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COMMONWEALTH ENVIRONMENTAL WATER OFFICEB LONG TERM INTERVENTION MONITORING PROJECT: LOWER LACHLAN RIVER SYSTEM 2017-18 TECHNICAL REPORT

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Commonwealth Environmental Water Office

Long Term Intervention Monitoring Project

Lower Lachlan river system 2017-18 Technical Report

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Front cover photos: Top left: Pelicans at Nooran Lake (Fiona Dyer); Bottom left: Turtle at The Ville (Fiona Dyer); Right: Vegetation surveys at Lake Tarwong (Alica Tschierschke)

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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
ER	Ecosystem Respiration
EWA	Environmental water allowance
GPP	Gross Primary Production
LTIM Project	Long Term Intervention Monitoring Project
MDBA	Murray-Darling Basin Authority
MDFRC	Murray-Darling Freshwater Research Centre
WQA	Water quality allowance

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1 INTRODUCTION

The record rainfall and widespread flooding of 2016-17 was followed with much drier conditions in 2017-18. While some wetlands remained inundated until well into 2017, river flows had returned to regulated conditions and the environmental watering actions focussed on supporting the recovery of instream biota following the floods and hypoxic blackwater events of 2016-17.

Two Commonwealth environmental watering actions were delivered to the Lachlan river system in 2017-18. Releases from Wyangala dam for the first action commenced on the 23rd September 2017 and concluded on the 13th November 2017, targeting outcomes for native fish in the mid (Forbes) and lower (Hillston) Lachlan. Water from the Forbes environmental water order that was not required to meet the order at Hillston was reregulated into the Brewster outflow wetlands to establish aquatic vegetation and support a pelican breeding event. At the conclusion of the first watering action there was a residual of environmental water (1,665 ML) held in the Brewster Weir. This was used at the end of May to achieve a small fresh in the river at Booligal. The small fresh passed Booligal between the 22nd May and the 2nd June.

The aim of the first Commonwealth watering action was to prevent the water level in the river from dropping during the Murray cod nesting period, to avoid nest abandonment. This action was followed by a release of Environmental Water Allowance (EWA) to provide a small fresh to support the movement and dispersal of larvae.

The aim of the second Commonwealth watering action was to use the reregulated volume held in Brewster weir to contribute to hydrological variability by providing a small fresh in the Lower Lachlan during a period of low flow in late autumn-early winter.

By providing flows to support breeding, and the movement and dispersal of larvae, the watering actions in the Lachlan draw on the watering priorities of the Murray Darling Basin Authority for threatened fish to focus on maintaining and improving existing populations of fish.

The Long-Term Intervention Monitoring Project (LTIM Project) is the primary means by which the Commonwealth Environmental Water Office (CEWO) undertakes monitoring and evaluation of the ecological outcomes of Commonwealth environmental watering. Monitoring activities implemented within the LTIM Project to evaluate the outcomes of Commonwealth environmental watering actions in the Lower Lachlan river system in 2017-18 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 report provides the technical reports for the fourth of five years of monitoring and evaluation of Commonwealth environmental watering in the Lower Lachlan river system. It is designed as a record of the supporting technical material for the summary report (Dyer et al. 2018). This report describes the context in which the water was delivered, the environmental objectives of the watering actions, the monitoring activities undertaken, and evaluates the outcomes of the watering actions.

2 LOWER LACHLAN RIVER SYSTEM – SELECTED AREA

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

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

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

The millennium drought (2001-2009) resulted in large areas of river red gums becoming stressed, and in wetlands, vegetation became dominated by terrestrial, drought tolerant species (Thurtell et al. 2011). Some recovery of the wetlands and rivers has been observed since 2010, attributed to natural flow events and environmental watering actions.

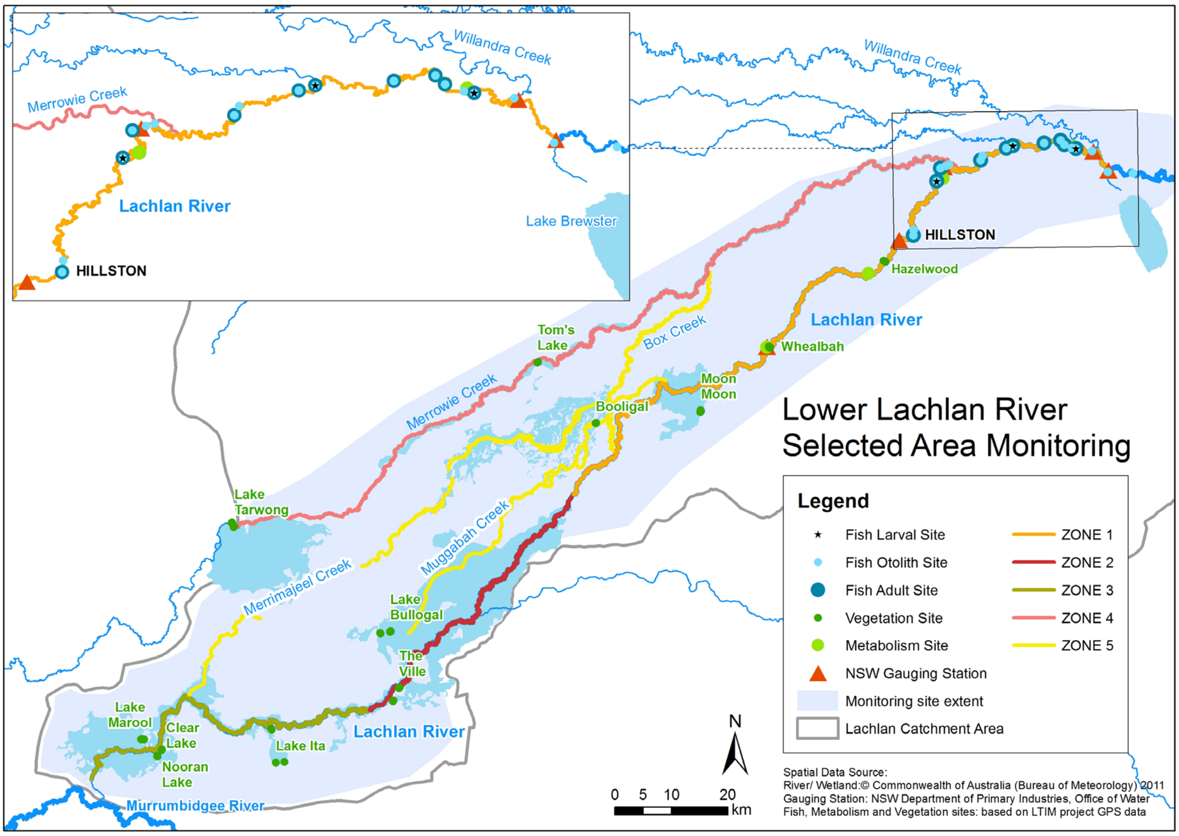


Figure 1. The Lower Lachlan river system showing the region for the LTIM Project.

3 COMMONWEALTH ENVIRONMENTAL WATERING ACTIONS 2017-18

3.1 CLIMATE AND WATER CONTEXT

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.

3.1.1 CATCHMENT AND WEATHER CONDITIONS

The Lower Lachlan River catchment experiences alternating periods of wet and dry conditions (Figure 2). The recent Millennium drought (2001- 2010) was the longest extended dry period on record during which the river ceased to flow. Water has been more abundant since the drought, with floods in 2010, 2012 and 2016, each progressively longer and greater in discharge.

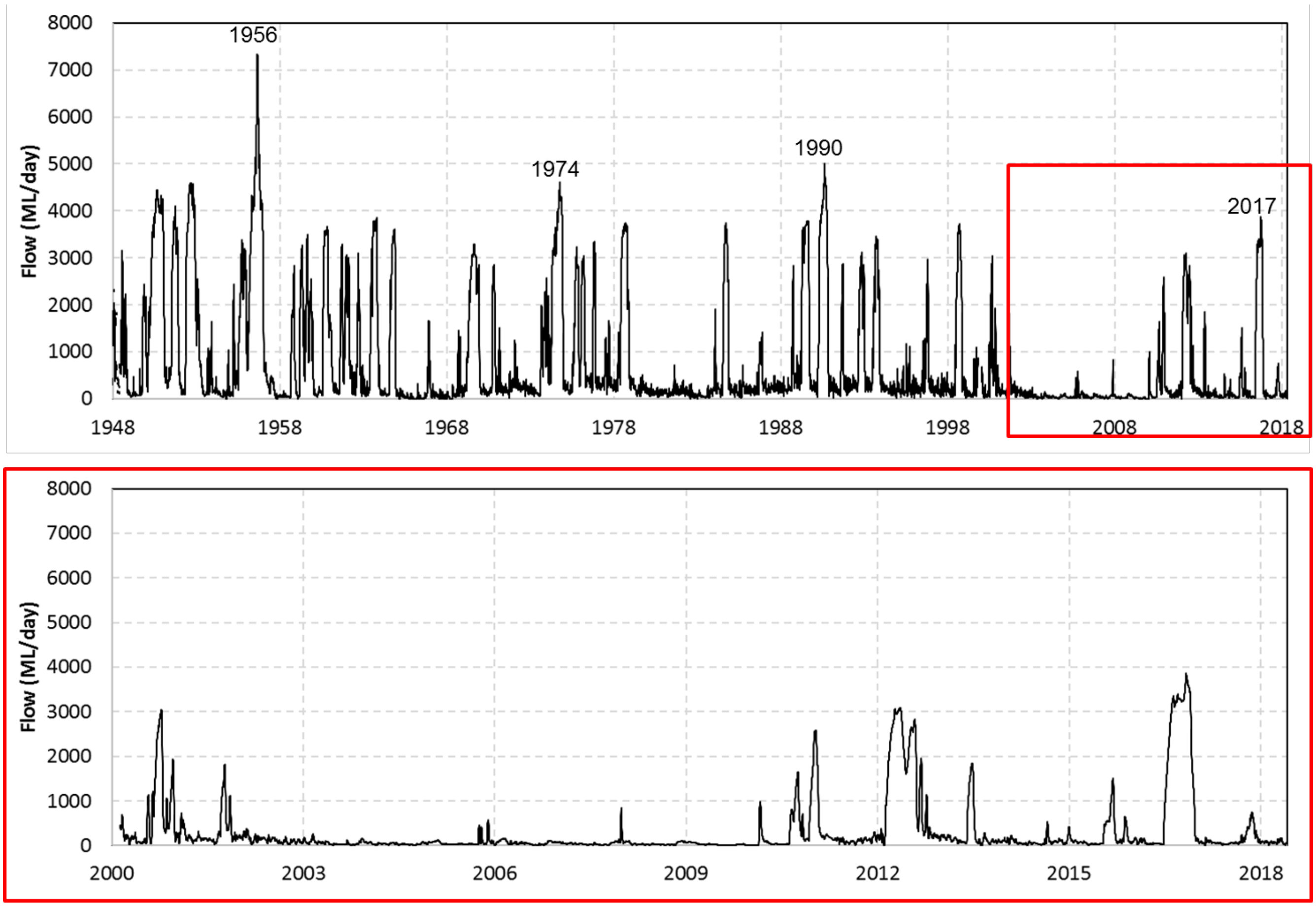
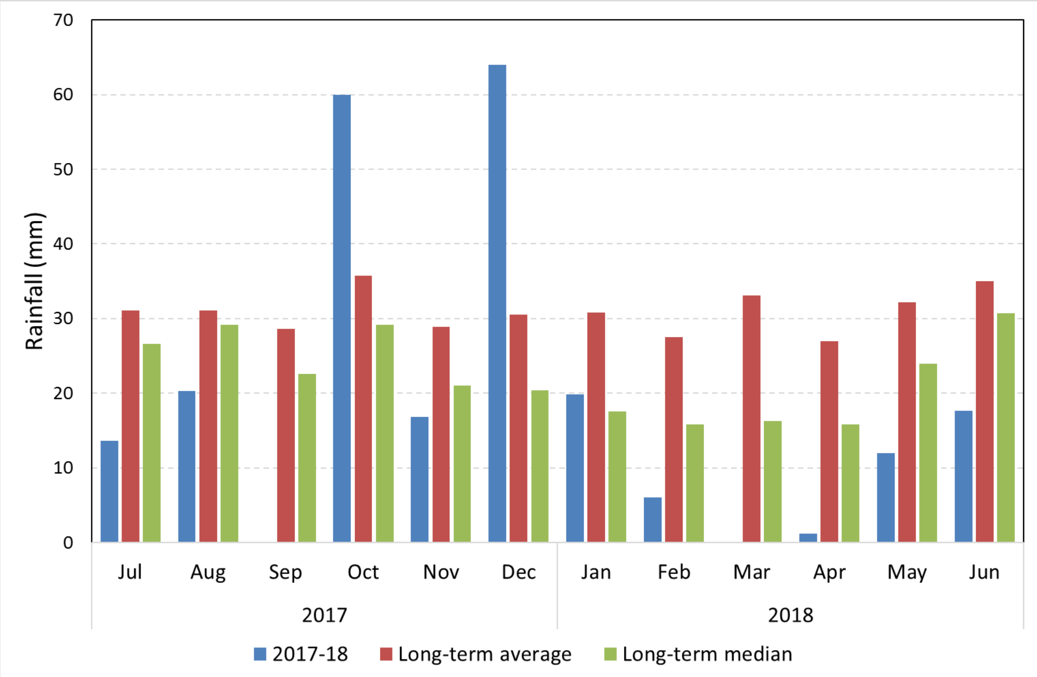


Figure 2. Hydrographs for the Lachlan River at Booligal illustrating the variability in flow in the river. The long term continuous flow record is shown at the top, the period from 2000 to present is shown at the bottom illustrating the Millenium drought and most recent flood events.

Conditions across the catchment have been dry since January 2017, with lower than average rainfall occurring in all months except October and December which had considerably higher than average rainfall (Figure 3). The effects of the 2016-17 flooding persisted well into 2017, with some wetland areas retaining significant areas of inundation into late spring

2017. These were topped up by the rainfall in October and December. It was notable that Lake Tarwong retained water in the deeper parts of the wetland through until December 2017 and consequently was not identified as a priority for environmental watering in 2017-18.



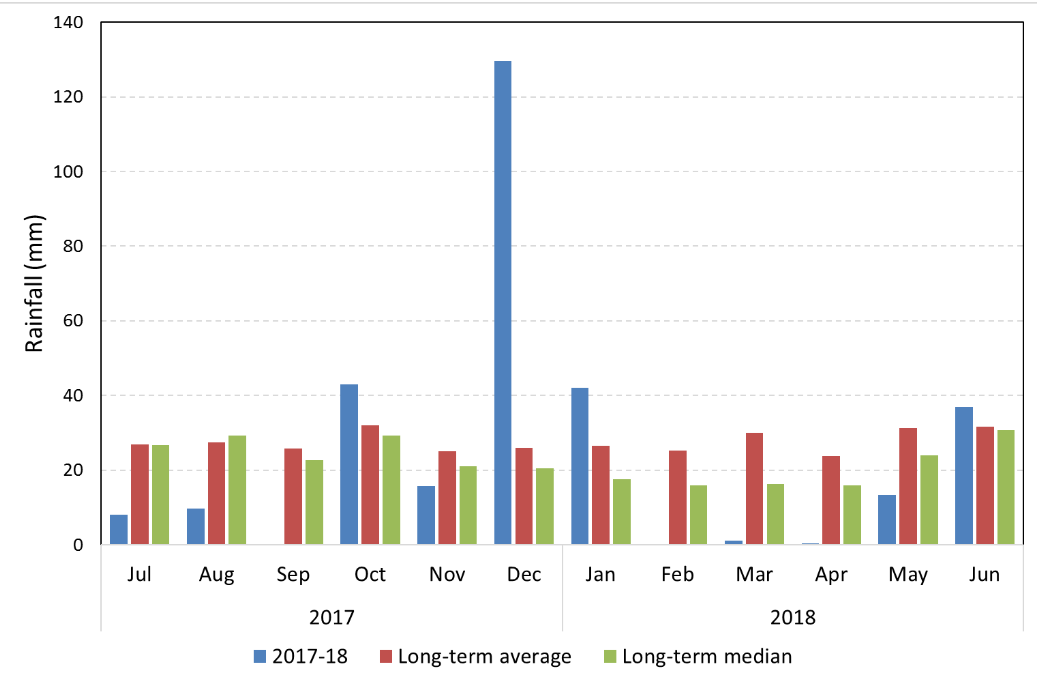


Figure 3. Monthly rainfall at Hillston Airport (075032, top) and Booligal (075007, bottom) during 2017-18 compared with the mean and median rainfall for the entire period of record.
Data sourced from Climate Data Online, Bureau of Meteorology. Note that data were missing for February 2018 at Booligal.

Temperatures were slightly above average throughout 2017-18 (Figure 4), particularly from January through to April 2018. This coincided with a period of well below average rainfall (Figure 3) resulting in very dry conditions across the catchment with very little groundcover vegetation present.

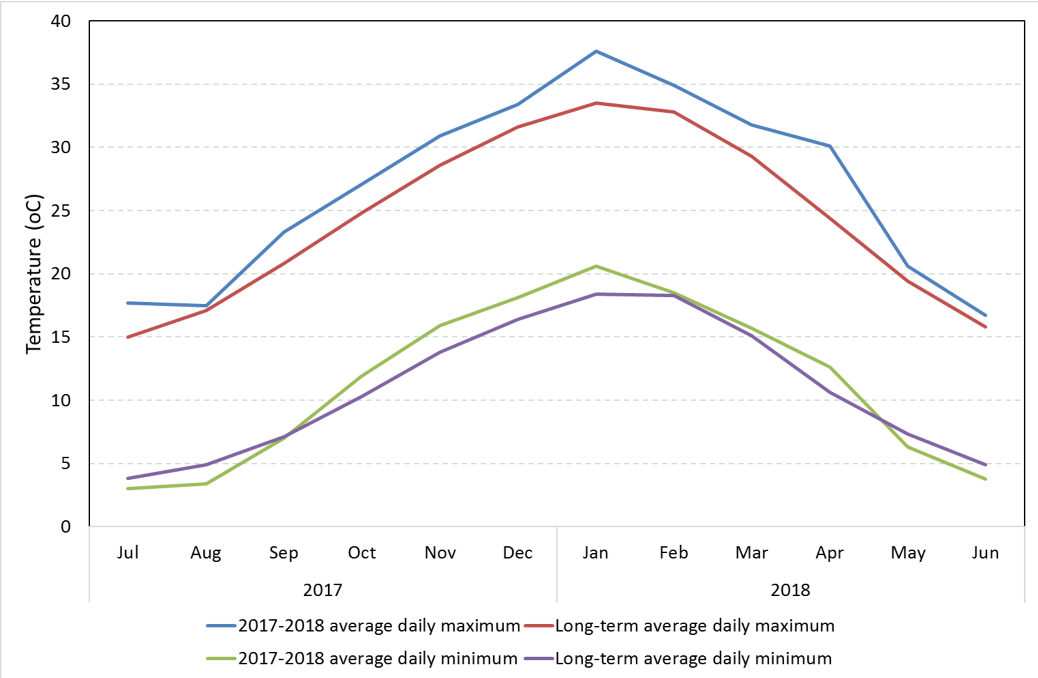


Figure 4. Average daily maximum and minimum temperatures for 2017-18 compared with the long term average daily maximum and minimum temperatures.

3.1.2 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 2017-18 water year, the Commonwealth government held a total of almost 87 856 ML in entitlement (Table 1).

Table 1. Environmental water holdings in the Lachlan River Valley as at 1 July 2017.

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

3.2 2017-18 WATERING ACTIONS

3.2.1 PLANNED WATER USE

Planning for environmental watering in 2017-18 was undertaken with moderate water resource availability and the knowledge that the widespread flooding in 2016-17 meant that many of the wetlands and low-lying areas were still inundated. This provided opportunities to build on the improvements arising from the wet conditions in 2016 and to build the resilience of populations and ecosystems (MDBA 2017a).

The annual watering priorities of the Murray Darling Basin Authority (MDBA 2017b) focussed around the southern connected basin, the Barwon/Darling system and generic objectives for threatened native fish. The *Commonwealth Environmental Water Portfolio Management Plan: Lachlan River 2017-18* (Commonwealth of Australia, 2017)[1] notes that the CEWO was aiming to contribute to the following 2017–18 Basin annual environmental watering priorities relevant to the Lachlan River region:

- Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales for the southern connected Basin.

[1] The *Commonwealth Environmental Water Portfolio Management Plan: Lachlan River 2017-18* (Commonwealth of Australia, 2017) includes a section on expected outcomes from the *Basin-wide Environmental Watering Strategy* (MDBA 2014). That section of the 2017-18 plan is included as Section 11: Appendix A as the 2017-18 plan is no longer available from the CEWO's website (has been replaced by the 2018-19 Portfolio Management Plan).

- Support viable populations of threatened native fish and maximise opportunities for range expansion and the establishment of new populations.
- Improve the abundance and diversity of the Basin's waterbird population.
- Enable recruitment of trees and support growth of understorey species within river red gum, black box and coolibah communities on floodplains that received overbank flooding during 2016 by inundating the floodplains again.

The 2017-18 plan also notes that the CEWO was considering supplying water in 2017-18 for the following actions:

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

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

3.2.2 IMPLEMENTED WATERING ACTIONS

The total Commonwealth environmental water delivery to the Lachlan river system in 2017-18 was 33 523 ML and through a process of re-regulation, was used to target multiple locations and ecological objectives at different times through the river system (Table 2).

Releases for the 2017-18 watering actions targeting native fish outcomes commenced at Wyangala dam on 23 September 2017 and while releases concluded on the 23rd November at the end of the Wyangala Environmental Water Allowance (EWA) releases, the environmental watering action progressed through the river system reaching the Great Cumbung Swamp in December 2017 and January 2018. The aim was to stabilise flows during the Murray cod nesting period and avoid nest abandonment. The environmental water in the river supported the maintenance of river heights during a drop in consumptive demand in late October 2017. Environmental water also contributed to the flow arriving at Hillston, buffering the rapid spikes and falls in the river that normally occur from irrigation extractions in that zone, with some contribution from the Brewster storage.

The watering action using EWA was designed to generate opportunities for native fish larvae to disperse (a dispersal pulse) and to support this, WaterNSW altered the operation of Jemalong weir gates during the dispersal pulse to create a wider opening to reduce shear stress on larvae in the water column. Between 27 November and 7 December 2017 the Booberoi regulator was opened to allow a proportion of the dispersal pulse to increase flows into Booberoi Creek. Booberoi Creek is not an LTIM site and hence this watering action is not reported on in this report.

Commonwealth environmental water was ordered to two accounting points to create the desired flow regime for native fish – one at Forbes (Cotton's Weir) and one at Hillston (Hillston Weir). As the watering action progressed it was found that more water than expected was required to maintain river levels and attenuation/losses down the system were lower than expected. These two factors, combined with localised rain events in the Lower Lachlan led to the need to incrementally increase the "target" flow at Hillston to account for these "surpluses'. Further surpluses arrived in the Brewster area and to avoid uncontrolled spilling of the Brewster Weir and potential nuisance flooding in the Hillston to Booligal area, approximately 3,165 ML of Commonwealth environmental water was directed into the Brewster wetlands. Of this, 1,500 ML was used for wetland plants and bird breeding in Lake Brewster. The remaining Commonwealth environmental water (1,665 ML) stored in the Brewster outflow wetland was used in May in combination with 805 ML of Lake Brewster Environmental Water Allowance to achieve a small fresh in the river at Booligal. After attenuating as it travelled downriver, the small fresh of 1,899 ML passed Booligal between 17 May and 2 June.

Planned actions for native fish in autumn were not progressed as the demand was met through operational delivery.

While the 2017-18 watering actions explicitly targeted the channel of the Lower Lachlan river system to provide benefits for fish, implied within the watering actions are outcomes for stream metabolism and hydrological connectivity. Outcomes for vegetation were not specifically targeted but the passage of this flow to the end of the system was expected to wet the central reed beds of the Great Cumbung Swamp and thus provide benefit.

Table 2. The 2017-18 Commonwealth environmental watering actions.

DESCRIPTION	DETAILS	
Action	1	2
Target Asset	Mid Lachlan River, main channel and Lower Lachlan River, main channel	Lower Lachlan River, main channel below Lake Brewster terminating in Great Cumbung Swamp
Reference	WAR 10053-02	WAR 10053-02
Accounting Location	Lachlan River at Forbes (Cotton's Weir), Hillston (Hillston Weir)	Lachlan River at Booligal
Flow component	Base flow and fresh flow	Fresh flow
Volume (CEW)	32 572 ML (accounted at Forbes) 951 ML (accounted at Hillston)	
WQA[1]		
Volume (NSW)	8,400 ML Wyangala Environmental Water Allowance (EWA)	805 ML Lake Brewster Adaptive Environmental Water
Total Volume (ML)	40 923 ML	805 ML
Re-use	30 204 ML re-regulated from the Forbes flow and accounted at Hillston	1,665 ML re-regulated from the Forbes Flow and accounted at Booligal
Objectives	To inundate areas of the river channel containing large woody habitat (snags) which is the preferred spawning habitat for nesting native fish such as Murray cod, River blackfish and Freshwater catfish. Avoid rapid drops in water level from late September to early December to prevent nest abandonment by native fish.	To create and maintain refugia as the Lachlan River enters the winter operational base (low) flow period. To flush fine sediment and organic material from the river bed, encourage mixing, improve water quality, and increase available habitat for water bugs and fish species. To provide a rise in flow (increased river height) to cover benches in the river channel, creating more food, access to more habitats and better breeding opportunities.
Basin Annual watering priorities 2017-18	Supporting viable populations of threatened native fish, maximising opportunities for range expansion and establishing new populations. Supporting lateral and longitudinal connectivity	Supporting lateral and longitudinal connectivity

4 DESIGNING FLOWS FOR FISH

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

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

Thus the relevant flow components identified were:

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

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

Maintaining habitat availability during nesting

The majority of the water in the river during the spring breeding season is delivered from storages (predominantly Wyangala Dam) to meet irrigation needs. River levels can fluctuate considerably depending on water orders and periods of low demand can result in very low flows. This places Murray cod nesting sites at risk. To avoid sudden drops in river heights, a minimum flow target of 1,400 ML/day (approximately 0.77m deep) at Cottons Weir (Forbes) was maintained for approximately 55 days (27/09–20/11/17 at Cottons). Environmental water was only required if downstream demand and WaterNSW operational releases fell below the 1,400 ML/day target.

This was accompanied by a minimum flow target of 500 ML/day (approximately 0.73 m deep) at Hillston Weir. The flow target was increased to 900 ML/day (approximately 0.89 m deep) during this period in response to lower than expected attenuation of the water from Forbes.

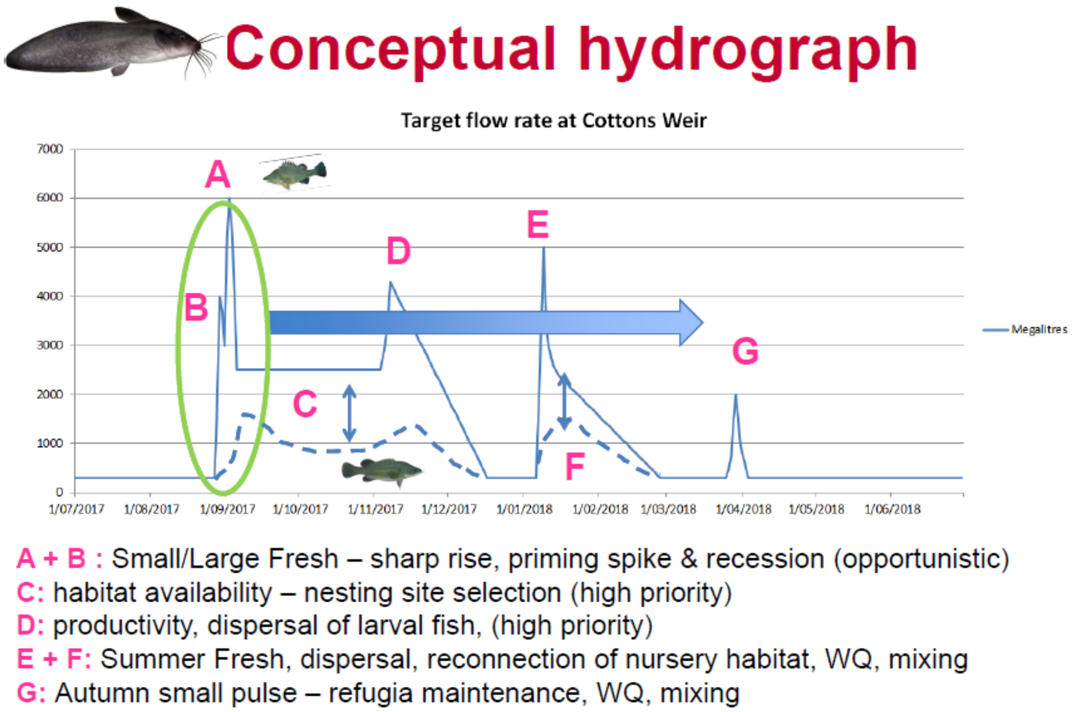


Figure 5. Conceptual hydrograph identifying key flow components to support Murray cod populations. Source: Sam Davis, NSW Fisheries based on the work of Ellis et al. (2016).

Supporting larval dispersal

The provision of a small fresh is designed to promote the dispersal of larval Murray cod. The dispersal flow was designed to occur at the end of the estimated nesting period (at the end of November) and involved a small peak with a gradual recession at both Cottons Weir (Forbes) and Hillston Weir (Hillston). At the same time the gates of Jemalong weir were operated to provide conditions that were conducive to dispersal and minimized the risk of larval mortality (lowering velocities by creating a wide opening at the weir).

Autumn Pulse

The provision of a small fresh in autumn was designed to provide a rise in the river to cover benches, provide a small pulse in productivity, increase available habitat, move fine sediment and organic matter, encourage mixing, and improve water quality.

5 HYDROLOGY

5.1 INTRODUCTION

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

In this section we evaluate the hydrological outcomes of providing Commonwealth environmental water to the Lower Lachlan river system. There are two components to the evaluation. The first is an evaluation of the hydrological outcomes in relation to the defined hydrological objectives of the watering actions and the second is an evaluation of the watering outcomes framed in the context of evaluation questions defined in the Long Term Intervention Monitoring and Evaluation Plan for the Lachlan river system (Dyer et al. 2014). The hydrological outcomes are linked to ecological outcomes and this section provides the analysis of the managed flow and water levels that will underpin the interpretation of the outcomes presented in later sections.

The context in which the 2017-18 environmental watering actions were delivered was one in which the river system was transitioning from very wet conditions to dry conditions. The flooding that occurred in 2016-17 was widespread and, in spite of generally below average rainfall in 2017, water persisted across the landscape in some of the wetlands until late spring/early summer 2017 (Figure 6 and Figure 7). Rainfall throughout 2017-18 was well below average with the exception of October and December during which significant rainfall topped up the rapidly drying wetlands. The persistence of water in the landscape throughout the early part of 2017 meant that the focus for environmental water delivery was supporting the recovery of instream biota.

Figure 6. Lake Tarwong on 14 December 2017. Photo: Alica Tschierschke.

Figure 7. Lake Bullogal on 15 December 2017. Photo: Alica Tschierschke.

Two watering actions involving Commonwealth environmental water were delivered to the Lower Lachlan river system in 2017-18 (Table 3). The first action targeted outcomes for native fish in the main channel of the mid (Forbes) and lower (Hillston) Lachlan River and the second action targeted ecological outcomes in the Lower Lachlan River (Booligal). Water from these actions was regulated and re-regulated to achieve environmental outcomes at multiple locations (see section 3.2 for further details).

The first watering action was designed to produce a hydrograph containing flow components that support native fish outcomes (Table 3), but was also expected to provide longitudinal connectivity by providing flow to the central reed beds of the Great Cumbung Swamp. The second watering action aimed to contribute to hydrological variability in the Lower Lachlan during periods of low flow.

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

5.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

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

5.1.2 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

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

Table 3. The 2017-18 Commonwealth environmental watering actions in the Lower Lachlan river system and their hydrological objectives.

