 1967; Roberts et al. 2008).

The spring fresh was delivered with water temperatures exceeding 20 °C, which is within the range of expected spawning temperatures for golden perch (King et al. 2005; Stuart and Jones 2006). Despite suitable temperature ranges, the fresh 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 2019. Contrary to other years where recruits were detected in the community fish sampling in autumn, there was little evidence of recruitment for this species at all for 2019-20 (see Section 7: Fish community). It is difficult to explain the recruitment failure of this species in the lower Lachlan

River in 2019-20, especially as eggs or larvae have never been detected during this monitoring program (despite the latter recruits showing up in great abundances during the fish community sampling in the following autumn), so the lines of evidence are missing with respect to early life history patterns in the lower Lachlan river selected area. Based on results from previous years of this monitoring program and from previous studies elsewhere (e.g. Balcombe et al. 2006), bony herring recruit over a wide range of hydrological conditions, including extreme flooding and low flow periods, so it appears as though hydrology alone is not the driver behind the lack of recruitment in 2019. This species is relatively long lived (5+ years) (Pusey et al. 2004).

In contrast to the previous two spawning seasons (2017 and 2018), abundances of small-bodied species were relatively low in 2019. In terms of Australian smelt, the spawning season of 2019 appears to have produced small abundances of recruits (based on larval fish sampling and fish community monitoring). Flat-headed gudgeon differ to Australian smelt in that whilst there were small abundances captured in larval sampling, abundances detected by fish community monitoring in autumn suggest equal highest number of recruits since monitoring began (with the spawning season of 2015). The driver behind the low abundances of larval small bodied fish in 2019 is not clear at this stage, but may be related to a general decline in food resources as the influx of organic material associated with the 2016 flooding is broken down.

Twenty larval common carp were captured in 2019, suggesting that although some spawning occurred, overall common carp spawning activity (as detected in the larval fish monitoring) in the targeted area was low. This is despite a distinct peak in flow during the possible carp spawning window. This reiterates previous findings from this program that in channel rises can be released with low risk of creating suitable conditions for a large common carp spawning event.

8.5 Evaluation

There was one Commonwealth environmental watering action in the lower Lachlan river system that aimed to have expected outcomes for native fish reproduction in 2019;

1) Spring fresh in the Lachlan River main channel

This watering action had one objective relating to native fish:

1) Maintain health of native fish populations prior to an expected dry summer.

The spring fresh delivered down the main channel of the Lachlan river is likely to have positively contributed to the health of native fish populations in the selected area. The primary mechanism for this would have been to produce increased primary productivity which would have increased available food for larval and small bodied fish (see section 5 and 6).

The spring fresh delivered down the main channel of the Lachlan river is likely to have positively contributed to the health of native fish populations in the selected area. The primary mechanism for this would have been to produce increased primary productivity which would have increased available food for larval and small bodied fish (see Section 6).

The fresh looks to have supported a strong recruitment response from Murray cod, which have been in recovery since a reduction in adult abundance associated with the flooding and related hypoxic water quality of 2016-17.

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:

8.5.1 Short-term (one year) evaluation questions:

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

In 2019 Commonwealth environmental water appears to have made a positive contribution to the spawning and early recruitment of Murray cod the lower Lachlan river system. Monitoring in 2019 indicates that production of small bodied larval fish was reduced compared to 2017 and 2018, and again both golden perch and bony herring were not present in the samples collected. Based on the evidence at hand (strong relative abundances of Murray cod, though low abundances of small bodied native species in 2019), the spring pulse delivered in October was partially successful in achieving expected outcomes for fish reproduction in the lower Lachlan Selected Area.

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. In the past we have inferred growth by an increase in species mean length across sampling trips. This was not evident in 2019, as both Murray cod and Australian smelt both had multiple peaks in spawning activity which straddled our first two sampling trips resulting in both species recording reductions in mean lengths across some sampling trips. Despite this, evidence from the stream metabolism monitoring indicates that stream productivity did increase somewhat following the spring pulse, and this would likely have increased food production for larval native fish.

8.5.2 Long-term (five year) evaluation questions:

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

The spring pulse has resulted in a strong recruitment year for Murray cod in the lower Lachlan river selected area. This cohort was strongly represented in the community monitoring in autumn 2020, indicating that this year should positively contribute to the breeding population in the next 3 – 5 years. This continues the recovery of this species in the selected area since the population declined dramatically in 2016, most likely because of fish kills associated with blackwater from the 2016-17 floods.

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

The main mechanism for Commonwealth environmental water to contribute to native fish species diversity in the lower Lachlan river system thus far has been to facilitate spawning and to produce sufficient resources for larval fish growth and survival. As mentioned above, the pulse in 2019 has resulted in a significant recruitment year for Murray cod in the selected area, as well as supporting spawning and early growth of small bodied larval fish species (albeit to a smaller scale than the previous two years). The real room for increase in diversity of the larval fish community would be to elicit a spawning response from the resident golden perch population, which thus far has not been detected in larval fish monitoring.

8.6 Final Comments and Recommendations

- Murray cod larval abundances in 2019 were the highest since this program began, despite a rapid fall in water level associated with the spring fresh in October. This indicates, at least for this year, that spawning of Murray cod can proceed uninhibited even when water levels are relatively variable in the middle of the nesting period.

CEWO Adaptive Management Response: Where possible the CEWO will seek to provide minimum base flows to prevent nest abandonment by Murray cod, especially when operational demand may decrease during the nesting period. Aligning the provision of a spring pulse and a longer recession more directly with the cod nesting season may assist with providing the outcomes being sought for cod spawning, recruitment and productivity.

- Golden perch recruitment is still not detectable (either by the larval fish sampling or fish community sampling). We believe that eliciting a golden perch spawning event in the lower Lachlan river selected area is a research and management priority and should water be available, a well-orchestrated delivery regime aimed at golden perch spawning should again be attempted.

CEWO Adaptive Management Response: The CEWO agrees that this is a priority for native fish in the Lachlan river system and other systems (e.g. the Edward/ Kolety-Wakool) that have also not detected spawning in Golden perch. Discussions with fisheries managers and scientists are continuing, including drawing on the lessons learnt in other catchments such as the Goulburn and Murrumbidgee where Golden perch spawning has occurred. Those discussions include how to try and secure a recruitment outcome if a Golden perch spawning event was to occur (e.g. exploring the potential of Lake Cargelligo as a nursery area). There is also a need to understand the movement patterns Golden perch in the Lachlan in relation to flow, temperature and barriers (such as weirs). The ability of Golden perch to be able to access preferred spawning and recruitment areas could also be informed by current habitat mapping efforts undertaken by NSW agencies.

- Whilst the absence of bony herring larvae from this program is common, the absence of recruits from the community monitoring program is of some concern. Furthermore, there was a large decline in abundance of non-recruits of this species as well in 2020. Although this species lives for 5+ years, a series of recruitment failures could have disastrous effects on this population.

8.7 Appendix 1: Estimating fish spawning dates 2019

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 Murray cod and Australian smelt larvae captured in 2014 – 2018 were aged to construct age-length keys outlined below), and this forced the use of less accurate indirect methods of aging and spawning date estimation.

Ages for Australian smelt were calculated using an age-length model (Age = -1/0.059904*LOG10 (1-Ln/19.738043)+3.712221) derived from Australian smelt known age fish collected from the Lachlan river 2014 – 2018 (Dyer et al. 2019a).

Ages of other small bodied species (carp gudgeon and flat headed gudgeon) were estimated from length-age equations for each species for a site on the lower Murray River 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 collected in the Lachlan River from 2014 – 2018 (Dyer et al. 2019a) (Age = -14.2478+(2.78*Ln)+1.924). 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. Age of larval common carp was estimated using age vs growth relationships from Vilizzi (1998), and hatching time was taken from Lintermans (2007).

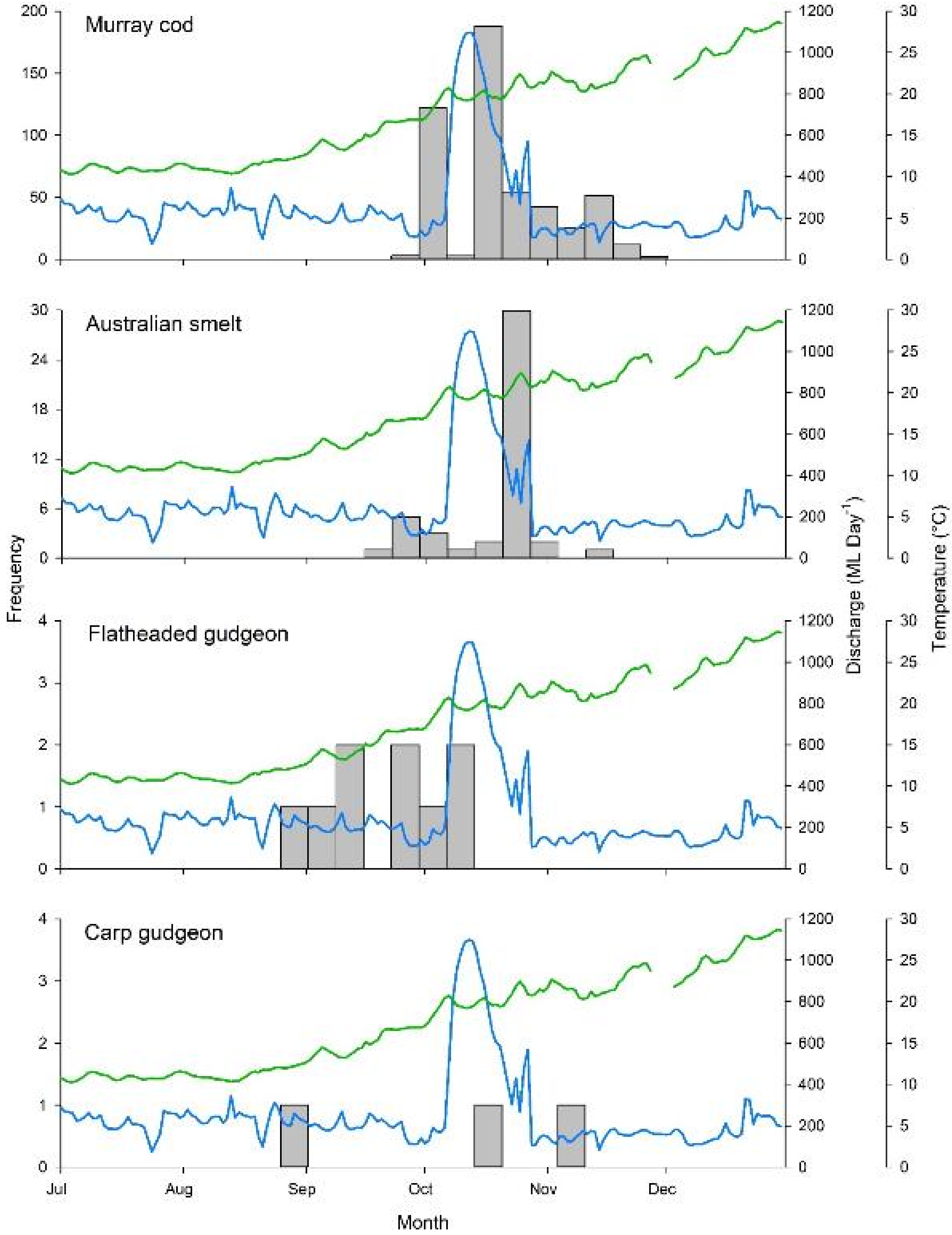


Figure 8-7. Estimated spawning date frequency (grey bars) and associated discharge and temperature for larval native fish species in 2019. Mean daily discharge from Lachlan River at Willandra Weir (blue line) and mean daily temperature from Lachlan River at Cowl Cowl (green line).

Note: Data are from all sites and methods combined.

8.8 Appendix 2: Results of Similarity percentage analysis (SIMPER) of annual differences in the larval fish community in the lower Lachlan river selected area

Table 8-3. 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 = 27.88

Species	Group 2014	Group 2015				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
flatheaded gudgeon	1.75	3.14	6.90	1.47	24.76	24.76
Eastern Gambusia	0.67	0.84	4.37	1.42	15.66	40.42
Common carp	0.33	1.14	4.24	1.37	15.20	55.62
Carp gudgeon	0.97	1.35	3.51	1.09	12.61	68.23
Murray cod	3.41	3.86	3.11	1.61	11.14	79.37
Freshwater catfish	0.67	0.00	2.92	1.30	10.46	89.83
Australian smelt	1.71	1.48	2.84	1.42	10.17	100.00

Groups 2014 & 2016
Average dissimilarity = 96.09

Species	Group 2014	Group 2016				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Murray cod	3.41	0.00	28.97	3.17	30.15	30.15
Common carp	0.33	3.26	24.09	1.77	25.07	55.22
Flatheaded gudgeon	1.75	0.00	13.98	3.51	14.55	69.77
Australian smelt	1.71	0.00	13.65	5.87	14.21	83.98
Carp gudgeon	0.97	0.00	6.72	1.31	7.00	90.97

Groups 2015 & 2016
Average dissimilarity = 84.45

Species	Group 2015	Group 2016				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Murray cod	3.86	0.00	26.10	5.06	30.90	30.90
Flatheaded gudgeon	3.14	0.00	20.96	5.72	24.82	55.72
Common carp	1.14	3.26	13.08	1.40	15.49	71.21
Australian smelt	1.48	0.00	9.96	2.52	11.79	83.01
Carp gudgeon	1.35	0.00	9.01	5.78	10.67	93.67

Groups 2014 & 2017

Average dissimilarity = 47.25

Species	Group 2014	Group 2017				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	1.71	5.44	16.19	3.47	34.26	34.26
Common carp	0.33	2.46	9.07	1.63	19.20	53.46
Murray cod	3.41	1.84	6.77	2.88	14.33	67.79
Eastern Gambusia	0.67	1.84	5.91	1.44	12.52	80.30
Carp gudgeon	0.97	0.33	3.44	1.33	7.28	87.58
Flatheaded gudgeon	1.75	2.44	3.24	1.03	6.86	94.44

Groups 2015 & 2017

Average dissimilarity = 38.23

Species	Group 2015	Group 2017				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	1.48	5.44	15.14	5.25	39.60	39.60
Murray cod	3.86	1.84	7.86	2.93	20.55	60.15
Common carp	1.14	2.46	4.81	1.09	12.59	72.74
Eastern Gambusia	0.84	1.84	3.96	1.47	10.36	83.10
Carp gudgeon	1.35	0.33	3.85	1.84	10.06	93.17

Groups 2016 & 2017

Average dissimilarity = 77.57

Species	Group 2016	Group 2017				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	0.00	5.44	31.22	7.91	40.24	40.24
Flatheaded gudgeon	0.00	2.44	14.13	5.86	18.21	58.45
Eastern Gambusia	0.00	1.84	10.63	6.87	13.70	72.15
Murray cod	0.00	1.84	10.44	7.02	13.46	85.61

Groups 2014 & 2018

Average dissimilarity = 40.57

Species	Group 2014	Group 2018				
	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 = 29.50

Species	Group 2015	Group 2018				
	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 = 96.80

Species	Group 2016	Group 2018				
	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

Species	Group 2017	Group 2018				
	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

Groups 2014 & 2019

Average dissimilarity = 27.57

Species	Group 2014	Group 2019				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Eastern Gambusia	0.67	1.17	5.53	3.19	20.05	20.05
Common carp	0.33	1.08	4.80	1.19	17.40	37.45
Murray cod	3.41	4.23	4.73	1.43	17.17	54.62
Carp gudgeon	0.97	1.06	3.32	1.22	12.04	66.65
Flatheaded gudgeon	1.75	1.28	3.22	1.75	11.69	78.34
Freshwater catfish	0.67	0.00	3.09	1.29	11.23	89.57
Australian smelt	1.71	1.81	2.88	1.43	10.43	100.00

Groups 2015 & 2019
Average dissimilarity = 21.66

Species	Group 2015	Group 2019				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Flatheaded gudgeon	3.14	1.28	8.32	2.97	38.41	38.41
Common carp	1.14	1.08	3.38	1.54	15.62	54.03
Murray cod	3.86	4.23	3.37	1.33	15.55	69.57
Australian smelt	1.48	1.81	2.90	1.38	13.39	82.96
Eastern Gambusia	0.84	1.17	2.24	0.88	10.33	93.29

Groups 2016 & 2019
Average dissimilarity = 85.52

Species	Group 2016	Group 2019				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Murray cod	0.00	4.23	30.92	5.55	36.16	36.16
Common carp	3.26	1.08	15.65	1.22	18.30	54.46
Australian smelt	0.00	1.81	13.01	4.81	15.21	69.67
Flatheaded gudgeon	0.00	1.28	9.44	4.27	11.04	80.70
Eastern Gambusia	0.00	1.17	8.57	7.27	10.02	90.72

Groups 2017 & 2019
Average dissimilarity = 41.00

Species	Group 2017	Group 2019				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Australian smelt	5.44	1.81	14.72	4.01	35.90	35.90
Murray cod	1.84	4.23	9.58	2.89	23.36	59.26
Common carp	2.46	1.08	6.27	1.21	15.29	74.55
Flatheaded gudgeon	2.44	1.28	4.75	3.48	11.59	86.14
Carp gudgeon	0.33	1.06	2.92	1.41	7.13	93.26

Groups 2018 & 2019
Average dissimilarity = 37.85

Species	Group 2018	Group 2019				
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Flatheaded gudgeon	5.18	1.28	14.38	4.77	37.99	37.99
Australian smelt	4.49	1.81	9.95	2.46	26.29	64.28
Murray cod	2.92	4.23	5.13	1.81	13.57	77.85
Common carp	0.33	1.08	3.50	1.26	9.24	87.09
Eastern Gambusia	1.78	1.17	2.61	1.59	6.89	93.98

9 VEGETATION

9.1 Introduction

Inundation by flooding facilitates the exchange of water, living organisms and resources (inorganic and organic matter) between the main channel, and the floodplain and is the predominant factor that controls the observed ecological patterns and processes, and biological productivity on the floodplain (Bayley 1995; Junk et al. 1989; Poff and Ward 1989). Plants on floodplains often require flooding for survival, growth and reproduction as rainfall alone is often insufficient (Catelotti et al. 2015; Doody et al. 2014; Roberts and Marston 2011). Flooding maintains tree condition in floodplain trees such as river red gum (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) (Holland et al. 2009). Flooding and flood recession stimulates germination and growth responses in many aquatic and semi-aquatic plants (Rea and Ganf 1994; Robertson et al. 2001; Van der Valk and Davis 1976), resulting in temporal shifts in plant community composition and structure of the groundcover in response to flooding and drying.

The lower Lachlan river system is a very low gradient alluvial plain, experiencing very low run-off, and river flows typically occur in response to rainfall in the upper catchment (Roberts et al. 2016). The lower Lachlan river (below the junction of the Lachlan River and Willandra Creek) is characterised by numerous distributary channels and anabranches, and an expansive network of irregularly flooded floodplains (Green et al. 2011), including many sites of national significance (Environment Australia 2001; SEWPaC 2011). Typical floodplain habitats in the lower Lachlan River include temporary floodplain lakes, river red gum woodlands, black box woodlands and lignum shrublands. These floodplain habitats depend on over-bank flows during wet periods and are distributed across floodplains in relation to flow related gradients in flood frequency and duration (Roberts et al. 2016).

Over the five years of the LTIM project (2014-19) the groundcover vegetation on the floodplain of the lower Lachlan River has displayed sequences of wet and dry phases depending on the prevailing hydrological and climatic conditions. During dry conditions, rainfall results in a flush of terrestrial dry species, while during and following flooding a diverse assemblage of amphibious species dominate. The context in which the 2019-20 environmental watering actions were delivered was one in which the flow of the Lachlan River was low and the only over bank flows were a result of environmental watering actions. The conditions in the lower Lachlan river catchment during 2019-20 were dominated by local rainfall. During the first half of the watering year the lower Lachlan River continued to experience the very dry conditions observed during 2018-19, while Autumn 2020 saw higher than average rainfall in the catchment.

During the 2019-20 watering season, two watering actions targeted vegetation outcomes. These watering actions (one in November 2019 and the other in May 2020) provided water to the central reed beds, and surrounding wetlands of the Great Cumbung Swamp, including Nooran Lake and the river red gum channel mound system at Juanbung. Environmental water was also used to fill the temporary floodplain lake at Noonamah in November 2019 to promote bird breeding. This action also partially inundated the surrounding black box woodland including our plots at Noonamah.

This technical report provides an evaluation of the outcomes for vegetation in the lower Lachlan river system and addresses the selected area specific evaluation questions (listed in 9.1.1). The results have been described in relation to the hydrological and climatic conditions, and environmental watering actions which have occurred over the 2019-20 watering year. The results gathered over the five years of LTIM project are used to provide context to this year's findings. The inclusion of a greater number of sites which receive environmental water, as of the commencement of the MER program (Spring 2019) has improved our ability to detect a response of the vegetation to environmental watering and address the specific evaluation questions.

The monitoring of vegetation diversity in the Lachlan selected area uses Category 2 methods to address the selected area evaluation questions.

9.1.1 Selected area specific evaluation questions

1) What did Commonwealth environmental water contribute to native riparian and wetland vegetation communities?
    a. What did Commonwealth environmental water contribute to populations of long-lived organisms (measured through cover and recruitment of tree species)?
    b. What did Commonwealth environmental water contribute to individual plant species across the Selected Area including changes to species presence, distribution and cover?
    c. What did Commonwealth environmental water contribute to vegetation communities within the interim Australian National Aquatic Ecosystem (ANAE) vegetation types, including changes in species richness, composition, cover and structure?

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. (2014b) and Table 9-3, on page 106.

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 13 sites (Figure 9-5, page 110) and Table 9-3, page 106) using the methods of Driver et al. (2003) described in Dyer et al. (2014b). Species abundance and cover were 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 14 sites (Figure 9-5, page 110) and Table 9-3, page 106) using the methods of Bowen (2013) described in Dyer et al. (2014b). An understory floristic survey was undertaken in a nested 0.04 ha plot inside the 0.1 ha plots. Tree condition was observed not sensitive to watering over the past five years of LTIM project, and as such stand and tree condition will now be recorded every five years and not annually. However, at the sites that were newly established stand and tree condition were recorded in Autumn 2020. 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 <10 cm diameter at breast height (DBH). In each 0.04 ha plot, the floristic survey recorded species abundance (of all species including trees) and cover. Stand and tree condition data is not presented in this report.

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

As a result of the learning from the past five years of monitoring (Dyer et al. 2019a), it was a recommendation that a greater number of sites that receive or may receive environmental water be monitored moving in to the MER program, as this increases our ability to evaluate the response of the vegetation to environmental water. Therefore, we established three additional sites which are more likely to receive environmental water and added two extra transects at Lake Marool in (OLM). The three new sites are Juanbung (JU), Lake Bunumburt (BU) and Lake Noonamah (NO) (see the vegetation monitoring strategy for the MERP (2019-22) for details that are to be incorporated into a future update of the MER Plan, (Dyer et al. 2019b)). At Juanbung and Bunumburt monitoring occurs within the woodland tree community and non-tree community, and only within the woodland tree community at Noonamah. Juanbung is a river red gum channel mound wetland to the west of the Great Cumbung Swamp (south-west of Oxley). Bunumburt and Noonamah are temporary floodplain lakes surrounded by intermittent black box swamps.

We have continued monitoring within Murrumbidgal Swamp (MB) as of Spring 2019. We have also included the reed bed of the Great Cumbung Swamp (RB) as a non-tree community site using data we collect as part of the research component of the MER program. Reed bed sites were established across a flooding gradient; therefore, we have included two paired sites within watering categories A, B and C. These paired sites are equivalent to the two replicate 100 m transects each with ten 1 X 1m transects used in the non-tree community surveys. The reed bed monitoring sites each consist of nine 1 X 1m quadrates (see chapter 11.2.1 for details).

As per the vegetation monitoring strategy for the MER program (2019-22) we now no longer monitor within six sites which have not and are unlikely to receive environmental water (Table 9-1 and Table 9-2).

Table 9-1. The flooding frequency of Woodland Community (plot) sites, within each community type and geomorphic unit. Site codes in red are sites which will no longer be monitored (HW = Hazelwood; WB = Whealbah; LI = Lake Ita; and CL = Clear Lake), while sites in blue are newly established sites (BU = Bunumburt; JU = Juanbung; and NO = Noonamah).

COMMUNITY TYPE	GEOMORPHIC DESCRIPTION	ESTIMATED FLOODING FREQUENCY					
		0/5	1/5	2/5	3/5	4/5	5/5
River Red Gum	Channel Mound Wetland	LBU, LT		MB		JU	
	Riparian Wetland	~~HW~~, ~~WB~~, ~~LI~~, ~~CL~~, LM	MM, NL, TV				
Black Box	Woodland	~~LI~~, LT	BO, TL	BU		NO	
Mixed	Riparian Wetland	TV					

Table 9-2. The flooding frequency of Non-Tree Community (transect) sites, within each community type and geomorphic unit. Site codes in red are sites which will no longer be monitored (BO = Booligal), while sites in blue are newly established or additional sites (RB1-3 = Reed bed sites; BU = Bunumburt; and JU = Juanbung, OLM = Open Lake Marool).

COMMUNITY TYPE	GEOMORPHIC DESCRIPTION	ESTIMATED FLOODING FREQUENCY					
		0/5	1/5	2/5	3/5	4/5	5/5
River Red Gum	Channel mound wetland	LBU, LT		MB		JU	
	Riparian Wetland		TV, HW, WB				
Open	Open Wetland		LM, MM, RB1	OLM, RB2	NL	RB3	
Black Box	Channel		~~BO~~				
	Riparian Wetland			BU			

Table 9-3. Wetland sampling dates and observations 2019-20. Watering categories correspond to the historical watering of the sites (see Table 9-4).

	OBSERVATION (inundation averaged across plots/transects at each site)				NOTES (plot and transect specific observations)		WATERING HISTORY (see Table 9-4)	
	Spring 2019		Autumn 2020					
SITE (CODE)	Transect	Plot	Transect	Plot	Transect	Plot	Transect	Plot
ZONE 1								
Hazelwood (HW)	dry		dry				B	
Whealbah (WB)	dry		dry				B	
Moon Moon (MM)	dry	dry	dry	dry			B	B
ZONE 2								
Lake Bullogal (LBU)	dry	dry	dry	dry			A	A
Murrumbidgal Swamp (MB)	dry	dry	dry	dry	Signs of surface water but none on transects		B	B
Noonamah (NO)		20%		dry		Plot 2 was partially inundated during Spring monitoring.		C
The Ville (TV): Mixed								
The Ville (TV): RRG	dry	dry	dry	dry			B	B
ZONE 3								
Nooran Lake (NL)	dry	dry	dry	dry	Evidence of flooding on the Lower part of the transects		C	B
Lake Marrool (LM)	dry	dry	dry	dry			B	A
Open Lake Marrool (OLM)	dry		dry				B	
Juanbung (JU)	20%	20%	80%	20%	Water on transect in Autumn trip and just prior to Spring trip	Evidence of recent flooding over some of the plots	C	C
Bunnumburt (BU)	dry	dry	dry	dry			B	B
Central Reed beds (RB)					Watering varied from dry to recently flooded		A-C	
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				B	B

9.2.1 Evaluation approach

9.2.1.1 Action specific evaluation

During 2019-20, Commonwealth environmental water was used to maintain and enhance the condition of the central reed beds of the Great Cumbung Swamp in November 2019. This watering event inundated or partially inundated our sites at Juanbung, Nooran Lake and the central reed bed (RB-Wet) (Figure 9-1 to Figure 9-3). Juanbung was also inundated with Commonwealth environmental water in May 2020, and the transects at Juanbung were still inundated from this event, in June during our site visit.

The woodland tree community site at Noonamah was inundated by environmental water which reached Lake Noonamah early November 2019. This water reached the surrounding black box and had partially inundated our plots during Spring 19 monitoring.

Figure 9-1. Water reaches the reed bed of the Great Cumbung Swamp, 9-11-2019. Photo taken by Fiona Dyer.

Figure 9-2. Lake Noonamah following an environmental watering action in November 2019. Photo taken by Fiona Dyer.

Figure 9-3. Photo of the intermittent river red gum floodplain swamp south of the Great Cumbung Swamp taken 17 June 2020 following an environmental watering action in May 2020. Photo taken by Matthew Young.

9.2.1.2 Selected Area evaluation

To address the Selected Area evaluation questions, the 2019-20 vegetation data were combined with the data collected over the previous five years and considered in the context of annual weather patterns and watering history. To enable this, the six years of monitoring were characterised in terms of the context provided by the annual weather patterns. At each site, transects and plots were assigned a watering history based on the watering that has occurred since 2012-13 (Table 9-4 and Figure 9-4). These categories were used to structure the data analysis and interpret the response of the vegetation observed. Sites were compared based on the occurrence of environmental water during the 2019-20 watering year.

Table 9-4. 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, 2019-20 • 2015-16 water was either translucent releases or environmental water or a combination, 2017-18 water was Commonwealth environmental water.

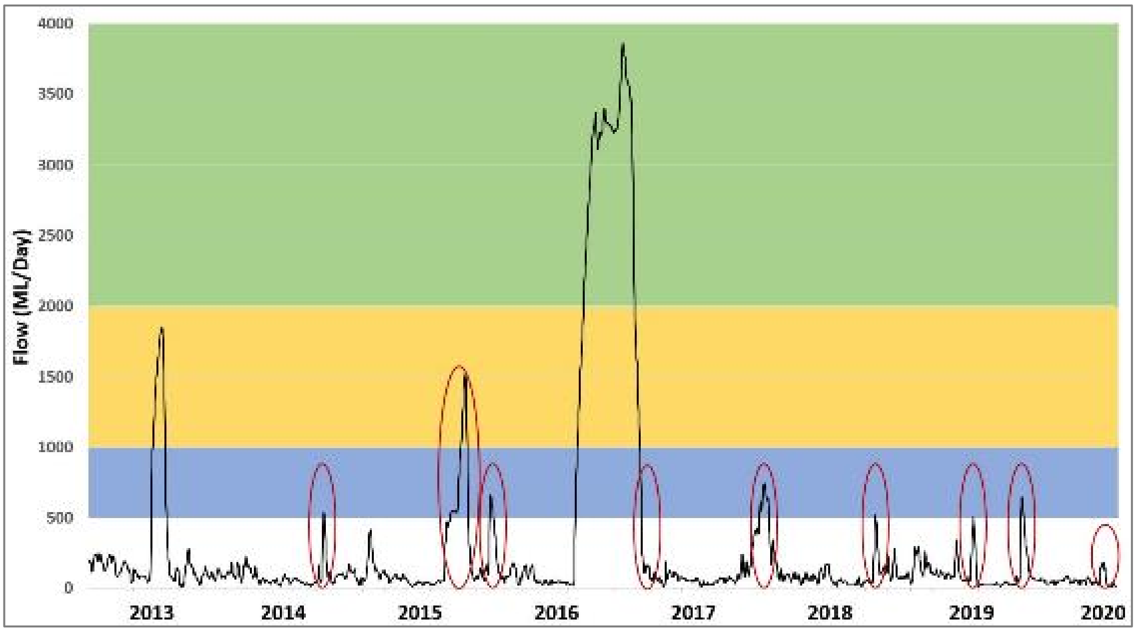


Figure 9-4. Conceptualisation of recent watering history categories (defined in Table 9-4).
Green shading represents watering category A, yellow shading represents watering category B and the blue shading represents watering category C. Red circles show environmental watering actions resulting in inundation of at least one LTIM monitoring site. Black line indicates river flow (ML/day) taken from the Lachlan River at Booligal.

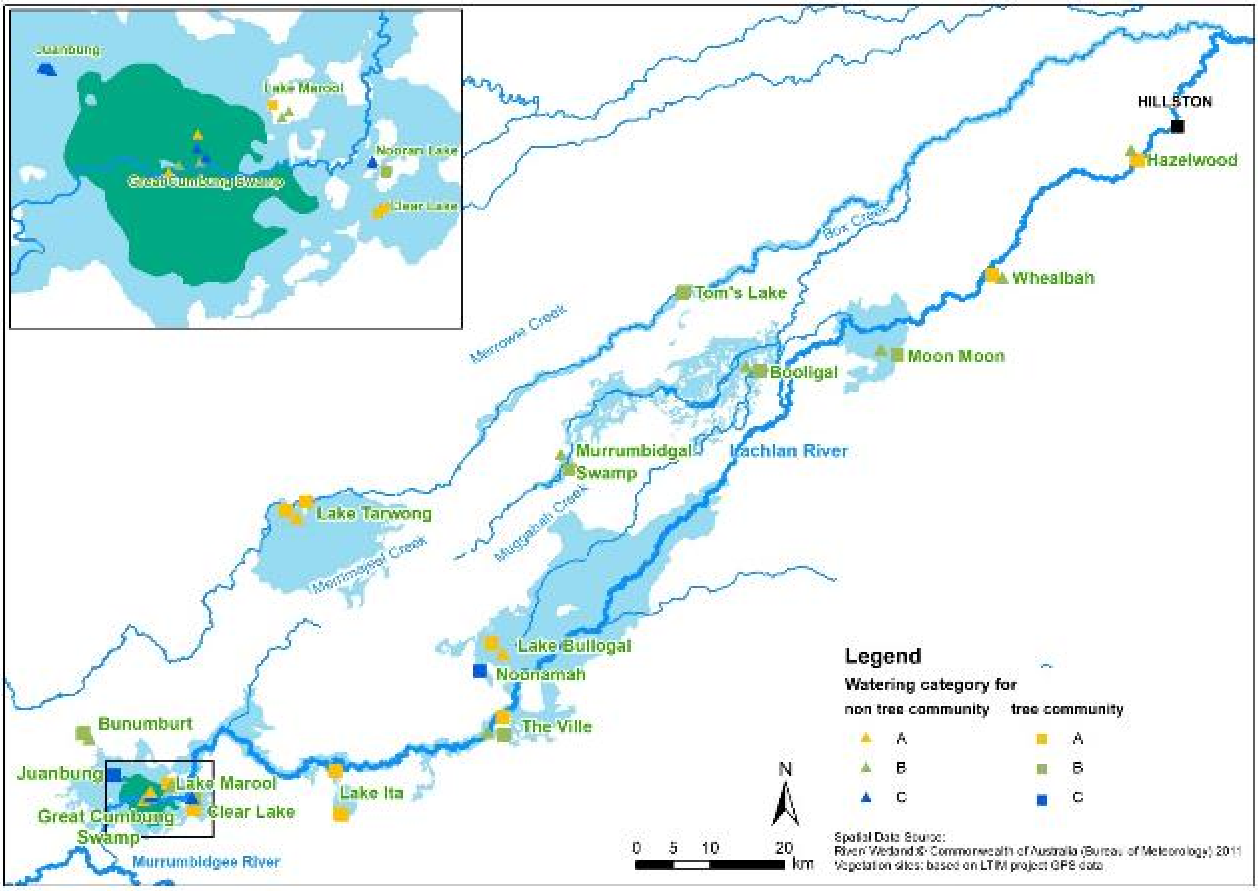


Figure 9-5. Map of the vegetation monitoring sites categorised according to watering history.