ACTION	TARGET	FLOW COMPONENTS	VOLUMES DELIVERED (COMBINED CEW, WQA AND NSW WATER)	HYDROLOGICAL OBJECTIVES	FLOW TARGETS
1a	Main channel Mid Lachlan River (Forbes) and Lower Lachlan River (Hillston)	Base flow	33 523 ML comprising 32 572 ML CEW (accounted at Forbes) 951 ML CEW (accounted at Hillston)	Explicit: Avoid rapid drops in water level, particularly from late September to early December to prevent nest abandonment by native fish Implied: Provide longitudinal connectivity through the passage of the watering action to the Great Cumbung Swamp	Maintain Lachlan River above 1,400 ML/day at Cotton's Weir, Forbes Maintain Lachlan River above 450 ML/day at Hillston Weir, Hillston[1]
1b		Fresh flow	8,400 ML NSW environmental water (EWA)	A short rise in flows at the end of November to promote the dispersal of larval/juvenile Murray cod, River blackfish and Freshwater catfish which leave their nest site within days-weeks post-hatching. It may also provide an additional productivity boost and hence replenish food sources for larvae as they begin to feed on their own	Designed 11 day fresh peaking at 1,200 ML/day with a slow recession at Cotton's Weir, Forbes
2	Main channel Lower Lachlan River (Booligal)	Fresh flow	1,665 ML re-regulated CEW 805 NSW AEW (Lake Brewster Adaptive Environmental Water Licence)	To provide hydrological variability in the Lower Lachlan during periods of low flow.[2]	Designed for 150 ML/day at Booligal for a minimum of 10 days

[1] The flow at Hillston re-used the water from the Cotton's Weir baseflow

[2] The water used for the autumn pulse was the residual water from the re-regulation of water from Watering Action 1a into Lake Brewster.

5.2 METHODS

As occurred in 2016-17, one of the target reaches for the first watering action is upstream of the Selected Area in which monitoring activities are undertaken. This means that it is outside the scope of the contracted monitoring and evaluation activities to address this watering action. However, the whole of river approach to the delivery of flows in 2017-18 means that the hydrological outcomes of this watering action are evaluated in this section.

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 8) and from the mid Lachlan (Figure 9). The selected gauging sites were those relevant to the locations at which monitoring activities were occurring as well as sites that could be used to evaluate the hydrological outcomes of Commonwealth environmental water.

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

River levels were obtained from the gauges and the water levels in the absence of Commonwealth and NSW environmental water were estimated from the rating curves at each site.

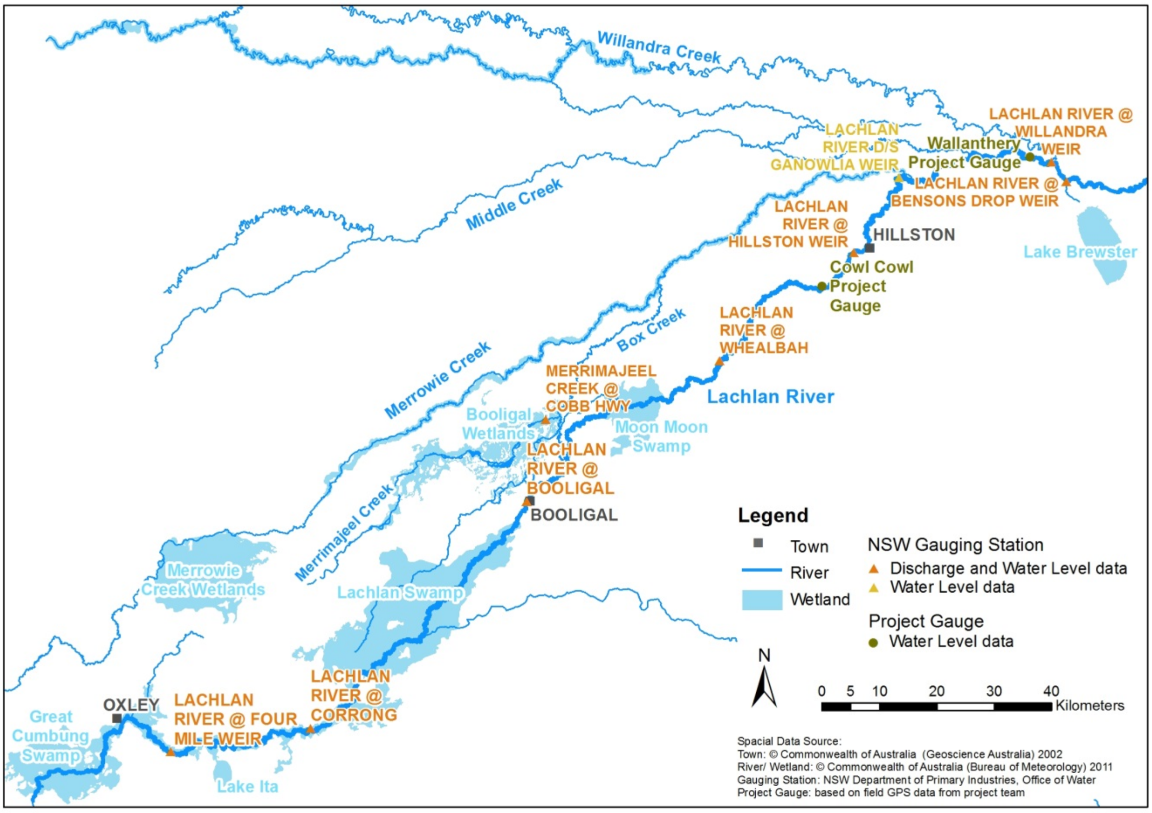


Figure 8. The location of relevant gauging stations in the Lower Lachlan river system.

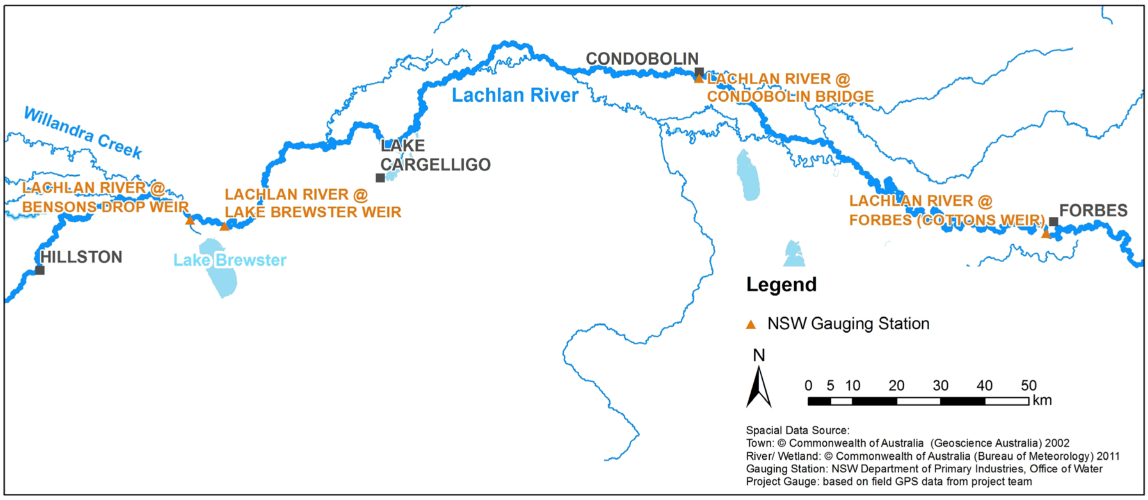


Figure 9. The location of relevant gauging stations in the mid Lachlan river system.

5.3 RESULTS

The total environmental water delivery to the Lower Lachlan river system in 2017-2018 was 40 189 ML and was made up of 33 523 ML of Commonwealth environmental water and 9,205 ML of NSW Environmental Water (8,400 from Wyangala and 805 from Lake Brewster). In 2017-18 Commonwealth environmental water contributed approximately 7% of the flow in the river at Forbes and the combined contribution of Commonwealth and NSW Water was approximately 9%. At Hillston, Commonwealth environmental water contributed more than 19% of the flow in the river and in combination Commonwealth and NSW Water contributed more than 24%. Estimates from NSW Water were that the combined contribution of environmental water at Booligal was approximately 58% of the flow in the river (Table 4).

Table 4. The 2017-18 accounted environmental water in the Lower Lachlan river system.

	TOTAL ANNUAL FLOW (ML)	COMMONWEALTH ENVIRONMENTAL WATER (ML)	EWA (ML)	ESIMATED TOTAL ENVIRONMENTAL WATER
Forbes (Cotton's Weir)	448 073	33 523	8,400	41 923
Hillston Weir[2]	153 009	At least 29 327	At least 8,029	At least 37 356[1]
Booligal	53 133	1,899 plus contributions from Watering Action 1	805 plus contributions from Watering Action 1	30 811[2]

[1] Note that the figure at Hillston is an underestimate. Watering Action 2 will have contributed more to the flow at Hillston.
[2] Figure supplied by NSW Water and takes into account all watering actions.

While the volume of Commonwealth environmental water was a small proportion of the annual flow in the river at Forbes, it was strategically delivered to modify the flow regime and at the time of delivery, comprised a significant proportion of the flow in the river. The details of this are described for each of the watering actions in the following sections.

5.3.1 WATERING ACTION 1: SUPPORTING NATIVE FISH OUTCOMES

The first watering action was delivered to provide flow components that support native fish outcomes. This included:

1. maintaining base flows in the river to maximise the number of potential nesting sites, and
2. a small fresh at the end of the nesting season to aid dispersal of larvae and provide a productivity pulse.

The base-flow targets were set for Forbes (Cotton's Weir) and Hillston (Hillston Weir) with the expectation that the environmental water used at Forbes would also be used to maintain water levels at Hillston.

Watering action 1 commenced on the 2nd October at Forbes and the 27th September at Hillston. Flow was maintained above the target of 1,400 ML/day at Forbes until the 7th November when it dropped below this target for 9 days reaching a low of 1,290 ML/day on the 9th November (Figure 10). The delivery of environmental water maintained the river above 0.7 m when it would otherwise have dropped 0.2 – 0.25 m (Figure 10).

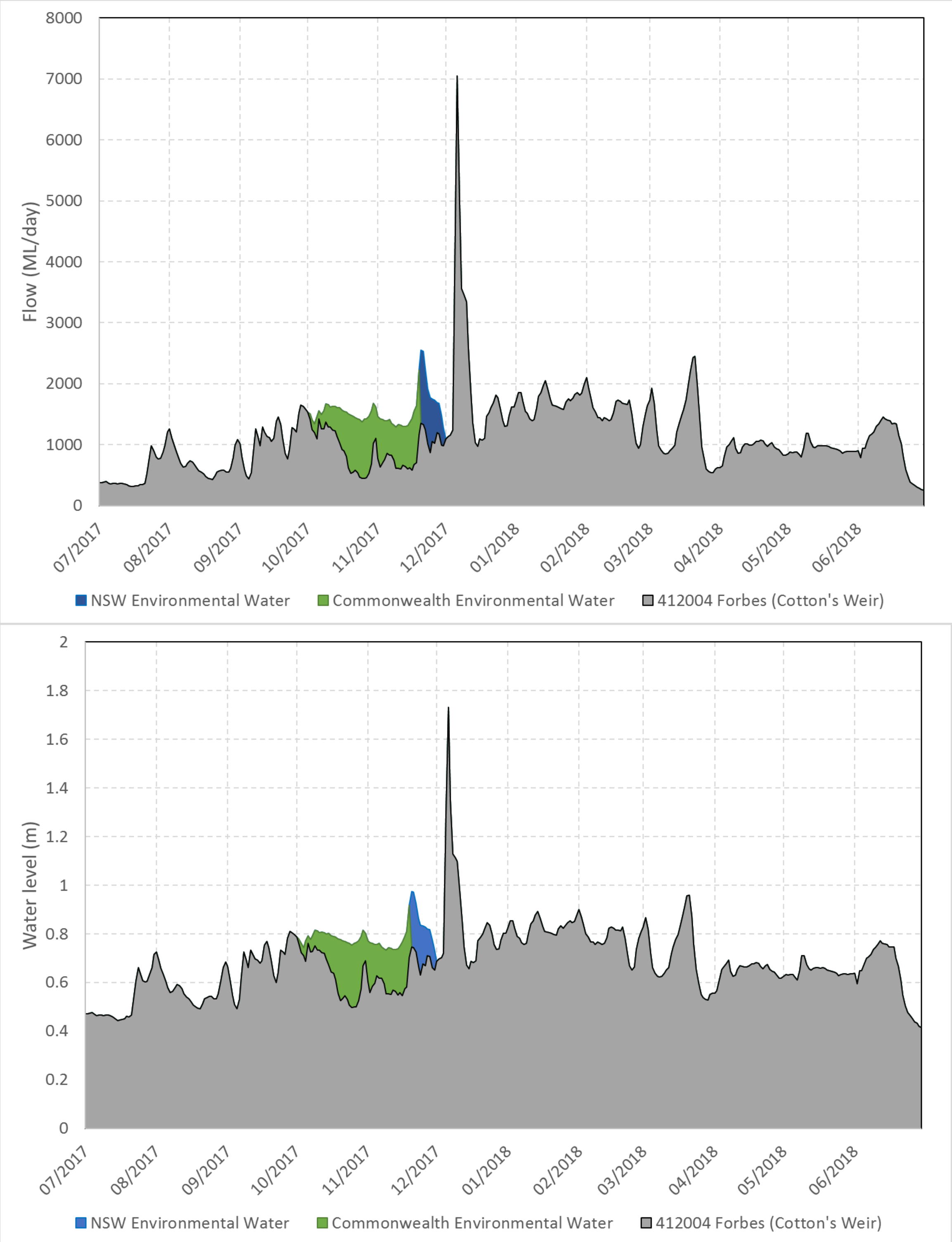
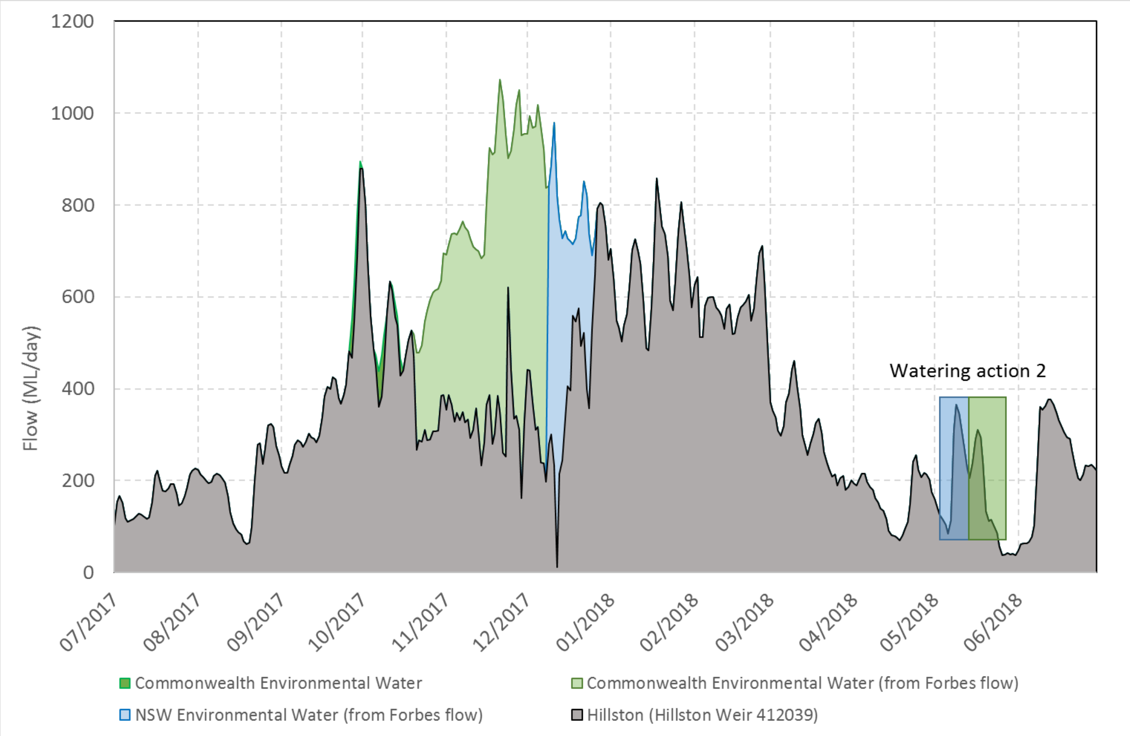


Figure 10. Flow (top) and water levels (bottom) at Cotton's Weir (Forbes) for the period 1 July 2017 to 30 June 2018 showing Watering Action 1.
Commonwealth (green) and NSW (blue) environmental water are shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey. Refer to Figure 9 for gauge locations.



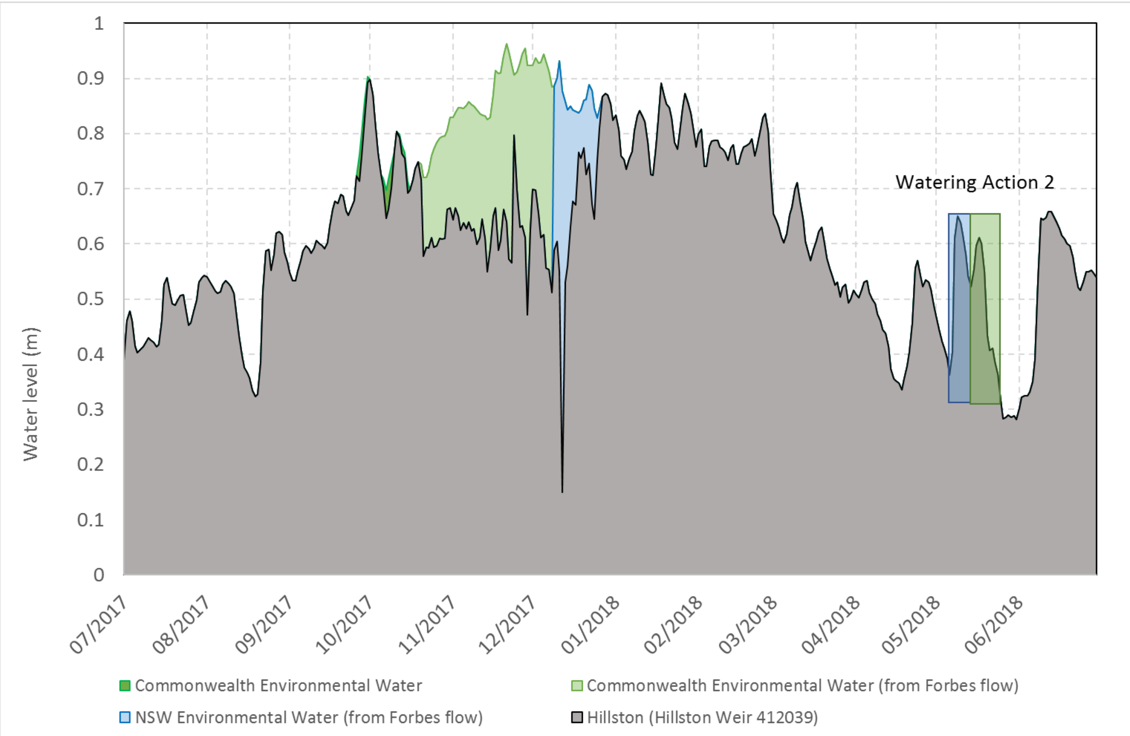


Figure 11. Flow (top) and water levels (bottom) at Hillston Weir for the period 1 July 2017 to 30 June 2018 showing Watering Action 1 and the approximate timing of Watering Action 2. Commonwealth (dark green), as well as re-regulated Commonwealth (light green) and NSW (blue) environmental water are shown along with estimates of river flow (flow including the licensed delivery of water but not including environmental water) in grey. Refer to Figure 9 for gauging locations and to text for the explanation of the watering actions.

Flow was maintained above 600 ML/day at Hillston between the 26th October until the 3rd January 2018 when normal deliveries generated flows between 490 and 850 ML/day (Figure 11). This maintained the river above 0.7 m when it would otherwise have dropped 0.2 – 0.25 m (Figure 11)

A small fresh was provided at Cotton's Weir (Forbes) between the 14th November and the 1st December, using predominantly NSW environmental water, to increase the flows from 1,300 ML/day to 2,300 ML/day. This increased the water level in the river by approximately 0.25 m (Figure 10). A corresponding pulse was not achieved at Hillston (Figure 11), however the presence of this water in the system as it passed Hillston avoided a significant drop in the river that would have otherwise occurred as a result of a short-term reduction in demand.

Commonwealth environmental water contributed slightly more than 40% (between 6 and 68%) of the flow in the river at Cotton's Weir (Forbes) between the 2nd October and the 19th November and NSW environmental water contributed about 40% (between 23 and 50%) of the flow between the 20th and 30th November. Commonwealth environmental water contributed almost 60% (ranging between 9 and 83%) of the flow in the river at Hillston weir between the 20th October and the 8th December.

Watering action 1 progressed through the river system providing a substantial rise in the river at Booligal in November and December (Figure 12) and arriving at Corrong at the edge of the Great Cumbung Swamp during December and January (Figure 13). This watering action made a significant contribution to flow in the lower reaches of the river between November and January.

5.3.2 WATERING ACTION 2: BOOLIGAL FRESH

Releases for the Booligal Fresh started on the 4th May from the Lake Brewster system, and concluded at Lake Brewster on the 15th May 2018. These flows reached Booligal on the 17th May increasing flows above the target of 150 ML/day between the 19th and the 28th May when the operational base flows at Booligal would have been less than 30 ML/day. The Booligal fresh resulted in a small (<0.1 m) rise in the river. (Figure 12). Commonwealth environmental water contributed just under 80% (between 47% and 93%) of the flow in the river during the 17 day pulse.

Some of the water from this action reached the Great Cumbung Swamp in June, contributing water to Spell Paddock, Nooran Lake, Clear Lake and the open water bodies near the river channel in the reed beds, including the open water area near Lake Marool.

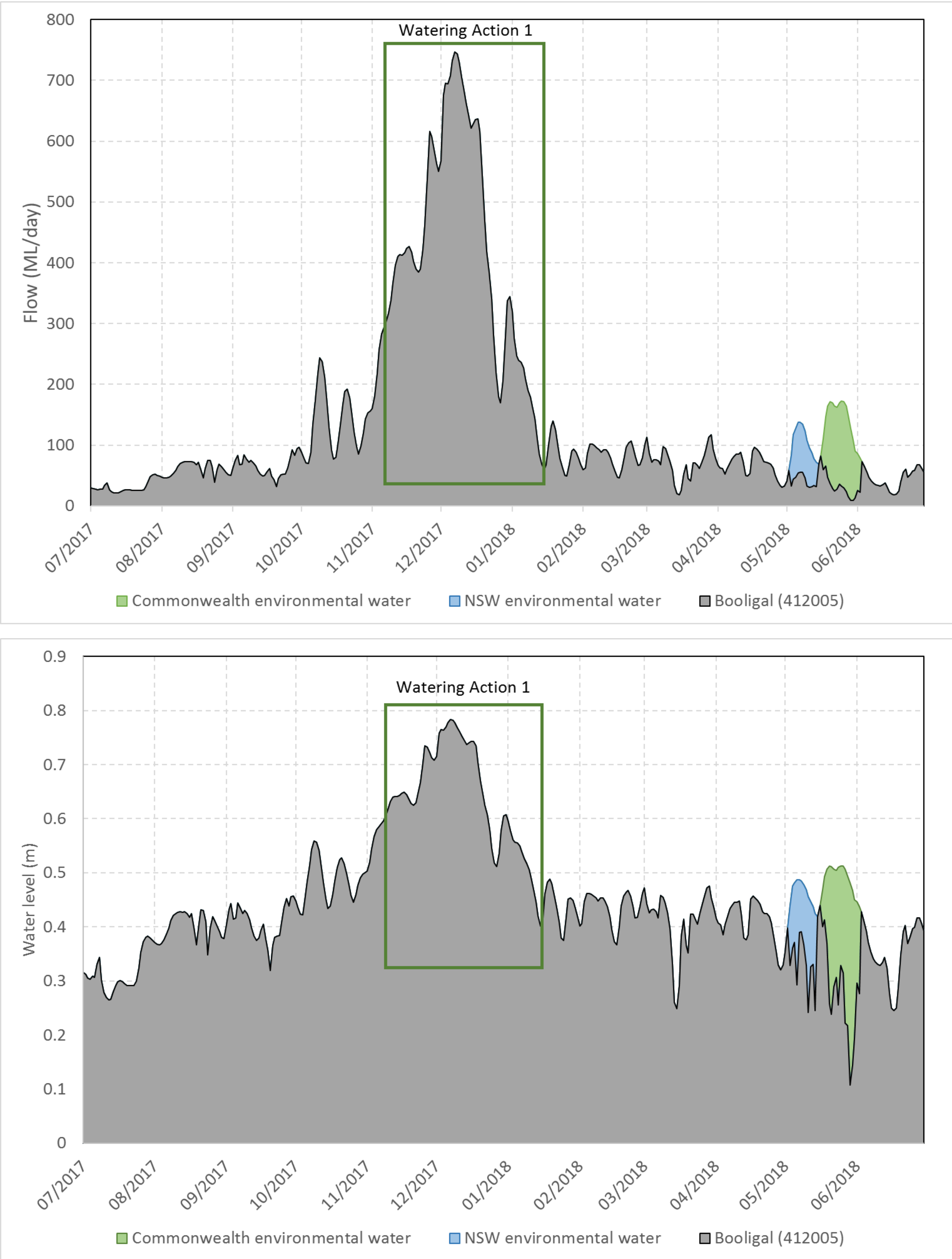
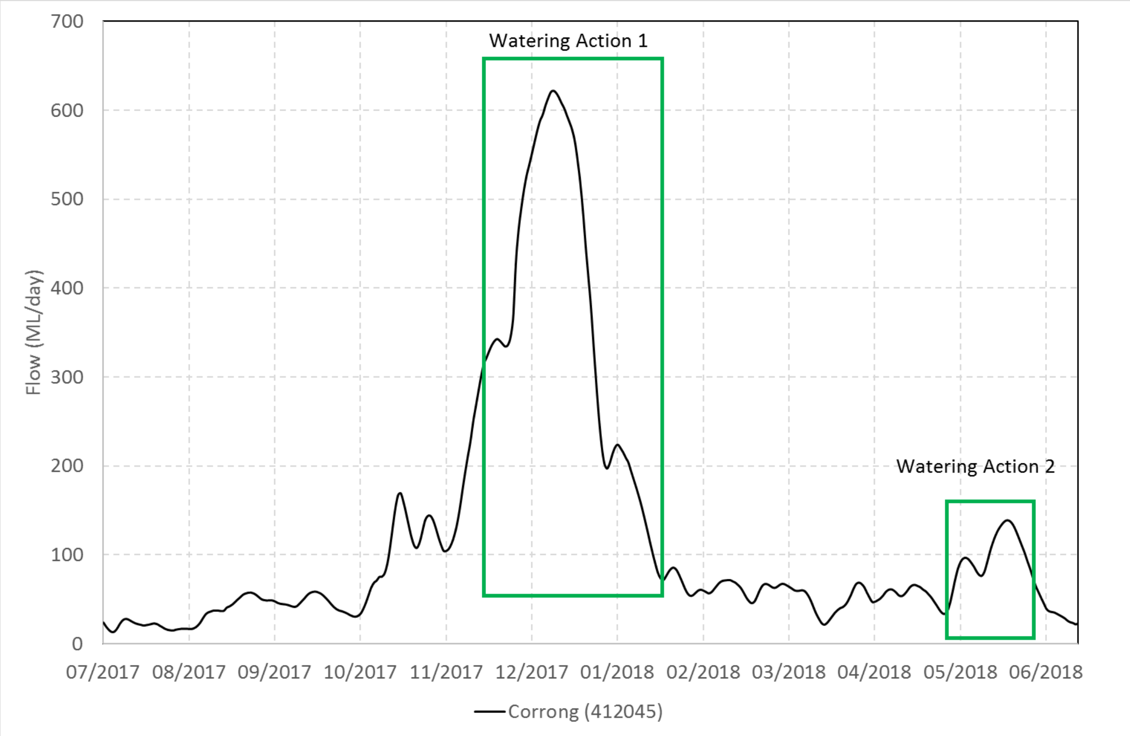


Figure 12. Flow (top) and water levels (bottom) at Booligal for the period 1 July 2017 to 30 June 2018 showing Watering Action 2 and the approximate timing of Watering Action 1. Commonwealth (green) environmental water is shown along with estimates of NSW (blue) environmental water and river flow (flow including the licensed delivery of water but not including environmental water) in grey. Refer to Figure 8 for gauging locations and to text for the explanation of the watering actions.



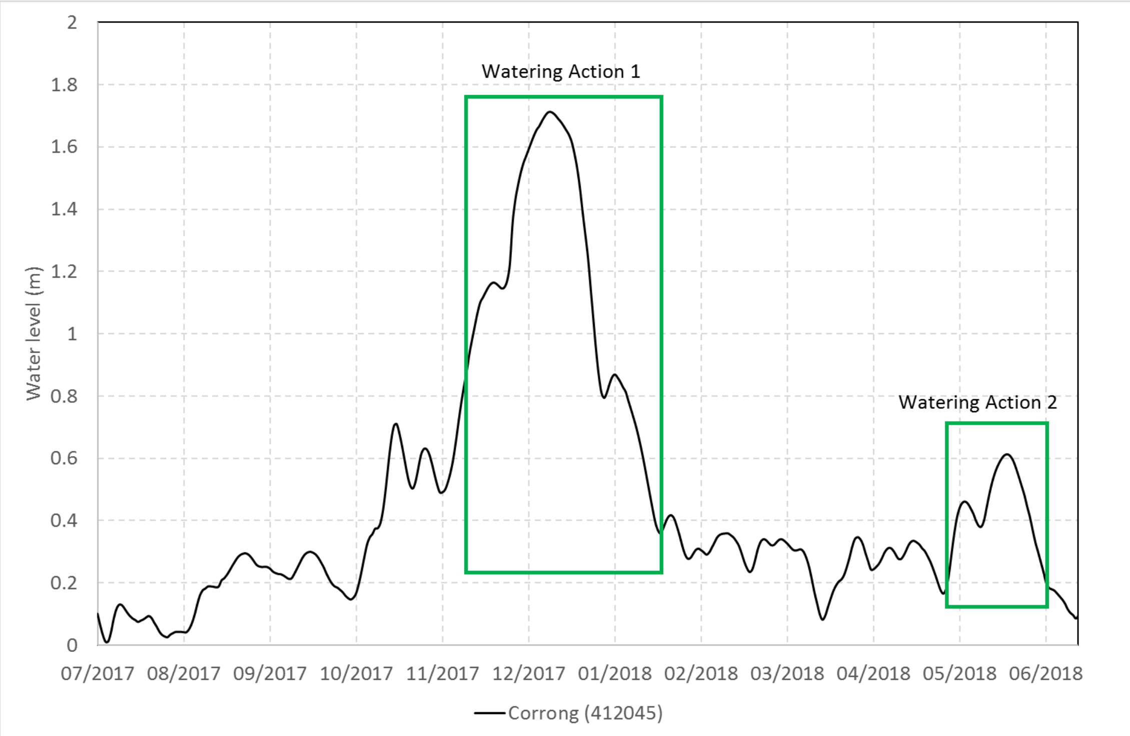


Figure 13. Flow (top) and water levels (bottom) at Corrong for the period 1 July 2017 to 30 June 2018 showing the approximate timing of Watering Actions 1 and 2 (both Commonwealth and NSW components).
Refer to Figure 8 for gauging locations and to text for the explanation of the watering actions.

5.4 EVALUATION

The floods that occurred in 2016-17 completely dominated the Lower Lachlan river system during the 2016-17 watering season. Widespread flooding resulted in the inundation of most of the wetlands across the catchment, many of which were filled well into 2017-18. The two environmental watering actions delivered in 2017-18 were modest and provided water to support native fish outcomes in the river system.

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

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

The first watering action maintained water levels in the river at Forbes between October and early December at around 0.8 m, preventing the river from dropping approximately 0.2 – 0.3 m (to below 0.6 m) during peak fish breeding season. While the river at the accounting point is trapezoidal in shape, there is some variability in channel shape in the mid Lachlan and the maintenance of water level will have prevented the exposure of small sections of banks during this time. During September, normal operational flows in the river resulted in water levels that fluctuated between 0.6 and 0.8 m in height.

The small fresh resulted in a short rise (of 0.25 m) in river level at the end of November, providing inundation of river banks that had been dry since the end of March 2017. This small fresh aimed to facilitate the dispersal of larval fish in the river system. It also provided an opportunity for a boost in productivity in the river channel.

As Watering Action 1 passed downstream, the contribution to habitat became more considerable. By the time the watering action reached Corrong on the edge of the Great Cumbung Swamp, it resulted in a marked rise in the river, likely inundating significant habitat. This water then passed into the Great Cumbung Swamp and fixed point cameras at Clear Lake (Figure 14) show the use of the aquatic habitat by waterbirds and Sentinel imagery shows the extent of inundation (Figure 15).

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

The two watering actions provided in 2017-18 strategically provided a small fresh in the mid reaches (Forbes) of the river at the end of November and a small fresh in the lower reaches (Booligal). At Forbes, the small fresh provided one of few (4) pulses to exceed 2,000 ML/day and one of 3 pulses that exceeded a river height of 0.9 m during the 2017-18 watering year. At Booligal the late fresh provided a very small increase in water level, extending flows in the system by almost 20 days.