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 9-5) 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 is presented as 13.1 and 13.2 Appendix.

Table 9-5. 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 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.

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

9.3.1 Species richness

9.3.1.1 Tree community

A total of 169 species were observed across the tree community plots during the 2019-20 watering year. This is substantially greater than the number of species observed during the previous (2018-19) watering year, and similar to that observed in 2015-16 and 2016-17.

The 2019-20 watering year exhibited the greatest mean number of species observed per site of all watering years. The number of species observed each year over the six years of monitoring has varied year to year, related to climate with lower numbers of species observed during dry periods (for example 2018-19) (Table 9-6).

Table 9-6. Overall and average per site species number observed over the last six watering years in the tree community

Watering season	SR (number of species across all sites)	Mean number of species at a site
2014-15	137	24.7
2015-16	166	28.7
2016-17	172	30.3
2017-18	156	26.6
2018-19	120	20.8
2019-20	169	32.9

A total of 106 species were observed across the woodland tree community sites during spring 2019 compared to 138 species during Autumn 2020. Differences in species richness between Spring 2019 and Autumn 2020 reflected differences in rainfall between spring and Autumn. Rainfall in spring 2019 was extremely low (total of 29 mm from Sept – Nov: compared with the long-term average for these months of 92.6 mm, rainfall taken at Hillston Airport (75032) (data source: Bureau of Meteorology).

In spring 2019, the number of species observed at a site ranged from 12 species at Moon Moon Swamp and 15 species at Tom's Lake to 51 species at Juanbung and 36 species at Nooran Lake. The groundcover in Spring 2019 was dominated by a range of Chenopods, primarily creeping saltbush (*Atriplex semibaccata*) (10 sites), bladder saltbush (*Atriplex vesicaria*) (7 sites), nitre goosefoot (*Chenopodium nitrariaceum*) (9 sites), climbing saltbush (*Einadia nutans*) (10 sites), black roly-poly (*Sclerolaena muricata*) (10 sites) ruby saltbush (*Enchylaena tomentosa*) (7 sites) and spiny saltbush (*Rhagodia spinescens*) (7 sites). These perennial species are tolerant of dry soil conditions and are common in Chenopod shrublands away from rivers and floodplains.

There was also a range of annual herb species observed during Spring 2019, including exotic species smooth mustard (*Sisymbrium erysimoides*) (7 sites), burr medic (*Medicago polymorpha*), and common sowthistle (*Sonchus oleraceus*) (6 sites), and native species desert spinach (*Tetragonia eremaea*) (7 sites), and common twinleaf (*Roepera apiculata*) (7 sites). Species small crumbweed (*Dysphania pumilio*), common spike-rush (*Eleocharis acuta*), common heliotrope (*Heliotropium europaeum*) and river mint (*Mentha australis*) were observed but at lower abundances.

In Autumn 2020, the number of groundcover species varied from 27 species at Tom's Lake and Bunumburt, to 64 species at Noonamah (the greatest number of species ever recorded at a site). This increase in species richness between Spring and Autumn was a result of high rainfall in Autumn 2020 (212.1 mm rainfall fell in Autumn 2020 compared to the long-term average of 93.2 mm (rainfall taken at Hillston Airport, 75032) (data source: Bureau of Meteorology).

The wet conditions in the months prior to monitoring resulted in a range of rain respondent annual forbs which dominated the groundcover, including a range of exotic species including burr medic (11 sites), smooth mustard (11 sites), spear thistle (*Cirsium vulgare*) (7 sites), black-berry nightshade (*Solanum nigrum*) (9 sites), common sowthistle (10 sites), Bathurst burr (*Xanthium spinosum*), (9 sites) and the perennial herb caustic weed (*Euphorbia drummondii*) (7 sites). The exotic grass species barley grass (*Hordeum leporinum*) was also abundant (6 sites). Native annual forb species which were abundant during Autumn 2020 included lesser joyweed (*Alternanthera denticulata*) (7 sites), small crumbweed (10 sites), annual spinach (*Tetragonia moorei*) (8 sites), and twin-leaved bedstraw (*Asperula gemella*) (6 sites). In Autumn 2020, chenopods were also a common part of the groundcover including creeping saltbush (11 sites), sprawling saltbush (*Atriplex suberecta*) (7 sites), climbing saltbush (11 sites), ruby saltbush (all 12 sites), spiny saltbush (9 sites), and black roly-poly (8 sites).

Site scale groundcover vegetation diversity (Simpson's diversity index) remained fairly consistent between Autumn 2019 and Spring 2019 and has reduced between Spring 2019 and Autumn 2020 within watering categories A and B, and within the newly established watering category C sites. The newly established watering category C plots had the greatest Simpson Diversity scores recorded of any year of the six years of monitoring in Spring 2019. These sites had recently been inundated with environmental water. While the number of species observed at a site was overall higher in Autumn 2020 compared to Spring 2019 in all three watering categories, the observed drop in Simpson's Diversity reflects a change in the proportional abundances of certain species, mainly an increase in the most abundant species, which were primarily annual rain respondent species. The drop in Simpson's Diversity Index in Autumn 2020 was most pronounced in watering category A, which exhibited the lowest Simpson's Diversity score observed across all watering categories in all 12 monitoring trips and similar to that observed in Autumn 2016 (Figure 9-6).

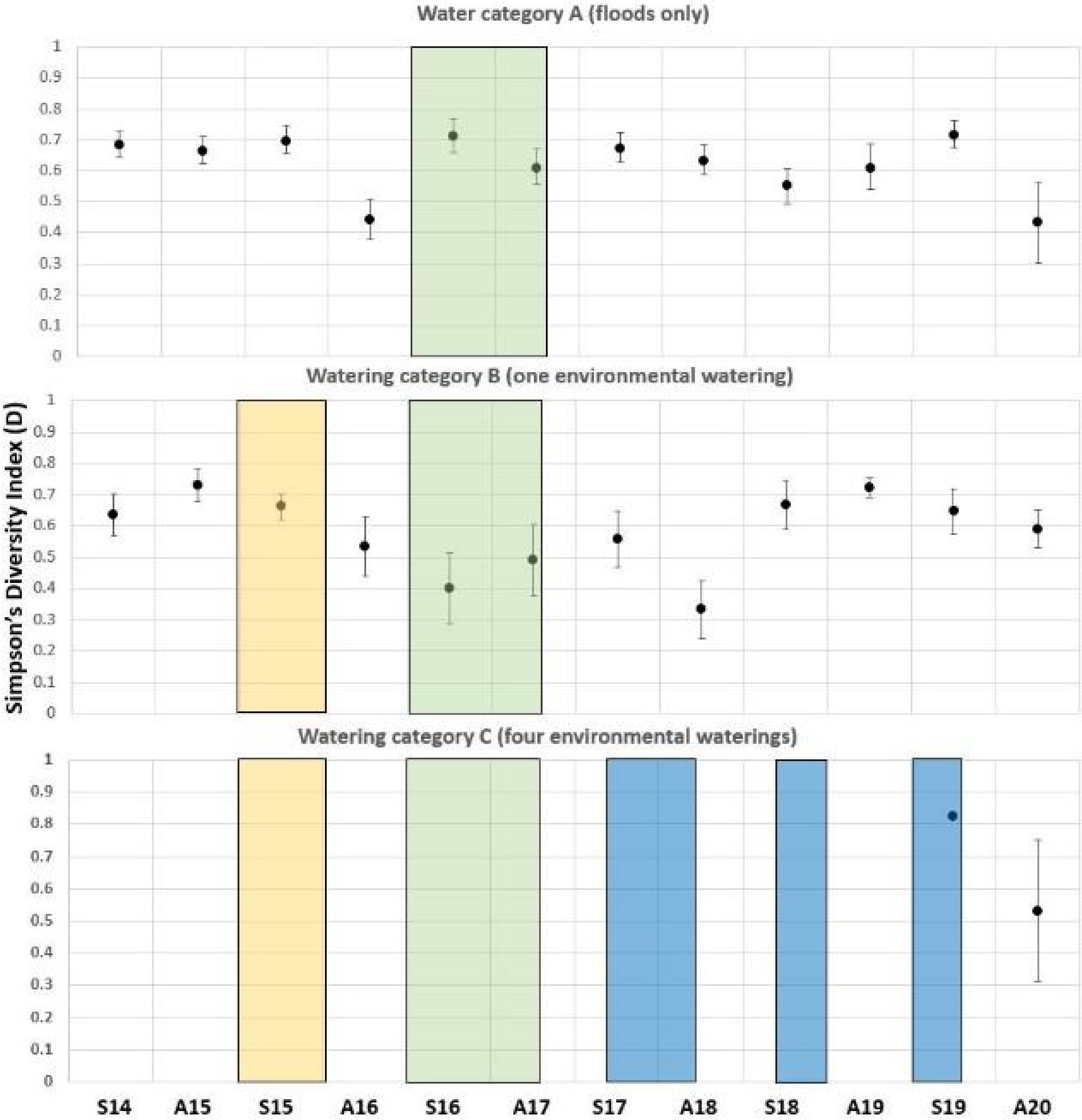


Figure 9-6. Comparison of groundcover vegetation diversity in the tree community between seasons and years using Simpson's diversity index (D).

The data points are the mean diversity index for each watering treatment (refer to Table 9-4, page 109).

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, the green represents the flooding event in 2016-17 that flooded all sites, and the blue represents the period that environmental watering occurred at sites in watering category C. Error bars represent ± 1 standard error of the mean.

9.3.1.2 Non-tree community

A total of 156 species were observed across the non-tree community sites during the 2019-20 watering year. This was the greatest number of species recorded within the non-tree community sites over the six-year monitoring program (Table 9-7). The non-tree sites had an average of 34 species per site observed over the 2019-20 watering year.

Table 9-7. Overall species numbers observed over the last six watering years in the non-tree community

Watering season	SR (number of species across all sites)	Mean number of species at a site
2014-15	98	29
2015-16	123	30
2016-17	96	26
2017-18	124	35
2018-19	98	25
2019-20	156	34

A total of 93 species were observed across the non-tree community sites during Spring 2019 monitoring. The number of species observed at a site ranged from four species at Moon Moon Swamp and six species at The Ville to 21 species at Lake Marool and 20 species at Bunumburt, Nooran Lake, and the reed bed – wet sites. In Spring 2019, chenopod species creeping saltbush (11 sites), sprawling saltbush (8 sites) climbing saltbush (13 sites), black roly-poly (9 sites) as well as exotic annual species burr medic (10 sites) and smooth mustard (9 sites) were common and dominant groundcover species.

The number of species observed was much greater in Autumn 2020 with a total of 135 species observed across the non-tree sites. The number of species at a site ranged from 16 species at Moon Moon Swamp and Bunumburt to 41 species at Booligal and 40 species at Juanbung.

In Autumn 2020, a range of annual forb species became much more abundant than they had been in Spring 2019, including lesser joyweed, shepherd's purse (*Capsella bursa-pastoris*), old man weed (*Centipeda cunninghamii*), paddy melon (*Cucumis myriocarpus*), small crumbweed, caustic weed, earth cress (*Geococcus pusillus*), and ferny buttercup (*Ranunculus pumilio*).

Site scale species diversity (Simpson's Diversity Index) remained fairly constant between Autumn and Spring 2019 in watering categories A and B, while dropping in Spring in watering category C. Species diversity has consistently remained higher at sites in watering category C compared to sites in watering category A and B over the past three years. Diversity has increased between Spring 2019 and Autumn 2020 in Watering categories A and C, while remaining constant during the same period in watering category B. Site scale species diversity appears to reduce during environmental water delivery and increase during the following monitoring trip as observed in watering category C over the past two years (Figure 9-7).

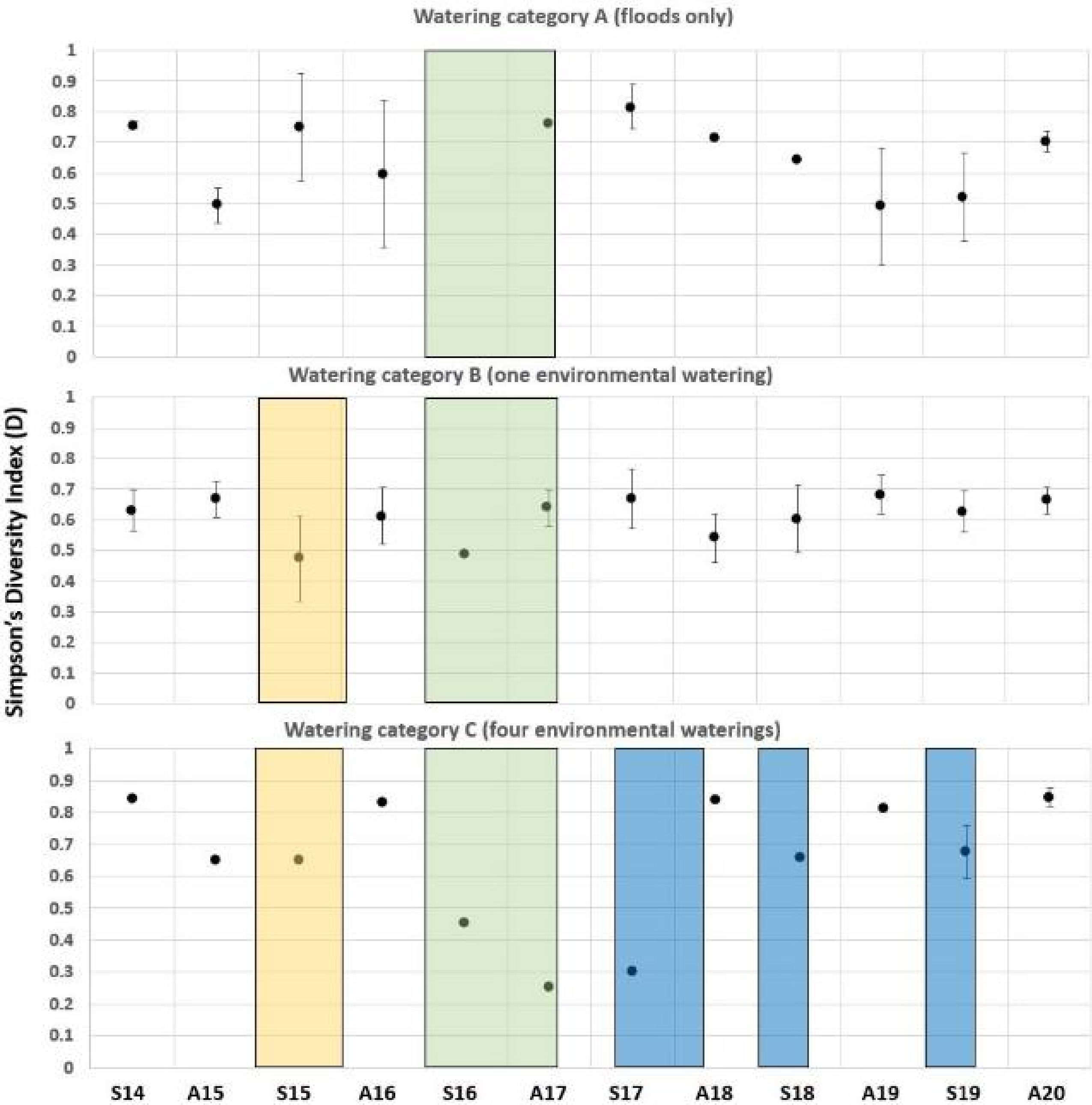


Figure 9-7. Comparison of groundcover vegetation diversity in the non-tree community between seasons and years using Simpson's diversity index (D).

The data points are the mean diversity index for each watering treatment (refer to Table 9-4, page 109).

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, S19: Spring 2019, and A20: Autumn 2020. Yellow represents the period that environmental watering occurred at sites in watering category B, the green represents the flooding event in 2016-17 that flooded all sites, and the blue represents the period that environmental watering occurred at sites in watering category C. Error bars represent ± 1 standard error of the mean.

9.3.2 Vegetation community diversity

9.3.2.1 Nativeness and functional types: tree community

Groundcover in 2019 was the lowest observed over the six years of monitoring, with percent groundcover in Spring 2019 remaining similar to that observed in Autumn 2019. Groundcover in Autumn 2020 was much greater, with some sites having the greatest groundcover observed in all years. The groundcover in both spring 2019 and Autumn 2020 was primarily dominated by terrestrial dry species, which increased in cover in Autumn 2020. The groundcover in watering category A was primarily dominated by terrestrial dry species with few amphibious species at very low cover in both Spring 2019 and Autumn 2020. The groundcover in watering categories B and C was primarily terrestrial dry species, but amphibious and terrestrial damp species made a notable contribution to the groundcover. Monitoring in Autumn 2020 occurred following considerable rainfall in the preceding months prior to field work. This rainfall contributed to the observed increase in groundcover of terrestrial dry species in Autumn 2020.

The terrestrial dry group in Spring 2019 was dominated by a range of chenopod species such as small-leaf bluebush (*Maireana brevifolia*), creeping saltbush, ruby saltbush, and spiny saltbush, while the increase in groundcover in Autumn 2020 was attributed to increases in annual herbs such as sand twin-leaf (*Roepera ammophila*), burr-medic, smooth mustard, rough bedstraw (*Galium gaudichaudii*), and small crumbweed. While the amphibious group consisted primarily of woody perennial species river cooba (*Acacia stenophylla*), and tangled lignum (*Duma florulenta*), and rhizomatous perennials common nardoo (*Marsilea drummondii*), common spike-rush (*Eleocharis acuta*), and spiny sedge (*Cyperus gymnocaulos*).

It should be noted that all amphibious species that have been observed within the tree community plots over the six years of monitoring are native. The amphibious group are dependent on flooding to persist and are therefore an important group of plants which we manage with environmental water. Some (native) amphibious species were only observed over the 2019-20 monitoring year at a single site, including species star fruit (*Damasonium minus*), water primrose (*Ludwigia peploides*) and upright water-milfoil (*Myriophyllum crispatum*) which only occurred at Juanbung, spiny lignum (*Duma horrida*) at Noonamah, and spiny sedge (*Cyperus gymnocaulos*) and tussock rush (*Juncus aridicola*) which only occurred at Bunumburt.

Over the six years of monitoring, there were some native amphibious species which have only been observed at one or two sites, including matted water-starwort (*Callitriche sonderi*) at Lake Bullogal and down’s nutegrass (*Cyperus bifax*) at Nooran Lake. Australian mudwort (*Limosella australis*) and the small annual sedge (*Isolepis australiensis*) were only observed at Lake Bullogal and Lake Tarwong. This highlights the variability in species assemblages of flood dependent species between locations on the floodplains of the lower Lachlan River which is likely to be attributed to differences in hydrological regime between sites.

The total number of amphibious species observed at a site over the six years of monitoring also varied between sites. Sites Clear Lake and The Ville River have had the greatest number of amphibious species recorded (15 species), followed by Nooran Lake (14 species), and Whealbah (13 species). In contrast, Lake Ita and Lake Marool have only had a total of three amphibious species recorded over the six years (Figure 9-8).

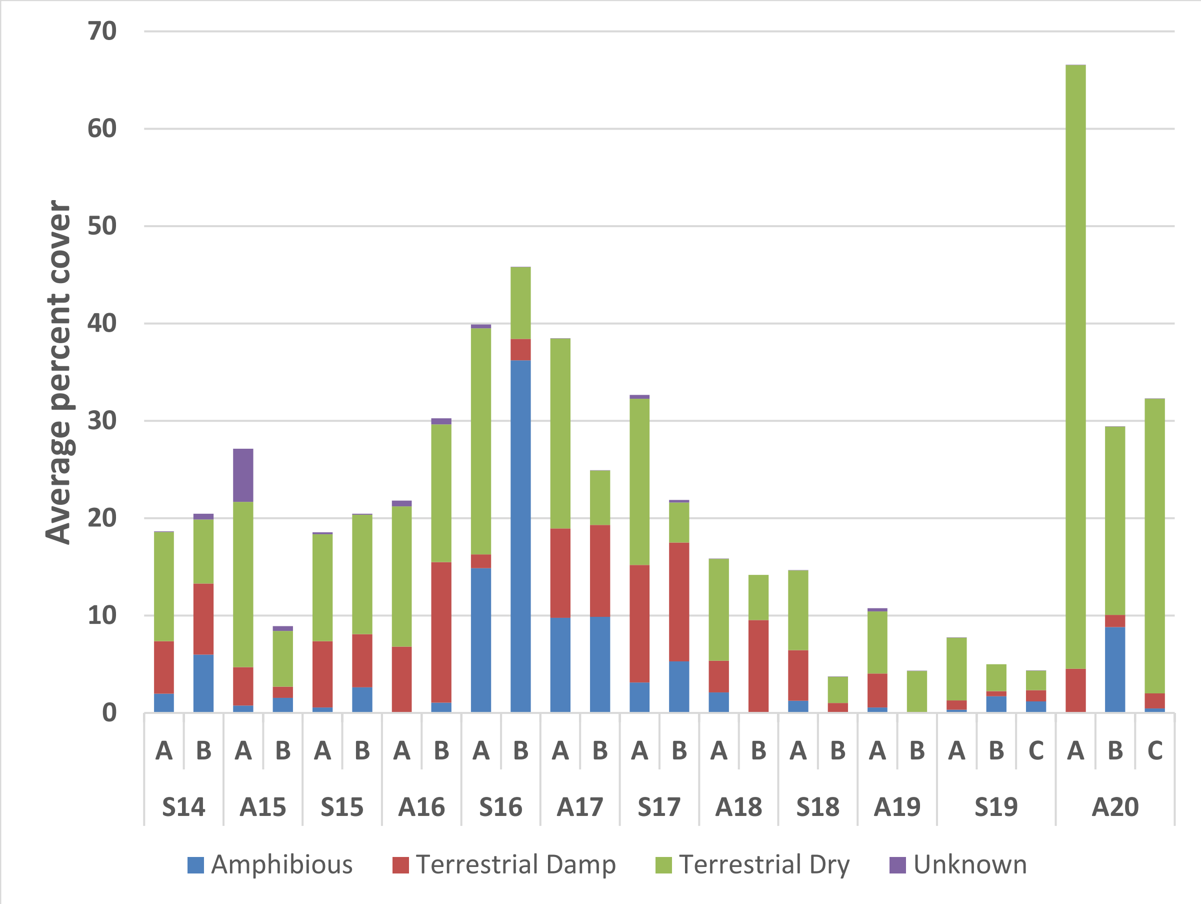


Figure 9-8. Average percent cover of terrestrial and amphibious species within the tree community for sites from each watering history over the sampling period.
Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018, S18: Spring 2018, and A19: Autumn 2019.Watering treatments are defined as A, B or C (refer to Table 9-4 for explanations, page 109).Unknown represents species that were unable to be identified to a suitable level for classification.

Approximately one third (33.06%) of the groundcover was made up of exotic species in Spring 2019, while this number was slightly lower in Autumn 2020 (27.95%). In Spring 2019, the proportion of exotic species did not vary significantly between watering categories. In Autumn 2020, the proportion of exotic species was greatest in sites in watering category B, followed by watering category A, while sites in category C showed considerably less cover of exotic species (< 10%) (Figure 9-9).

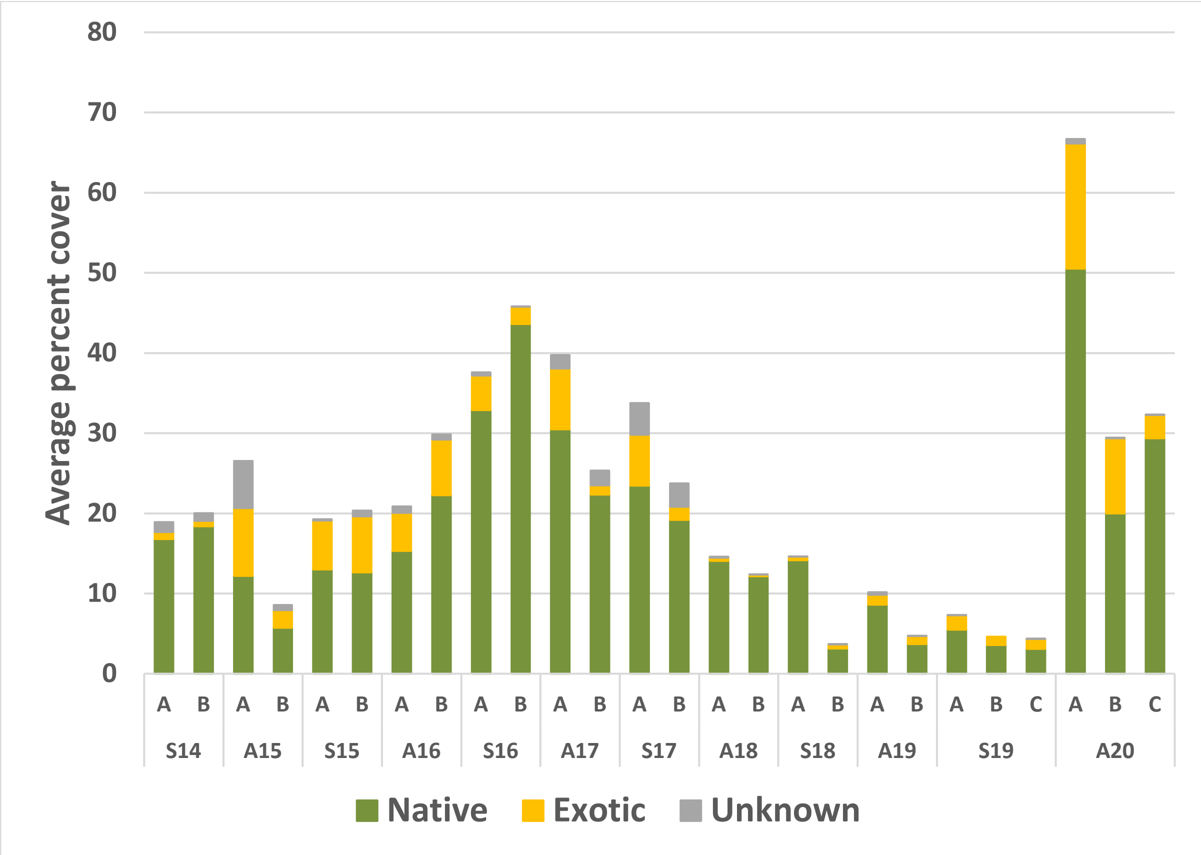


Figure 9-9. Average percent cover of native and exotic species for the tree communities for sites from each watering history over the sampling period.

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, B or C (refer to Table 9-4 for explanations, page 109).

9.3.2.2 Nativeness and functional types: non-tree community

Groundcover in the non-tree community sites remained low in Spring 2019. The observed differences in cover between Autumn 2019 and Spring 2019 are at least in part a result of the inclusion of additional sites and removal of others. This difference is especially evident in watering category C, as the number of sites in this category has increased from a single site (Nooran Lake) which was monitored between 2014-19 to three sites since Spring 2019. This increase in number of watering category C sites has made our data more representative of the different communities on the floodplains of the lower Lachlan River, especially those in lower lying parts of the floodplain. The additional watering category C sites, Juanbung and reed bed-wet had a much greater cover of amphibious species compared to Nooran Lake, for instance in Autumn 2020 Nooran Lake only had 1% cover of amphibious species, while Juanbung had 19.6%, and GCS-W had 28.7%, thus the increase in cover in watering category C between Autumn and Spring 2019. At Juanbung, common amphibious species included water primrose, common nardoo, and swamp buttercup (*Ranunculus undosus*), while GCS-W was dominated by common reed (*Phragmites australis*).

In Spring 2019, sites in watering category C had the greatest groundcover and watering category A had the lowest groundcover. In spring 2019, amphibious and terrestrial-damp species made up a greater proportion of the groundcover in watering category C compared to watering category A and to a lesser extent watering category B. While terrestrial-dry species made up the majority of groundcover (50.4%) in watering category A, and least in watering category C (26%).

The high rainfall in Autumn 2020, resulted in an increase in groundcover at sites surveyed in Autumn 2020. There was a notable increase in the proportion of terrestrial-dry species in Autumn 2020 at sites in all watering categories, but especially watering category A. In Autumn 2020, the cover of amphibious species increased in watering category C from 9% to 16.4%, while remaining fairly constant between Spring 2019 and Autumn 2020 in the other watering categories that had not received environmental water (Figure 9-10).

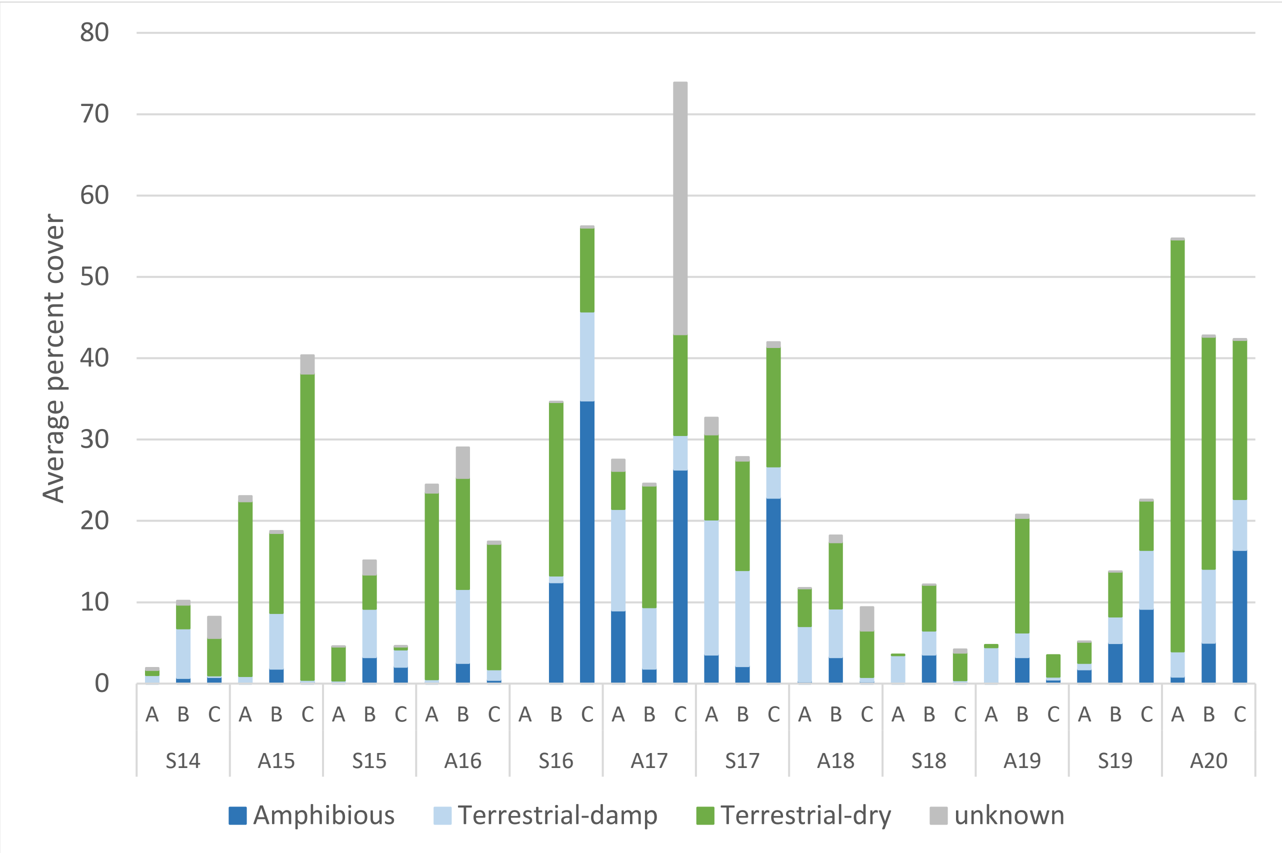


Figure 9-10. Average percent cover of terrestrial and amphibious species within the non-tree community for sites from each watering history over the sampling period.

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 or C (refer to Table 9-4 for explanations, page 109).Unknown represents species that were unable to be identified to a suitable level for classification.

Across all of the monitored sites, more than 75% of the recorded species in the groundcover were native. The cover of exotic species was greater in Autumn 2020 (27%) compared to Spring 2019 (18%). In Spring 2019, the proportion of exotic plants in the groundcover was greatest in watering category C (27%) and lowest in watering category A (13%). In Autumn 2020, the watering categories had a similar proportion of exotic to native groundcover. There were however large differences between sites in cover of exotic species. For example, exotic species contributed to 59% of the total groundcover at Nooran Lake and 45% at Murrumbidgil (both sites are grazed by livestock and/or cropped). In contrast, exotic species only contributed <3% of the total groundcover at Noonamah, Bunumburt, and Booligal. This shows the possible influence of factors other than watering, such as land-use on cover of exotic species (Figure 9-11).