Figure 14. Fixed point camera image from Clear Lake in December 2017 and January 2018 showing the filling of the lake and use by Pelicans.

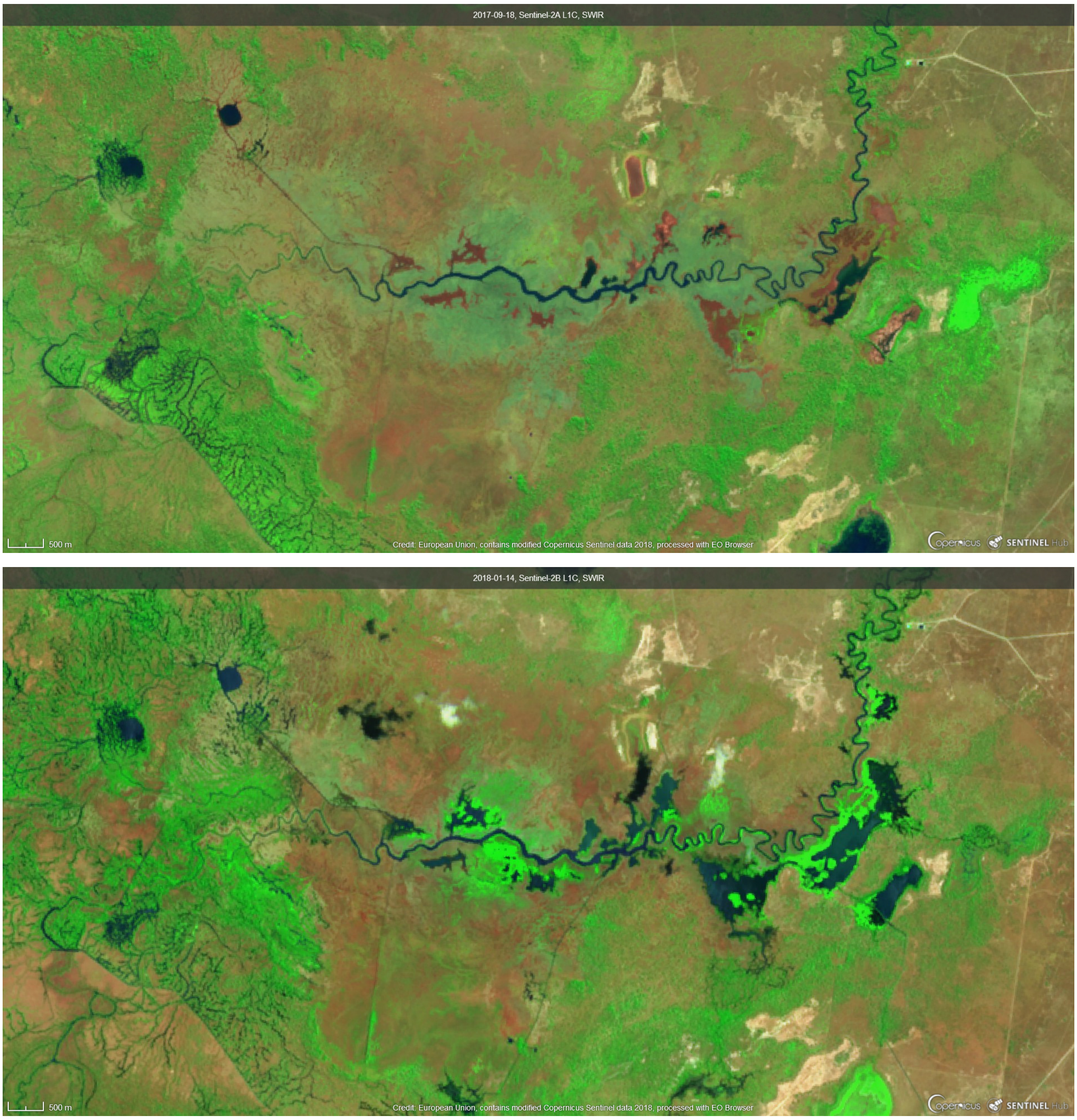


Figure 15. Sentinel imagery from the Great Cumbung Swamp prior to the arrival of environmental water (18 September 2017, upper image), and at the peak of the watering (14 January 2018, lower image).
Images sourced from https://www.sentinel-hub.com/explore/sentinel-playground

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

The two watering actions delivered in 2017-18 connected in-channel habitats and provided flow to the end of the river system. Commonwealth environmental water achieved short periods of connectivity in channel, raising river levels at the weir pools in the river by 0.25 m. As the water progressed downstream, the in-channel connections generated became more substantial and at Corrong, the river level was raised by almost 1 m.

The longitudinal connections provided by Commonwealth environmental water were significant with the environmental flows providing water to the Cumbung Swamp for several months over summer. This generated opportunities for water birds to access habitat and provided water to the aquatic vegetation.

5.4.1 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.

- It would be valuable to have access to habitat mapping in the river to better inform the water level required to maintain nesting habitats. Given the changes in water level, it is possible that holding the river at 0.6 m may have been sufficient to maintain the inundation of key habitats.
- The style of environmental water management employed in the Lachlan catchment in in 2016-17 and again in 2017-18 is responsive and benefits from using a single parcel of water to achieve multiple benefits throughout the river system. While such an approach is an efficient and effective use of water it presents substantial challenges for evaluating the watering actions. Documentation of the watering actions improved in 2017-18 from 2016-17, but some difficulties, particularly with the accounting of water, remained. Watering actions that are targeted in one reach and then ‘reused’ in other parts of the river presents accounting challenges that are not well managed throughout the watering year. The water available for Watering Action 2 was a surprise to the water managers and a more regular review of the water account would ensure that such events are not surprises.
- In addition, obtaining water accounting data for 2017-18 and getting agreement on volumes between agencies has been inordinately difficult. It is recommended that better mechanisms for reviewing and agreeing on accounting data would facilitate more timely evaluation and learning from watering actions. It is suggested that quarterly accounts be prepared rather than annual accounts to assist with this.

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 increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream (Boulton and Lake 1992, MDFRC 2013, Stewardson et al. 2013).

In this section we evaluate the outcomes of providing Commonwealth environmental water to the Lower Lachlan river system in terms of measured changes in GPP, ER and water nutrients. The 2017-18 watering actions involving Commonwealth environmental water in the Lower Lachlan river system are described in sections 1-3 above.

The first watering action targeted native fish breeding and delivered 40 923 ML to the Lachlan River. This action targeted the mid Lachlan and was not explicitly delivered to produce significant water quality or metabolism benefits in the Lower Lachlan river system.

The second watering action delivered 1,460 ML to the Lower Lachlan River and had three main objectives (Table 2, page 20). These included improvements in water quality and creation of food resources (increased metabolism).

The evaluation in this section is focussed on the evaluation questions defined in the Long Term Intervention Monitoring and Evaluation Plan for the Lachlan river system (Dyer et al. 2014).

6.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

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

6.2 METHODS

The evaluation of the stream metabolism and water quality outcomes used a combination of river height data (as described in section 5, Hydrology), water quality data and stream metabolism data (dissolved oxygen measurements modelled to calculate GPP and ER, and reaeration K).

Data are collected from four sites (Wallanthery, Whealbah, Cowl Cowl and Lanes Bridge (Figure 16). Water quality parameters (dissolved oxygen, temperature, pH, turbidity, conductivity, concentrations of nitrogen and phosphorus) were recorded using a combination of automatic loggers and manual point measures. Dissolved oxygen and temperature were measured using the stream metabolism loggers. Conductivity, pH and turbidity were recorded using a handheld water quality meter. For nitrogen and phosphorus, duplicate water samples were taken 2 meters from the water's edge at 1 meter depth. These were placed on ice and returned to University of Canberra for analysis for total nitrogen, nitrate/ nitrite, total phosphorus, dissolved reactive phosphorus and ammonia.

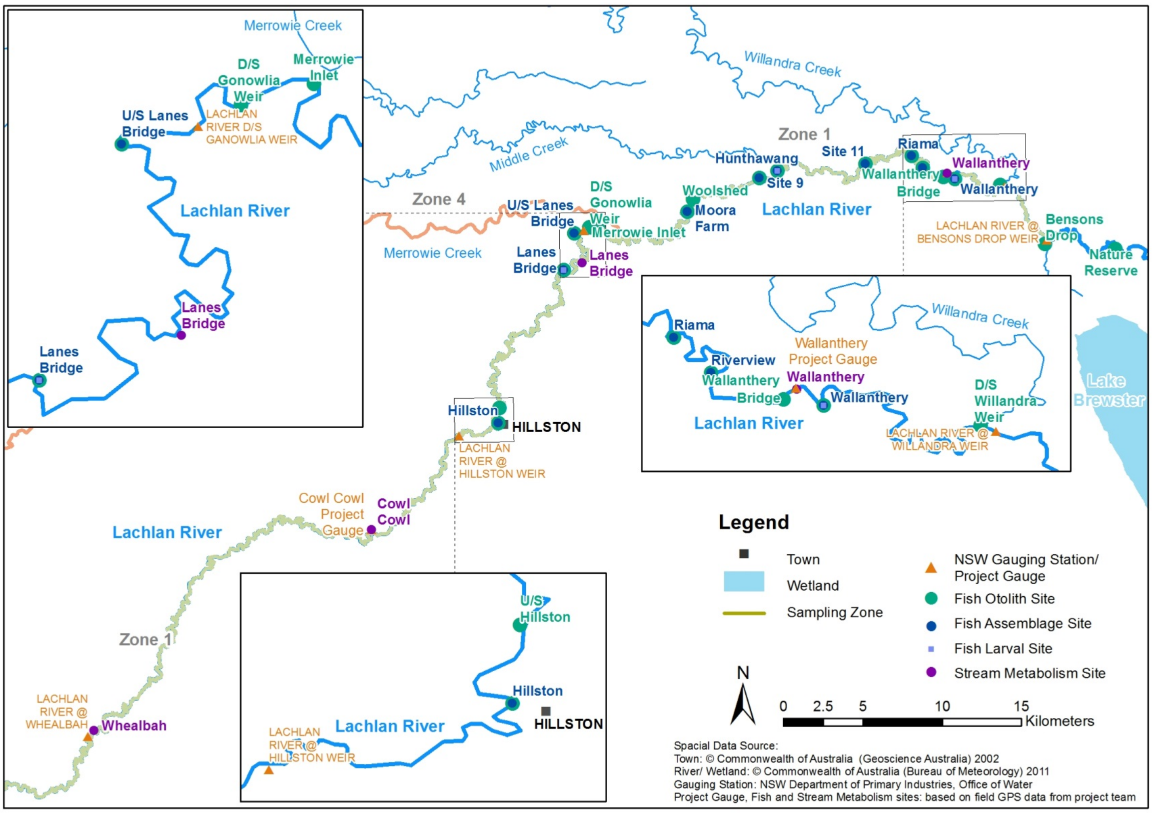


Figure 16. Map of monitoring sites for fish, larval fish and stream metabolism in Zone 1.

Stream metabolism was measured applying the standard methods for the LTIM project. An oxygen logger was installed at each site in the middle of the water column. 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). Before and after placement, the loggers were put in an O_2 saturated solution and then together in the stream for 1 hr to account for probe drift, and if required, linear corrections were applied prior to metabolism calculations. 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. The version of the model used incorporated a series of updates which have been applied across the LTIM project, and was current from the 18th of June 2018 (V2.3.3).

After this process the acceptance criteria had been applied and estimates derived from curve fits with $R^2 < 0.90$ and/or CV for GPP of > 50% were discarded.

6.3 RESULTS

6.3.1 COMPARISON OF LOGGER TYPES

To validate the use of both the D-Opto and miniDOT loggers, at two sites (Lanes Bridge and Whealbah) both logger types were used and the results compared (Table 5). After a comparison of the percentiles for both logger types, for which a GPP/ER estimate could be modelled under the standard acceptance criteria for June and July 2017 (Table 5) we decided to use the miniDOT to graph and discuss GPP, ER and K values exclusively for the four study sites. The exceptions to this were when the miniDOT loggers failed due to membrane defects at Cowl Cowl (before 01/08/2017 (dissolved oxygen saturation between 111 and 144; D-Opto data used for the period 06/06-31/07/2017) and Wallanthery (data not able to be used until 15/03/2018).

Table 5. Stream metabolism data obtained from the four sites on the Lower Lachlan river system from June to July 2017 (06/06 - 31/07/2017, logged data days each 56 days) for comparison of the two logger type outputs.
Shown are the data days (Y) and percentile (%) for which a GPP/ER/K estimate could be modelled under the standard acceptance criteria.

LOGGER TYPE >	D-OPTO		MINIDOT	
SITE	Y	%	Y	%
LANES BRIDGE (LB)	44	79	48	86
COWL COWL (CC)	49	88	-	-
WHEALBAH (WB)	27	48	40	71
WALLANTHERY (WAL)	4	7	-	-

6.3.2 WATER QUALITY

Water temperature showed a typical seasonal pattern, ranging from 9 degrees Celsius in winter, to 30 degrees Celsius in summer, with no clear association with flow events (Figure 17). Water temperatures were lower following the first environmental watering event. There was no clear association between pH and flow, but some evidence of reductions in turbidity and weaker evidence of lower salinity following the first watering event (Figure 17). This is potentially indicative of initial dilution of ions and fine sediment associated with the flow event. There was no clear evidence of any effects of the second environmental watering event on water quality.

Results for nutrients (Figure 18) were consistent with those for the water quality parameters above. There is a limited amount of data available for both of the watering events, and no clear evidence for effects on water quality, including chlorophyll. There is some indication of release of phosphorus after the first event, but this is not conclusive.

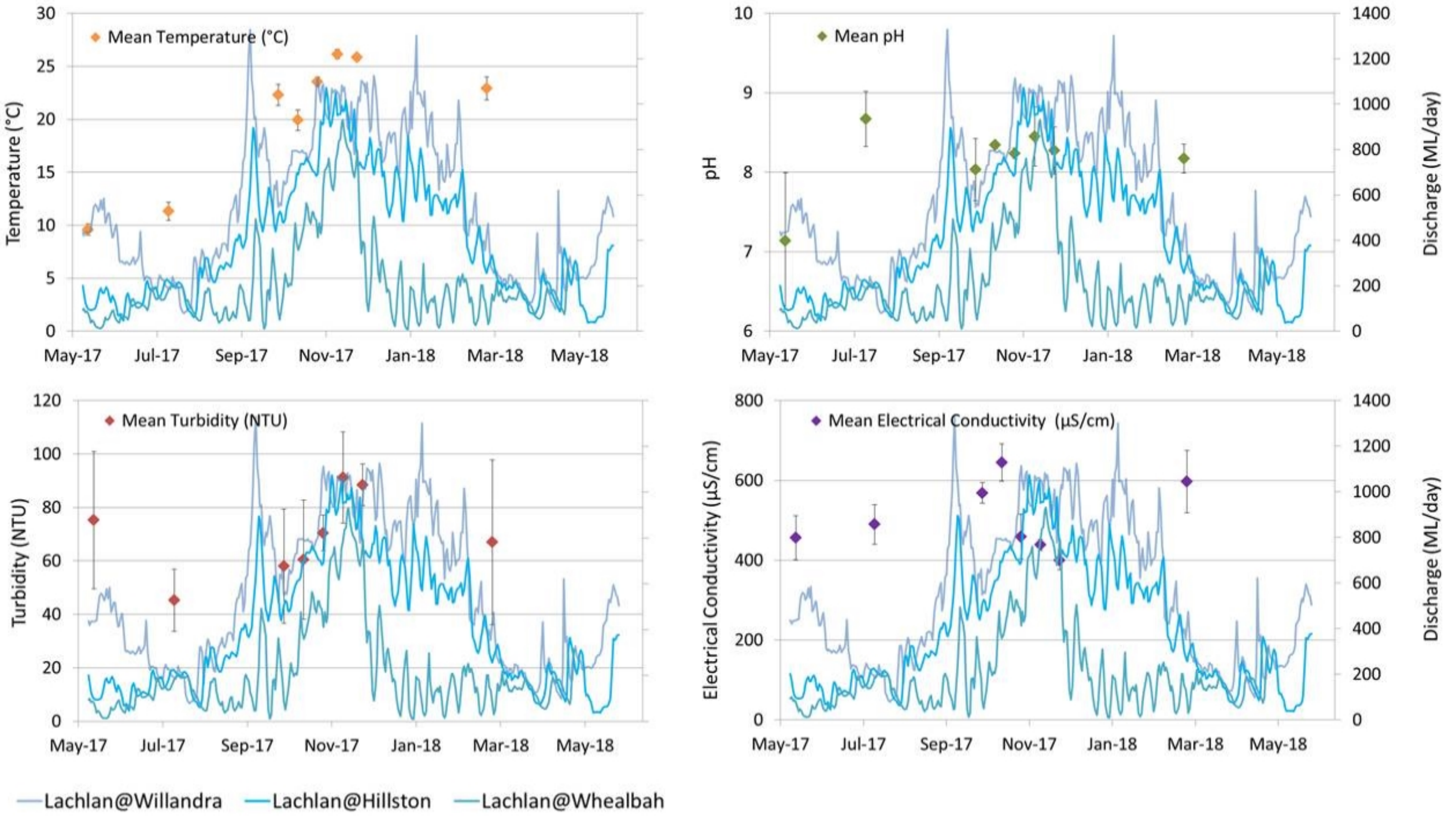


Figure 17. Mean water quality measurements (± standard error) for four sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2017-18: physico chemical attributes.

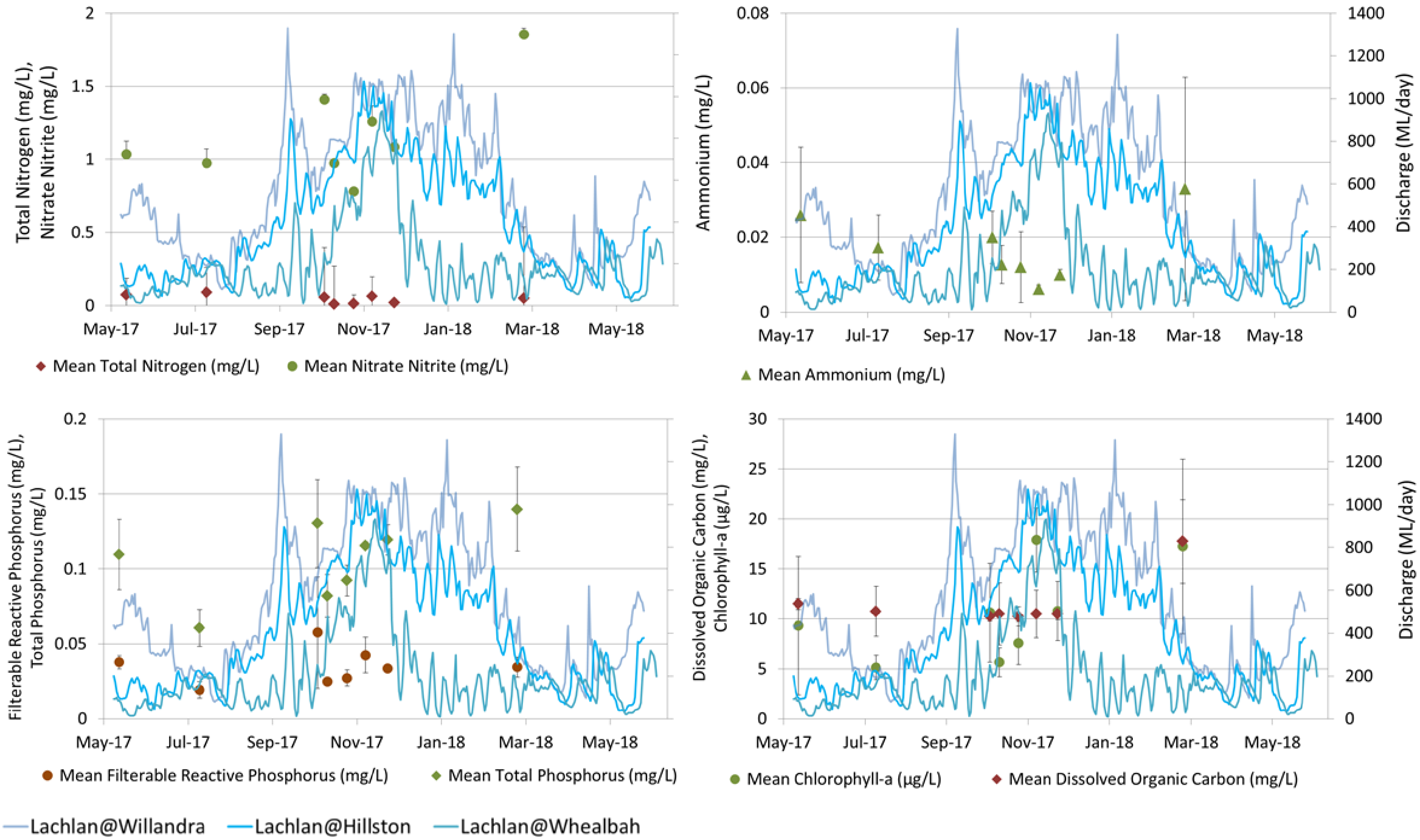


Figure 18. Mean water quality measurements (± standard error) for the four sites (Cowl Cowl, Lane's Bridge, Wallanthery and Whealbah) over the sampling period 2017-18: nutrients and chlorophyll a.

Additional water quality data became available from Water NSW for the Lachlan system for a suite of NSW gauging stations (Figure 19) and is reported on below. These included data on temperature, pH, dissolved oxygen and electrical conductivity (Figure 20). As for the dataset above, there were no clear patterns in water quality that could be related to environmental watering events, although there were clear seasonal patterns.

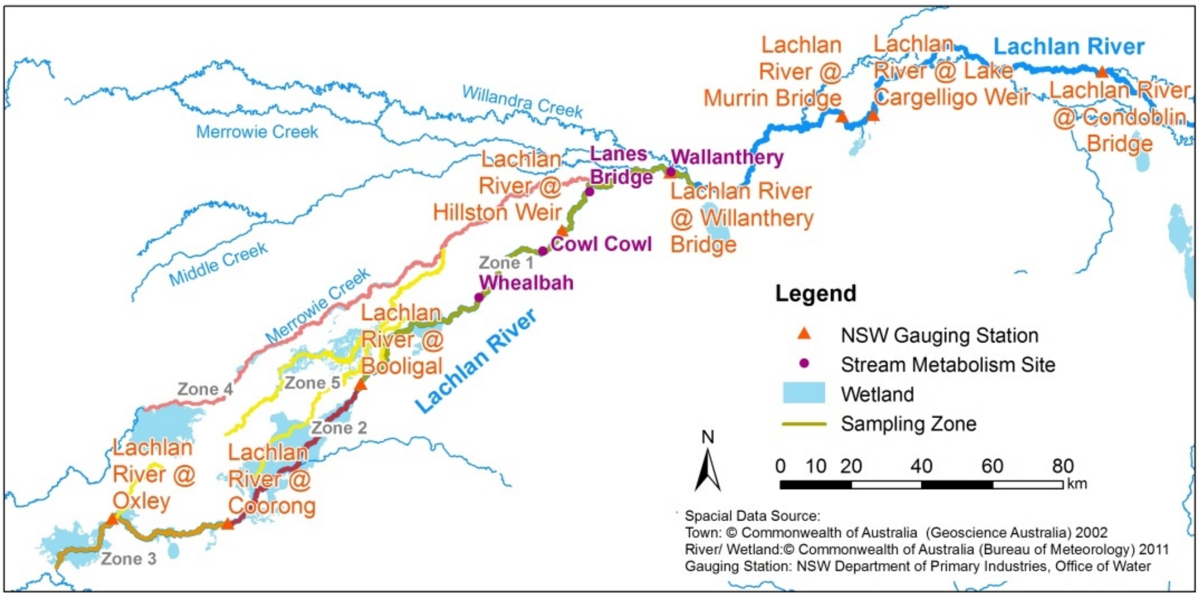


Figure 19. Location of 8 additional water quality measurements from Water NSW at the Lower Lachlan River.

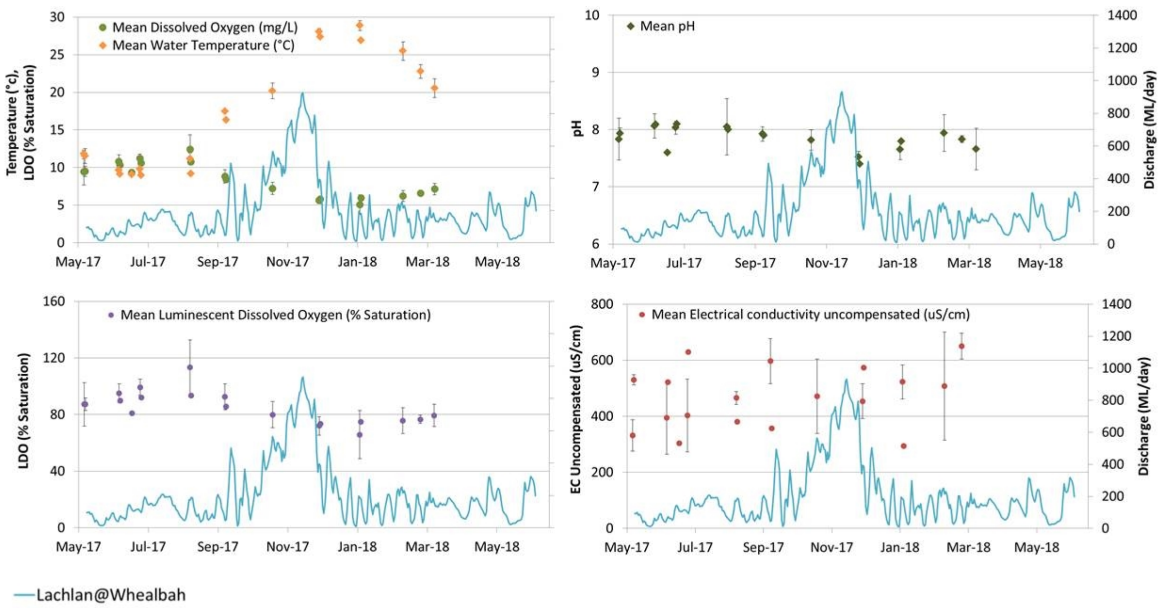


Figure 20. Mean water quality measurements (± standard error) from 8 additional Water NSW stations.

6.3.3 STREAM METABOLISM

Stream metabolism data was able to be used from an average of 72% of days (range Wallanthery [WAL] = 57% to Lanes Bridge [LB]/Whealbah [WB] = 85%) (Table 6). After applying the standard numerical acceptance criteria, we rejected 7 data days (1 from LB, 6 from WB) by visually checking the plotted GPP, ER and K values (K values at 40).

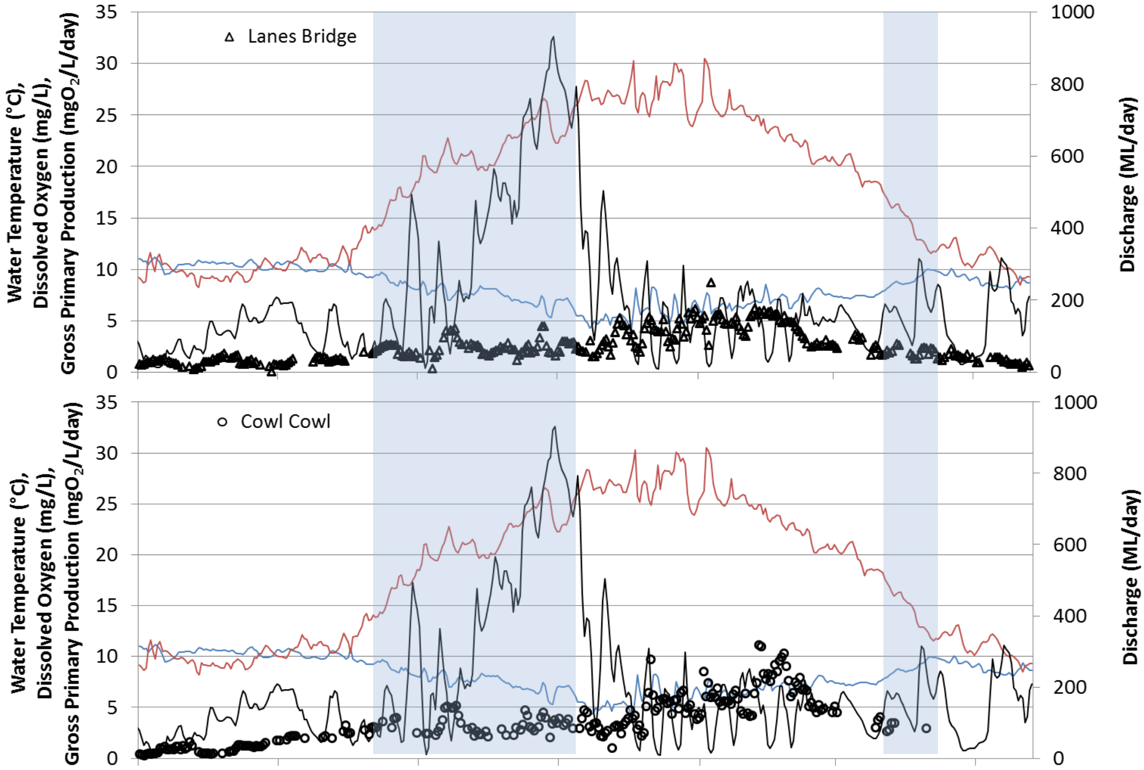
Table 6. Stream metabolism data obtained from the four sites on the Lower Lachlan river system June 2017 to June 2018.
Shown is the number of logged days of oxygen data for each site (data days = Y) and the percentile (%) for which a GPP/ER /K estimate could be modelled under the standard acceptance criteria.

SITE	PERIOD	COUNT DAYS	Y	%
LANES BRIDGE (LB)	06/06/2017-30/06/2018	390	330	85
COWL COWL (CC)	06/06/2017-30/06/2018	390	236	61
WHEALBAH (WB)	06/06/2017-30/06/2018	390	333	85
WALLANTHERY (WAL)	16/3/2018-30/06/2018	107	61	57

Time series plots of temperature, dissolved oxygen, flow, GPP, ER, reaeration (K) and the GGP/ER ratio for the four sites are shown in Figure 21 to Figure 24. There was some evidence of increased GPP and ER around the commencement of environmental watering event 1 for the three sites that had data (Figure 21, Figure 22). Similarly, for Whealbah there is some evidence of increased GPP associated with the second environmental watering event (Figure 21). This second pattern was strongly associated with increased reaeration (Figure 23).

In order to model stream metabolism in some critical periods (e.g. at peak flows) K values > 5 (Figure 23) were accepted in order to allow any estimates to be extracted. It should be noted that high K values lead to potential over-estimates of ER.

When results were represented as GPP/ER ratios (Figure 24), there is also evidence for increases in GPP/ER associated with the environmental watering event in May, but no apparent pattern in the larger environmental watering event in September to December.