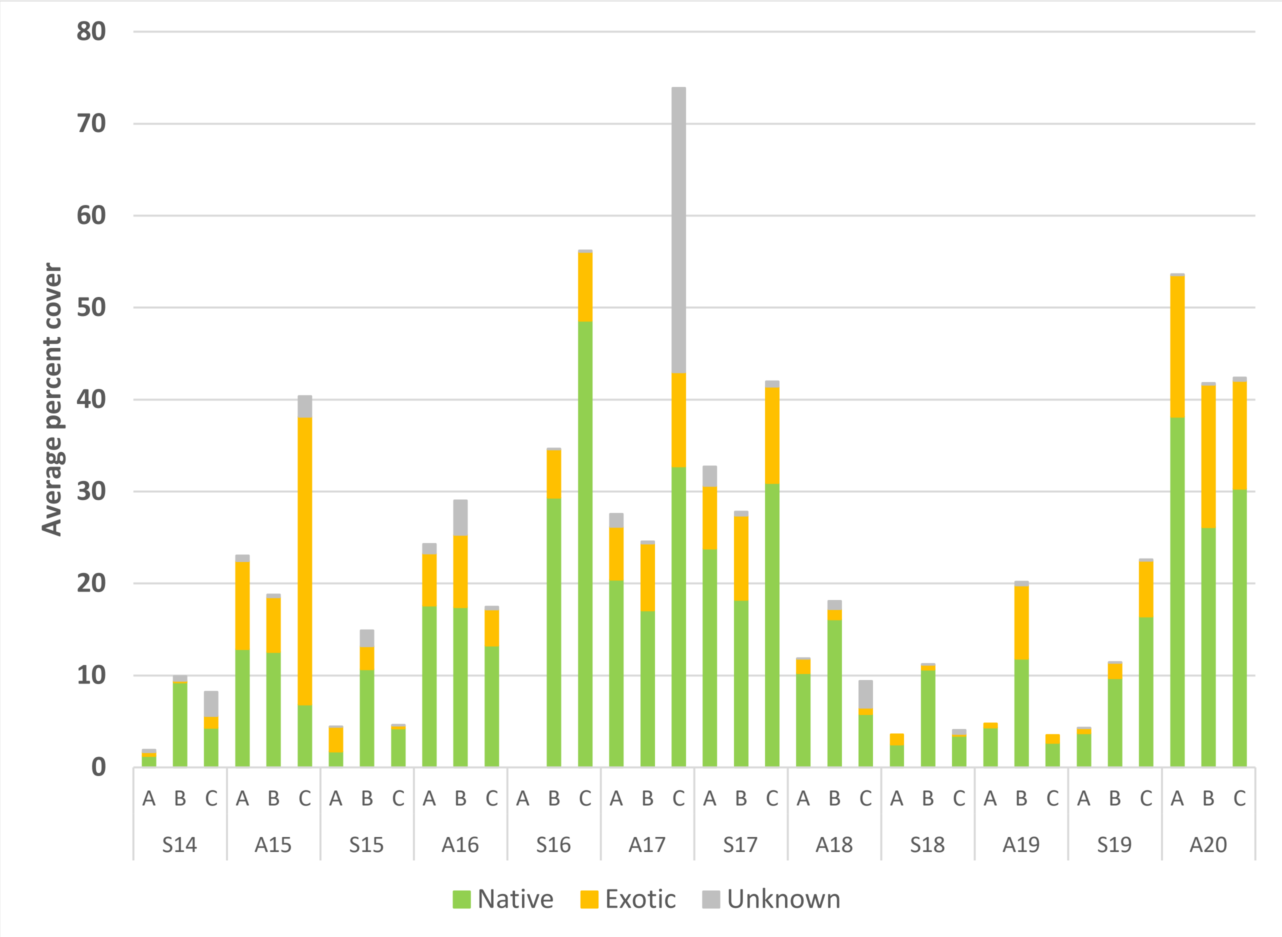


Figure 9-11. Average percent cover of native and exotic species for the tree communities for sites from each watering history over the sampling period.

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, B or C (refer to Table 9-4 for explanations, page 109).

9.4 Discussion

The monitoring of vegetation in 2019-20 marks the first year of the MER program, and continues the long-term monitoring which has occurred for the past six years as part of LTIM project. The 2019-20 watering season in the Lachlan Catchment, has encompassed drought conditions, broken by a wet Autumn. The dry climate in the Lachlan catchment over 2018 and 2019 was reflected in the low groundcover and number of species observed in Autumn and Spring 2019. Spring 2019 had the lowest percent groundcover in tree community sites of the six years of monitoring. Rainfall in early 2020 resulted in a substantial increase in percent groundcover and number of species, producing the greatest percent cover observed in tree community sites over the six years. This dramatic increase in vegetation was attributed to increases in ruderal (fast growing) annual terrestrial-dry species. These rain respondent species germinate in large numbers following large and consecutive rainfall events and establish, grow and reproduce quickly. In Autumn 2020, watering category A had the greatest cover of terrestrial dry species of all watering categories.

Repeated watering over consecutive years appears to generate diverse vegetation communities with a range of amphibious species with relatively high cover observed at sites which have received environmental water multiple times over the past few years (watering category A). Non-tree sites which received environmental water over the past few years have a greater cover of amphibious species compared to sites which have not been flooded since the natural floods in 2016-17. Environmental water is maintaining and promoting these amphibious species. Few amphibious species occurred at sites which had not received any environmental water.

The additional monitoring sites which receive environmental water has improved our ability to detect a response of the vegetation to environmental water. The non-tree sites (Nooran Lake, Juanbung and reed bed – wet) in watering category C were targets for environmental water in 2019-20. These sites maintain a number of perennial, emergent amphibious species which do not occur at any other site, such as water primrose, upright water-milfoil, swamp buttercup, and common reed. These species depend on dormant rhizomes as well as seed banks to re-establish following re-wetting. These sites have been flooded with environmental water multiple times over the past few years and this suggests that environmental water has an effect on this assemblage and promotes these species.

At sites Lake Tarwong and Lake Bullogal which are flooded less often and have not been watered with environmental water in at least the past six years, the (non-woody) amphibious species which occur are ruderal annual species (such as Australian mudwort, starwort and ferny buttercup). These ruderal annual species are short lived (< 1 year) not surviving as rhizomes, and depending entirely on long-lived soil seed banks. This highlights how certain life-history strategies are successful under specific hydrological conditions, and environmental water maybe important for some groups more than others.

As observed in non-tree community sites environmental water reduces species diversity during flooding, which then increases shortly after flood recession. The regular watering is maintaining a diverse assemblage of plants as shown by the Simpson's Diversity index which has been consistently higher (following flood recession) over the past 2 years in the non-tree community within watering category C compared to the other watering categories which have not been flooded since 2016-17. A study using remote sensing to investigate floodplain vegetation dynamics across the Murray-Darling Basin by Broich et al. (2018) found that flooding during the season in which floodplain vegetation was monitored resulted in a negative effect on floodplain vegetation dynamics, while flooding one season prior to vegetation response was the most important flood variable on floodplain vegetation dynamics, related to a positive vegetation response. Concurrent flooding, and flooding two seasons prior were also important in explaining vegetation dynamics (Broich et al. 2018).

The past six years of vegetation diversity monitoring in the lower Lachlan River has highlighted that the vegetation on the floodplains of the lower Lachlan River is diverse and many sites have a unique assemblage of plant species which do not occur at other sites. Sites also vary in the number of plant species observed, including the number of amphibious and aquatic species. The species assemblage observed at a site are likely to be related to historic and recent hydrological regime and land management practices. This spatial variability in species assemblages highlights the need to manage at a landscape scale and that different wetland sites have unique values and management needs.

9.4.1 What did Commonwealth environmental water contribute to populations of long-lived organisms (measured through cover and recruitment of tree species)?

Stand and tree condition data were collected in Autumn 2020 at the newly established sites. These data will be combined with the data collected at all other sites and reported every five years.

9.4.2 What did Commonwealth environmental water contribute to individual plant species across the Selected Area including changes to species presence, distribution and cover?

Environmental water has contributed to the species assemblage and their cover at sites which received water over the 2019-20 watering year. The sites which have received environmental water have a range of amphibious plants which were not observed at any other site. These sites also have a greater proportion of native species compared to sites which have not received environmental water. These sites are providing important refuges for flood dependent plants. While environmental water floods a site on the floodplain the diversity and cover of species reduces, then increases shortly after the water recedes. Environmental water has maintained a greater diversity of species in the groundcover over the past three years at sites which have received environmental water compared to sites which have not been flooded since the natural flood in 2016-17.

9.4.3 What did Commonwealth environmental water contribute to vegetation communities within the interim Australian National Aquatic Ecosystem (ANAE) vegetation types, including changes in species richness, composition, cover and structure?

During the 2019-20 watering year, environmental water has reached four ANAE vegetation types within the lower Lachlan River (Table 9-8). These sites contain a wide and varied assemblage of species. Environmental water has maintained the species richness, composition and cover at these sites and through doing so has contributed to landscape diversity within the lower Lachlan river catchment.

Table 9-8. ANAE vegetation types for the four monitoring sites that environmental water reached in the watering year 2019-20

Site	ANAE Classification
The central reed bed of the great Cumbung swamp (RB)	Temporary tall emergent floodplain marsh
River red gum channel mound system on Juanbung (JU)	Intermittent river red gum floodplain swamp
Noonamah (NO)	Temporary floodplain lake surrounded by Intermittent black box woodland floodplain swamp
Nooran Lake (NL), only transects	Temporary floodplain lake

9.5 Further comments and recommendations

The observations from the past six years of monitoring in the lower Lachlan river catchment have improved our understanding of the response and requirements of the vegetation to watering. The six years of monitoring have revealed trends in how floodplain plants change in abundance, cover and assemblage in response to the prevailing conditions and how recent and historic hydrological conditions have shaped these floodplain communities.

9.5.1.1 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.

The research which is currently being conducted in the reed bed of the Great Cumbung Swamp (see Section 11: Research) aims to identify indicators of condition of reed beds to environmental watering. Through identifying which of these indicators respond to environmental water, the results of this research can guide the development of measurable and explicit objectives. For example, an increase of X% in the cover of common reed in the Great Cumbung Swamp or an increase of X in the average height of common reed across a specified area.

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.

9.5.1.2 Recommendation 2: 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.

9.5.1.3 Recommendation 3: Consider landscape vegetation diversity when setting objectives for vegetation outcomes

The floodplain of the lower Lachlan River contains diverse and unique wetlands, with a unique assemblage of species observed at many of our monitoring sites. These sites vary in their hydrological regime and land management, which has shaped the vegetation communities we observe. This uniqueness makes environmental water allocation a challenge. The results over the six years of monitoring has also identified that sites vary in the number of species we observe and the type of species which occur (for example amphibious/aquatic or terrestrial, ruderal persistent seedbank or rhizomatous perennial, or native or exotic). This highlights that different sites have varying levels of value and may require different management. Further, land management (private – grazing, floodplain cropping, nature reserve) and the ability to get environmental water into a site and the amount of water needed are considerations when prioritizing watering actions.

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 prioritizing environmental watering actions and 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 a strategic 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.

9.5.1.4 Recommendation 4: 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 river 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.**

9.5.1.5 Recommendation 5: 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).

9.5.1.6 Recommendation 6: 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 trialing 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.

9.5.1.7 Recommendation 7: Consider winter-spring releases of environmental water to support vegetation outcomes.

Observations from the NSW environmental water program suggests that the delivery of environmental water into wetlands such as Murphy’s Lake and Noonamah early in the season results in a positive aquatic vegetation response. It is thought that having the lakes/wetlands full before Spring enables sediment to settle (less turbidity) and improves light penetration and occurs prior to peak carp movement. Preliminary results from the Lachlan MER research suggests that *Phragmites* growth may benefit significantly from environmental water being delivered early in the season. Delivering a fresh from Wyangala Dam in late autumn or winter so it passes through the Lower Lachlan river system before cod nesting and arrives in the great Cumbung before spring could maximise vegetation outcomes and avoid disturbance to Cod nesting season. It is also likely to incur fewer losses and be easier to incorporate into operational delivery scenarios. This could be followed up with a stable cod nesting flow if required and then a large fresh in Spring–Summer from Lake Brewster to provide the productivity boosts for recruitment.

10 COMMUNICATION AND ENGAGEMENT

10.1 Introduction

There are a diversity of views and interest groups across the Murray-Darling Basin and the long-term success of environmental watering programs requires strong relationships with stakeholders, including local communities. The CEWO recognise the importance of effective communication and engagement in building relationships and achieving their goals for environmental watering across the Basin. Thus, communication and engagement (C&E) activities are an integral part of the MER program within Selected Areas.

Under the MER program, the lower Lachlan river selected area has resources dedicated to C&E that support two components of communication and engagement activities. The first is operational project communication which relates to the activities associated with the delivery of the core monitoring and evaluation component of the MER program. This involves the project team, the CEWO, key water delivery stakeholders and other operational stakeholders. The second is external communication and engagement which involves stakeholder groups outside of the delivery of the MER Plan and includes landholders, affected communities and the general public.

10.2 Results

This chapter of the technical report provides an overview of the C&E activities delivered in 2019-20.

10.2.1 Operational Project Communications

Operational project communication has underpinned the delivery of the monitoring and evaluation activities. It has involved our primary stakeholders: the project team, landholders who support ongoing access to MER sites, key water delivery stakeholders and other operational stakeholders (Table 10-1). The objectives of our operation project communications (defined in the Lachlan MER Plan, (Dyer et al. 2019b)) are to:

- Facilitate smooth and efficient implementation of the MER Plan (Objective C1).
- Facilitate engagement and support on-going relationships among core stakeholders (Objective C2).
- Disseminate learning and results from project activities (Objective C3).
- Contribute to on-going adaptive management associated with environmental watering (Objective C4).
- Foster opportunities for collaboration among core stakeholders to optimise the use of public funds for monitoring, evaluation and research in the Lachlan Selected Area and across the Basin (Objective C5).

Activities that meet the aims of the operational were divided into four activity streams and the activities delivered are summarised in Table 10-2. In addition to these activities there have been numerous phone calls among the key stakeholders to communicate findings, observations and operational matters.

Table 10-1. Primary stakeholders for the Lachlan Selected Area MER program

STAKEHOLDER GROUPS	
M & E Delivery	Project Team
Operational Stakeholders	CEWO – Lachlan Delivery Team Lachlan environmental water manager Regional operations group with responsibility for the Lachlan River watering Members of the Lachlan Environmental Water Advisory Group (EWAG) Key members of other state agencies incl. NSW OEH Science Team, DoI Water, Water NSW
MER program teams	Basin MER Team Other Selected Area MER Teams CEWO MER program Team
Key Landholders	Landholders who provide access to monitoring sites[3].

Table 10-2. Operational project communication activities for the Lachlan Selected Area delivered in 2019-20

ACTIVITY	ACTIVITIES	OBJECTIVE ADDRESSED	OUTCOMES ACHIEVED
ACTIVITY STREAM: DELIVERY			
Monthly project meetings (PM)	Nine (9) monthly project meetings held between the project leader and CEWO contact. These meetings have typically also included the research theme lead and frequently another team member.	C1, C2, C3, C4	Verbal project updates that have • ensured that the project is tracking as expected; • dealt with issues arising from the monitoring; • communicated early observations from monitoring • communicated a variety of operational matters
Selected Area working group meetings (PM)	One formal Selected Area working group meeting and numerous informal meetings among the project team members.	C1, C2, C3, C4	Regular contact between project partners and sub-contractor personnel has been used to establish and revise workplans; ensure project is tracking as expected; deal with any issues arising from the monitoring; communicate early observations from monitoring; and coordinate activities
Quarterly Progress Reports (PM)	Four written progress reports provided in September, December, March and June	C1	Ensured clear communication of project progress against milestones
Quarterly Outcomes Newsletter (PM)	Four quarterly outcomes newsletters provided for September, December, March and June.Newsletters underwent considerable redesign for	C3 O1 and O4	Quarterly outcomes newsletter re-designed and used to communicate with a broader public audience.

[3] Of the 29 monitoring sites included in this project, 20 are only accessible via agreement and support of private landholders.

ACTIVITY	ACTIVITIES	OBJECTIVE ADDRESSED	OUTCOMES ACHIEVED
	December 2019 edition and has been widely disseminated - see also C&E highlights. These are now published at https://www.environment.gov.au/water/cewo/publications/lachlan-mer-quarterly-reports		
Annual Summary and Technical Report (PM)	Annual Technical and Summary reports developed	C3 O1 and O4	Annual technical report communicated detailed scientific findings to a technical audience; annual summary report focuses on annual highlights
ACTIVITY STREAM: OPERATIONAL STAKEHOLDERS			
Lachlan EWAG meetings (C&E)	Three EWAG meetings were attended, 2 in person and 1 online during Covid restrictions. Two of the EWAG meetings involved subsequent field trips.	C1, C2, C3, C4 and C5 O1, O3 and O4	Presentation of project findings at the EWAGs which support an exchange of information and intelligence that supports the implementation of the MER program and environmental water delivery in the catchment
TAG meetings (C&E)	Three TAG meetings attended associated with the Spring Pulse	C1, C2, C3, C4 and C5 O1, O3 and O4	Attendance at TAG meetings which have supported an exchange of operational information and underpinned decision-making processes.
ACTIVITY STREAM: MER PROGRAM TEAMS			
Steering Committee Meetings (PM)	Steering committee was established in mid 2020 and the first meeting	C1, C2, C3, C4 and C5	Established a process for regular contact between project leaders across Selected Areas and the Basin Team.
Annual forum (PM)	Presentations given at the 2019 Forum (held in Late July 2019) to report on the end of the LTIM project and the 2020 Annual forum (held in September 2020).	C1, C2, C3, C4 and C5	Provided opportunities to share learning and to learn from other selected areas.
Flow MER Stories (C&E)	Content for the web site provided and is at: https://flow-mer.org.au/selected-area-lachlan/ .	O1, O2, O4	Landing place available for people to find information about the monitoring and research activities being undertaken in the Lachlan Selected Area.
Thematic working groups meeting (PM)	Team members attended: • 3 Diversity Theme meetings, • 2 Vegetation Theme meetings	C1, C2, C3, C4 and C5	
ACTIVITY STREAM: KEY LANDHOLDERS			
Landholder Access Protocols (LAPs) (C&E)	Landholder access protocols were reviewed and new protocols developed for new sites.	C1	Ensures clear communication about site access and ensures landholders wishes in regard to site access are documented.

ACTIVITY	ACTIVITIES	OBJECTIVE ADDRESSED	OUTCOMES ACHIEVED
Landholder update (C&E)	Landholders provided with links to quarterly newsletters and to the annual reports. Species lists were provided to interested landholders following field activities.	C1, C2, C3 O1, O2, O4	Tailored information, relevant to the landholders, was provided.

10.2.2 External Project Communication

The external project C&E activities build on the work of the LTIM project which were focussed on informing key stakeholders of watering events and monitoring activities and activities which convey findings to the broader scientific community. Under the LTIM project, external engagement activities tended to be 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. Under the MER program, continuity of support for these activities has been a central tenet with additional targeted activities supported by the flexibility to tackle small amounts of C&E opportunistically.

The objectives of the external LTIM project C&E activities – in greater detail defined in the Lachlan MER Plan (Dyer et al. 2019b) - are to:

- To increase awareness, understanding and value of water for the environment and its benefits (Objective O1).
- To promote water for the environment as being normal and necessary part of river operations and a health environment (Objective O2).
- To secure support, acceptance and advocacy for water for the environment (Objective O3).
- To increase credibility and trust in the management of water for the environment and CEWO (Objective O4).

The ultimate goal of the external C&E activities under the MER program is to influence attitudes towards use of environmental water in the Lachlan Catchment.

The 2019 - 20 external C&E activities can be grouped into 4 activity streams:

1. Communication products
2. Community events
3. Media
4. Citizen Science

Activity highlights are provided in the following sections.

10.2.2.1 Communication products

A highlight of our MER activities this year has been the redevelopment of the Quarterly Outcomes Newsletter into an accessible and visually appealing format. This newsletter is now printed and distributed throughout the mid and lower communities of the catchment from May 2020 (Figure 10-1). Eighty copies of the October-December 2019 newsletter and 80 copies of the January-March 2020 newsletter were printed and distributed throughout towns and districts from Condobolin to Hay. In general, these newsletters have been spread between local council offices, community centres, schools, libraries and to individual landowners. DPIE–EES also send links and copies to their lower Lachlan landholder stakeholder email list of over 60 community stakeholders.

Figure 10-1. A graphic that was used to promote the distribution of printed MER Quarterly Outcomes newsletters in May 2020.

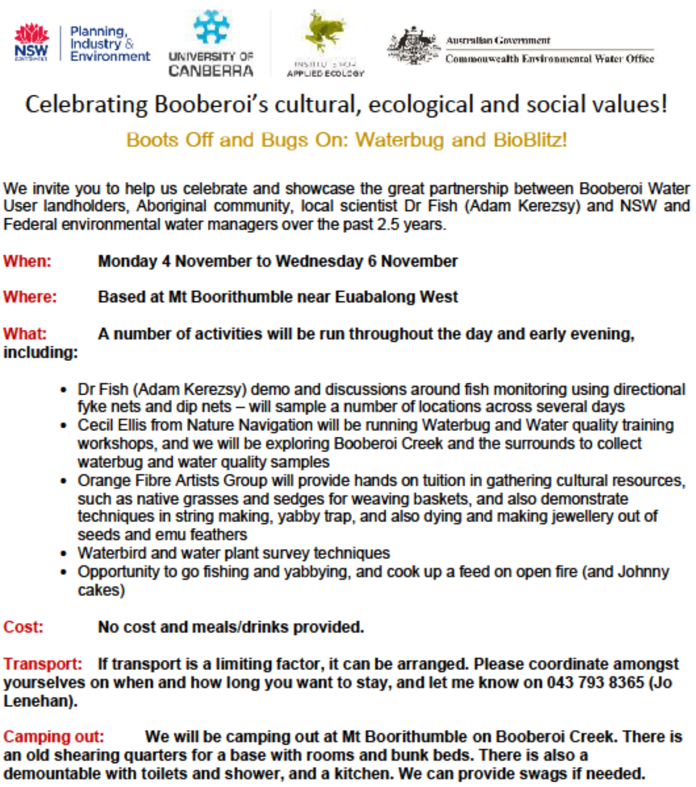
10.2.2.2 Community events

The MER program was associated with six community events in 2019-20. Stories from these provided material for the Quarterly Outcomes newsletters and provided opportunities for local print media to engage. A small focus has been on engaging and building capacity within Aboriginal communities along the Lachlan. Highlights of our community events included the Booberoi Creek cultural weekend; a fish demonstration event associated with an EWAG meeting; olive perchlet surveys olive perchlet surveys and involvement of community and commercial fish organisations (Australian, New Guinea Fishes Association (ANGFA) and K & C Fisheries Global Pty Ltd, and a Down the Track weekend.

In addition, the MER engagement program has consistently supported involvement of the Murrin Bridge Community Development Program (CDP) participants and local community through WaterWatch and WaterBug Blitz events on Murrin Bridge, Booberoi Creek and Lake Cargelligo. The Murrin Bridge CDP Program has partnered with Flow-MER, DPIE–EES, Aboriginal Fishing Trust to incorporate the Flow-MER vegetation monitoring methods into assessing the health and condition of the oxbow lagoon on Murrin Bridge, as well as providing skill training and an employment work program around water quality paramaters (WaterWatch) and water bugs as an indicator of river and wetland health. Identification and collection of culturally significant plants (e.g. *Cyperus gymnocaulos*) and weaving workshops have complimented this work along with canoe trips to collect water quality data in-stream. Flow-MER co-funded a workshop on plant propagation with local high school students, Murrin Bridge CDP and community, and continues to support the active participating of Aboriginal cultural knowledge and input into environmental watering events. The documentation of these achievements through high quality photographic stills and video has boosted the profile and recognition of community elders and groups, such as Down the Track and Orange Fibre Artist Group and built upon the cross-cultural learnings from bringing together Aboriginal and non-Aboriginal stakeholders together around common values.

Booberoi Creek cultural-environmental flows

MER support of Booberoi Creek cultural–environmental flows has continued to provide opportunities for Ngiyampaa Elders to reconnect with their country and for local landowners and interested parties to participate in multi-faceted workshop days. Following the first workshop weekend (2018-19), a follow-up two-day event occurred at Mt Boorithumble station in November 2019 (Figure 10-2).



Celebrating Booberoi's cultural, ecological and social values!

Boots Off and Bugs On: Waterbug and BioBlitz!

We invite you to help us celebrate and showcase the great partnership between Booberoi Water User landholders, Aboriginal community, local scientist Dr Fish (Adam Kerezsy) and NSW and Federal environmental water managers over the past 2.5 years.

When: **Monday 4 November to Wednesday 6 November**

Where: **Based at Mt Boorithumble near Euabalong West**

What: **A number of activities will be run throughout the day and early evening, including:**

- Dr Fish (Adam Kerezsy) demo and discussions around fish monitoring using directional fyke nets and dip nets – will sample a number of locations across several days
- Cecil Ellis from Nature Navigation will be running Waterbug and Water quality training workshops, and we will be exploring Booberoi Creek and the surrounds to collect waterbug and water quality samples
- Orange Fibre Artists Group will provide hands on tuition in gathering cultural resources, such as native grasses and sedges for weaving baskets, and also demonstrate techniques in string making, yabby trap, and also dying and making jewellery out of seeds and emu feathers
- Waterbird and water plant survey techniques
- Opportunity to go fishing and yabbying, and cook up a feed on open fire (and Johnny cakes)

Cost: **No cost and meals/drinks provided.**

Transport: **If transport is a limiting factor, it can be arranged. Please coordinate amongst yourselves on when and how long you want to stay, and let me know on 043 793 8365 (Jo Lenehan).**

Camping out: **We will be camping out at Mt Boorithumble on Booberoi Creek. There is an old shearing quarters for a base with rooms and bunk beds. There is also a demountable with toilets and shower, and a kitchen. We can provide swags if needed.**

Figure 10-2. A flyer for the second two-day workshop event held at Mt Boorithumble, Booberoi Creek, in early November 2019.

Fish sampling demonstration in conjunction with EWAG meeting, October 2019

Fish sampling was undertaken in Yarrabandai Lagoon and Wallamundry Creek in the mid-Lachlan (in the vicinity of Condobolin) in October 2019 as an addition to the EWAG meeting held overnight at Yarrabandai Creek Homestead. In addition to members of the CEWO and EWAG, participants also included local landowners, all of whom were pleasantly surprised when a freshwater catfish was sampled at a Wallamundry Creek site on the morning of October 21 (Figure 10-3).

Figure 10-3. A freshwater catfish sampled during a fish monitoring demonstration in Wallamundry Creek in October 2019. Photo by Francis Horacek.

Lake Brewster olive perchlet population check, March 2020

On March 14 and 15 fish monitoring was undertaken at the Lake Brewster weir pool by Adam Kerezsy from Dr Fish Contracting, Nathan McGrath (DPIE), and two enthusiastic volunteers (Lachy Nevinson and Dave Matheson) from NSW ANGFA, the Australia and New Guinea Fishes Association. Perchlet were found to be present within their known range, including at least one juvenile (Figure 10-4).

Figure 10-4. Nathan McGrath (DPIE), David Matheson and Lachy Nevinson (ANGFA) helping with a survey of endangered olive perchlet at the Brewster weir pool in March 2020. Photo by A. Kerezsy

Down the Track weekend, March 2020

The following letter/article from Lana Masterson, who runs the Lake Cargelligo 'Down the Track' program for disadvantaged and at-risk youth, is perhaps the best way to summarise the event:

> ***Down The Track's Island Adventure***
>
> *On Saturday 21st March, 5 Down The Track participants along with representatives from Cargelligo Wetlands and Lakes Council (CWLC), the NSW Department of Planning, Industry and Environment, Lachlan Shire Council, Lake Cowal Foundation and ecologist Adam Kerezsy embarked on a 24 hour adventure to Robinson Crusoe Island.*
>
> *All participants were transported to the Island by the CWLC barge skippered by Peter Skipworth, and camped the night on the Island.*
>
> *The camp had it all - from bird identification, bush walking, photography of native species to sampling and counting fish and taking water quality measurements. The waters around the Island again yielded great results, with five native fish species sampled in healthy numbers (bony bream, gudgeon, flathead gudgeon, Australian smelt and hardyhead). The results will be passed on to both NSW and Commonwealth agencies charged with delivering environmental water in the Lachlan catchment, and they appear to be a great example of the benefits of keeping Lake Cargelligo as full as possible through the drought.*
>
> *Lana Masterson, from Down The Track, would like to thank everyone that volunteered their time and expertise to make the camp happen.*
>
> *The DTT crew fully immersed themselves in the Island, the wildlife and the outdoor camping experience and are looking forward to doing it all again.*

Figure 10-5. The Down The Track crew on Robinson Crusoe Island preparing to go birdwatching in March 2020. Photo Adam Kerezsy.

10.2.2.3 Media

Local media articles have included a feature article in The Lake News (April 1 2020) relating to a successful engagement weekend at Robinson Crusoe Island (Lake Cargelligo) with members of the youth-at-risk focussed Down The Track program (see Figure 10-5), as well as articles in three local newspapers (Condobolin Argus, Hillston and Ivanhoe Spectator and Lake News; Figure 10-6) highlighting the publication and availability of MER Quarterley Newsletters throughout the catchment (i.e. in Condobolin, Lake Cargelligo, Hillston and Booligal/Hay (see below ‘Community updates’).

Lake kids explore island oasis

Lake News, Wednesday, April 1, 2020

ectator" Wednesday 27th May 2020 — 3

What's Going on in the River?

People with an interest in all aspects of the ecology and biology of the Lachlan River can now catch up on the latest research going on in heir backyard.

The Lachlan MER onitoring, Evalu- on and Research) iect looks at ev- hing from fish to to vegetation and pported by the onwealth Envi- tal Water Office

arterly news- can be ac- n-line (envi- v.au/water/ lications/ r-quarter- but from will also n print- ghout lower

towns in the catchment.

In Hillston, the printed newsletters will be distributed at the council offices, at The Shed, the LLS office and the library, and copies will also be given to the schools. All local people are encouraged to drop in and read up on their topic of interest.

Although the topics are 'scientific' (for example larval fish in the Lachlan), the writing is simple and informative, so whether people are into flows, trees, birds or fish, there's something for everyone.

Anyone with these interests is encouraged to stay up-to-date with the latest in local research by accessing this resource.

Figure 10-6. Newspaper articles from the Lake News (1 April 2020, left) and the Hillston-Ivanhoe Spectator (27 May 2020) publicizing the activities of the Lachlan MER program.

These traditional media outputs have been accompanied by social media activities. Field teams have tweeted images from their field work using the hash tag #LowerLachlanMER and tagging @FlowMERprogram. In addition, field teams have provided photographs to enable @theCEWH to tweet with specific messaging.

10.2.2.4 Citizen Science

The Lachlan MER program also provided support for a Waterwatch and Waterbug Blitz Team at Murrin Bridge Aboriginal community and Lake Cargelligo (Figure 10-7). This included a 'Bioblitz' weekend involving 'Inspiring Australia' and Local Land Services.

Kerezsy (2020) confirmed the benefits of community and stakeholder driven fish monitoring projects, such as the DPIE–EES and Flow-MER partnership in Booberoi Creek over several years. The majority of participants – but most notably the landowners – expressed interest (and surprise) at both the variety and abundance of small-bodied native fish, macroinvertebrates and macrophytes (habitat). Most commented that although they had lived adjacent to the creek for extended periods, they were largely unaware of the local biodiversity and requested ongoing engagement activities and monitoring to further their understanding of the relationship between environmental water delivery, and how such flows consider the various lifecycle needs of biota. A greater appreciation for local biodiversity has motivated them to consider complimentary actions on their behalf as to better protect a resource they have become to value more and more through exposure to environmental water planning, implementation and monitoring.

Similarly, support of the Murrin Bridge Community Development Program (CDP) is highly valued by participants and residents of Murrin Bridge, as well as supporting organisations such as Murrin Bridge Local Aboriginal Land Council (LALC) and Regional Enterprise Development Institute Ltd (REDI.E), the peak provider of services to Indigenous communities in western NSW. The key to success has been partnerships with Flow-MER and DPIE–EES, and an adaptive and flexible suite of activities that can respond to community identified needs and interests, rather than a pre-programed set of outputs and outcomes. The four broad objectives outlined previously have been met via meaningful participation through relationship building with 'people' rather than 'process'. The Flow-MER and DPIE–EES consultation has assisted position local Aboriginal Elders from the Ngiyampaa nation as key knowledge holders and leaders on designing environmental flows for Booberoi Creek both locally and state-wide. Importantly, this grass-roots approach has brought people from all generations and backgrounds together around the nexus of providing water for their environment, which then enables them to understand the broader Basin-scale objectives of the environmental watering program as a whole across the Lachlan Catchment, including the lower Lachlan Selected Area. As a result, those involved in the Flow-MER and DPIE–EES partnership C&E program over the past 6 years have become advocates for environmental water, as evident in The Land article in response to criticism of the Spring Pulse (Figure 10-8).

Figure 10-7. Waterbug Blitz in 2019 with Murrin Bridge CDP and Lake Cargelligo community.

Figure 10-8. Booberoi Creek Facebook post from The Land newspaper article in support of environmental flows during Spring Pulse.

11 RESEARCH

11.1 Introduction

Reed beds are a common and important component of wetlands, providing important habitat, trapping and processing sediment and nutrients, and maintaining water quality (MDBA 2012a; Tanner 1996; Zierholz et al. 2001). Reed beds are typically comprised of the common reed (*Phragmites australis* (CAV.) Trin ex Streud.), which is a widely distributed emergent aquatic perennial rhizomatous grass (Poaceae) species (PlantNET 2019), of considerable ecological and economic value (Hawke and José 1996). Growth and condition of common reed is mediated by inundation frequency (Whitaker et al. 2015). Declines and dieback in common reed have been observed in Europe and Australia, attributed to changes in hydrology, erosion, grazing pressures, mechanical damage, and direct destruction (Ostendorp 1989; Roberts 2000; Thomas et al. 2010). Common reed has experienced range expansions in North America attributed to changes in hydrology and nutrient regimes (Chambers et al. 1999; Galatowitsch et al. 1999).

The numerous ecosystem services supported by reed beds, has prompted a growing need for regular and accurate data collection to document their expansion or deterioration, and inform management and implement adaptive management strategies effectively. Assessing reed bed condition typically occurs through field-based assessments and using remote sensing techniques. Field-based assessments typically involve the measurement of physical indicators (such as density, number of green and dry stems, height and diameter of stems) within 1 X 1 m quadrates (Corti Meneses et al. 2017; Hawke and José 1996) while data collection through remote sensing typically involves the use of satellite or drone imagery and LiDAR and multi spectral cameras (Assmann et al. 2018).