Lanes Bridge
Cowl Cowl
Water Temperature (°C), Dissolved Oxygen (mg/L), Gross Primary Production (mgO2/L/day)
Discharge (ML/day)
0
5
10
15
20
25
30
35
0
200
400
600
800
1000

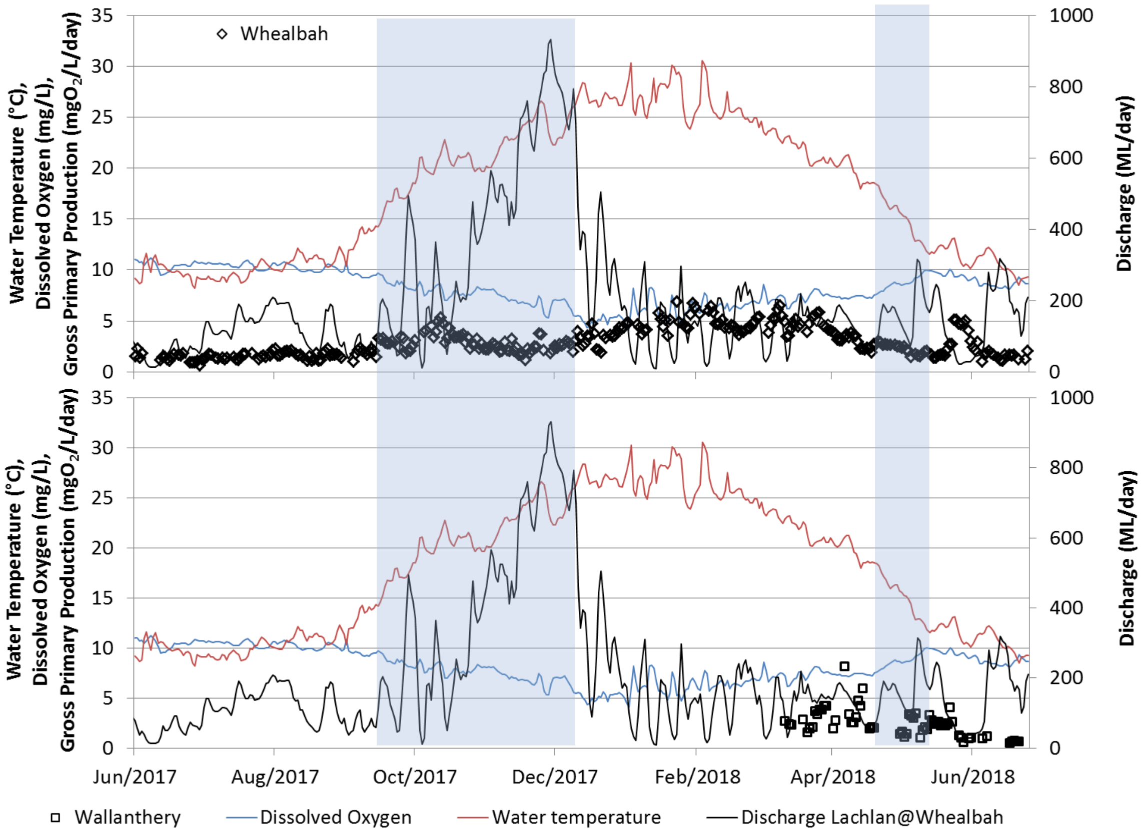
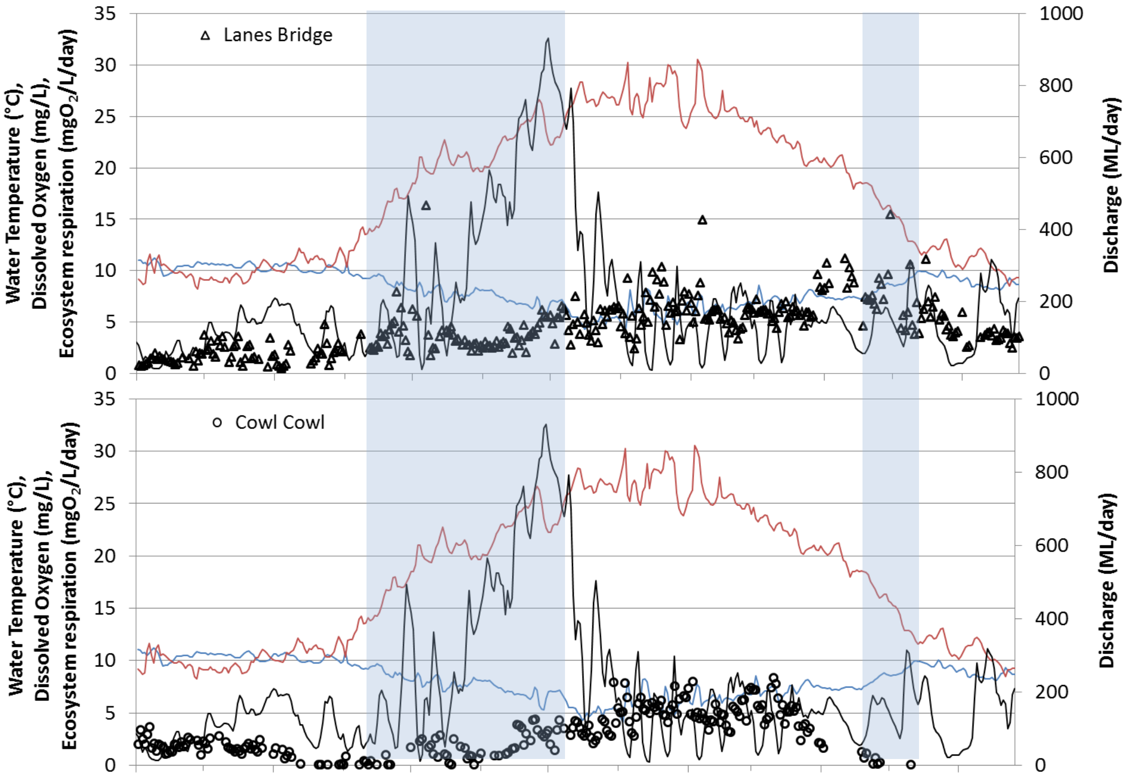


Figure 21. Gross primary production (GPP) from four sites in the Lower Lachlan river system, June 2017-June 2018.
Grey shaded vertical bars indicate watering actions. Symbols for each site are modelled gross primary production values.



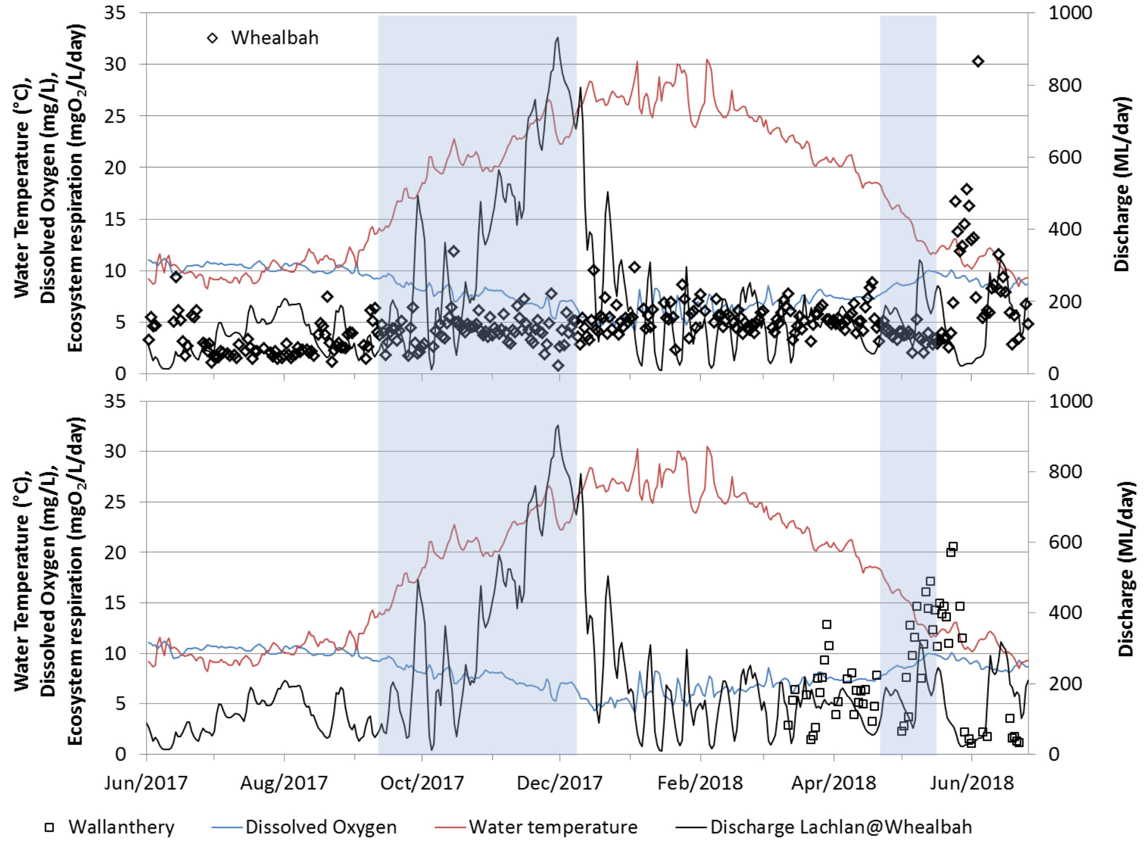
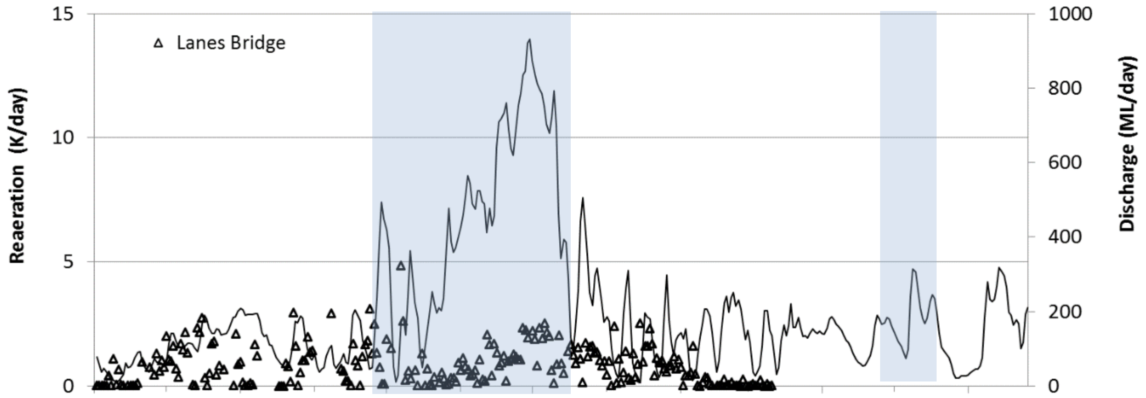


Figure 22. Ecosystem respiration (ER) from four sites in the Lower Lachlan river system, June 2017-June 2018.
Grey shaded vertical bars indicate watering actions. Symbols for each site are modelled ecosystem respiration values.



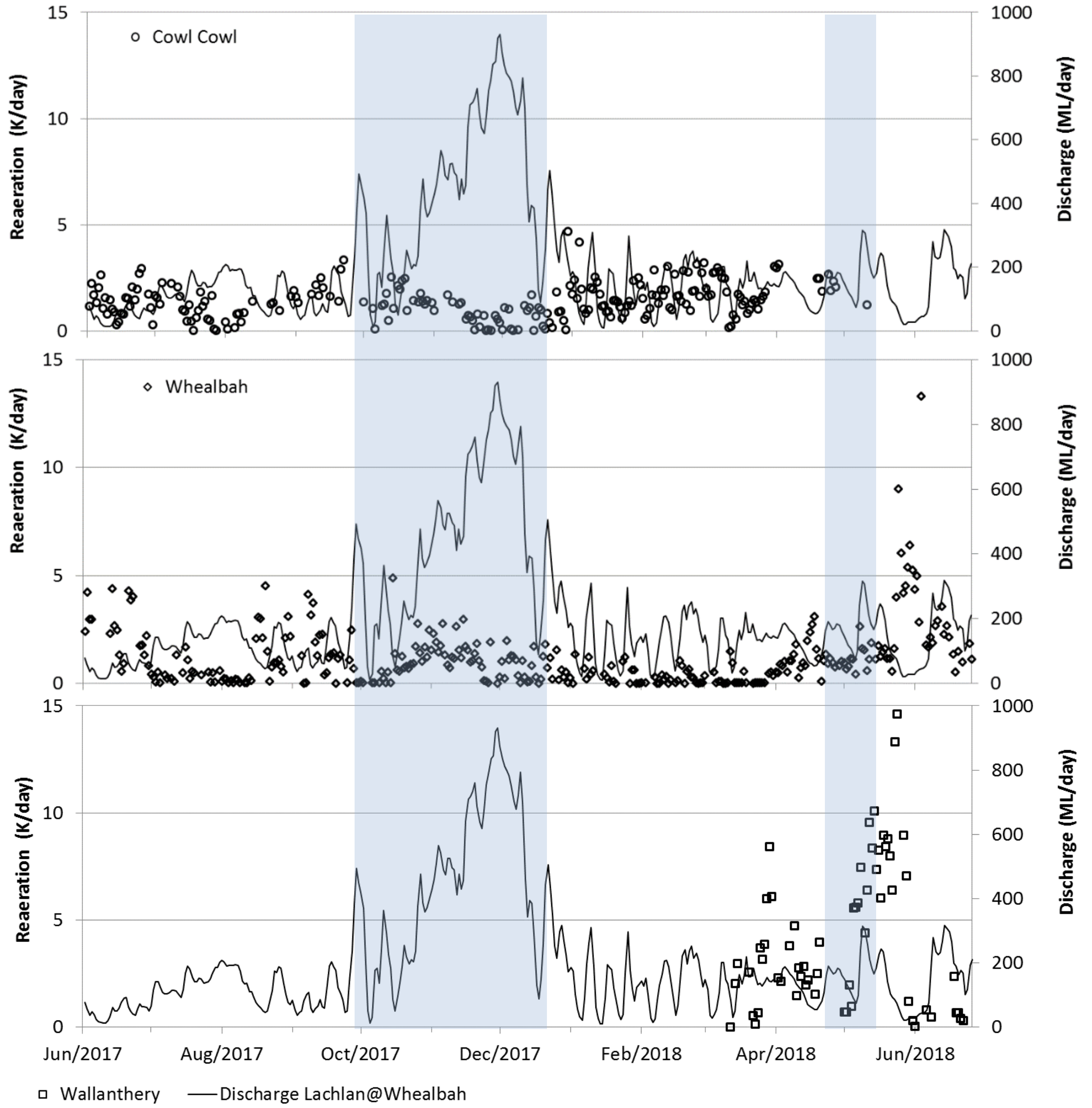


Figure 23. Reaeration (K) from four sites in the Lower Lachlan river system, June 2017-June 2018. Grey shaded vertical bars indicate watering actions. Symbols for each site are modelled reaeration values.

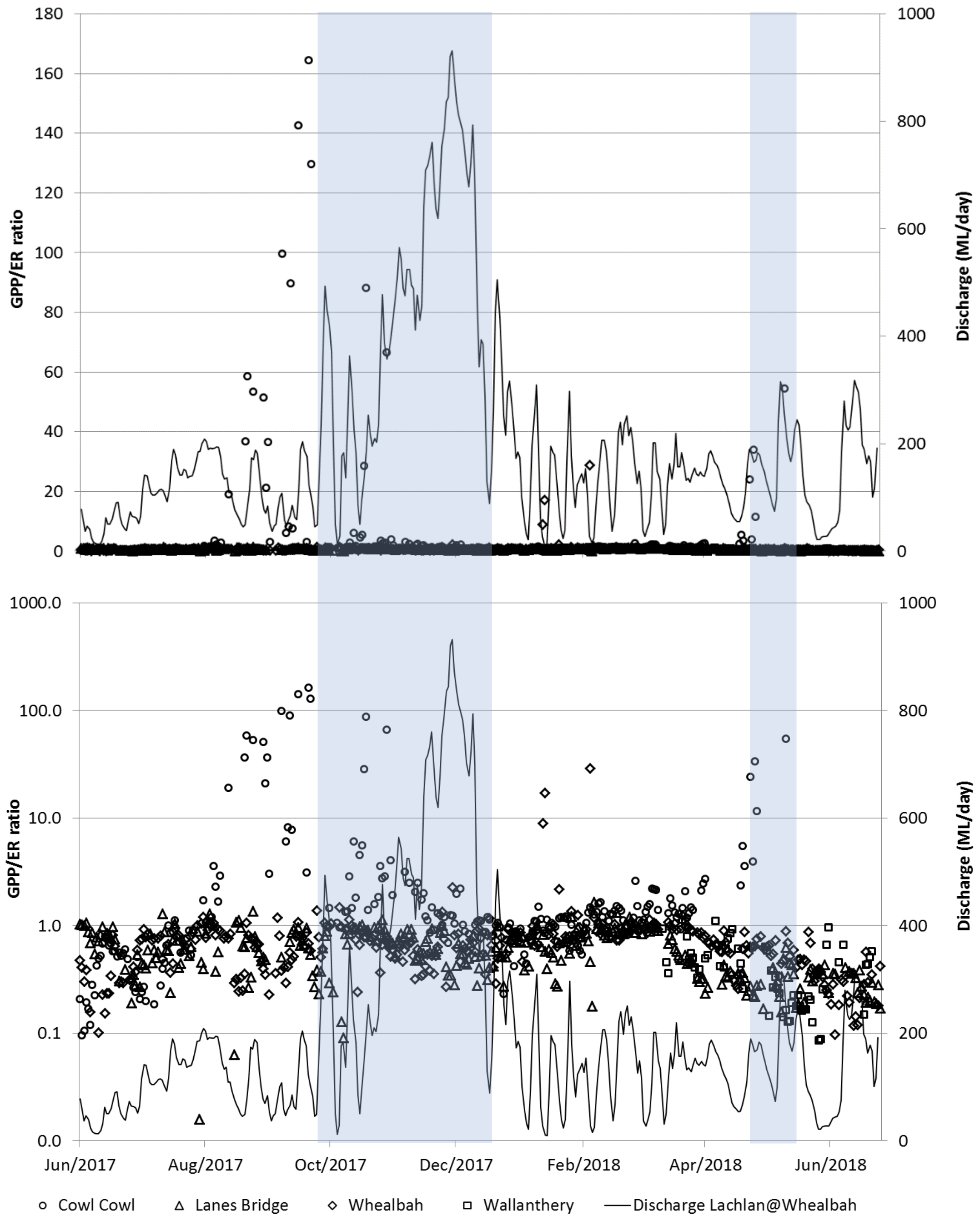


Figure 24. Gross primary production and ecosystem respiration ratio (GGP/ER) from the four sites in the Lower Lachlan river system, during the sampling period 2017-18 (bottom panel on a log scale). Grey shaded vertical bars indicate watering actions.

6.3.4 WATERING ACTION 1

The 2017-18 watering actions targeting native fish outcomes commenced with releases from Wyangala dam on the 23rd of September 2017 and concluded at Wyangala with the commencement of Wyangala Environmental Water Allowance (EWA) releases on the 13th of November 2017. The aim was to stabilise flows during the Murray cod nesting period and avoid nest abandonment. The environmental water in the river supported the maintenance of river heights during a drop in consumptive demand in late October 2017. Environmental water also contributed to the flow arriving at Hillston, with some contribution from the Brewster storage.

The watering action using EWA was designed to generate opportunities for native fish larvae to disperse (a dispersal pulse) and to support this Water NSW altered the operation of Jemalong weir gates during the dispersal pulse to create a wider opening to reduce shear stress on larvae in the water column. Between the 27th of November and 7th of December 2017 the Booberoi regulator was opened to allow a proportion of the dispersal pulse to increase flows into Booberoi Creek.

Collectively these flows generated a prolonged period of high flows through spring and early summer through the monitoring reach. There did not appear to be major effects on water quality or metabolism although transient reductions in turbidity and nutrient concentrations, and short term increases in GPP and ER could be interpreted.

6.3.5 WATERING ACTION 2

A portion of Commonwealth environmental water (1,665 ML) stored in the Brewster outflow wetland was used in May in combination with 805 ML of Lake Brewster Environmental Water Allowance to achieve a small fresh in the river at Booligal. The small fresh passed Booligal between 22 May and 2 June.

There was some evidence for increased GPP and strong evidence for increased ER as a consequence of this flow. This met one of the objectives for the flow which was to create food in-stream through inundation of in-channel benches.

6.4 DISCUSSION

The sampling period was dominated by two environmental watering actions, one of which persisted over much of early summer, and a second much smaller action in May. Water quality data did not capture either watering action well, and there were no clear water quality effects of the two watering actions. This is in contrast to 2016-17 where much larger and shorter term environmental flow releases did have effects on water quality, with consequent impacts on chlorophyll concentrations.

Metabolism data in the 2016-17 year was negatively affected by loss of loggers and prolonged high natural flows. The 2017-18 year generated longer series of data from all sites. The revised BASE model was able to fit curves to a larger number of data days, but there remains a major difference between the number of days able to be modelled from Lanes Bridge/Whealbah (>85%) and Cowl Cowl/Wallanthery (<65%). The data series from Wallanthery was particularly short due to equipment failure. As opposed to previous years, when there was missing data from the highest flow events, the relatively lower flows in 2017-18 were well represented in the metabolism data.

The delivery of environmental flows has the potential to increase primary production and organic matter breakdown by mobilising carbon and nutrients off the floodplain or from upstream (e.g. Baldwin et al. 2016, Wallace and Furst 2016). There was evidence of a small peak in GPP in early October associated with delivery of environmental water, but this was relatively transient in nature. A similar small peak can be interpreted after the May flows, particularly at the Whealbah site. Results for ER responses to the first environmental flow are more equivocal, but there is a clear peak in ER associated with the May environmental flow. This is suggestive of mobilisation of carbon from in-stream benches, and is likely to have supported provision of resources to biota.

6.4.1 MANAGEMENT RECOMMENDATIONS

a) The flow regime of the Lachlan River was dominated by environmental flow allocations, particularly in late spring and early summer.

b) The second environmental flow (in May) was targeted to provision of food resources, and there was a response in GPP and ER, suggesting that inundation of in-channel benches may be mobilising carbon and nutrients.

c) Provision of environmental water as a short term, relatively small event in autumn did appear to meet the objective of generating a resource pulse in-channel.

6.5 EVALUATION

In comparison to 2016-17 when floods 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 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 (particularly focussing on watering event 1)?

There was not strong evidence for an effect of either watering event on water quality parameters, and any effects appear to be relatively transient.

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

There was evidence for both watering events generating short pulses of GPP and ER. This was particularly true for the second event in May. This is of interest, as the relatively cooler water temperatures may be expected to mute productivity responses. The relatively larger response in ER suggests that mobilisation of carbon off in-channel benches may be an important mechanism driving this response. Emerging from this result is the hypothesis that autumn pulses may generate in-channel productivity and effectively ‘prime’ ecosystems for positive responses to spring flows.

6.6 FINAL COMMENTS AND RECOMMENDATIONS

Commonwealth environmental water was a relatively larger proportion of flows in the Lower Lachlan River system in 2017-18 compared to 2016-17. Environmental water was used strategically to support fish breeding in late spring/summer and for broader ecosystem responses in autumn. These actions appeared to generate a pulse of in-stream productivity that is likely to have benefited higher consumers. Trialling small pulses in the cooler months would provide additional insight into the generality of this response, and could provide a useful management approach to improving system condition to allow great responses to spring flows.

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). 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 2004a).

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

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

In 2014-15 the CEWH instigated a Long Term Intervention Monitoring (LTIM) Project across the Lower Lachlan river system to quantify changes in ecosystem health in response to Commonwealth environmental water delivery. This included monitoring the fish community. To assess the contributions of Commonwealth environmental water to the fish community, the relevant short term and long term questions to be evaluated are:

7.1.1 SHORT-TERM (ONE-YEAR) QUESTIONS:

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

7.1.2 LONG-TERM (FIVE-YEAR) QUESTIONS:

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

The fish community monitoring implemented within the Lower Lachlan river system is designed to elucidate the role of environmental water in promoting fish population processes at the Basin scale, with analyses undertaken elsewhere. The current study reports on the fourth year of the five-year Long Term Intervention Monitoring Project, and where possible draws links between annual flow delivery targeting native fish outcomes, although we note this is not the primary aim behind the design of this program. Here we present the annual changes in the fish community, in terms of abundance, biomass and community composition, in the Lower Lachlan river system Selected Area.

Two watering actions were undertaken in 2017-18 (Table 2, section 3.2, page 20), although only the first of these is relevant to this section of the report. The first watering action provided flows to support native fish populations in both the mid and Lower Lachlan river system, however, monitoring is confined to the Lower Lachlan river system (Table 3, section 5, page 26) and our subsequent evaluation is confined to the Lower Lachlan river system. In the Lower Lachlan river system, the first watering action resulted in maintenance of flows above 600 ML day^{-1} at Hillston between 26th October 2017 until the 3rd January 2018 when normal deliveries generated flows between 490 and 850 ML day^{-1} (Figure 11, section 5, page 31). This maintained the river above 0.7 m when it would otherwise have dropped 0.2–0.25 m. The objective of this 2017-18 watering action was to avoid rapid drops in water levels to prevent nest abandonment in native fish species such as freshwater catfish and Murray cod.

7.2 METHODS

The short-term evaluations of outcomes for native fish in the Lachlan River are reported in the larval fish and stream metabolism sections. As part of the Basin scale evaluation of fish responses to environmental water delivery (expected outcomes at 5 years and greater), fish community data is collected annually from 10 in-channel sites in the Lower Lachlan river system Selected Area, from Wallanthery to Hillston (see Figure 16, page 40) (Dyer et al. 2014, Hale et al. 2014). All sites were randomly selected for this study, or had previously been randomly selected as part of another study (i.e. SRA; Davies et al. 2008, 2012). Sampling was undertaken in March 2018, and each site was sampled once using a suite of passive and active gears including boat-electrofishing (n=32 operations, each consisting of 90 seconds 'on-time'), unbaited bait traps (n=10) and small fyke nets (n=10) (Hale et al. 2014). Additionally, large fyke nets were used at each site to target freshwater catfish (n=4). Decapods were also surveyed and these were sampled using baited opera house traps (n=5).

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

Total catch was pooled for all sites and methods, with the exception of calculation of SRA metrics where the first 12 electrofishing shots and bait trap data were used (Davies et al. 2010). To determine differences between years (2015, 2016, 2017 and 2018) abundance and biomass data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA, Anderson et al. 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between years.

Sustainable Rivers Audit (SRA) fish community condition indices (Expectedness, Nativeness, Recruitment) were calculated to quantify overall condition of the fish community assemblage. Data were first portioned into recruits and non-recruits. Large-bodied and generally longer lived species (maximum age >3 years) were considered recruits when length was less than that of a one year old. Small-bodied and generally short-lived species, that reach sexual maturity in less than one year, were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 7). Eight fish metrics were calculated using the methods described by Robinson (2012). These metrics were subsequently aggregated to produce three indicators (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition index. Metric and indicator aggregation used Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) (Davies et al. 2010, Carter 2012).

Table 7. 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 (Pusey et al. 2004, Llewellyn 2007)
Freshwater catfish	83 mm (Davies 1977)
Golden perch	75 mm (Mallen-Cooper 1996)
Murray cod	222 mm (Gavin Butler, Unpublished data)
Un-specked hardyhead	38 mm (Pusey et al. 2004)
Alien species	
Common carp	155 mm (Vilizzi and Walker 1999)
Eastern gambusia	20 mm (McDowall 1996)
Goldfish	127 mm (Lorenzoni et al. 2007)
Redfin perch	60 mm (maximum reported by Heibo et al. 2005)

The Expectedness index is the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition. The index value is derived from two input metrics; the observed native species richness relative to the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). The Nativeness index is the proportion of native compared to alien fishes, and is derived from three input metrics; proportion of total biomass that is native, proportion of total abundance that is native and proportion of total species richness that is native (Robinson 2012). The Recruitment index represents the recent reproductive activity of the native fish community, and is derived from three input metrics; the proportion of native species showing evidence of recruitment, the average proportion of sites at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three indicators are aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition is then partitioned into five equal categorical bands to rate the condition of the fish community as “Good” (80–100), “Moderate” (60–79), “Poor” (40–59), “Very Poor” (20–39), or “Extremely Poor” (0–19).

7.3 RESULTS

A total of 12 402 fish comprising six native and four alien species were captured across 10 in-channel sampling sites in 2018 (Table 8).In order, bony herring, carp gudgeon (*Hypseleotris* spp.), eastern gambusia (*Gambusia holbrooki*), and common carp were the most abundant species (Table 8; Figure 25). In order, common carp, Murray cod, golden perch and bony herring contributed the greatest overall biomass in 2018 (Figure 26).

New recruits (juveniles) were detected in two native longer-lived species; bony herring (10 of 10 sites) and Murray cod (2 of 10 sites; Figure 25; Figure 27), and two native short-lived species (Australian smelt (10 of 10 sites) and carp gudgeon (10 of 10 sites; Figure 25; Figure 27). No golden perch or unspecked hardyhead new recruits were captured (Figure 25; Figure 27). New recruits of three alien species were captured (common carp (*Cyprinus carpio*) (10 of 10 sites), goldfish (*Carassius auratus*) (3 of 5 sites) and eastern gambusia (*Gambusia holbrooki*) (8 of 10 sites); Figure 25; Figure 27).

Sustainable Rivers Audit indices varied substantially in the target reach. Nativeness rated "Moderate" (mean ± SE score: 79.4 ± 3.1), Expectedness was "Poor" (46.0 ± 2.6) and Recruitment was "Very Poor" (37.1; zone metric). The Overall Condition of the fish community was rated "Very Poor" (37.7 ± 1.8) (Table 9).

There were significant differences in the abundance ($Pseudo\text{-}F_{3,36}$ = 12.662, P <0.001) of the fish community among years. Pair-wise comparisons indicated that the differences in abundance were between all combinations of years except between 2015 and 2016 (t=1.316, P=0.141). These differences were driven by higher abundances of native carp gudgeon, Australian smelt and bony herring in 2018, and a lower abundance of common carp in 2018 compared with 2017 (Table 10).

Similarly, differences in biomass occurred among years ($Pseudo\text{-}F_{3,36}$ = 5.4293, P <0.001), with these differences between all combinations of years except between 2015 and 2016 (t=1.237, P=0.201). Differences in biomass were driven by a higher biomass of native Murray cod and golden perch in 2018, and a reduced biomass of common carp and goldfish in 2018 compared with 2017 (Table 10).

Table 8. Total (non-standardised) catch from the Lower Lachlan river system target reach. Sampling was undertaken in autumn 2017 using a combination of five sampling gear types.

	SAMPLING METHOD					
COMMON NAME	BOAT ELECTRO-FISHING	SMALL FYKE NET	LARGE FYKE NET	BAIT TRAP	OPERA HOUSE TRAP	TOTAL
Fish (Native species)						
Australian smelt	230	30				260
Bony herring	6341	342	71		1	6755
Carp gudgeon complex	7	4217		27		4251
Flatheaded gudgeon						
Freshwater catfish						
Golden perch	93		10			103
Murray cod	29		1			30
Un-specked hardyhead	2					2
Fish (Alien species)						
Common carp	363	5	35	1	4	408
Eastern gambusia	17	559	1			577
Goldfish	12	1				13
Redfin perch	3					3
Turtles						
Long-necked turtle			10			10
Murray River turtle			4			4
Decapods						
Freshwater prawn		6620	108	198	110	7036
Freshwater shrimp		259		2		261
Freshwater yabby		16	6	2	4	28

Table 9. Summary of SRA fish indices over the four LTIM sampling years in the Lachlan River.

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

Table 10. Contributions of fish species abundance and biomass to variability among years in the Lachlan River, determined through SIMPER analysis.
Note that only species contributing ≥10% (dissimilarity) to changes in community composition are included. Comparisons between 2015 and 2016 are not included as there were no significant differences in abundance or biomass.