The Great Cumbung Swamp (GCS) is a terminal reed swamp that lies at the termination of the low-gradient Lachlan river system, west of Hay, NSW, where the Lachlan River joins the Murrumbidgee River during floods which occur in 15-20% of years (MDBA 2012a; O'Brien and Burne 1994). The GCS supports one of the largest areas of common reed in NSW (MDBA 2012a). The size of the GCS makes it one of the most important wetlands for waterbirds in south western NSW, 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 reed beds of the GCS also provide an important drought refuge for birds (MDBA 2012a).

The reed beds of the GCS have not been monitored as part of the LTIM project for logistical and financial reasons. The reed beds of the GCS 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 in the GCS (MDBA 2014) and they have been targeted with environmental water over the past five years (see Dyer et al. 2016). As such, the inability to monitor the reed beds of the GCS is a notable omission.

For these reasons, research has been undertaken to address two key research questions: what are the key indicators of condition for reed beds? and what is an appropriate monitoring program for stands of common reed and their response to watering? The benefits of this research are three-fold:

1. During the development of the monitoring approach, data will be collected that will facilitate the evaluation of the reed bed response to watering during the MER program, thus enhancing the evaluation provided for the vegetation diversity in the Lachlan Selected Area.
2. Methods will be developed that will underpin monitoring in subsequent programs.
3. Methods will be transferable to other areas in which water is provided to support stands of reeds.

This technical report provides the results and findings from the first year of a three-year research program. As such, here we report only the results of the field-based monitoring approach and evaluate data collected in the field. In this report we describe indicators of condition collected in the field and their response to watering during the 2019-20 watering season. This provides a foundation in which to compare the data collected through remote sensing (using drones and satellite imagery) in 2020-21 and 2021-22 technical reports.

11.2 Methods

11.2.1 Study area

The GCS is a semi-arid environment, which experiences an (mean) annual rainfall of 367.4 mm, but rainfall is highly variable (Bureau of Meteorology 2020). The GCS has a mean maximum and minimum temperature of 33.1°C in January and 15.1°C in July respectively (Bureau of Meteorology 2020). The GCS is a terminal reed swamp surrounded by floodplain forests, woodlands, and shrublands (MDBA 2012a). The central GCS contains a large reed bed dominated by common reed, which is the most extensive environment within the GCS (O'Brien and Burne 1994). In the central reed beds, common reed surrounds bodies of open water along the channel of the Lachlan River and smaller ephemeral flood channels (Driver et al. 2011; O'Brien and Burne 1994) (Figure 11-1).

The typical timing of floodplain inundation in the lower Lachlan River including the GCS is spring, but lower lying parts of the floodplain (including the GCS) can connect to the river throughout the year (Higgisson et al. 2020). Water resource development has intensified in the Lachlan River Catchment, since the construction of the Wyangla Dam in 1935 (Kingsford 2000). Regulation and flow extraction of the Lachlan River has reduced the flow of the Lachlan River (current flows at Oxley (near the Great Cumbung Swamp) are approximately half that under undeveloped flow conditions (Driver et al. 2011)), which has changed the behavior and distribution of floodwaters variability (Driver et al. 2004; Higgisson et al. 2020).

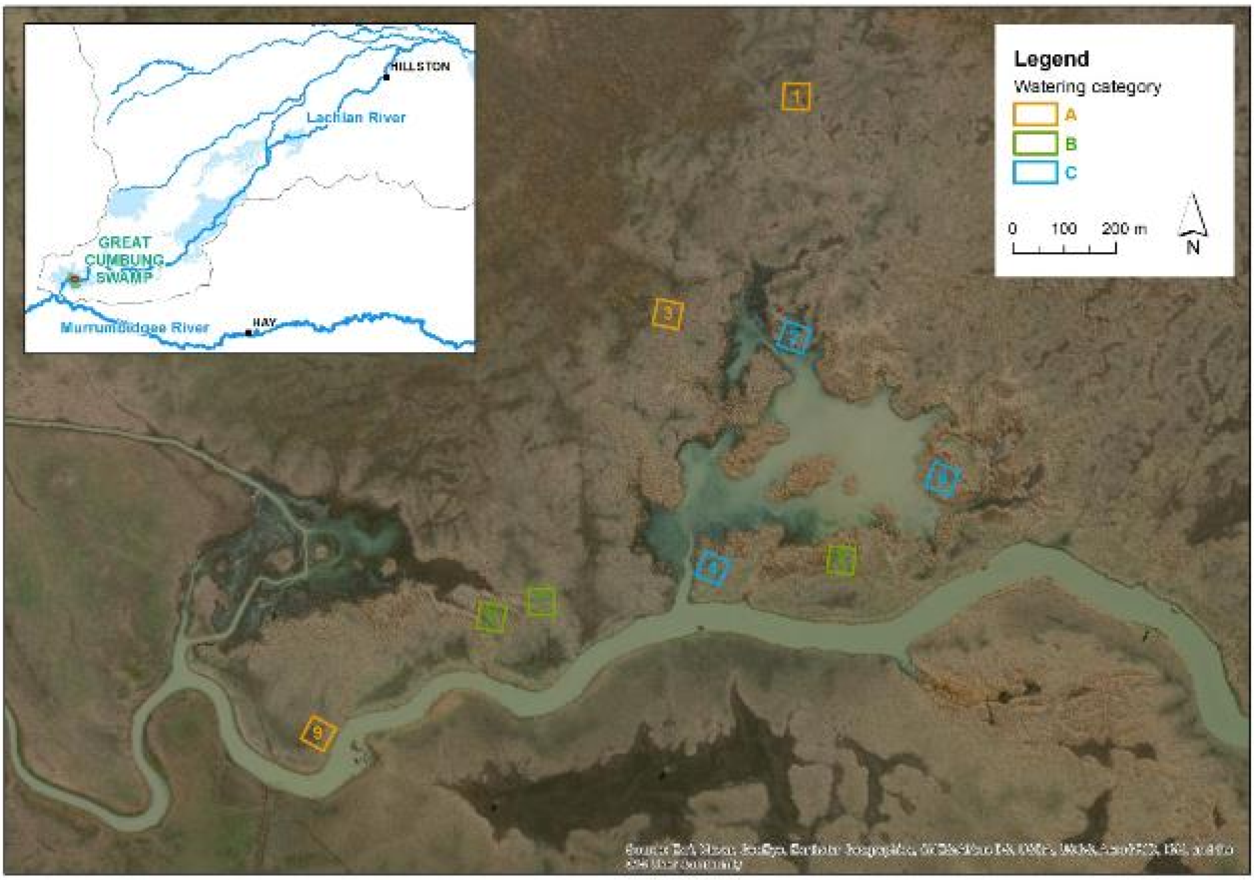


Figure 11-1. The location of the nine 50 X 50 m sites within the reed bed of the Great Cumbung Swamp. Sites in: watering category A have not been inundated since > January 2017, watering category B received one environmental watering in June 2019, and watering category C received two environmental watering actions in 2019 (in June and November).

11.2.2 Field methods

A total of nine 50 X 50 m fixed sites were selected within the reed bed of the GCS. These sites were selected across a flooding gradient. In eastern Australia, the Spring/Summer period is the main growth period of common reed (Roberts and Marston 2011), therefore, each site was monitored five times between October 2019 and June 2020 (October, November 2019, and January, March, and June 2020) using field-based and drone-based monitoring methods. Field based monitoring occurred within nine 1m^2 (replicate) quadrates at each site (Figure 11-2). Within each replicate 1m quadrate indictors of reed bed condition (average) reed height, number of green and dry reeds, number of green and dry flower heads, percent cover of reeds, bareground and leaf litter, and cover and number of other plant species were recorded. The drone captured each 50 X 50m site, flying at a height of 20 m, with an overlap of 85% and 75%.

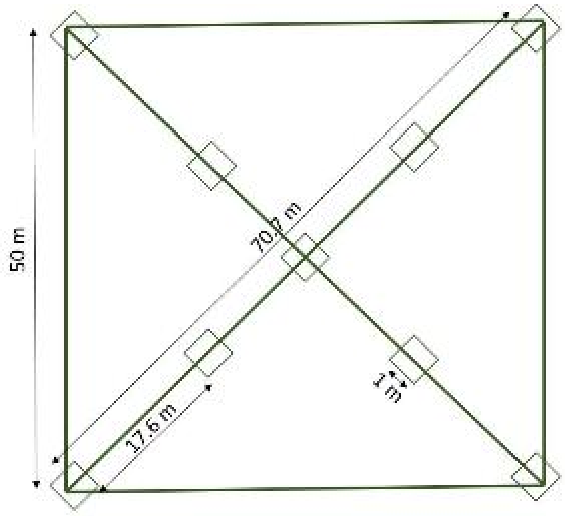


Figure 11-2. Diagram of the layout of quadrates used in field-based monitoring of reed beds and size and shape of sites used in field and drone-based monitoring.

11.2.3 Characterising the hydrology of each site

Using sentinel imagery from all existing imagery (August 2015 – June 2020) on the platform sentinelhub https://www.sentinel-hub.com/, important characteristics of the flooding regime on floodplains were calculated for each of the nine sites. These flooding characteristics included flood frequency and duration, number of days between floods, maximum flooding duration and maximum dry spell, as well as the number of environmental watering events within 2019. As this research primarily focuses on the response of the reed bed to environmental water, each site was grouped into one of three watering categories, based on the number of environmental watering actions it had received in the past 12 months (the 12 months of 2019). These categories align with the approach adopted for the vegetation monitoring (Table 9-4, page 109). These categories were:

- Watered only during natural flooding in > Jan 2017 (3 sites) (category A)
- Watered only in November 2019 with Environmental water (3 sites) (category B)
- Watered in June and November 2019 with Environmental water (3 sites) (category C)

11.3 Results

Some of the physical indicators of condition responded to the environmental watering actions which occurred in 2019, while others did not differ between sites which received environmental water compared to those that did not. Three physical indicators of condition (height of green shoots, percent cover of green shoots, and number of flowerheads) responded to the environmental watering actions in 2019.

The height of green shoots peaked in March and by June most of the tall green shoots turned brown and a small number of new green shoots had started emerging (thus, the drop in height of green shoots: Figure 11-3). Height of green shoots was related to the occurrence of flooding at a site, with sites which were flooded in June 2019 having a much greater average height of green shoots in October compared to sites that had not been flooded. Sites that had been flooded in June, continued to increase in height between October through to January. The average height of green shoots in sites that received a second flood in

November was slightly higher in March compared to sites that only received flooding in June. Sites that did not receive any environmental water during the 2019-20 watering year, were much shorter than those that were flooded and remained at a similar height throughout the growing season (Figure 11-3).

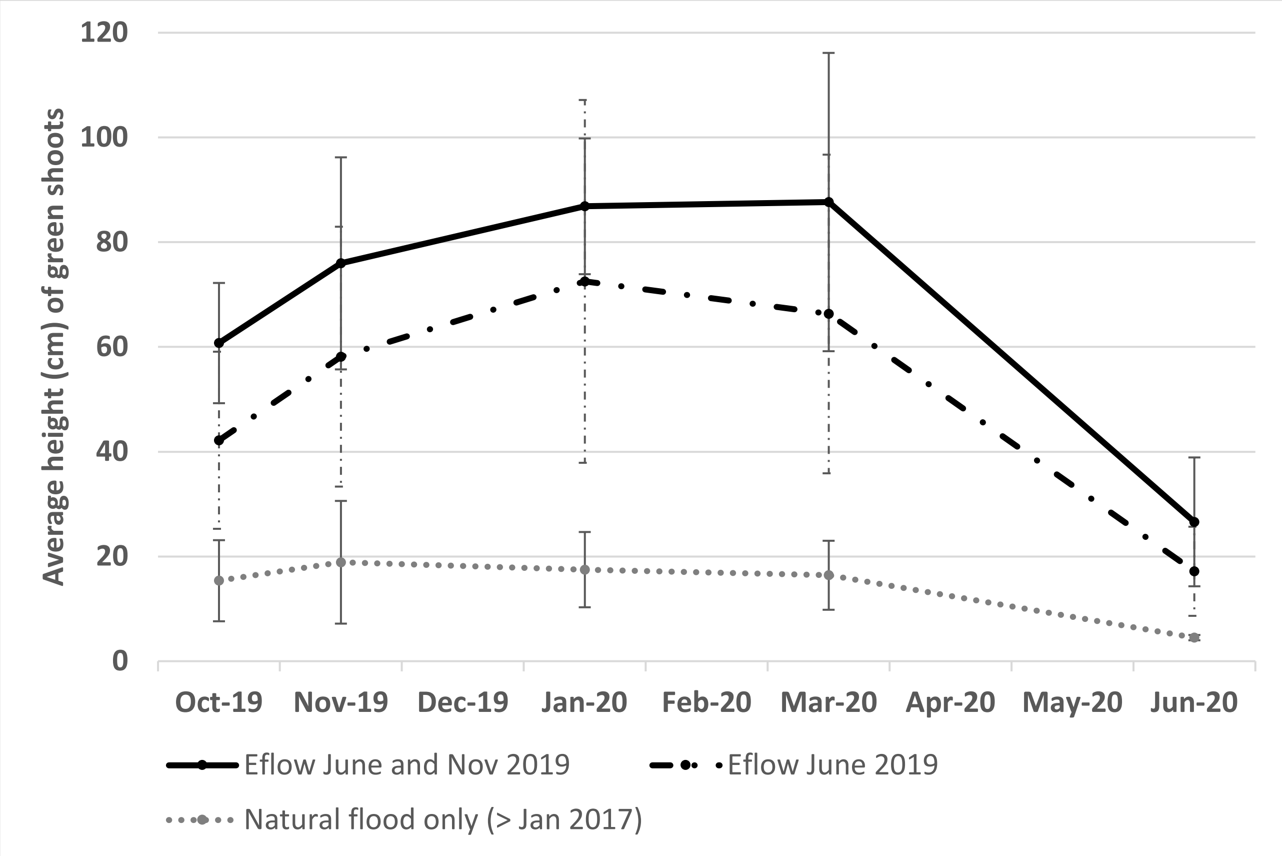


Figure 11-3. Average height of green shoots within the three watering categories in October and November 2019, and January, March and June 2020. Error bars represent ± 1 standard error of the mean.

Sites that were flooded in June exhibited a greater cover of reeds in October compared to sites that had not been flooded showing the response to this watering action. The sites that were flooded again in November showed a further increase in cover in January and March compared to sites that were only flooded in June (Figure 11-4). The cover of reeds at sites that were flooded in June and November peaked in January (mean cover of 7.6%). The cover at sites that did not receive environmental water in 2019 remained low (< 2.2%) over the five monitoring trips. By June, most reeds had turned brown, and the cover of green shoots was <1% at all sites.

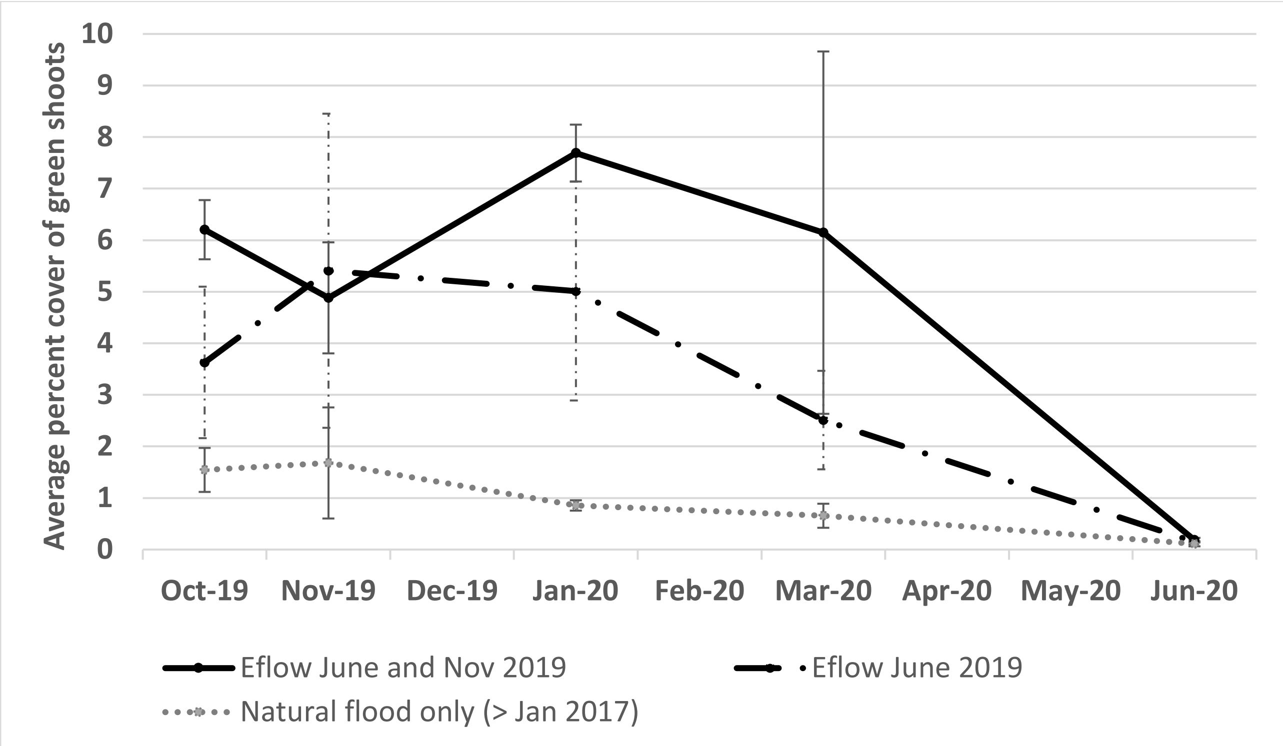


Figure 11-4. Average percent cover of green shoots of common reed within the four watering categories in October and November 2019, and January, March and June 2020. Error bars represent ± 1 standard error of the mean.