INDICATOR	YEAR COMPARISON	SPECIES	CONTRIBUTION TO DIFFERENCE (%)	YEAR WITH GREATER VALUE	
ABUNDANCE	2015-2017	common carp	28		2017
		eastern gambusia	13		2017
		Murray cod	13	2015	
		carp gudgeon	11		2017
		goldfish	10		2017
	2015-2018	carp gudgeon	28		2018
		Australian smelt	17		2018
		bony herring	13		2018
	2016-2017	common carp	29		2017
		carp gudgeon	11		2017
		goldfish	11		2017
	2016-2018	carp gudgeon	26		2018
		Australian smelt	18		2018
		bony herring	12		2018
	2017-2018	common carp	23	2017	
		carp gudgeon	17		2018
		Australian smelt	16		2018
		bony herring	11		2018
BIOMASS	2015-2017	Murray cod	34	2015	
		common carp	20		2017
		golden perch	12	2015	
		goldfish	11		2017
	2015-2018	Murray cod	25	2015	
		goldfish	14		2018
		common carp	14		2018
		golden perch	13	2015	
	2016-2017	Murray cod	28	2016	
		common carp	27		2017
		goldfish	12		2017
		golden perch	10	2016	
	2016-2018	Murray cod	22	2016	
		common carp	17		2018
		goldfish	13		2018
		bony herring	12		2018
		golden perch	12		2018
	2017-2018	Murray cod	27	2018	
		common carp	21		2017
		goldfish	15		2017
		golden perch	11	2018	

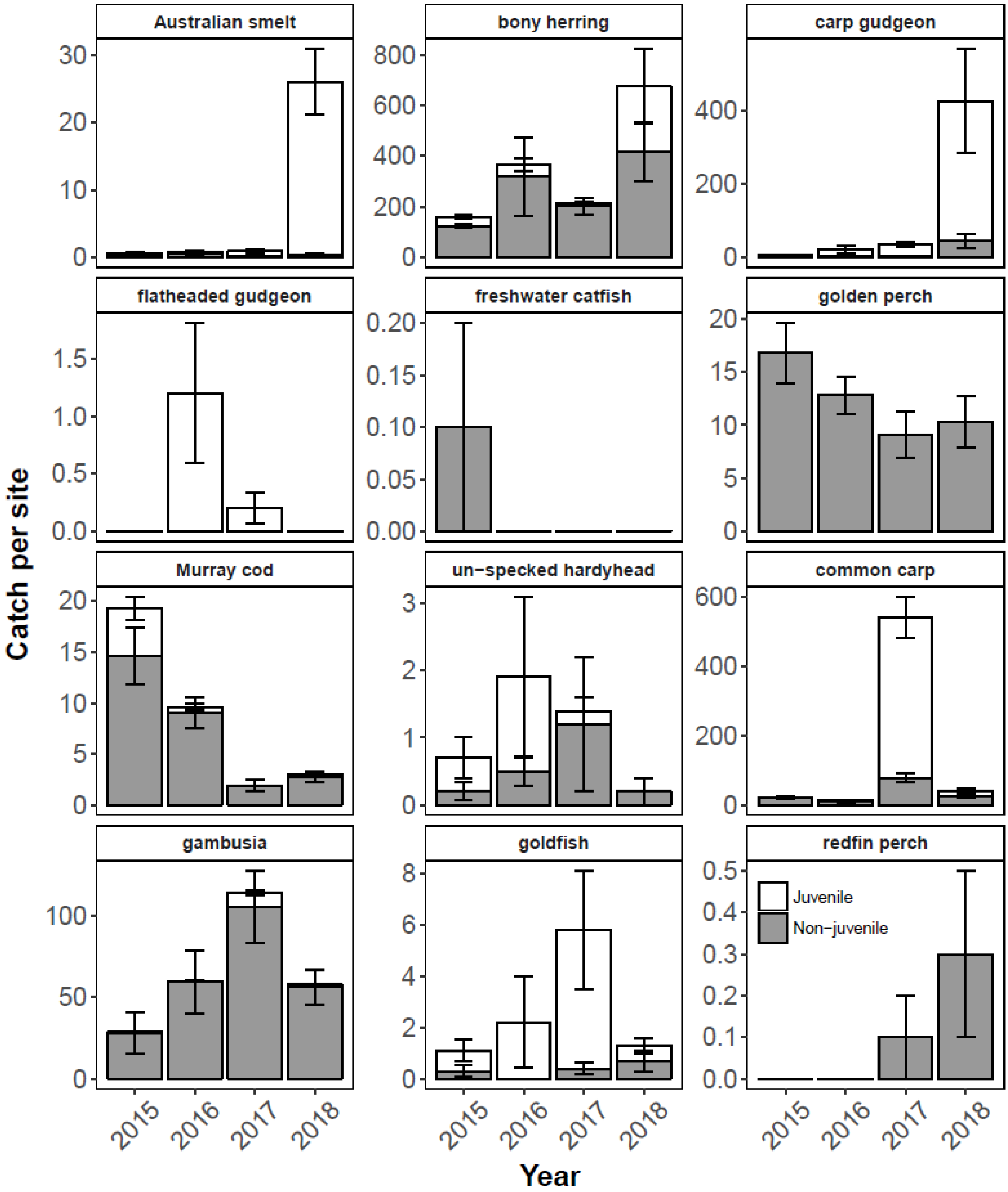


Figure 25. Catch per site (number of fish; mean ± SE) of each fish species within the Lower Lachlan river system target reach, sampled from 2015-2018.

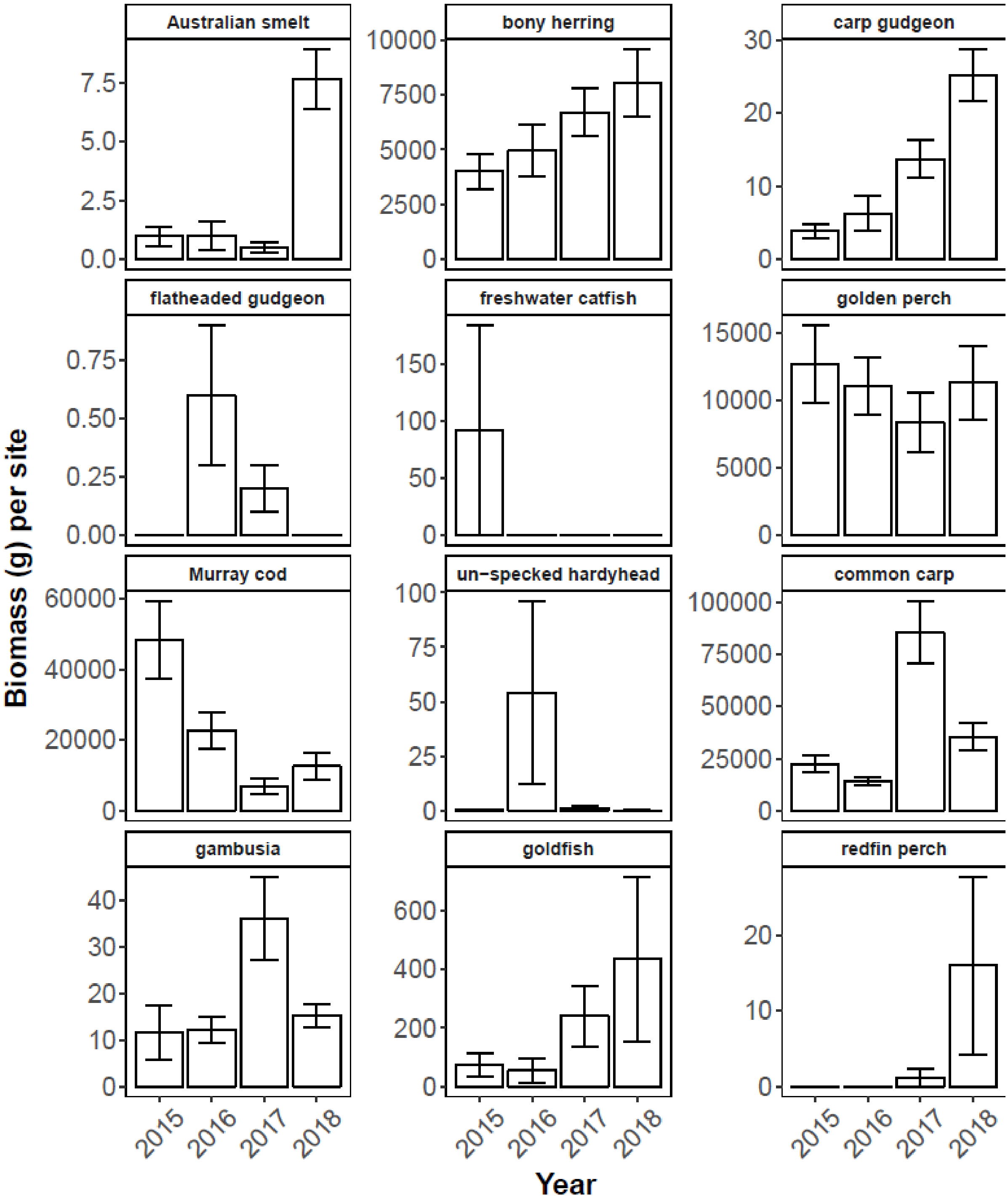


Figure 26. Biomass per site (g; mean ± SE) of each fish species within the Lower Lachlan river system target reach, sampled from 2015-2018.

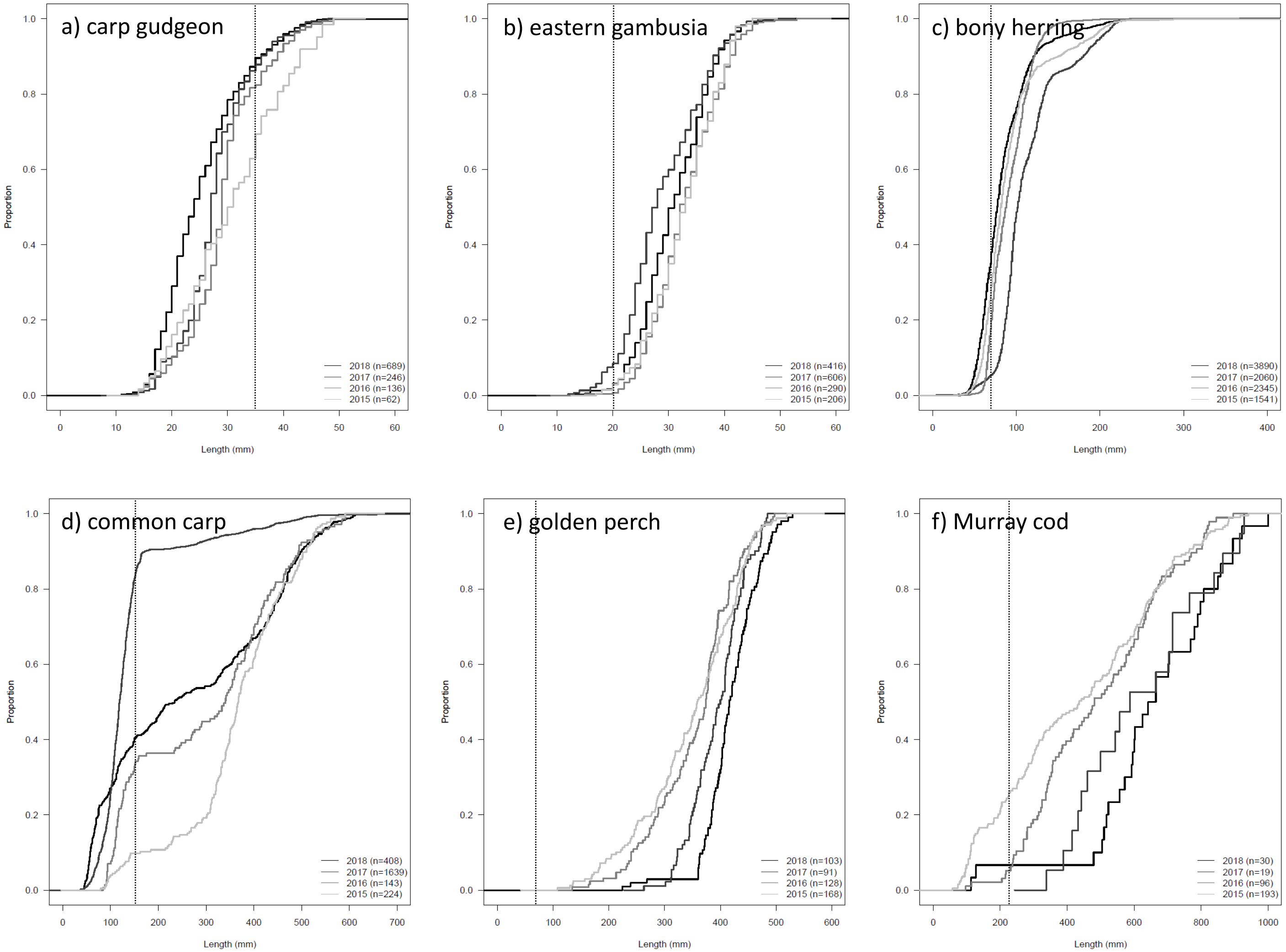


Figure 27. Proportionate length-frequencies of the six most abundant species captured in the Lachlan River from 2015–2018. The dashed line indicates approximate size limits used to distinguish new recruits for each species (see Table 7).

7.3.1 BY-CATCH

A total of 14 turtles were captured during fish community monitoring, 10 long-necked turtles and four Murray River turtles (Table 8). Freshwater prawns were the most abundant taxa in small mesh fyke nets, bait traps and opera house nets (Table 8). Only a small number of Yabbies (n=28) were captured across the 10 monitoring sites (Table 8).

7.4 DISCUSSION

The current study resulted in the capture of six native species of freshwater fish in the Lachlan Selected Area in 2018. Freshwater catfish were not captured in 2018 despite additional targeted sampling for this species using large fyke nets. In addition flatheaded gudgeon were not captured in 2018, despite this species being captured during 2016 and 2017 sampling. Two native species, Murray-Darling rainbowfish and silver perch, although presumed to have been historically common in lowland sections of the Lachlan Basin, are now rarely encountered within the target reach and were not detected in the current study. Consistent with previous results, four native fish species (flathead galaxias, olive perchlet, southern purple spotted gudgeon and southern pygmy perch), which were historically present, were not detected in 2018. Of these, olive perchlet is the only species to have been recently detected (Wallace and Bindokas 2011, DPI Fisheries, unpublished data). Despite the absence of a number of native species, the native species richness in the Lachlan Selected Area is generally higher than in other parts of the catchment (MDBA 2012).

Based on the use of SRA metrics, the native fish community composition stayed in the same Overall Condition (very poor) as previous years (2015–2017). New recruits of two longer-lived species (bony herring and Murray cod) and two smaller native species (Australian smelt and carp gudgeon) increased the 2018 Recruitment score (Very poor), when compared with 2015 (Extremely poor), but the 2018 score was down when compared with 2017 (Poor), potentially due to a lack of recruitment of flatheaded gudgeon in 2018. Nativeness, which reflects a key measure of the proportional abundance and biomass of native compared with alien species, declined from Good in 2015–2016, to Very poor in 2017, but recovered slightly to Moderate in 2018. The decline in Nativeness from 2015 to 2018 partially reflects reduced abundance (and subsequent biomass) of large long-lived species such as golden perch and Murray cod. The subsequent improvement, from 2017 to 2018, mostly reflects increases in abundance and biomass of the majority of native species over this period and a reduction in the abundance and biomass of alien common carp over this period. However, common carp continued to make up a large proportion of the total biomass in the Lachlan Selected Area, even though the abundance and biomass of this species declined substantially in 2018, from a peak in 2017. A number of behavioural and physiological traits, including a wide range of environmental tolerances, ability to rapidly colonise habitats and high reproductive output, enables common carp to continue to dominate freshwater fish communities in the Murray-Darling Basin (Koehn 2004).

It is to be expected that differing flow regimes across years will favour some species in some years and not in others. In 2018 several native species (i.e. carp gudgeon, Australian smelt and bony herring) responded positively to hydrological conditions, in comparison to previous years, with increases in recruitment, abundance and biomass. These species are among a guild that Baumgartner et al. (2014) described as “foraging generalists”, which are resilient to prolonged periods of low flow, require no flow stimuli to spawn, and may in some cases increase in numbers during dry periods and drought. Conversely, responses of other native species, such as Murray cod, golden perch and freshwater catfish, to hydrological conditions in 2018, were less marked, with only small increases in abundances occurring for Murray cod and golden perch and no freshwater catfish observed. These species are long lived and particularly susceptible to poor water quality. Therefore, the recovery of these species, following the rapid declines in abundance occurring from 2015 to 2017, can be expected to be slow.

The declines in abundances of several fish species that occurred in the Lachlan River from 2015 to 2017 have been attributed to observed concentrations of dissolved oxygen in the Lachlan River being at or below the levels required to induce mortality in a number of large-bodied native species during 2016-17 (i.e. 3.1 mg L^{-1}, Small et al. 2014). While widespread fish kills were not observed to be associated with the flooding event and associated dissolved oxygen crash in the Lachlan River in 2016-17, anecdotal reports from local landholders suggest that fish kills resulting from hypoxia are the most likely explanation for the reduced abundance (and associated biomass) of Murray cod in the focal reach. Substantial fish kills associated with widespread flooding 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 also in 2016-17 (CEWO 2017). Encouragingly, recent evidence from the Edward-Wakool system indicates that recovery of the Murray cod population from the 2010-11 fish kills was predominantly driven by localised spawning and recruitment originating from surviving remnant adults (Thiem et al. 2017). Given evidence in the Lachlan Selected Area of a remnant adult population, as well as documented localised spawning in 2015, 2016 and 2018 under this LTIM program, 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 fish pre-spawning and inundating spawning habitat during nesting periods.

Consistent with the results from 2015-2017, golden perch new recruits were not captured in 2018. This result alone does not provide definitive evidence of a lack of spawning within the lowland Lachlan River as other Selected Areas (e.g. the Murrumbidgee; Wassens et al. 2015) that have detected spawning in this species rarely encounter new recruits either as a result of 1) high larval mortality, 2) inappropriate sampling methods or locations, or a combination of both. Golden perch abundance in 2018 was unchanged from 2017 but was reduced compared with 2015–2016, following a similar trend to that exhibited by Murray cod. Stocking of golden perch has been undertaken in the Lachlan River since the 1970's, including on numerous occasions within the Selected Area in the past 10 years (http://www.dpi.nsw.gov.au/fishing/recreational/resources/stocking and DPI Fisheries, *unpublished data*). It remains unknown whether the current adult population of golden perch is a result of stocking, wild-spawning, or a combination of the two. This represents an important knowledge gap when developing expected outcomes for future watering events. Recent published evidence suggests substantial variability in the contribution of stocking to riverine populations of golden perch (Crook et al. 2016, Forbes et al. 2016) and declines in stocking effectiveness have been observed with increasing riverine connectedness (e.g. Hunt et al. 2010). As golden perch are "Flow pulse specialists", which rely on freshes to trigger spawning responses (Baumgartner et al. 2014), it is important that freshes occur in the Lachlan River, in order to promote increased spawning and subsequent recruitment for this species.

7.5 CONCLUSION

The flow regimes provided for native fish in the Lachlan catchment have been directed at supporting spawning (see section 8: Spawning and larval fish) and associated larval fish survival through the provision of food resources. Evaluation of the outcomes for the adult fish community requires longer than annual time frames. The data presented here provide an indication of the temporal variation in the fish community under the provided flow regimes. The substantial variability in flow conditions over the past four years is expected to mask any response to environmental watering events, but provides the context for a longer term evaluation. Recovery of the native fish population is expected to take a long time (>20 years), and the use of environmental water represents one of a suite of complementary actions required to improve native fish populations in the Lachlan catchment.

7.6 RECOMMENDATIONS

- Future water delivery, focussing on native fish outcomes, should utilise natural triggers such as tributary inflows;
- During low resource years the primary focus of environmental flows should be on maintenance of native fish populations, through provision of Baseflows and Small Freshes at the required return intervals.;
- The source (stocked or wild) of the existing golden perch population should be investigated to establish whether recent hydrological events may have led to wild-spawning and recruitment.
- The watering actions provided in 2016-17 and 2017-18 had a focus on the mid Lachlan reaches rather than the Lower Lachlan. Monitoring has only been undertaken in the Lower Lachlan. To better understand the outcomes of environmental watering activities, monitoring should also occur in the mid Lachlan.

7.7 APPENDICES

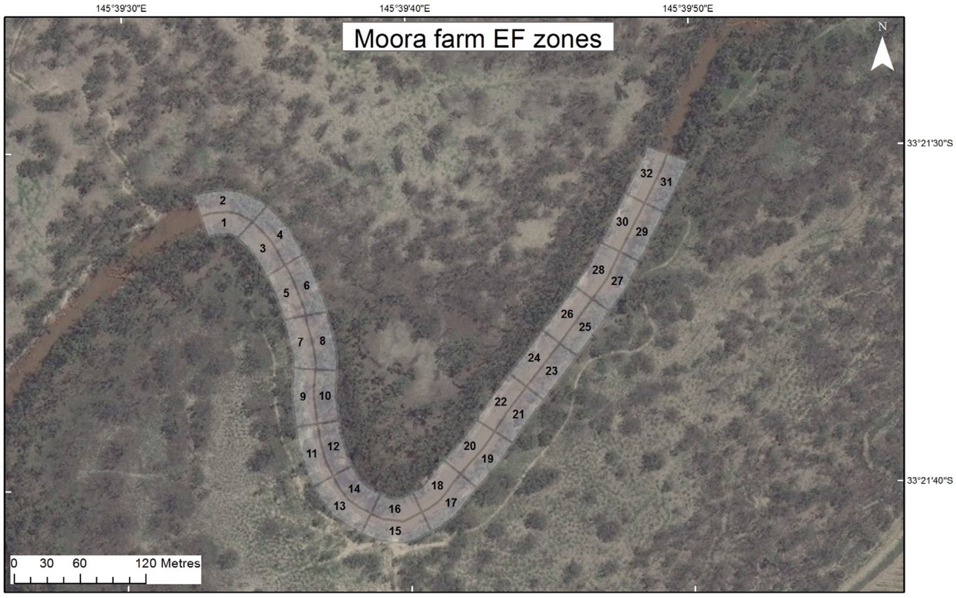


Figure 28. Example of mapped boat electrofishing units used for Category 1 fish community sampling in the Lachlan River. Each unit was sampled using 90 seconds of 'on-time'.

Table 11. Pre-European (PERCH) list of the expected native fish species present in the lowland Lachlan Basin, their associated rarity and subsequent detection during the LTIM 2016 census.

COMMON NAME	SCIENTIFIC NAME	OCCURRENCE[1]	2015 LTIM CENSUS	2016 LTIM CENSUS
Australian smelt	*Retropinna semoni*	common	Y	Y
bony herring	*Nematalosa erebi*	common	Y	Y
carp gudgeon	*Hypseleotris spp*	common	Y	Y
freshwater catfish	*Tandanus tandanus*	common	Y	
golden perch	*Macquaria ambigua*	common	Y	Y
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	common		
silver perch	*Bidyanus bidyanus*	common		
Murray cod	*Maccullochella peelii*	occasional	Y	Y
un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*	occasional	Y	Y
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		

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

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 behaviour, and larval and juvenile survival (Junk et al. 1989, Humphries et al. 1999, King et al. 2003, Balcombe et al. 2006). Since the strength of recruitment to adulthood is largely driven by spawning success, 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:

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

8.1.2 LONG-TERM (FIVE YEAR) EVALUATION QUESTIONS:

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

The larval fish monitoring implemented within the Lower Lachlan river system is directed at Basin scale evaluation and is confined to a single zone within the Lower Lachlan river system Selected Area. There are likely to be strong differences in the fish community and habitats between zones within the Selected Area resulting in the evaluation of outcomes for the Selected Area being confined to the target reach (i.e. Zone 1) (Dyer et al. 2014). There are two components to the evaluation provided in this report. The first evaluates the 2017-18 watering actions in relation to the specific objectives for fish, the second aims to address the short-term evaluation questions.

8.2 METHODS

8.2.1 FIELD SAMPLING

Larval fish were sampled at three sites (Dyer et al. 2014) on the Lower Lachlan river system Selected Area (Wallanthery, Hunthawang and Lanes Bridge, see Figure 16, page 40). To capture larval fish, three drift nets and 10 light traps were set overnight at each site (for more detail see Dyer et al. 2014). Samples collected from drift nets were processed separately. Samples collected from light traps were pooled per site per trip. Five sampling events were undertaken at fortnightly intervals between 17th October 2017 and 14th December 2017:

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

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

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.

8.3 RESULTS

A total of 3 225 larval fish were captured across the five sampling events of spring-summer 2017 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 12). Light traps captured the majority of larval fish, though this was mostly driven by extremely high abundances of Australian smelt (Table 12). Numbers of larval fish were variable between sampling events, with trips 1, 3 and 5 capturing the majority of fish (96% of all trips) comprising 59%, 25% and 12%, respectively. Australian smelt were by far the most numerous species caught, comprising 85% of the total number of larval fish captured in 2017 (Table 12). Common carp were the next most dominant species, comprising nearly 10% of the total number of fish captured (Table 12).

Larval fish were captured for only two of the six target species in 2017: one Equilibrium species, Murray Cod, and one 'Opportunistic' species, carp gudgeon (albeit a single individual) (Table 12). No 'Periodic' representative species (golden perch or bony herring) were collected during larval sampling in 2017 (Table 12). Murray cod were captured in the first three trips only, with the majority (55%) of individuals captured from a single site during sampling event 1 (Wallanthery) (Figure 29). Larval Murray cod ranged in length from 7.82 – 9.92 mm, corresponding to ages of 5 – 20 days (Figure 30). Estimated spawning window for Murray cod in 2017 was between 19/9/17 – 29/10/17, with two peaks between 24/9/17 – 3/10/17 and 18/10/17 – 31/10/17 (see Figure 34, section 8.6). Mean length of Murray cod was relatively consistent between sampling events 1 – 3 (Figure 30).

Table 12. Capture summary of larval fish from sampling conducted between mid-October to mid December 2017 in the Lower Lachlan river system Selected Area.

SPECIES	DRIFT NETS	LIGHT TRAPS	TOTAL
Murray cod	17	25	**42**
flat headed gudgeon	26	83	**109**
Australian smelt	196	2 534	**2 730**
carp gudgeon	0	1	**1**
freshwater catfish	0	0	**0**
golden perch	0	0	**0**
eastern gambusia	0	35	**35**
common carp	209	99	**308**
TOTAL	**448**	**2 777**	**3 225**

Three opportunistic species were collected during larval sampling in 2017. These were Australian smelt, flat headed gudgeons and a carp gudgeon. Australian smelt were captured in light traps during all five sampling events and in drift nets in four of the five sampling events. Australian smelt larvae were detected on all sampling events, though were most abundant on sampling events 1, 3 and 5 (Table 12 and Figure 29). Australian smelt were captured at each site and were most numerous at Wallanthery. Australian smelt captured ranged in size from 3.71 – 25.73 mm (Figure 30) and ranged in estimated age from 1 – 72 days. Length frequency distribution and associated back calculation of estimated spawning dates indicate that Australian smelt had an extended spawning window spanning late-July to early-December in 2017 (see Figure 34, section 8.6). Peaks in spawning activity occurred around mid-September and again around mid-October, when water temperatures were around 11 – 14 °C and 19 – 21 °C, respectively (see Figure 34, section 8.6). Mean length of

Australian smelt increased between each sampling event, though only marginally between sampling events 3 and 4 (Figure 30).

Flat headed gudgeon were captured in all sampling events except for sampling event 1 (17/10/17). The majority (76%) of flat headed gudgeon were captured in light traps. Flat headed gudgeon ranged in length from 4.985 – 19.91 mm (Figure 30), with an estimated age of 9 – 108 days. This corresponds to an estimated spawning window from early August to late October, with an extended peak between late-August and late-October 2017 when water temperatures were ~13 - 23 °C (see Figure 34, section 8.6). Mean length of flat headed gudgeons increased between sampling events 2 and 3 but reduced between sampling events 4 and 5 (Figure 30).

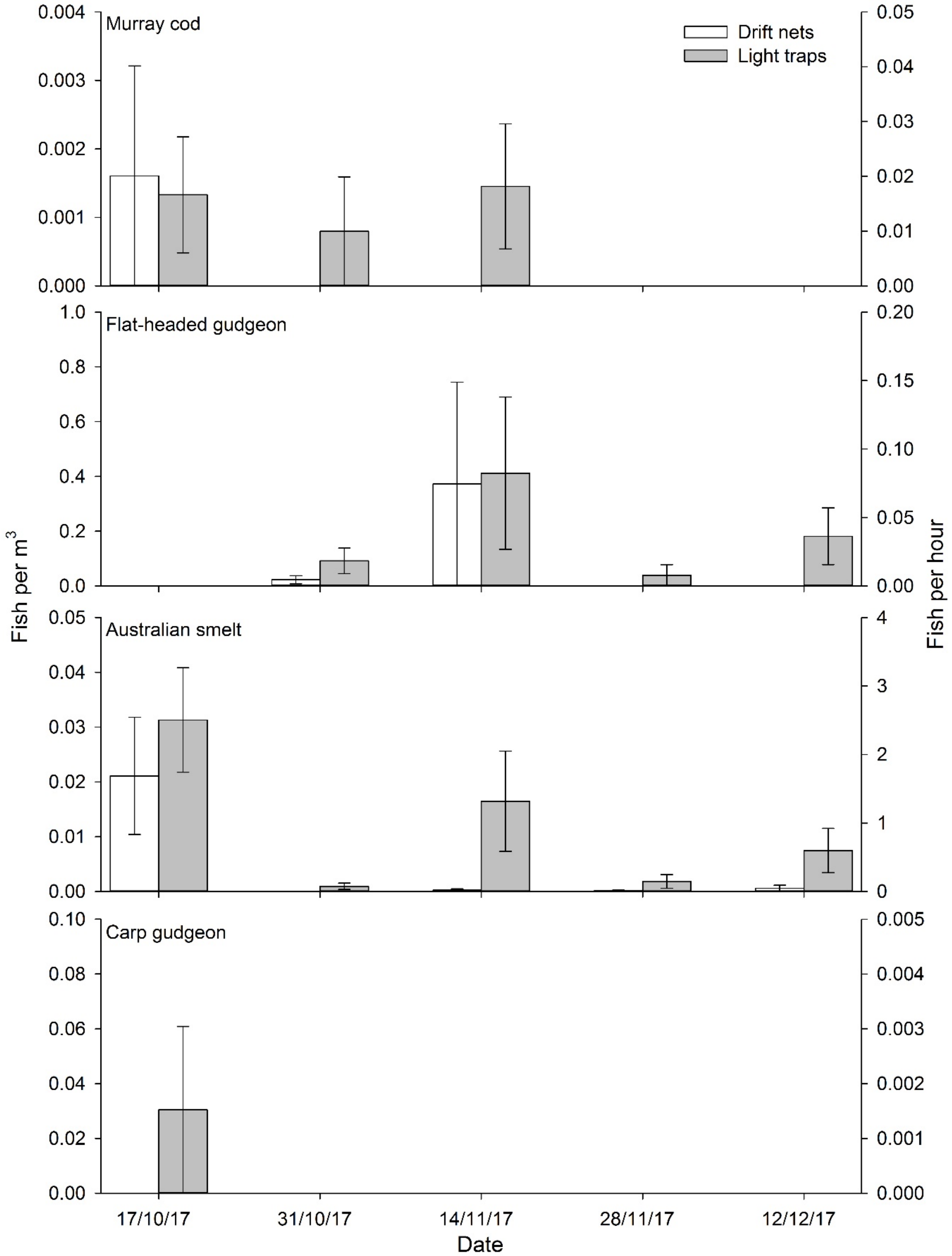


Figure 29. Mean catch per unit effort (± standard error) of the commonly caught larval native fish for drift nets (left axis, white bars) and light traps (right axis, grey bars) per sampling event in spring summer 2017.

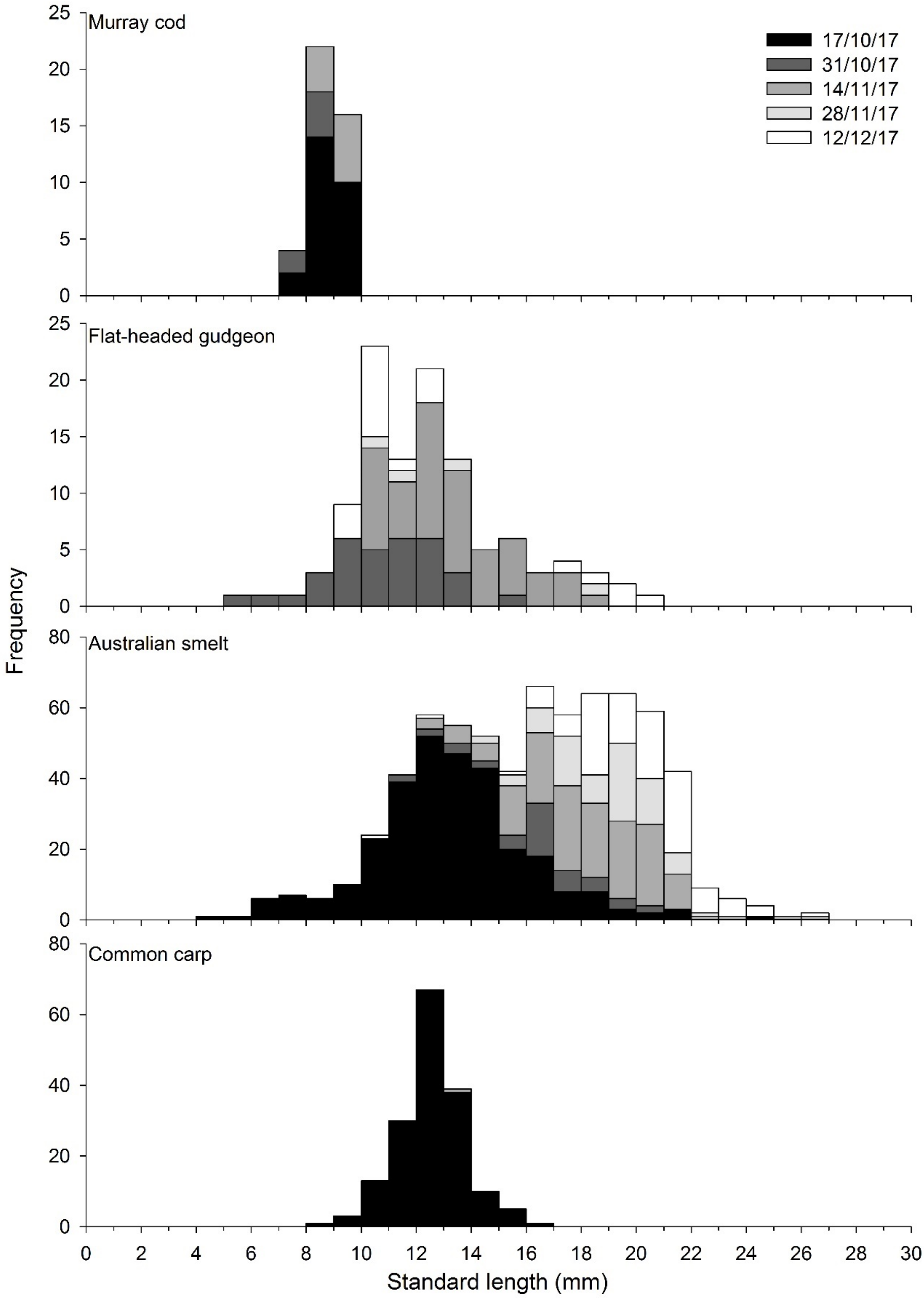


Figure 30. Length frequency histograms for each sampling event of commonly captured larval native fish species with site (n = 3) and sampling technique (n = 2) combined for 2017.

A total of 343 alien fish larvae were captured in 2017 comprising 308 common carp and 35 eastern gambusia (Table 12). The vast majority (95%) of common carp were captured during sampling event 1 from a single site (Wallanthery). Common carp ranged in length from 7.52 – 15.23 mm and estimated ages from 10 – 66 days old. The estimated spawning window of common carp spanned mid-august to mid-October, with a pronounced peak from mid to late-September when water temperature was 14 – 17 °C (see Figure 34, section 8.6). Eastern gambusia were captured in all sampling events except sampling event 2. The majority (63%) of eastern gambusia were captured during sampling event 1. Eastern gambusia ranged in size from 10 – 17 mm and were between 26 and 46 days old (based on estimated length vs age estimate equations presented in Humphries et al. (2008).

8.3.1 2017 VS PREVIOUS YEARS

There was a significant difference in the larval fish community between years in the Lower Lachlan River selected area (Table 13). Although 2014 and 2015 were similar, differences between these two years are driven by higher abundances of flat headed gudgeon and common carp in 2015 (Figure 31, Figure 32 and section 8.7). The large abundance of common carp was the discriminating factor between 2016 and all other years (Figure 31, Figure 32 and section 8.7). The larval fish community in 2017 was typified by far higher abundances of Australian smelt than all other years (Figure 31, Figure 32 and section 8.7).

Table 13. Results of PERMANOVA analysis of larval fish captures (fourth-root transformed numerical data from drift net and light traps combined) in the Lower Lachlan River selected area 2014 – 2018.

SOURCE	DF	SS	MS	PSEUDO-F	P(PERM)	PERMS
Year	**3**	**19 017**	**6 339**	**18 439**	**0.0002**	**7 317**
Site(Year)	8	2750.3	343.78	No test		
Total	11	21767				

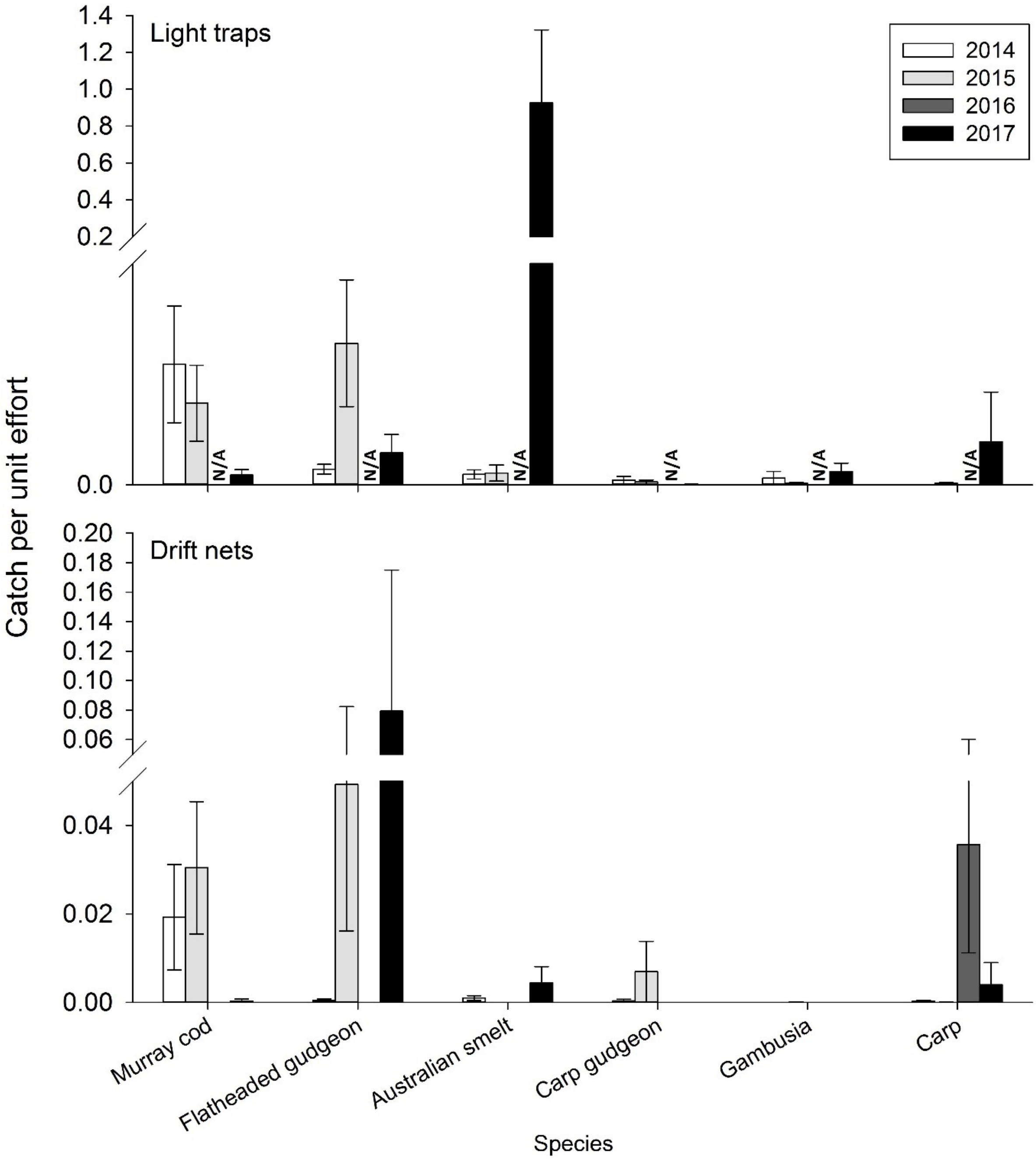


Figure 31. Mean catch per unit effort (± standard error) of larval fish species captured in light traps (CPUE = catch-per-hour, top) and drift nets (CPUE = individuals capture per m^3 of water sampled; bottom) from spring – summer 2014 – 2017.
Note: N/A indicates gear type was not used in that sampling year.

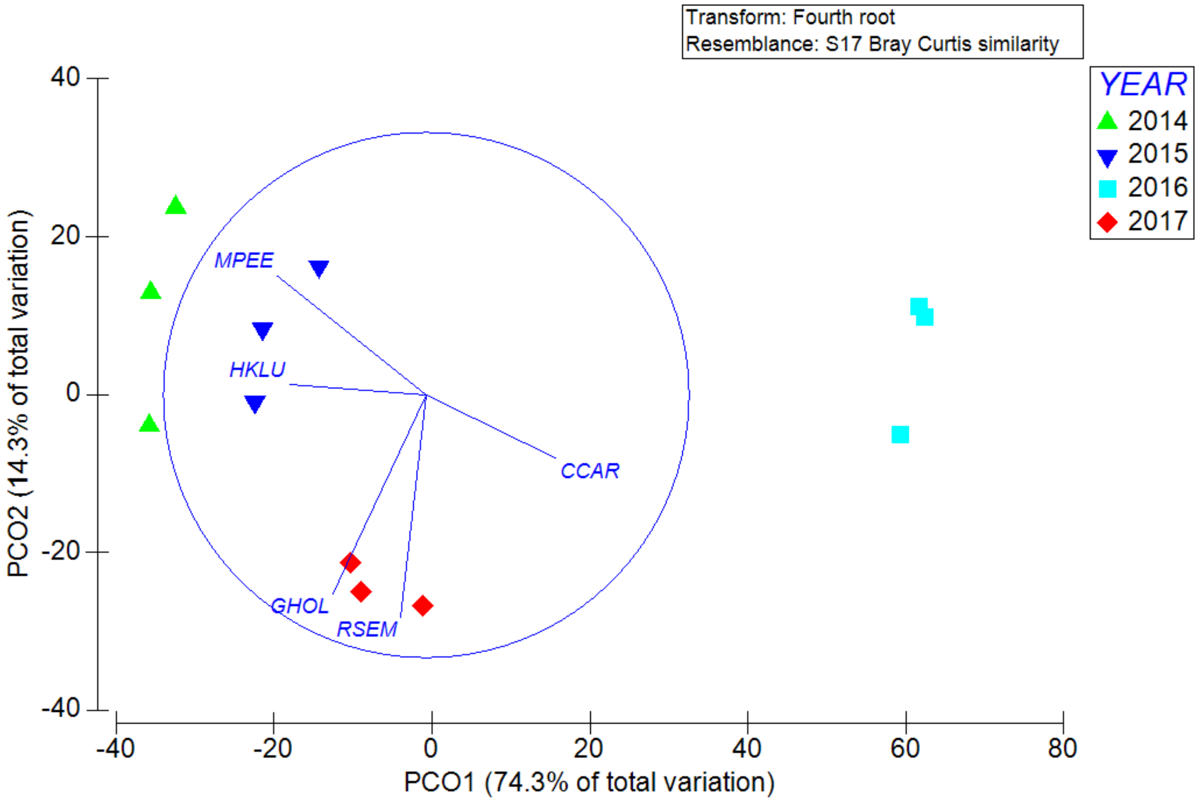


Figure 32. Annual larval fish community composition per site (plotted in multidimensional space via principal component analysis ordination) captured from the Lower Lachlan River Selected Area using drift nets and light traps from spring/summer 2014 – 2017.
(MPEE = Murray cod; HKLU = Flat headed gudgeon; GHOL = eastern gambusia; RSEM = Australian smelt; CCAR = common carp).

8.4 DISCUSSION

8.4.1 GENERAL DISCUSSION

The 2017 spawning season for native fish in the Lower Lachlan Selected Area saw a return to in-channel regulated flows. A hydrological floor was set to prevent reductions in stream water level to protect Murray cod nests. A late winter early spring pulse (to promote stream productivity and native fish spawning movements) was proposed, however the order was not placed in time for delivery.

The results of the larval fish monitoring in 2017 indicate that expected outcomes for the flows, in terms of providing suitable cues and access to habitat for spawning as well as larval growth and survival, were partially met. Spawning was observed for non-flow dependent species; however, there was no evidence (eggs or larvae) of flow dependent species (golden perch) or bony herring spawning in September-December 2017 (young-of-year of the latter were captured in fish community sampling – see section 7).

Murray cod spawning was a key target for the watering actions of 2017-18, and although spawning was detected at all three sites, relative abundance was well below that of 2014 and 2015. There are two possible explanations for the low relative abundance of Murray cod larvae in 2017 (compared to that of 2014 and 2015), of which either or all could have contributed. The first, and likely to be the main driver behind the low relative abundances of larval Murray cod in 2017, is related to relative abundance of adult Murray cod stock in the monitored reach. Fish community monitoring undertaken in autumn 2017 indicated that Murray cod adult stock had been significantly reduced, most likely as a result of deaths from hypoxic flood waters or emigration out of the study reach (see Dyer et al. 2017). It could be that reduced adult stock resulted in reduced number of spawning events and a reduced number of larval Murray cod in 2017.

Secondly, hydrology may have had an impact on Murray cod larval abundance. Of the three years where Murray cod recruitment has been detected (2014, 2015 and 2017), 2015 had the highest relative abundance of Murray cod. The spawning months (September – October) of 2015 were different to both 2014 and 2017 in that September had much higher mean daily discharge (2,706 ML Day^{-1}), compared to 2014 (433 ML Day^{-1}) and 2017 (594 ML Day^{-1}), a result of the translucent flow release in 2015 (Figure 33). It must be noted that estimated spawning dates of Murray cod in 2015 followed the end of the translucent release when river discharges returned to lower levels (< 1,000 ML Day^{-1}) (Figure 33).

Other than the influence of the translucent flow, the mean daily discharge of September and October is magnitudinally similar for all three years, albeit slightly higher in October 2017 (726 ML Day^{-1}) compared to 2014 (436 ML Day^{-1}) and 2015 (499 ML Day^{-1}) (Figure 33). The sudden decreases in river discharge at the end of September/ start of October 2017 (900 – 440 ML/day over 3 days – see Figure 10, in section 5: Hydrology) occurred during the first peak in estimated spawning dates of Murray cod (Figure 34). Although difficult to extrapolate reach wide, this sudden reduction in discharge resulted in a 0.61 m decrease in river level in the Lachlan River (at the gauge downstream of Ganowlia Weir).

It is possible that this sudden drop in water level during the peak spawning period (as indicated by 2017 larval fish back-calculations) could have led to some degree of Murray cod nest abandonment in shallower nest sites (those less than 1.0 m depth). Ideally, the peak and recession would have occurred earlier in September prior to Murray cod spawning (as for the 2015 spawning season), to prevent the potential for shallow nest abandonment. Flows and resultant river water level changes experienced during the 2017 Murray cod spawning season highlight the challenges of managing a working river with multiple demands. A hydrological floor was set (using commonwealth environmental flows), however hydrology during the spawning and nesting time was influenced by fluctuations in operational flows.

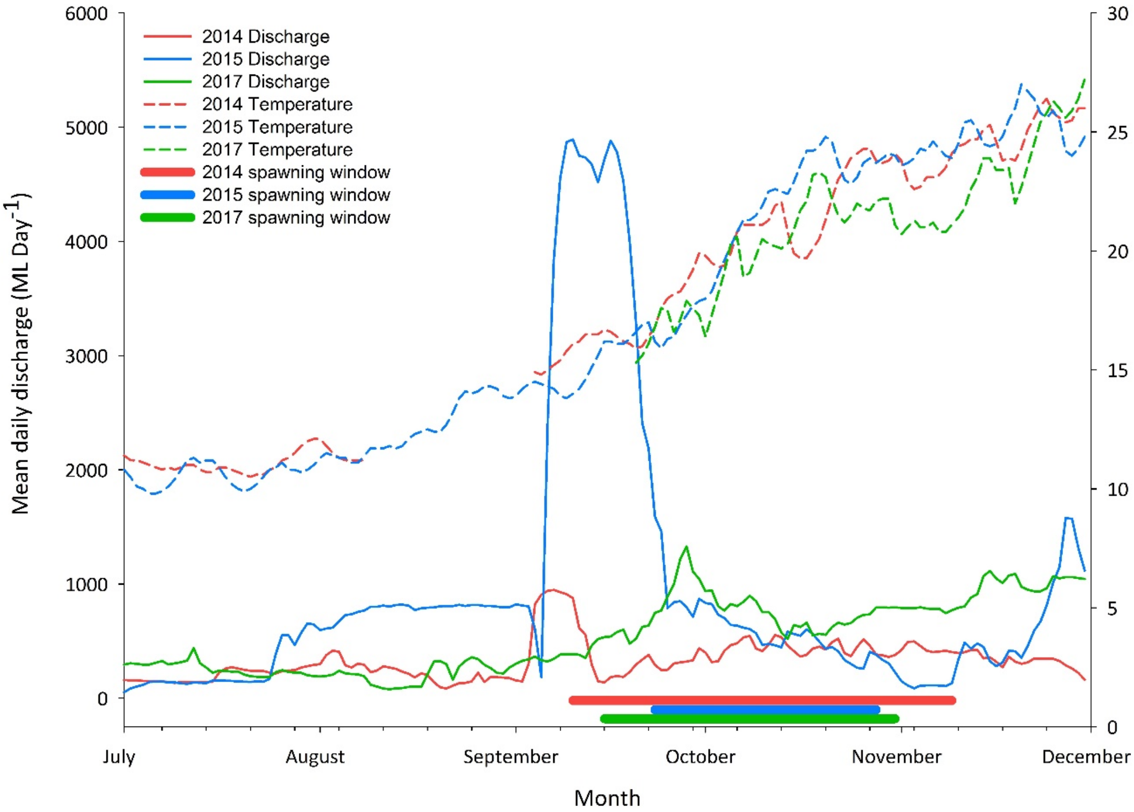


Figure 33. Mean daily temperature and discharge of the Lachlan River (taken at Willandra Weir) during the spawning window of Murray cod in years 2014, 2015 and 2017.

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

Although the spawning season of 2017 did see a rise in discharge in late September, maximum water temperatures did not exceed 18 °C, which may not have reached the minimum spawning temperature for this population. A smaller secondary rise in mid-November occurred when water temperatures were 21 – 24 °C (ideal range - see previous paragraph). Despite optimum temperature, the secondary rise failed to result in a detectable spawning event of golden perch in the target reach. A probable factor contributing to the lack of golden perch spawning may be related to suitable hydraulic conditions for golden perch spawning not being attained. There is a growing belief that hydraulics, and in particular flow velocity, is important in native fish spawning and recruitment. However, relationships at this stage are not well established. Currently a degree of uncertainty exists regarding the lack of spawning response of golden perch in the Lachlan River.

As for all other monitoring years, bony herring were again not detected during larval monitoring in 2017. This continues to be surprising given that recruits were again detected at the majority of sites in the fish community monitoring in early 2018 (see Fish community, section 7). This species is known to spawn in December and January when water temperatures reached 21-23 °C in the lower Murray River (Puckridge and Walker 1990). The last sampling event was in early December, which may have preceded the onset of spawning (even though temperatures had reached ~28 °C). Certainly, the detection of young-of-year in the fish community sampling component of the monitoring program (see Fish community, section 7) suggests that spawning of bony herring occurred outside the temporal or spatial range of the sampling program.

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

Australian smelt in the Lachlan River selected area may have utilised inundated off channel habitats to spawn in late 2016, resulting in an increased stock of adults for the spawning season of 2017. Inundation of off channel habitats is also linked to boosts in in-channel productivity and available resources as organic matter is introduced and broken down, and this process almost certainly occurred in the Lachlan River in late 2016 (Dyer et al. 2017). The increased food resources available, along with reduction in abundance of predatory fish species (Murray cod and Golden perch), may have also resulted in high survival rates and growth of Australian smelt leading up to the spawning season of 2017, which may have resulted in the increased level of spawning and recruitment detected in the larval fish monitoring. Fish community sampling detected nearly 30-fold the number of captured Australian smelt compared to any other year, with the majority of these being young-of-year. These results indicate that conditions in the Lower Lachlan River during the watering year were favourable for Australian smelt spawning, larval growth and survival.

Larval carp gudgeon were rare in 2017, which is surprising as this species was found to have enhanced recruitment during flooding (associated with wetland inundation) (Beesley et al. 2012) or used floodplain inundation for recruitment (King et al. 2003). Furthermore, fish community sampling conducted in autumn 2018 detected high relative abundances of young-of-year carp gudgeon, which makes the lack of larval carp gudgeon even more surprising in 2017. At this stage, it is unclear why captures of larval carp gudgeon were rare in 2017.

The vast majority of larval carp captured in 2017 were captured from a single sampling trip from a single site (trip 1 at Wallanthery). Furthermore, the majority of larval carp were very similar in size (and therefore similar estimated spawning date (see Appendix 1: Estimating fish spawning dates 2017). This suggests carp spawning (as detected in the larval fish monitoring) in the targeted area was largely short term and localised. The peak of estimated carp spawning occurred during a peak in discharge (see Appendix 1: Estimating fish spawning dates 2017). Although carp spawning has been linked to inundation of off channel habitats (e.g. King et al. 2003, Crook and Gillanders 2006, Stoffels et al. 2013) the rise in discharge associated with carp spawning in 2017 would have easily remained within channel. It's more plausible that the rise in discharge inundated some suitable spawning habitat in channel, or the rise in discharge acted as a cue for localised spawning activity.

8.4.2 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 2017 - 2018;

1. Stable flow during Murray cod spawning season (provide a 'floor' in the hydrograph that discharge would not drop below)

This watering action had two expected outcomes relating to reproduction of native fish:

2. Native fish condition, movement, reproduction, larval abundance and recruitment opportunities are supported

To avoid adult Murray cod nest abandonment, the first objective of the 2017 – 2018 watering year was to prevent river discharge from dropping below 500 ML/day at the Hillston weir in the targeted monitoring reach during nesting season. However, from the 13th October 2017 until the end of the watering action (26th November 2017), there was sufficient surplus environmental flows arriving at Brewster Weir from the Forbes account to meet the progressively greater targets at Hillston Weir (increased in stages up to 900 ML/day during the spawning season). Based on back-calculations associated with length of larvae, Murray cod spawning in 2017 in the targeted reach commenced on 17th September and ceased on the 29th October. Given that eggs take around 5 – 7 days to hatch, Murray cod would have been nesting up until around early – mid November. Discharge (as measured at Hillston weir) remained above the target of 500 ML/day from 29th September throughout the extent of Murray cod nesting season in 2017.

In terms of maintaining the water level for the duration of the Murray cod nesting season, the objective was largely met, both in timing and discharge level. Where it failed to meet the minimum discharge level was that it hit the target a little later than Murray cod would have started nesting in the target reach (approximately 12 days) and did dip below the minimum target on the 16th October, albeit by just 60 ML/Day (which is unlikely to have caused any disturbance to nesting cod in this part of the river). The hydrological floor did protect potential nest abandonment associated with a large decrease in the operating river level in late October (which would have been similar in magnitude of the decrease in water level in late September). Unfortunately, largely achieving the hydrological objective did not result in a high abundance of larval Murray cod or young-of-year juveniles, which is unlikely because of minor shortcomings in delivery and most likely because of reasons discussed earlier (low adult stock, potential nest abandonment associated with fall in discharge during peak spawning).

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

Short-term (one year) evaluation questions:

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

The 2017 – 2018 watering action directed at native fish provided a hydrological 'floor' that discharge would not drop below during Murray cod spawning season. The main purpose of this was to protect Murray cod nests from abandonment or desiccation because of sharp declines in water level whilst eggs and early larvae were present. Hydrologically, the watering action was largely a success, though its success in enhancing Murray cod spawning and larval abundance was less obvious. It is likely that other factors inhibited a stronger recruitment to larvae response from Murray cod (discussed earlier in this report).

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. However, increases in mean length of larval fish captures were observed per sampling trip for Australian smelt and flatheaded gudgeon indicating that conditions during early development of these species were suitable for survival and growth. Furthermore, the presence of 0+ individuals (Australian smelt, flatheaded gudgeon, carp gudgeon, Murray cod and bony herring) in the fish community monitoring (see Section Fish Community) provides an indication that growth and survival did occur for small bodied native fish, one medium bodied native fish and one large-bodied native fish in the selected area. However, disentangling the contribution of Commonwealth environmental water to growth in 2017 – 2018 is difficult, as the watering action aimed to provide a 'floor' in the hydrograph, which because of high irrigation demands, mean that minimal Commonwealth environmental water was used.

Long-term (five year) evaluation questions:

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

This is the fourth year of a five year program (the last being a major flooding anomaly) and without baseline data, addressing long-term evaluation questions is not appropriate at this stage. It is well recognised that environmental water is only one intervention that may contribute to the long term rehabilitation of native fish communities across the Murray Darling Basin (MDBC 2004b, Lintermans 2007). This includes the objectives above of improving native fish populations and species diversity in the Lachlan catchment. While the objectives above define 'long term' as being 5 years, for some species and populations, the long term rehabilitation process may take decades (e.g. Murray cod reach sexual maturity at 4-7 years of age (Humphries and Walker 2013). The recommendations below reflect the potential for the CEWO to progress the longer term fish objectives further.

8.5 FURTHER COMMENTS AND RECOMMENDATIONS

- Small bodied species look to have benefitted (in terms of increased recruitment, especially Australian smelt) from the productivity pulse provided by the 2016-2017 flood.
- Murray cod spawning was detected, albeit at a relatively low level (compared to 2014 and 2015). It is likely that reduced adult stock (as a result of the blackwater event in late 2016) is a key driver behind the reduced level of spawning.
- Murray cod are still in a state of recovery following the blackwater events associated with the 2016 flood, though have shown the potential to rebound following flood years (King et al. 2007, Thiem et al. 2017). Future environmental watering should aim to provide the preferable conditions for spawning and early development of this species, including (following Ellis et al. 2016);
    - Flow pulse in late-winter early-spring (recession complete by mid-September)
    - Stable water levels during the nesting period in the Lower Lachlan Selected area (mid-September – early November)
    - Dispersal and productivity pulse at the end of the nesting period (mid-November)
- Downstream Ganowlia Weir is the only gauge in the selected area that is not immediately upstream of a weir. We recommend that Ganowlia weir gauge be upgraded to include discharge so that accurate estimates of Commonwealth Environmental Water on river channel heights can be more adequately evaluated.
- Common carp appear to have spawned on the pulse in late September - early October. It appears as though common carp utilised newly available channel habitat on the flow pulse to spawn resulting in a localised recruitment event for this species in the selected area.
- To avoid adding to further increases in local carp populations, the planned use of environmental water in the Lachlan catchment during 2018-19 may, depending other environmental needs identified, want to target:
    - in-channel habitat rather than floodplain, wetland and lake habitats (preferred spawning habitat for carp)
    - delivery during winter and early autumn when temperatures are less than 16°C and less likely to contribute to carp recruitment (following Koehn et al. 2016).
- To progress the longer term fish objectives further it is recommended that the CEWO continues to consider:

- how it may participate in other intervention options (water quality monitoring, habitat rehabilitation, removal of barriers to movement, use of fish screens on irrigation intakes) that complement the use of environmental water,
- methods that may improve and complement current LTIM fish monitoring methods, such as the use of environmental DNA (e-DNA) methods.

8.6 APPENDIX 1: ESTIMATING FISH SPAWNING DATES 2017

The most accurate and precise method of estimating larval fish age and hence deriving a spawning date is by direct daily aging using otoliths of larval fish (Anderson et al. 1992, Campana and Thorrold 2001). Resource constraints meant direct aging was not currently feasible for this project (although larvae captured in 2014 – 2017 have been stored for potential otolith analysis should funds be available), and this forced the use of less accurate indirect methods of aging and spawning date estimation.

Ages of small bodied species (carp gudgeon, Australian smelt and flat headed gudgeon) ages were estimated from length-age equations for each species for a site on the Lower Murray floodplain (Lindsay Island), provided in Humphries et al. (2008) and matched to capture month. Hatching times for small bodied species were taken from Lintermans (2007). Murray cod larval age were estimated by multiplying length by 1.372 (a factor to compensate for shrinkage in ethanol) matched against linear length age equation derived from length-age data in Serafini and Humphries (2004) (Age = 6.6302ln-48.104). This age along with estimated incubation period (= 20.67-0.667*[WaterTemp(°C)] taken from Ryan et al. (2003) – where water temperature was for the five days prior to the estimated spawning date was subtracted from the capture date to provide an estimate of spawning date. Age of larval common carp was estimated using age vs growth relationships from Vilizzi (1998), and hatching time was taken from Lintermans (2007).

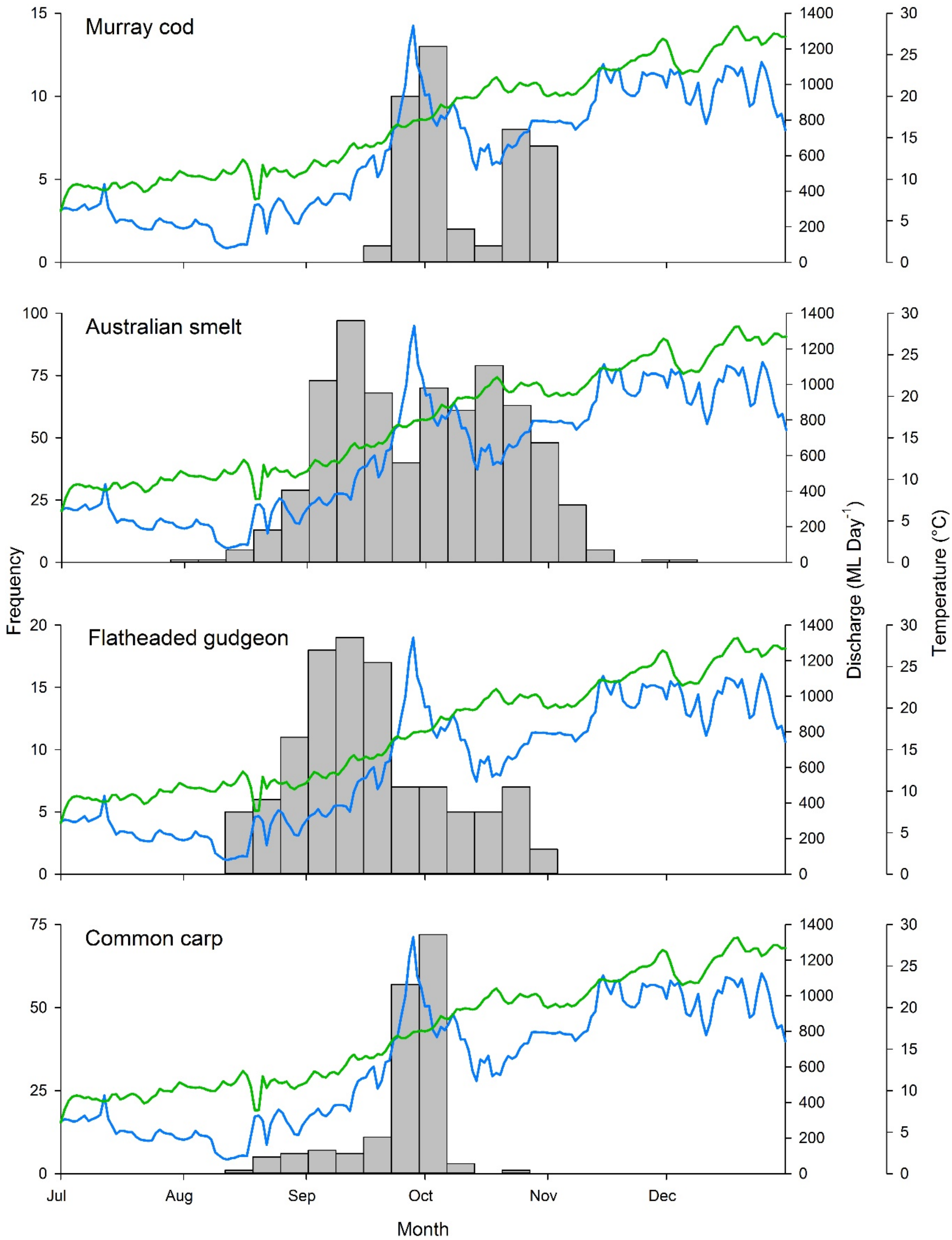


Figure 34. Estimated spawning date frequency (grey bars) and associated discharge and temperature for larval native fish species in 2017.
Mean daily discharge from Lachlan River at Willandra Weir (blue line) and mean daily temperature from Lachlan River at Cowl Cowl (green line). Data are from all sites and methods combined.

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

Table 14 Results of Similarity percentage analysis (SIMPER) of annual differences in the larval fish community in the Lower Lachlan River selected area.

Groups 2014 & 2015

Average dissimilarity = 29.37

	Group 2014	Group 2015				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
PGRA	1.75	3.14	6.63	1.58	22.57	22.57
CCAR	0	1.14	5.61	3.19	19.09	41.66
RSEM	1.71	1.48	3.94	1.64	13.42	55.08
HKLU	0.97	1.35	3.54	0.79	12.05	67.13
GHOL	0.67	0.84	3.49	0.95	11.87	79
MPEE	3.41	3.86	3.14	1.29	10.68	89.68
TTAN	0.67	0	3.03	1.12	10.32	100

Groups 2014 & 2016

Average dissimilarity = 100.00

	Group 2014	Group 2016				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
MPEE	3.41	0	30.08	2.37	30.08	30.08
CCAR	0	3.25	26.28	2.17	26.28	56.36
RSEM	1.71	0	14.21	3.73	14.21	70.57
PGRA	1.75	0	13.9	10.33	13.9	84.48
HKLU	0.97	0	6.58	1.11	6.58	91.06

Groups 2015 & 2016

Average dissimilarity = 84.95

	Group 2015	Group 2016				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
MPEE	3.86	0	25.58	8.89	30.11	30.11
PGRA	3.14	0	20.94	4.18	24.65	54.75
CCAR	1.14	3.25	13.65	1.27	16.06	70.81
RSEM	1.48	0	10.01	1.95	11.78	82.59
HKLU	1.35	0	9.07	3.67	10.68	93.27

Groups 2014 & 2017
Average dissimilarity = 47.79

	Group 2014	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
RSEM	1.71	5.44	16.55	2.39	34.63	34.63
CCAR	0	2.46	10.36	1.94	21.68	56.31
MPEE	3.41	1.84	6.9	1.84	14.43	70.75
GHOL	0.67	1.84	5.54	1.14	11.6	82.35
PGRA	1.75	2.44	3.37	0.85	7.04	89.39
TTAN	0.67	0	2.58	1.15	5.4	94.78

Groups 2015 & 2017
Average dissimilarity = 38.21

	Group 2015	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
RSEM	1.48	5.44	15.07	6.53	39.44	39.44
MPEE	3.86	1.84	7.72	3.59	20.19	59.63
CCAR	1.14	2.46	5	1.11	13.1	72.73
HKLU	1.35	0.33	3.94	1.81	10.31	83.03
GHOL	0.84	1.84	3.81	1.51	9.96	93

Groups 2016 & 2017
Average dissimilarity = 73.39

	Group 2016	Group 2017				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
RSEM	0	5.44	31.5	6.01	42.93	42.93
PGRA	0	2.44	14.38	3.97	19.6	62.53
GHOL	0	1.84	10.79	4.61	14.71	77.23
MPEE	0	1.84	10.43	21.55	14.21	91.45

9 VEGETATION

9.1 INTRODUCTION

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

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

The floodplain and wetland vegetation communities of the Lower Lachlan river system naturally display sequences of dry and wet phases depending on regional climatic conditions. However, during the Millennium drought (2001-2009), the health of the wetland vegetation declined rapidly with reductions in red gum canopy cover recorded at a number of significant wetlands (Armstrong et al. 2009). Observations and measurements of the reed beds and red gums made during the years immediately after the drought (2010-2012) suggested some degree of drought recovery was occurring within wetland vegetation communities, but by early 2012 aquatic vegetation, such as within the Great Cumbung Swamp, Lake Bullogal and Lake Merrimajeel was starting to show drought effects again (Driver et al. 2011, Driver et al. 2013a, Driver et al. 2013b).