Flower heads were only observed at sites that had been flooded during 2019, with no flowerheads observed at sites that were not flooded (Figure 11-5). Flower heads were first observed in January 2020, at sites that had been flooded in June and November 2019, and only in June 2019. In March, the number of flowerheads observed increased at sites that were flooded in June and November 2019, while remaining consistent at sites that were only flooded in June 2019.

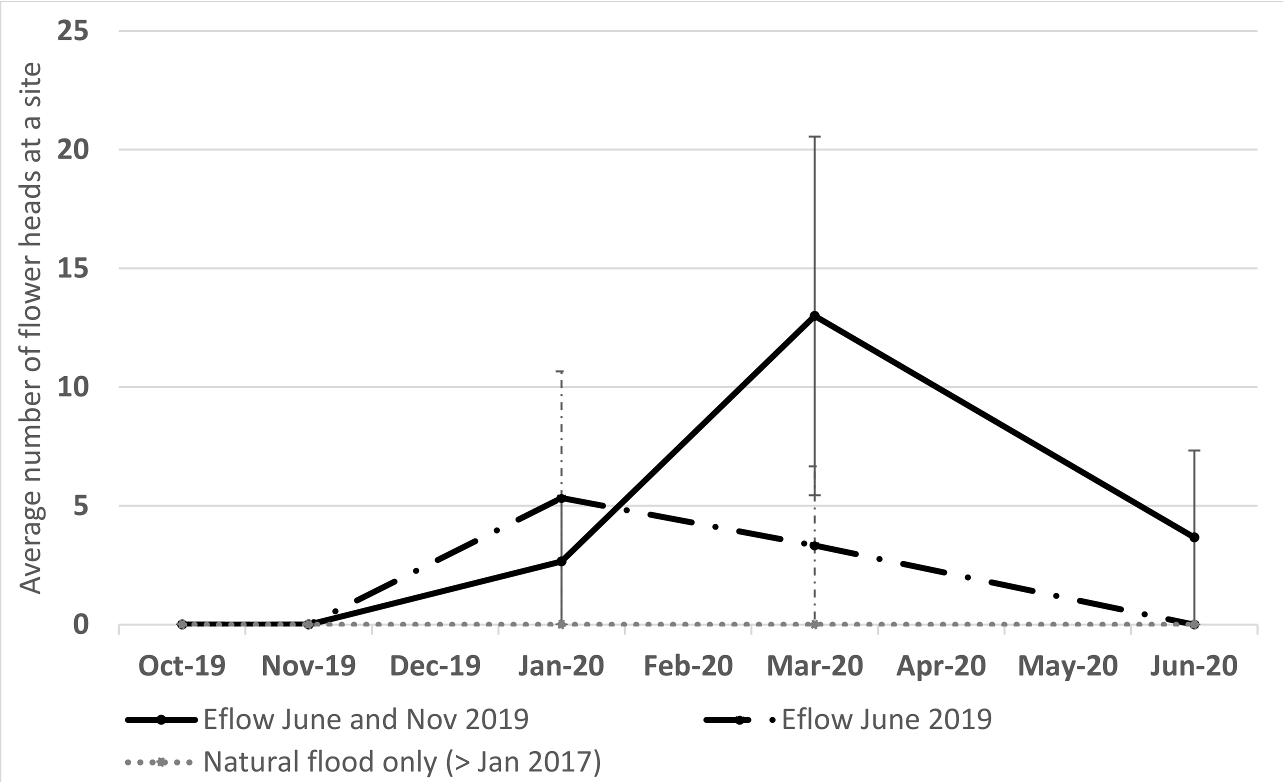


Figure 11-5. Average number of flowerheads at a site within the four watering categories in October and November 2019, and January, March and June 2020. Error bars represent ± 1 standard error of the mean.

Some physical indicators of condition including number of green shoots, leaf litter, and cover of other vegetation did not show a strong response to the environmental watering actions which occurred in 2019. Cover of other vegetation was strongly associated with rainfall, as percent ground cover remained consistent in all watering categories (between 5-20%) for the first four monitoring trips, then increased in all watering categories (to between 30-50%) in June 2020 following rainfall between March and June 2020.

11.4 Discussion

The presence of surface water by flooding appears to be a major determinant on growth and vigour of common reed in the GCS, with height and cover showed to be strongly related to recent flooding. Research using analysis of satellite imagery by Brady et al. (1998) also showed that flooding was the major determining factor on growth of common reed within the GCS. Sites that received environmental water in June 2019, had a greater cover of reeds and taller reeds in October 2019 compared to sites that were not flooded in June, which remained much shorter in height and lower in cover, and these metrics did not change through the growing season at these (unflooded) sites. Sites in the reed bed of the Macquarie Marshes which were more frequently flooded were also found to have taller reeds with greater biomass compared to sites higher on the floodplain which were flooded less frequently (Whitaker et al. 2015). The sites which received a second flood in November 2019, increased in cover and to a lesser extent height compared to sites that only received a single flooding event in June 2019, showing these metrics continue to improve with multiple floods within one year.

Growth and development of common reed has been observed to be S-shaped with rapid initial growth, being the most important in determining the final height (Haslam 1969). By our first field survey in October, sites which had received environmental water in June had experienced the majority of growth they would experience over the growing season, with height of green shoots in October being 58% and 70% of the total height they would reach, in watering categories B and C respectively. This result is contrary to that described by Roberts and Marston (2011), that the shoots of common reed begin to grow in October. This early growth was likely attributable to the environmental watering action in June, which suggests that growth of reeds is related to timing of inundation more so than season (or time of year).

The partitioning of resources to sexual reproduction also appears to be driven by surface water by flooding, as flowerheads were only present at sites that had been flooded during the 2019-20 watering season. The second flood considerably increased the number of flowerheads at a site showing the possible benefit to sexual reproduction in common reed provided by multiple flooding events within a year.

While height and cover of reeds, and number of flowerheads were related to recent environmental watering, the number of green shoots at a site didn't vary between sites which received environmental water and those that did not. The three sites which did not receive environmental water during 2019, have not been flooded in at least three years (since at least January 2017). Common reed in the GCS has been reported to access and depend on local shallow groundwater, especially during droughts (Driver et al. 2011). A water deficit has been shown to reduce leaf production, leaf area and biomass, and increase leaf shedding in common reed (Pagter et al. 2005). The results show that common reed which occurs on parts of the GCS which haven't been flooded in the past three years, persists as short (< 20 cm) green shoots. Shallow local groundwater may play an important role in maintaining common reed between flooding events (Driver et al. 2011), and the reduced leaf area reduces water demand (Pagter et al. 2005). The reed bed of the GCS was observed to reduce in cover during the Millenium drought, related to a drop in the depth of groundwater, with evidence of recovery observed following re-wetting in 2010 (Driver et al. 2011).

Environmental water is maintaining the central reed beds of the GCS, promoting growth, cover and reproduction. Overbank flows into the reed beds only occur during large (natural) flood events which haven't occurred since January 2017 or through environmental watering actions such as those that occurred twice during 2019. These environmental watering actions contributed to growth and cover of reeds and promoted sexual reproduction within the central reed beds, while also recharging the local groundwater.

The presence of cattle was described as a major factor in the condition of the reed bed in the GCS (Brady et al. 1998). The GCS on the western side of the Lachlan River, including a large portion of reed bed (including our research sites) was purchased by the Nature Conservancy Australia in 2019 https://www.natureaustralia.org.au/what-we-do/our-priorities/land-and-freshwater/land-freshwater-stories/saving-the-great-cumbung/. During our field trips, there were no signs of land-use actions such as livestock grazing or burning, which would impact reed growth or condition. Therefore, apart from pig tracks which occurred throughout some of the taller reeds, the response in reed growth indicators reported here are assumed to be related to hydrology and possibly climate.

The results reported here are from field-based monitoring of the reed beds within the GCS. The fact that three metrics (height of green reeds, cover of green reeds, and number of flowerheads) responded to environmental water, show their utility to detect measurable responses in reed bed condition to environmental watering. The height of green shoots has been shown to be correlated with stem diameter, leaf size (Poulin et al. 2010) and plant biomass (Whitaker et al. 2015), showing that this indicator may be useful as an overall measure of condition.

While an environmental watering action occurred in November during our field-work season, this did not hinder site access and there were no major issues around access. During the field trip in November, flood water was only present in the lower-lying open parts of the GCS, which could be avoided while walking to and from sites. A larger watering event may reduce access. None of the sites had surface water during our field trips and surface water may reduce our ability to safely undertake our field-based data collection without harm to the reed bed. Movement in and around sites was challenging at sites where reed height and cover were high which reduced our ability to work efficiently and effectively. For these reasons, remote sensing through drone-based monitoring is being used. As height of green reeds, cover of green reeds and number of flowerheads responded to environmental watering, these indicators will be estimated using data derived through remote sensing. These results will be presented and compared in following technical reports.

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13 Appendix

13.1 Species observed during monitoring (2019-20) within the tree community plots

Species Names

Abutilon theophrasti
Acacia stenophylla
Alternanthera denticulata
Asperula gemella
Asteraceae
Atriplex
Atriplex eardleyae
Atriplex holocarpa
Atriplex leptocarpa
Atriplex pseudocampanulata
Atriplex semibaccata
Atriplex suberecta
Atriplex vesicaria
Austrostipa scabra
Brachyscome
Brachyscome basaltica
Brassicaceae
Calotis hispidula
Calotis scabiosifolia
Calotis scapigera
Capsella bursa-pastoris
Carpobrotus
Carrichtera annua
Centaurea melitensis
Centipeda cunninghamii
Chenopodium album
Chenopodium murale
Chenopodium nitrariaceum
Cirsium vulgare
Convolvulus
Conyza
Conyza bonariensis
Cucumis melo
Cucumis myriocarpus
Cullen australasicum
Cuscuta
Cuscuta campestris
Cynodon dactylon
Cyperus gymnocaulos
Damasonium minus
Daucus glochidiatus
Duma florulenta
Duma horrida
Dysphania pumilio
Echium plantagineum
Eclipta platyglossa
Einadia nutans
Eleocharis acuta
Enchylaena tomentosa
Epaltes australis
Epilobium billardiereanum
Eragrostis dielsii
Erodium
Erodium crinitum
Eucalyptus camaldulensis
Eucalyptus largiflorens
Euphorbia drummondii
Fumaria capreolata
Galium
Galium aparine
Galium gaudichaudii
Galium murale
Geococcus pusillus
Glinus lotoides
Goodenia heteromera
Haloragis glauca
Heliotropium curassavicum
Heliotropium europaeum
Hibiscus tridactylites
Hordeum
Hordeum leporinum
Juncus
Juncus aridicola
Lachnagrostis filiformis
Lactuca
Lactuca saligna
Lactuca serriola
Lamium amplexicaule
Lepidium

Lepidium fasciculatum
Lepidium hyssopifolium
Ludwigia peploides
Lycium ferocissimum
Lysimachia arvensis
Lythrum hyssopifolia
Maireana
Maireana brevifolia
Maireana coronata
Malva
Malva parviflora
Malva preissiana
Malvaceae
Marrubium vulgare
Marsilea drummondii
Medicago minima
Medicago polymorpha
Melilotus indicus
Mentha australis
Myosurus australis
Myriophyllum crispatum
Nicotiana
Nicotiana suaveolens
Nitraria billardierei
Onopordum acanthium
Oxalis corniculata
Paspalidium jubiflorum
Persicaria decipiens
Persicaria prostrata
Phalaris
Phalaris aquatica
Phyla nodiflora
Physalis
Plantago
Poa fordeana
Poaceae
Polygonum aviculare
Polygonum plebeium
Polypogon monspeliensis
Pratia concolor
Pseudognaphalium luteoalbum
Psilocaulon granulicaule
Pycnosorus chrysanthus
Ranunculus
Ranunculus pumilio
Ranunculus sceleratus
Ranunculus undosus
Rhagodia spinescens
Rhodanthe corymbiflora
Roepera ammophila
Roepera apiculata
Roepera iodocarpa
Rorippa
Rorippa laciniata
Rumex
Rumex crispus
Rumex crystallinus
Rytidosperma caespitosum
Salsola australis
Scleroblitum atriplicinum
Sclerolaena birchii
Sclerolaena brachyptera
Sclerolaena deserticola
Sclerolaena diacantha
Sclerolaena eriacantha
Sclerolaena lanicuspis
Sclerolaena muricata
Sclerolaena obliquicuspis
Sclerolaena tricuspis
Senecio
Senecio cunninghamii
Senecio runcinifolius
Sida
Sisymbrium erysimoides
Sisymbrium irio
Solanum
Solanum esuriale
Solanum nigrum
Sonchus oleraceus
Sporobolus mitchellii
Stemodia florulenta
Tetragonia eremaea
Tetragonia moorei
Teucrium racemosum
Unknown
Verbena
Verbena officinalis
Verbena supina

Vittadinia cuneata
Xanthium occidentale
Xanthium spinosum

13.2 Species observed during monitoring (2019-20) within the non-tree transect sites

Species name
Abutilon theophrasti
Acacia stenophylla
Alternanthera denticulata
Asperula gemella
Asteraceae
Atriplex
Atriplex eardleyae
Atriplex leptocarpa
Atriplex nummularia
Atriplex pseudocampanulata
Atriplex semibaccata
Atriplex suberecta
Atriplex vesicaria
Azolla
Boerhavia dominii
Brachyscome
Brachyscome basaltica
Brassica
Brassicaceae
Calendula arvensis
Capsella bursa-pastoris
Carrichtera annua
Centipeda
Centipeda cunninghamii
Centipeda minima
Chenopodium murale
Chenopodium nitrariaceum
Cirsium vulgare
Convolvulus
Convolvulus remotus
Conyza
Conyza bonariensis
Cucumis myriocarpus
Cynodon dactylon
Cyperus gymnocaulos
Duma florulenta
Dysphania pumilio
Echium plantagineum
Eclipta platyglossa
Einadia nutans
Eleocharis acuta
Enchylaena tomentosa
Epaltes australis
Eragrostis dielsii
Erodium crinitum
Euphorbia drummondii
Fumaria capreolata
Galium
Galium murale
Gamochaeta
Geococcus pusillus
Geraniaceae
Glinus lotoides
Goodenia heteromera
Haloragis glauca
Heliotropium curassavicum
Heliotropium europaeum
Heliotropium supinum
Hordeum
Hordeum leporinum
Lachnagrostis filiformis
Lactuca
Lactuca saligna
Lactuca serriola
Lamium amplexicaule
Lemna
Lepidium fasciculatum
Ludwigia peploides
Lycium ferocissimum
Lysimachia arvensis
Lythrum hyssopifolia
Maireana
Maireana brevifolia
Malva
Malva parviflora
Malva preissiana
Marrubium vulgare
Marsilea drummondii

Medicago laciniata
Medicago minima
Medicago polymorpha
Melilotus indicus
Mentha australis
Myriophyllum
Nitraria billardierei
Onopordum acanthium
Oxalis corniculata
Paspalidium jubiflorum
Paspalum distichum
Persicaria decipiens
Phalaris
Phragmites australis
Phyla nodiflora
Plantago
Poa fordeana
Poaceae
Polygonum
Polygonum aviculare
Polygonum plebeium
Polypogon monspeliensis
Pratia concolor
Psilocaulon granulicaule
Ranunculus
Ranunculus pumilio
Ranunculus sceleratus
Ranunculus sceleratus
Ranunculus undosus
Rapistrum rugosum
Rhagodia spinescens
Rhodanthe floribunda
Roepera ammophila
Roepera apiculata
Roepera iodocarpa
Rorippa eustylis
Rumex
Rumex crystallinus
Salsola australis
Scleroblitum atriplicinum
Sclerolaena
Sclerolaena birchii
Sclerolaena brachyptera
Sclerolaena lanicuspis
Sclerolaena muricata
Scleroleana muricata
Senecio
Senecio cunninghamii
Senecio quadridentatus
Senecio runcinifolius
Sida
Sisymbrium erysimoides
Sisymbrium irio
Solanum
Solanum esuriale
Solanum nigrum
Sonchus oleraceus
Sporobolus mitchellii
Stemodia florulenta
Stemodia glabella
Tetragonia eremaea
Tetragonia moorei
Triglochin hexagona
Unknown
unknown germinants A
unknown germinants B
unknown germinants C
unknown germinants D
Urtica dioica
Urtica incisa
Urtica urens
Verbena
Verbena officinalis
Xanthium
Xanthium occidentale
Xanthium spinosum