Monitoring of floodplain and wetland sites for the LTIM program has been conducted since 2014 and has encompassed vastly different annual rainfall and hydrological conditions. These have ranged from very dry conditions in 2014-15 to the fourth largest flood on record in 2016-17. The floodplain and wetland vegetation communities have continued to display dry and wet phases depending on the prevailing conditions (Dyer et al. 2017). The context in which the 2017-18 environmental watering actions were delivered was one in which the river and wetlands were in the drying phase that follows major flooding. Water persisted across the landscape well into 2017, with some wetland areas retaining significant areas of inundation into late spring 2017 (Figure 35). These were topped up by the rainfall in October and December. Field observations were that tree condition (canopy) appeared to be in good condition for mature wetland trees and that some of the younger trees in the deeper areas of wetlands were beginning to show signs of stress (yellowing of the canopy). As a consequence, a decision by Commonwealth water managers was made to allow the majority of sites to complete the natural drying sequence in 2017-18.

Figure 35. Lake Tarwong on the 15th of December 2017. Photo: Alica Tschierschke.

The passage of the two watering actions in 2017-18 to the end of the system was expected to wet the central reed beds of the Great Cumbung Swamp and thus provide benefit. This objective was not clearly articulated (as specific, measurable objectives) in the documentation associated with the watering actions which instead focus on the expected outcomes for native fish. This means that action specific evaluation questions are difficult to formulate for the vegetation.

This technical report provides an evaluation of the outcomes for vegetation and addresses the questions listed below. In doing so, the response of vegetation to the drying conditions within the catchment is described in relation to watering history.

9.1.1 ACTION SPECIFIC EVALUATION QUESTIONS:

1) What did Commonwealth environmental water contribute to native riparian and wetland vegetation communities?

9.1.2 SELECTED AREA SPECIFIC EVALUATION QUESTIONS:

Given the limited monitoring sites which had received Commonwealth environmental water in 2017-18, the selected area specific evaluation questions have been re-framed in the context of watering history.

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

9.2 METHODS

Vegetation monitoring sites were selected to provide a sample from the different vegetation communities distributed across wetlands and riparian zones with different environmental watering probabilities, see Dyer et al. (2014) and Table 15 on page 91.

The non-tree community survey was conducted along 2 replicate 100 m transects extending from the fringing woodland into the deeper section of the wetlands and billabongs at each of 10 sites (Table 15) using the methods of Driver et al. (2003) described in Dyer et al. (2014). Species abundance (and cover) was recorded in 1 m^2 quadrats placed at 10 m intervals along the 100 m transects (n=10 per transect).

Woodland tree communities were surveyed in a minimum of 2 replicate 0.1 ha plots at each of 12 sites (Table 15) using the methods of Bowen (2013) described in Dyer et al. (2014). An understory floristic survey was undertaken in a nested 0.04 ha plot inside the 0.1 ha plots. In each 0.1 ha plot, measures of stand and tree condition (basal area, canopy openness, canopy extent, live/dead limbs) were recorded as well as the number of seedlings and saplings <10cm dbh. In each 0.04 ha plot, the floristic survey recorded species abundance (of all species including trees) and cover.

All plants observed (including grasses) were identified to species either during field surveys or from field specimens which were preserved for later identification. Where plants were not able to be identified to species (because of a lack of suitable identifying features) they were recorded to the lowest taxonomic level possible and as distinct species based on morphological differences.

Table 15. Summary of vegetation monitoring sites.
The location of the sites within each Zone has been provided, however we do not consider the vegetation to be clearly separated according to zone.

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

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

SITE (CODE)	GEOMORPHIC DESCRIPTION	ANAE CLASSIFICATION	VEGETATION COMMUNITY	TREE COMMUNITY: RIPARIAN PLOTS	NON – TREE COMMUNITY: TRANSECTS
Lake Marrool (LM)	Open lake fringed with red gum	Lt2.1: Temporary floodplain lakes	River red gum	2	2
ZONE 4					
Tom's Lake (TL)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	0
Lake Tarwong (LT)	Floodplain wetland Channel mound wetland	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	0
		Pt1.1.1: Intermittent River red gum floodplain swamp	River red gum	2	2
ZONE 5					
Booligal (BO)	Floodplain distributary channel	Pt1.2.1 Intermittent black box floodplain swamp	Black box/river cooba/lignum	2	2

Table 16. Wetland sampling dates and observations 2017-18. Percentages indicate the estimated inundation of the plot or transect at the time of sampling. Watering categories correspond to the historical watering of the sites (see Table 17).

	OBSERVATION (inundation averaged across plots/transects at each site)				NOTES (plot and transect specific observations)		WATERING HISTORY (see Table 17)	
	Spring 2017		Autumn 2018					
SITE (CODE)	Transect	Plot	Transect	Plot	Transect	Plot	Transect	Plot
ZONE 1								
Hazelwood (HW)	dry	dry	dry	dry			B	A
Whealbah (WB)	dry	dry	dry	dry			B	A
Moon Moon (MM)	dry	dry	dry	dry			B	B
ZONE 2								
Lake Bullogal (LBU)	25%	dry	dry	dry	Spring > T1: 20% and T2: 30% ongoing flood from 2016-17 (depths up to 0.3 m)		A	A
The Ville (TV): Mixed		dry		dry				A
The Ville (TV): RRG	dry	dry	dry	dry			B	B
ZONE 3								
Lake Ita (LI): BBX		dry		dry				A
Lake Ita (LI): RRG		1%		dry		Spring > only Plot 3: 2% ongoing flood from 2016-17 (depths 0.05 m)		A
Clear Lake (CL)		dry		dry	Watering Action 1 contributed water to Clear Lake and Nooran Lake in December, January and February and the Nooran Lake transects were partially inundated			A
Nooran Lake (NL)	dry	dry	dry	dry			C	B
Lake Marrool (LM)	dry	dry	dry	dry			B	A
ZONE 4								
Tom's Lake (TL)		dry		dry				B
Lake Tarwong (LT): BBX		dry		dry			A	A
Lake Tarwong (LT): RRG	40%	10%	dry	dry	Spring > T1 and T2 each 40% ongoing flood from 2016-17 (depths up to 0.7 m)	Spring > only Plot 4: 20% ongoing flood from 2016-17 (depths 0.5 m)	A	A
ZONE 5								
Booligal (BO)	dry	dry	dry	dry			B	B

9.2.1 EVALUATION APPROACH

9.2.1.1 Action specific evaluation

Commonwealth environmental water reached parts of the Great Cumbung Swamp in late spring and summer (Figure 15). This was expected to provide benefit to the central reed beds of the Swamp. The reed beds of the Great Cumbung Swamp are not monitored as part of the LTIM project for logistical and financial reasons. This means it is not possible to evaluate the outcomes of the 2017-18 watering for the reed beds. However, two of our monitoring transects at Nooran Lake on the edge of the Great Cumbung Swamp were partially inundated which enables some evaluation of the use of Commonwealth environmental water in 2017-18 for the native riparian and wetland vegetation in the Great Cumbung Swamp.

9.2.1.2 Selected area evaluation

To address the Selected Area evaluation questions, the 2017-18 vegetation data are combined with the data collected over the previous 3 years and considered in relation to annual weather patterns and watering history. To enable this, the four years of monitoring were characterised in terms of the context provided by the annual weather patterns: 2014-15 was dry, 2015-16 was moderately wet, 2016-17 was very wet and 2017-18 was drying. At each site, transects and plots were assigned a watering history based on the watering that has occurred since 2012-13 (Table 17 and Figure 36). These categories were used to structure the data analysis and interpret the response of the vegetation observed.

Commonwealth environmental water has only been used in one (2015-16) of the four years of monitoring in the Lower Lachlan river system to target vegetation outcomes. There was no observable effect of historical watering actions in the vegetation responses to flooding in 2016-17 (Dyer et al. 2017) and it is not expected that the 2015-16 environmental watering would produce an observable effect into 2017-18 because the magnitude of the intervening (2016-17) large flood is likely to have an overwhelming effect.

Table 17. Watering history used to structure analysis of vegetation data.

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

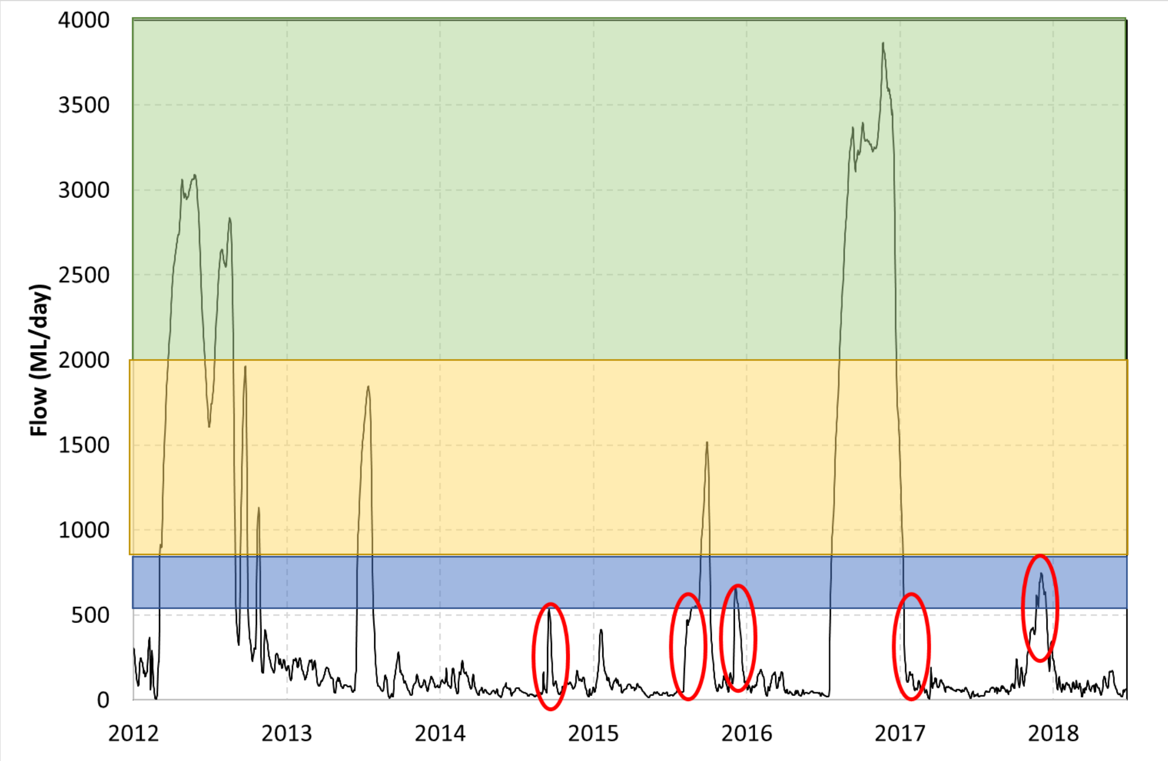


Figure 36. Conceptualisation of recent watering history categories defined in Table 17. Green shading represents watering category A, yellow sharing represents watering category B and the blue shading represents watering category C. Red circles show planned environmental water use.

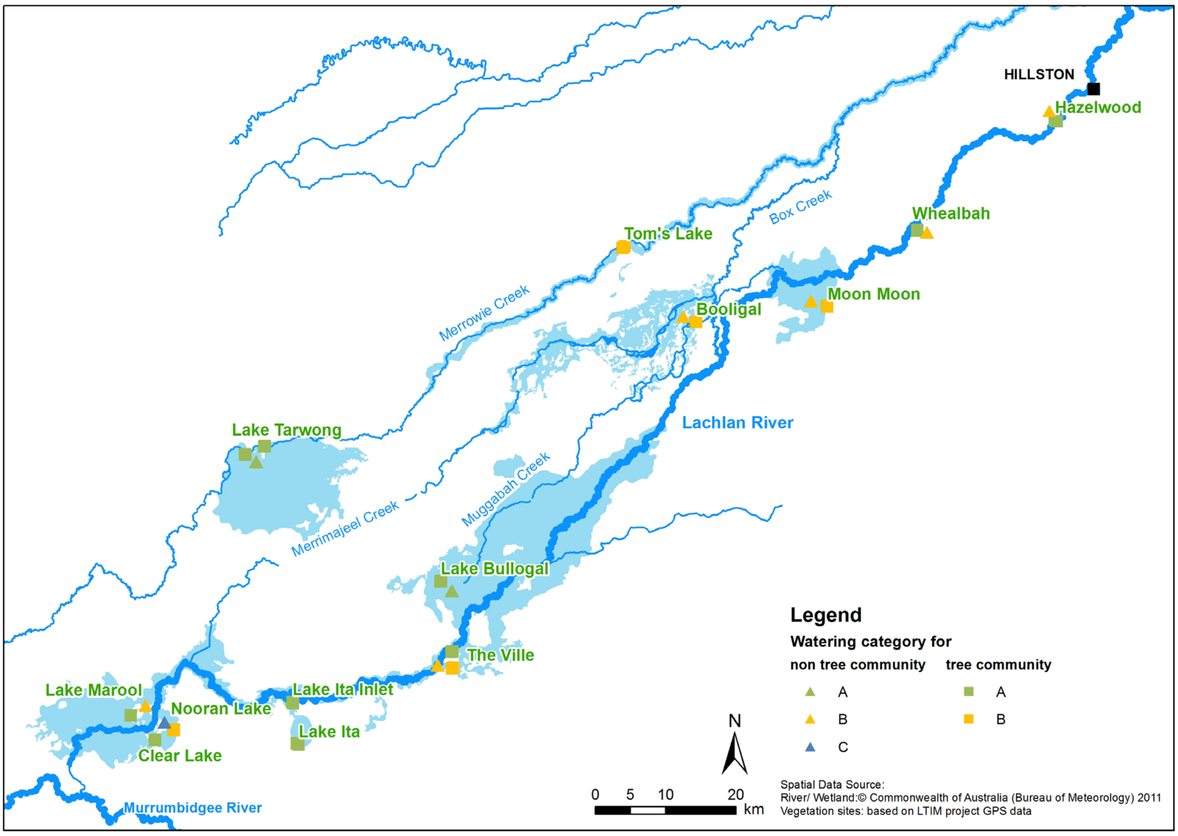


Figure 37. Map of the vegetation monitoring sites categorised according to watering history.

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 sampling unit 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 18) of Brock and Casanova (1997) and Casanova (2011). Species were also classified as native/non-native using information provided on PlantNET (http://plantnet.rbgsyd.nsw.gov.au/).
- The condition of floodplain and riparian trees is defined as the canopy cover of the floodplain trees (river red gums and black box). For the evaluation condition metrics (Table 18) are derived from Bowen (2013), Bowen and Simpson (2010) and Bowen et al. (2012) and are adapted from Cunningham et al. (2007).
- Long lived organisms refers to the floodplain and riparian trees (river red gum, black box and river cooba). The contributions to populations of long-lived organisms means ensuring that there are new cohorts in the population. The evaluation was based on the number of eucalypt seedlings following watering and their persistence over time.

- The numbers of seedlings and saplings present in all plots per site were aggregated to give a combined count per time of sampling and facilitate comparison between monitoring dates.

Table 18. Plant functional group classifications of Brock and Casanova (1997) and Casanova (2011).

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

9.2.2 DATA ANALYSIS

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

- Species richness was calculated as an average of the data from multiple plots or transects at each site.
- Simpson's Diversity Index (D) is calculated as: $D = 1 – (\sum n(n-1)/N(N-1))$ where
  n = the total number of organisms of a particular species
  N = the total number of organisms of all species.
- Measures of stand and tree condition at each site were calculated as the average of the plot data from each vegetation community at each site. This means that for sites with more than one vegetation community, there are two measures of stand and tree condition provided (e.g. Lake Tarwong black box and Lake Tarwong river red gums).

Table 19. Plant condition classification derived from Bowen (2013), Bowen and Simpson (2010) and Bowen et al (2012) and are adapted from Cunningham et al. (2007).

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

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

9.3 RESULTS

In 2017-18, more than 97% of taxa were identified to species level.

9.3.1 VEGETATION SPECIES RICHNESS AND DIVERSITY

9.3.1.1 Non-tree community

A total of 124 species were identified across the non-tree community sites during the 2017-18 watering season compared with 96 species identified during the 2016-17 watering season, 154 species identified during the 2015-16 watering season and 130 species identified during the 2014-15 watering season. In 2017-18, the majority of the species were recorded in spring (112 species) and only 63 species were recorded during the autumn sampling. The greatest number of species during spring sampling was at the Lachlan Valley State Conservation Area at Booligal Station (34 species) and during autumn sampling at Lake Tarwong (15 species).

In Spring 2017 the plant community across all sites was dominated by asters (old man weed *Centipeda cunninghamii*, yellow twin heads *Eclipta platyglossa* and spear thistle *Cirsium vulgare*), chenopods (mainly black roly-poly *Sclerolaena muricata*, fat hen *Chenopodium album* and saltbushes *Einadia nutans subsp. nutans,* and *Atriplex semibaccata*), grasses (many too small to identify, but some blown-grass *Lachnagrostis filiformis*, common couch *Cynodon dactylon*, and barley grass *Hordeum leporinum*) and knotweeds (*Polygonum plebeium*), and brassicas, mainly smooth mustard *Sisymbrium erysimoides* and *Rorippa eustylis.* The same species were present in autumn, but chenopods had become more numerically dominant and verbenas had replaced the brassicas.

During 2017-18, the plant community at Nooran Lake changed from one dominated by common spike rush (*Eleocharis acuta*), barley grass (*Hordeum leporinum*) and nardoo (*Marsillea drummondii*) to one dominated by chenopods (mainly black roly-poly *Sclerolaena muricata*). A large number of germinants (mainly forbs) were also recorded in the autumn sampling; these had appeared in response to recent rain.

Patterns in site scale vegetation diversity (Simpson's diversity index) appear to be related more strongly to the prevailing weather conditions than to watering history (Figure 36).The data suggests a slight (not significant) peak in diversity in Spring 2017 at sites that only receive water from natural flooding (Figure 36).

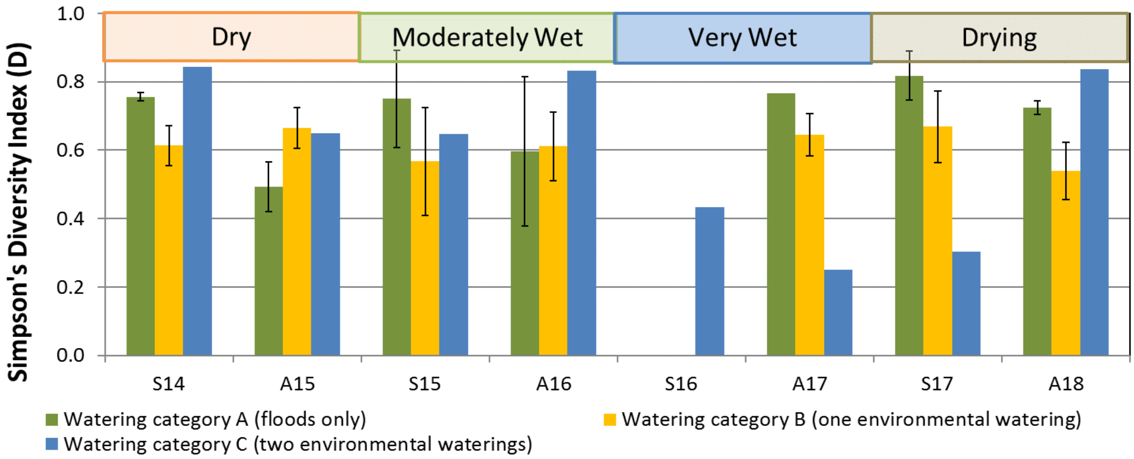


Figure 38. Comparison of groundcover vegetation diversity in the non-tree community between seasons and years using Simpson's diversity index (D).
The data points are the mean diversity index for each class of watering history (refer to Table 17, p. 94) and the weather context from each watering year is shown as band across the top of the graph. 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.
Error bars represent ± the standard error. The absence of error bars either means they are smaller than the symbol size or there is only one data point.
Note that data are not shown for the peak of the flood event in Spring 2016 (Flood Peak), because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

9.3.1.2 Tree community

A total of 156 understorey species were identified across the tree community plots during the 2017-18 watering season compared with 181 species identified during the 2016-17 watering season, with 166[3] species identified during the 2015-16 watering season and 137 species identified during the 2014-15 watering season. The greatest number of species during spring sampling were recorded in 2017 (141 species) and in autumn during sampling in 2018 (85 species).

The greatest number of species were recorded at Lake Ita Inlet (33) in the Lachlan Valley State Conservation Area in Spring 2017 and at Lake Bullogal (24) in Autumn 2018. Of note was again the recording of Mossgiel daisy (*Brachyscome papillosa*) at Lake Ita Inlet which is a species listed as vulnerable in NSW[4] and has only been recorded since the 2016-17 floods. In addition, common (or Narrow-Leaved or Aromatic) peppercress (*Lepidium hyssopifolium*) was found at Clear Lake near the Great Cumbung Swamp which is also a species listed as endangered in NSW.

In Spring 2017 the groundcover in the tree community was dominated by asters (old man weed *Centipeda cunninghamii*, yellow twin heads *Eclipta platyglossa,* spear thistle *Cirsium*

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[3] Four species not identified in 2015-16 were identified in 2017 and are included here.
[4] https://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10106

vulgare, and tall groundsel *Senecio runcinifolius*), chenopods (mainly saltbushes *Einadia nutans subsp. nutans, Atriplex semibaccata,* black roly-poly *Sclerolaena muricata,* and nitre goosefoot *Chenopodium nitrariaceum*), then grasses (blown-grass *Lachnagrostis filiformis*, barley grass *Hordeum leporinum*, common couch *Cynodon dactylon*, and sweet swamp-grass *Poa fordeana*). Brassicas, mainly smooth mustard *Sisymbrium erysimoides* and yellow cress *Rorippa palustris*, and knotweeds (Small Knotweed *Polygonum plebeium*) were the next most common.

In Autumn 2018 the chenopods became more numerically dominant, followed by asters, nightshades (black-berry nightshade *Solanum nigrum*), verbena and spurges (caustic weed *Euphorbia drummondii*).

Sites that have only received water from natural flooding during the LTIM monitoring show reasonably consistent site scale groundcover vegetation diversity (Simpson's diversity index) across years with the exception being in autumn 2016 when the diversity was low (Figure 37) across both watering categories. The diversity of vegetation at sites that have received one environmental watering action (in 2015-16) over the four year period resulted in the lowest diversity in Spring 2016 when the sites were under water (Figure 37). The diversity at these sites had increased by autumn 2017.

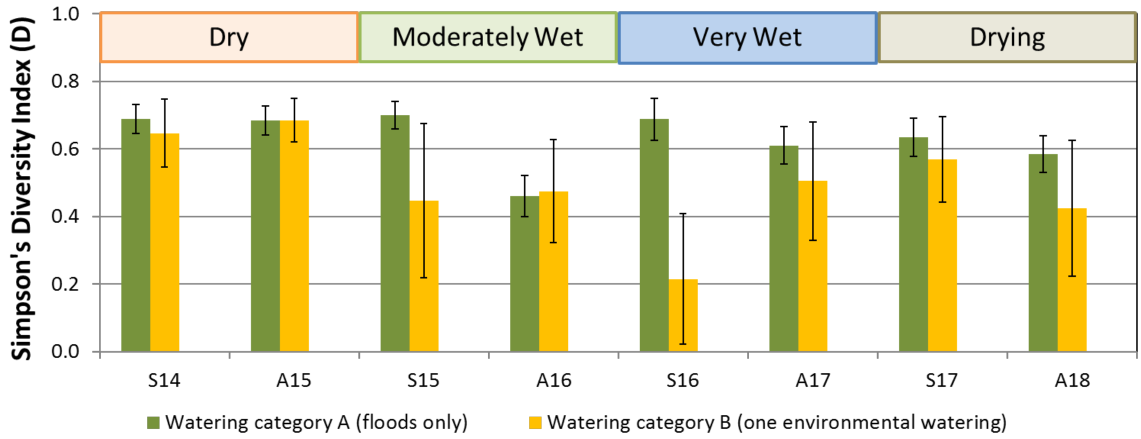

Figure 39. Comparison of groundcover vegetation diversity in the tree community between seasons and years using Simpson's diversity index (D).
The data points are the mean diversity index for each watering treatment (refer to Table 17, p. 94). Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018.
Error bars represent ± the standard error. The absence of error bars either means they are smaller than the symbol size or there is only one data point.

9.3.2 VEGETATION COMMUNITY DIVERSITY

9.3.2.1 Nativeness and functional types: non-tree community

Overall groundcover decreased between spring 2017 and autumn 2018, with the loss of amphibious and terrestrial damp species (such as Australian mudwort *Limosella australis* and ferny buttercup *Ranunculus pumilio*) as the floodplain and associated wetlands dried out (Figure 38). Groundcover appears to be returning to be similar proportions to those observed during the 2014-15 dry phase at all sites, including at Nooran Lake which was partially watered in 2017-18. There was no obvious effect of the past four years of watering frequency on the response of the groundcover vegetation.

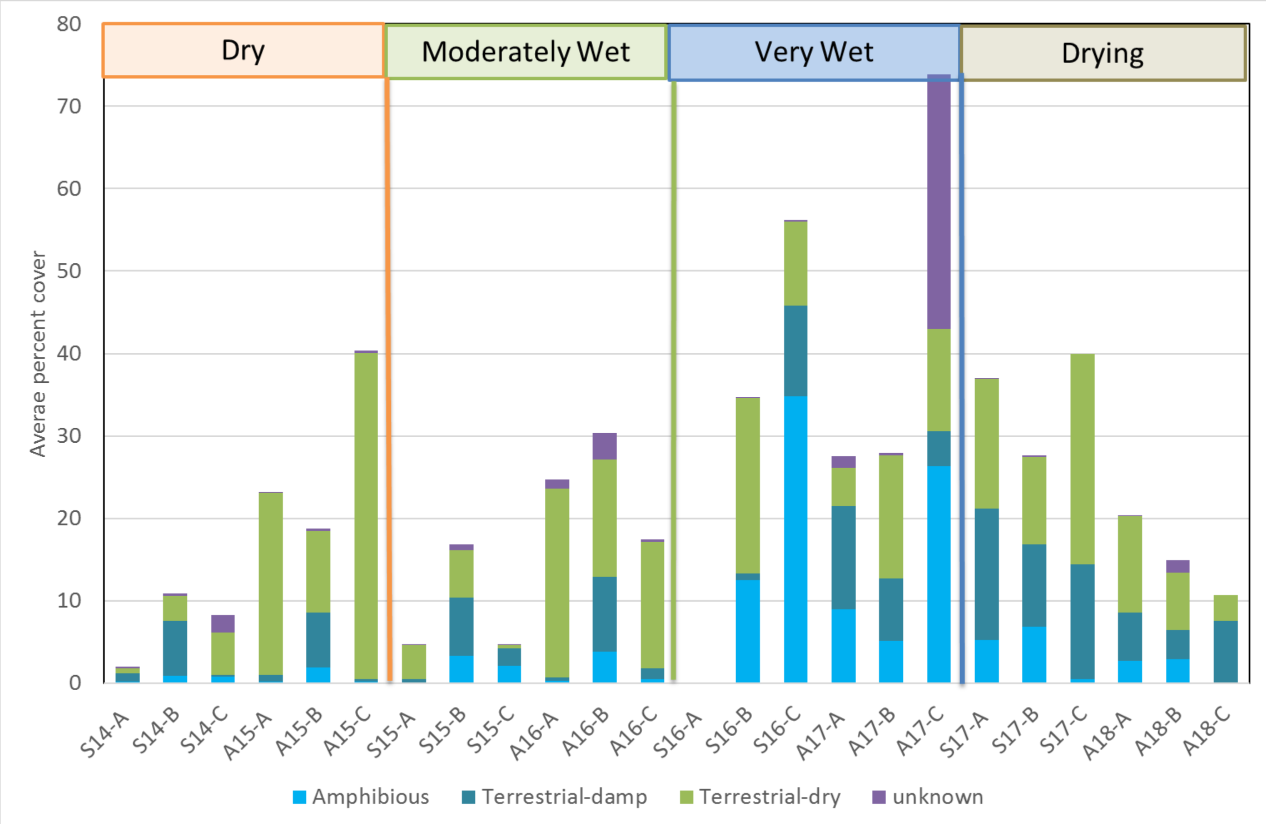

Figure 40. Average percent cover of terrestrial and amphibious species within the non-tree community for sites from each watering history over the sampling period.
Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018.
Watering treatments are defined as A, B and C (refer to Table 17 for explanations, p. 94).
Unknown represents species that were unable to be identified to a suitable level for classification.
Note that data are not shown for the peak of the flood event in Spring 2017. This is because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

More than 60% of the vegetation cover at the monitored sites in 2017-18 was native and this increased to as high as 95% in autumn 2018 at some sites. There was no noticeable influence of the past four years of watering history on the proportion of native species present during the drying phase (Figure 40). It was noted that some sites which had been inundated for a long period of time had a very low number of exotic plants present as they dried (Figure 41). For example, field observations at Lake Tarwong, which has previously had a large number of thistles present (e.g. spear thistle *Cirsium vulgare*) in the deeper parts of the wetland had very few present during the autumn surveys. It is thought that the long duration of flooding removed the thistle seedbank and favoured native species (large numbers of blue-rod, *Stemodia florulenta*, were present instead). This pattern was not consistent across sites (Figure 41), making it difficult to recommend durations to minimise exotic species.

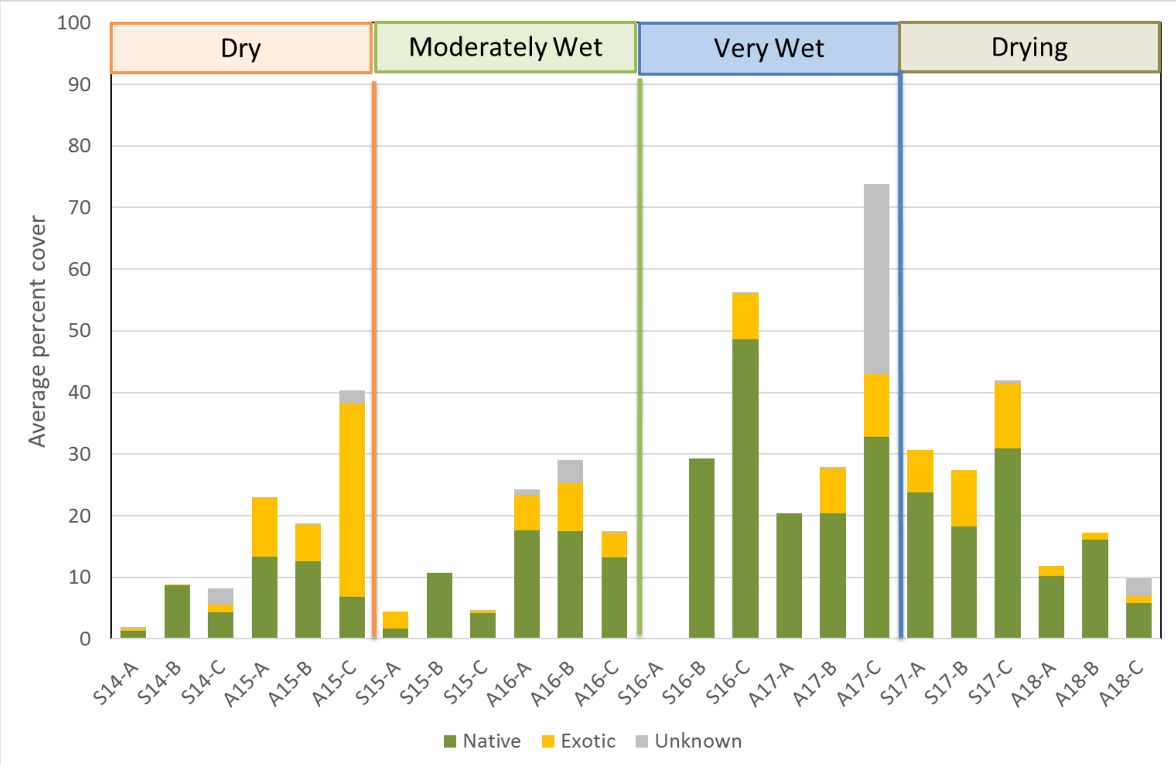

Figure 41. Average percent cover of native and exotic species for the non-tree communities for sites from each watering history over the sampling period.
Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018.
Watering treatments are defined as A, B and C (refer to Table 17 for explanations, p. 94) Note that data are not shown for the peak of the flood event in Spring 2016 (Flood Peak), because the sites were either inaccessible or under more than 0.7 m of water and did not have any 'groundcover' vegetation present.

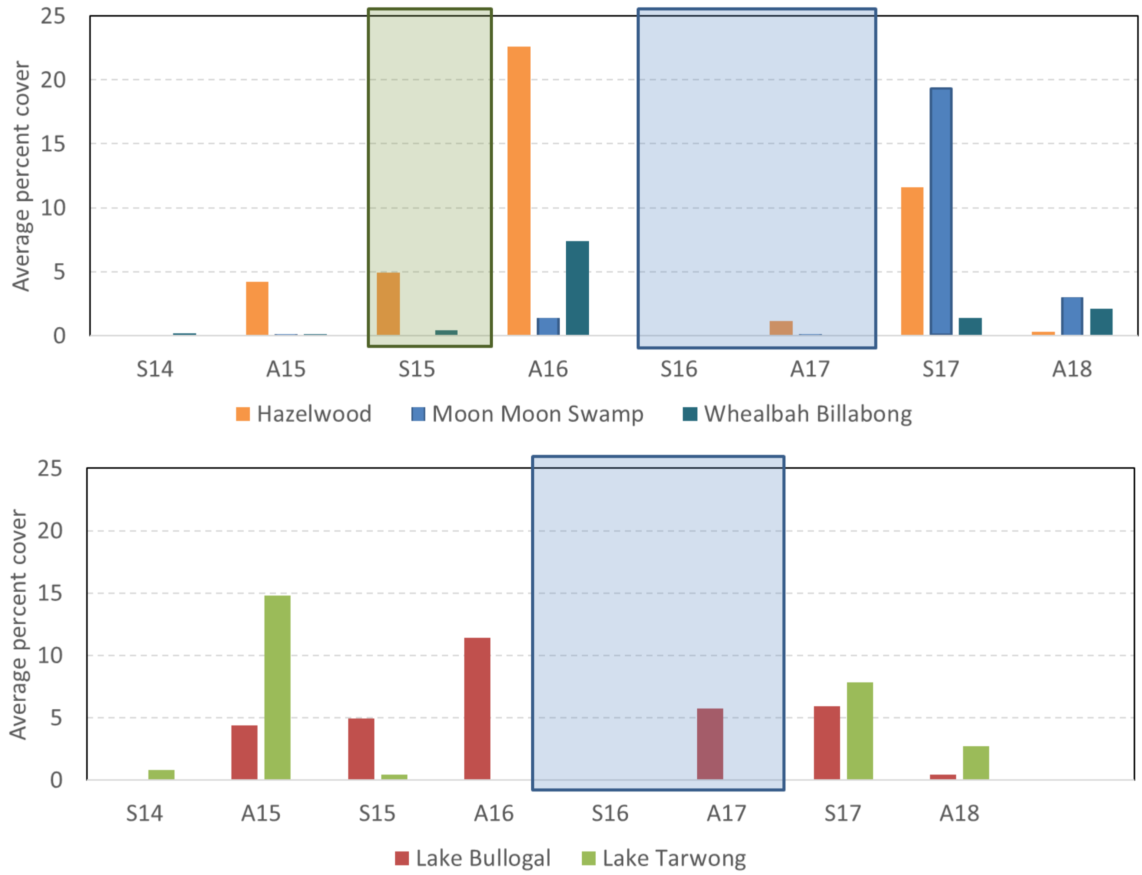

Figure 42. Average percent exotic cover at sites inundated for long periods of time by environmental water (green band) and floodwaters (blue band).
The upper graph shows sites inundated in 2015-16 and in 2016-17 and the lower graph shows sites only inundated in 2016-17.

9.3.2.2 Nativeness and functional types: tree community

Within the tree community, the groundcover decreased between spring 2017 and autumn 2018 with the loss of amphibious species and a reduction in the cover of terrestrial damp species as the sites dried out. Groundcover within the tree community in autumn 2018 was similar to that recorded at the commencement of monitoring in 2014-15, reflecting the return to dry conditions. Sites that had been watered more frequently (watering category B, Figure 42) retained a greater proportion of terrestrial-damp species in 2017-18 than sites watered less frequently (watering category A, Figure 42)

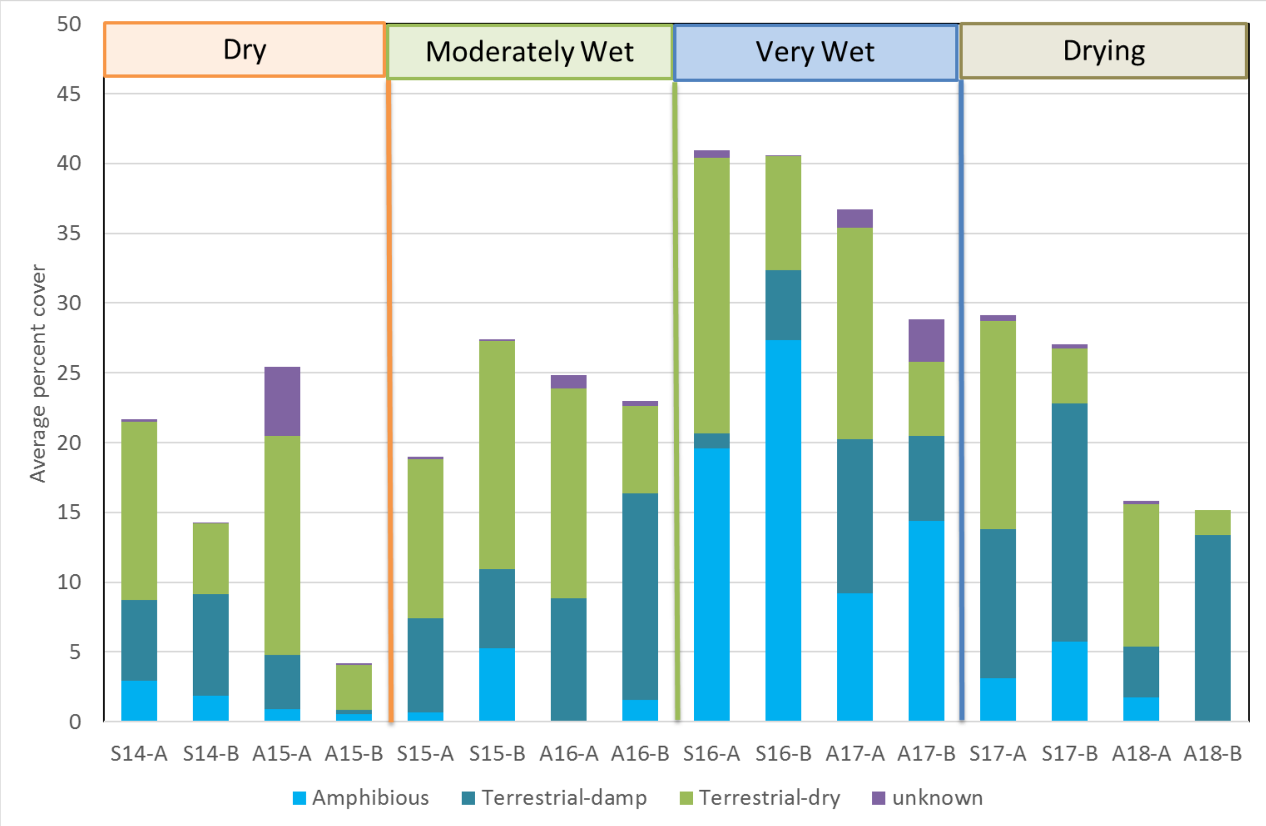

Figure 43. Average percent cover of terrestrial and amphibious species within the tree community for sites from each watering history over the sampling period.
Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018.
Watering treatments are defined as A and B (refer to Table 17 for explanations, p. 94).
Unknown represents species that were unable to be identified to a suitable level for classification.

A very high degree of nativeness was maintained into the drying phase with more than 70% of the groundcover vegetation made up of native species (Figure 43). It is noted that very few exotic species were recorded in the Autumn 2018 sampling and more than 95% of the groundcover was native species.

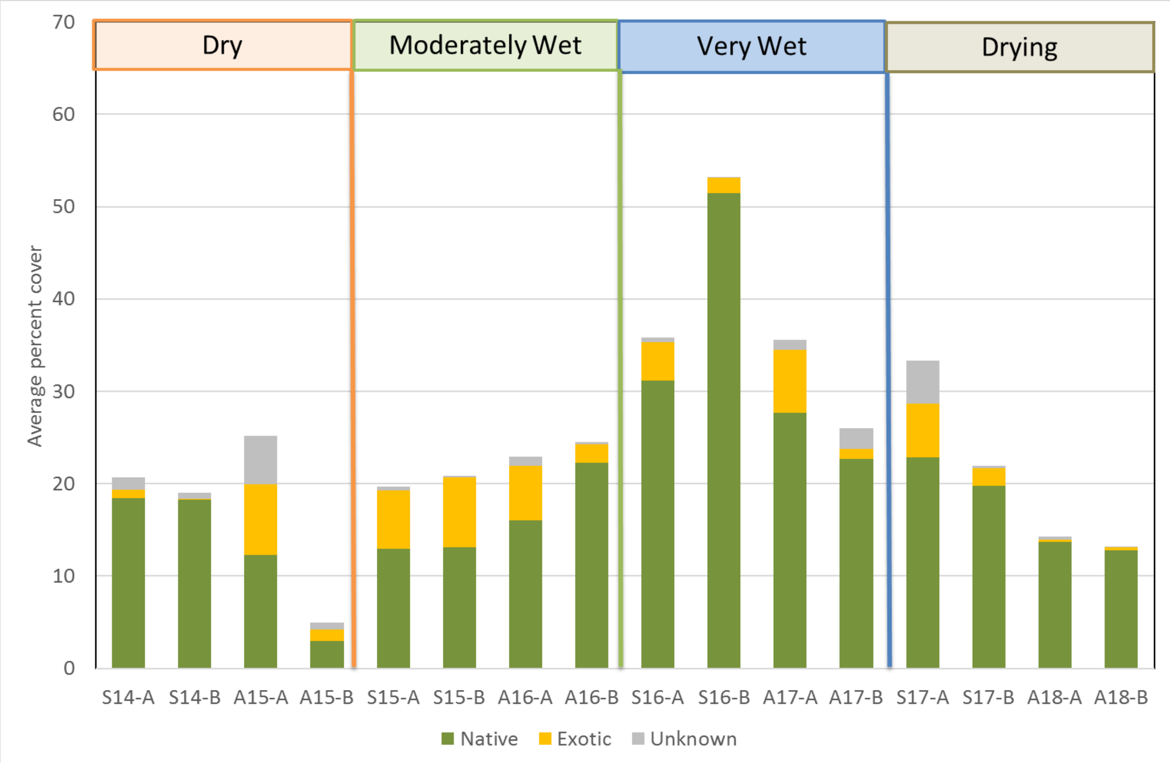

Figure 44. Average percent cover of native and exotic species for the tree communities for sites from each watering history over the sampling period.
Seasons are defined as S14: Spring 2014; A15: Autumn 2015; S15: Spring 2015; A16: Autumn 2016; A17: Autumn 2017, S17: Spring 2017, A18: Autumn 2018.
Watering treatments are defined as A and B (refer to Table 17 for explanations, p. 94)

9.3.3 CONDITION OF FLOODPLAIN AND RIPARIAN TREES

The percent foliage cover decreased slightly in 2017-18 at all sites, compared with 2016-17 in response to the drying of the catchment (Figure 42). Sites that have only been watered with natural flood events display more marked changes in foliage cover in response to the prevailing catchment conditions than the sites that have received environmental water.

There was no change in the proportion of dead canopy between 2016-17 and 2017-18 (Figure 43).

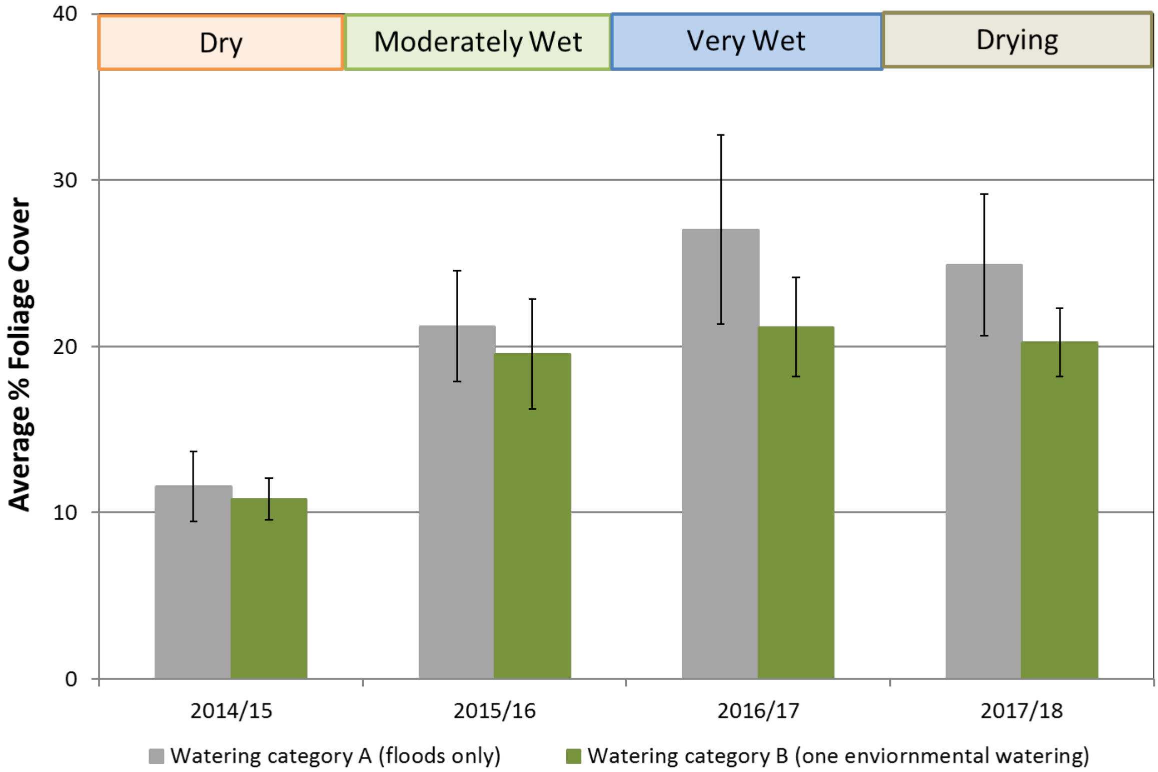

Figure 45. The percent foliage cover over the four monitoring seasons for the woodland vegetation community sites from the two different watering categories.
Watering treatments are defined as A and B (refer to Table 17 for explanations, p. 94)

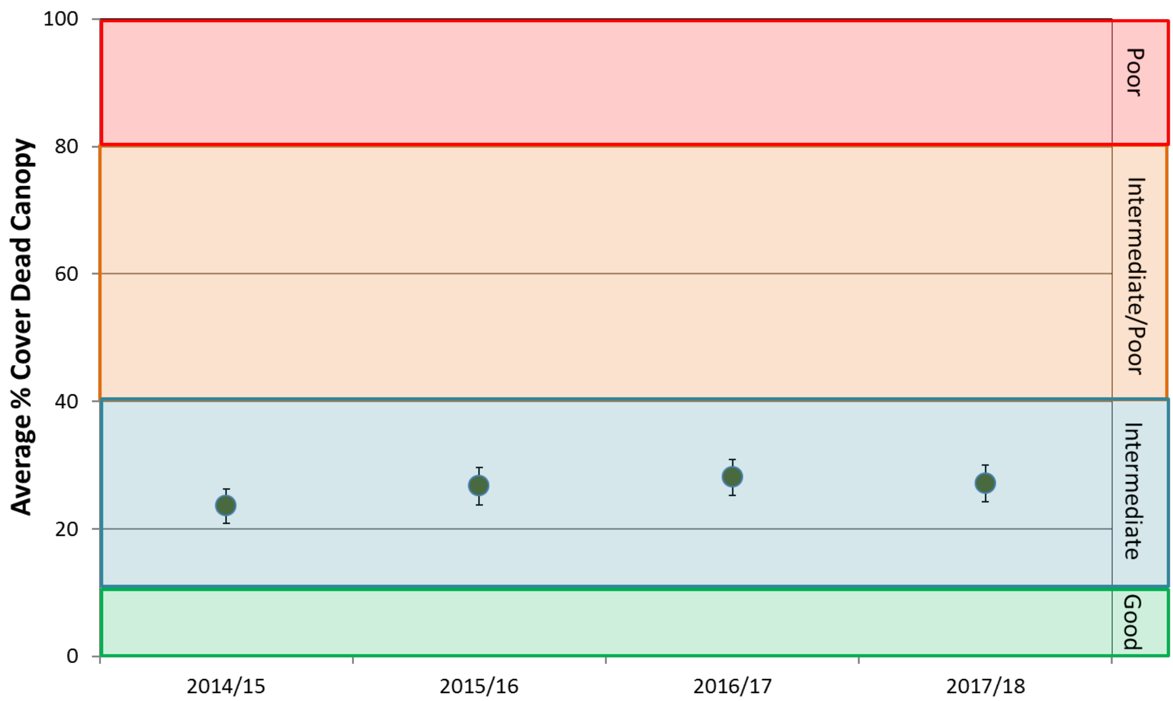

Figure 46. Change in the percent dead canopy over the four monitoring seasons for the woodland vegetation community of the Lower Lachlan river system.
Condition classification after Bowen (2010) is shown by coloured bands (see Table 18, p. 97).

9.3.4 CONTRIBUTIONS TO LONG LIVED PLANTS

There was a marked response of seedlings to flooding, particularly in river red gum communities with sites at which the floodwaters recently receded (particularly at Lake Ita and Lake Tarwong) recording large numbers of seedlings. Very few seedlings were observed at Moon Moon swamp at which floodwaters had recently receded, which likely reflects landuse at the site (Table 20).

Some of the black box seedlings which germinated in the 2016-17 flooding have survived into Autumn 2018.

Table 20. The average number of seedlings and saplings per site.

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

9.4 DISCUSSION

The catchment annual weather and hydrological conditions are strong drivers of vegetation cover and community composition. Greater vegetation cover is present during wetter conditions and when there is residual water in the landscape (through the drying phase) than in years when the sites have been dry. The appearance of amphibious and terrestrial-damp plants in both the tree and non-tree community suggests there is a seedbank that is able to respond to flooding or environmental watering and these species are present during the wetter phases and into the drying phase. This suggests some resilience of the floodplain and wetland plant community in the Lower Lachlan river system.

In 2017-18 a decision was made to allow sites to complete a natural drying phase following the floods of 2016-17 and Commonwealth environmental water was not used for specific vegetation outcomes. However, the watering actions delivered in 2017-18 passed through the river system to the Great Cumbung Swamp and were expected to provide benefit to the central reed beds.

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

Both of the watering actions delivered in 2017-18 resulted in water reaching the Great Cumbung Swamp, contributing water to the central reed beds as well as Nooran Lake, Clear Lake, Spell Paddock and open water bodies adjacent the river channel (see the Hydrology Technical report: Section 5). Watering action 1 made a significant contribution to water in the lower lying wetlands and in the absence of this water, these wetlands would have continued to dry out. Watering action 2 contributed water to these wetlands again in June 2018 continuing to keep them wet.

The only monitored site to have received water in 2017-18 was at Nooran Lake. This is the only site to be defined as having been received water in every year of monitoring (Watering Category C, Table 17). The vegetation data from Nooran Lake (as the site representing watering Category C) suggests that overall weather conditions were a greater driver of vegetation response in 2017-18 than environmental watering at this site (see sections 9.3.1.1 and 9.3.2.1). This information should be used with caution. It is based on data from a single site, which is at the margin of the extent of the watering and was only partially inundated by the watering action and thus has limited inferential power.

A deliberate decision was made in 2017-18 to not provide environmental water to wetlands other than through the end of system flow to the Great Cumbung Swamp. This enabled the majority of wetland sites to complete a natural drying phase following the major floods of 2016-17. This appears to have been a robust decision. It did not result in a reduction in tree condition in the catchment and the groundcover vegetation shifted towards a more terrestrially dominated plant community with a corresponding reduction in plant cover.

9.4.2 VEGETATION RESPONSES TO ANNUAL WEATHER AND HYDROLOGICAL CONDITIONS

The data collected from monitoring activities enabled documentation of the response of the vegetation at the LTIM vegetation monitoring sites through a drying phase and contributes to a broader discussion around considering environmental watering actions for vegetation.

The flooding of 2016-17 produced a distinct response in the vegetation as it peaked and receded. There were notable differences between sites that had been inundated to greater than 0.4 m and those with shallow inundation. The influence of the flood on the groundcover vegetation persisted through spring 2017 as sites still retained water. As sites dried through 2017-18, the number and cover of amphibious and terrestrial-damp species have declined and been replaced by a more terrestrial-dry dominated community. This has been accompanied by a reduction in groundcover vegetation. This was most evident in autumn 2018 after a particularly dry summer.

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

9.4.3 THE INFLUENCE OF COMMONWEALTH ENVIORNMENTAL WATER IN THE CONTEXT OF RECENT WATERING HISTORY

1) What did Commonwealth environmental water, in the context of the recent watering history of the sites, contribute to vegetation species diversity in 2017-18?

There was an increase in the number of groundcover plant species recorded in 2017-18 in the non-tree community compared with 2016-17. Conversely there was a decrease in the number of groundcover plant species observed in the tree community. Site scale diversity at sites which received shallow, relatively short duration of flooding in 2016-17 (watering category A) remained relatively consistent throughout 2017-18. The vegetation diversity at watering category B sites (which had received environmental water in 2015-16 and floodwaters in 2016-17) declined slightly during 2017-18 and remained lower than category A sites. In contrast, the site scale diversity at the only wetland to receive environmental water in both 2015-16 and 2017-18 (Nooran Lake, the only site in watering category C) increased markedly in diversity in autumn 2018, returning to the levels of diversity observed in the drier times of 2014-2016. This appears to be driven by a shift in the vegetation community from a wet phase dominated by a few aquatic and amphibious species (and no terrestrial species) to a community which still retains some aquatic and amphibious species, but has an increasing number of terrestrial species.

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

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

The monitored sites retained a high degree of nativeness in 2017-18. More than 70% of the vegetation cover within the tree community comprised native species and 60% within the non-tree community. This increased to more than 90% within both communities in autumn 2018. The proportion of native species was reasonably consistent across sites with different recent watering histories which suggests that recent watering history has not influenced the nativeness of the groundcover vegetation.

There was a decrease in the cover and number of amphibious and terrestrially damp species in 2017-18 compared with the previous year, reflecting the drying of the catchment and a return to a dominance of terrestrial dry species. This was observed across all sites, irrespective of recent watering history.

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

There was a slight decline in tree condition in 2017-18 with a reduction in foliage cover. This follows the improvements noticed over the previous two seasons in response to wetter conditions. Watering history does not appear to have influenced the response of foliage cover when considered in the context of the response to annual weather conditions. There was no discernible change in dead canopy cover between 2015-16, 2016-17 and 2017-18 and all sites remain classified as being in intermediate condition based on the condition classification of Bowen (2010).

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

Tree seedlings were observed at all sites in 2017-18 and included black box, river red gums and river cooba seedlings. The greatest response was observed within the Lake Ita red gums and at Lake Tarwong, however this response may also have been a function of the timing of our visit in relation to the drying of the wetlands. At the time of survey, these wetlands had not long dried out and there was still residual moisture at the sites to support seedling growth. At most other sites, the numbers of seedlings had declined from the surveys conducted in autumn 2017, an expected response to drying, and in some cases to herbivory.

9.4.4 FURTHER COMMENTS AND RECOMMENDATIONS

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

9.4.4.1 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 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. This can be incorporated into the existing 'river run' approach to annual hydrograph planning.

9.4.4.2 Recommendation 2: Further enable a multiple outcome focus for watering actions

The design of flow regimes within the river system that target multiple outcomes is a feature of environmental water planning that is developing in sophistication within the Lachlan system. Planning forums, such as Technical Advisory Group (TAG) meetings, tend to be focussed on single outcomes (e.g. fish) and **it is recommended that discussions and related decision making at forums to become multiple outcome in focus, rather than the current single outcome focus** (e.g 'fish TAG' and/or 'fish flow') approach.

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

Landscape position influences the depth and duration of watering and the vegetation that occurs at them. The vegetation present within the sequences of dry and wet phases differs depending on the landscape position and the current approach to evaluating the changes has provided some valuable understanding to date but needs to be considered within a landscape diversity context for future watering actions. **It is recommended that landscape vegetation diversity be a consideration when setting objectives for vegetation outcomes and that a nested set of objectives may be appropriate.**

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

It is also noted that the establishment of objectives for wetland vegetation has been the subject of work by the EWKR 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.**

9.4.4.5 Recommendation 5: Future water use should be based on a combination of field observations and sequences of wet and dry conditions.

At the time of writing this report (October 2018), the Lachlan catchment has continued into a drying phase. If water availability continues to decline into 2019-20, the provision of flows to these vegetation sites may prove to be important in maintaining their health as the catchment potentially transitions from dry to very dry conditions. Subject to an assessment of monitoring sites in summer 2018, environmental water holders may want to:

- consider the provision of flows to vegetation sites that are showing a decline in tree condition as they continue to dry. These flows may be provided in May-June or July-August 2019 and in conjunction with stock and domestic replenishment flows if also being provided at that time.
- consider maintaining flows to wetland vegetation sites that received environmental water in 2015-16 and 2017-18 (Nooran Lake) to determine if the longer term provision of water to these sites maintains or continues to increase vegetation diversity at these sites.

9.4.4.6 Recommendation 6: Consider exotic weeds when using environmental water

Flows may have the capacity to assist with managing invasive weed species at certain sites, through a combination of appropriate timing, duration and depth. Environmental water managers may want to:

- consider the option of trialling an experimental design that would enable the impact of flows to manage invasive weed species and the re-establishment of native plant species.

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

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

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

There are a number of factors other than the provision (or not) of environmental water, including herbivory, that can impact on the vegetation response observed at monitoring sites. Environmental water managers may want to:

- consider the option of trialling an experimental design that would enable the impact of excluding herbivory (e.g. the use of herbivore exclusion fencing) to be examined in relation to the associated use of environmental water at monitoring sites.

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11 APPENDIX A: EXPECTED OUTCOMES FROM USING COMMONWEALTH ENVIRONMENTAL WATER IN THE LACHLAN CATCHMENT 2017-18

The following text is taken from the *Commonwealth Environmental Water Portfolio Management Plan: Lachlan River 2017-18* (Commonwealth of Australia, 2017) regarding expected outcomes relevant to the Lachlan catchment from the *Basin-wide Environmental Watering Strategy* (MDBA 2014). This document is no longer publicly available and the text is provided here as context for the 2017-18 watering actions.

Expected outcomes from the Basin-wide environmental watering strategy (MDBA 2014) that are relevant to the Lachlan catchment are described below.

11.1 RIVER FLOWS AND CONNECTIVITY

Baseflows are at least 60 per cent of the natural level.

A 10–20 per cent increase in the frequency of freshes, bankfull and lowland floodplain flows.

11.2 VEGETATION

Maintain the current extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain.

Improve condition of black box, river red gum and lignum shrublands.

Improved recruitment of trees within black box and river red gum communities.

Increased periods of growth for non-woody vegetation communities that closely fringe or occur within the river and creek channels, and for common reed and cumbungi in the Great Cumbung Swamp.

Table 21. Vegetation extent for condition score.

AREA OF RIVER RED GUM (HA)	AREA OF BLACK BOX (HA)	AREA OF COOLIBAH (HA)	SHRUBLANDS	NON–WOODY WATER DEPENDENT VEGETATION
41,300	58,000	N/A	Lignum in the Lower Lachlan	Closely fringing or occurring within the Lachlan River and Willandra Creek; and Common reed and Cumbungi in the Great Cumbung Swamp

Table 22. Vegetation condition score for Black box woodland.

VEGETATION CONDITION SCORE		PERCENT OF VEGETATION ASSESSED (WITHIN THE MANAGED FLOODPLAIN)
0 –6	>6 –10	
72 %	28 %	45 %

Table 23. Vegetation condition score for River red gum woodland.

VEGETATION CONDITION SCORE					PERCENT OF VEGETATION ASSESSED (WITHIN THE MANAGED FLOODPLAIN)
0 – 2	>2 – 4	>4 – 6	>6 – 8	>8 – 10	
3 %	8 %	21 %	41 %	26 %	93 %

11.3 WATERBIRDS

Maintain current species diversity.

Increase Basin-wide abundance of waterbirds by 20–25 per cent by 2024.

A 30–40 per cent increase in nests and broods (Basin-wide) for other waterbirds.

Up to 50 per cent more breeding events (Basin-wide) for colonial nesting waterbird species.

Table 24. Important basin environmental assets for waterbirds in the Lachlan River.

ENVIRONMENTAL ASSET	TOTAL ABUNDANCE AND DIVERSITY	DROUGHT REFUGE	COLONIAL WATERBIRD BREEDING	SHOREBIRD ABUNDANCE	IN SCOPE FOR COMMONWEALTH WATERING
BOOLIGAL WETLANDS	*		*		Yes
GREAT CUMBUNG SWAMP	*		*		Yes
LAKE BREWSTER	*		*		Yes*
LAKE COWAL	*		*		No

As a regulated water storage that also support large Pelican colonies at time, environmental water may be used to order past Brewster flows that would otherwise inundate nesting colonies.

11.4 FISH

No loss of native species.

Improved population structure of key species through regular recruitment, including;

Short-lived species with distribution and abundance at pre-2007 levels and breeding success every 1–2 years;

Moderate to long-lived with a spread of age classes and annual recruitment in at least 80 per cent of years.

Increased movements of key species.

Expanded distribution of key species and populations.

Table 25. Key fish species for the Lachlan River.

SPECIES	SPECIFIC OUTCOMES	IN-SCOPE FOR COMMONWEALTH WATERING IN THE LACHLAN?
Flathead galaxias (*Galaxias rostratus*)	Considered extinct. Reintroduction using southern populations may be an option in the longer term, with the Lachlan a potential candidate site.	Only if re-introduced.
Freshwater catfish (*Tandanus tandanus*)	-	Yes
Golden Perch (*Macquaria ambigua*)	A 10–15 per cent increase of mature fish (of legal take size) in key populations	Yes
Macquarie perch (*Macquaria australasica*)	Range expansion of at least 2 current populations in the Lachlan is a priority. Establish 1–3 additional riverine populations within the Lachlan catchment	Yes
Murray cod (*Maccullochella peelii peelii*)	A 10–15 per cent increase of mature fish (of legal take size) in key populations	Yes
Olive perchlet (*Ambassis agassizii*)	Expand the range (or core range) of existing populations in the Lachlan River.	Yes
River blackfish (*Gadopsis marmoratus*)	-	No
Silver perch (*Bidyanus bidyanus*)	-	No
Southern purple-spotted gudgeon (*Mogurnda adspersa*)	Establish/improve core range of populations in the Lachlan.	Only if populations are established
Southern pygmy perch (*Nannoperca australis*)	Expand the range of the Lachlan populations. Establish 1–3 additional populations in the Lachlan catchment.	Yes
Trout cod (*Maccullochella macquariensis*)	Establish additional populations in the Lachlan	Only if additional populations are established

Table 26. Important Basin environmental assets for native fish in the Lachlan River.

ENVIRONMENTAL ASSET	KEY MOVEMENT CORRIDORS	HIGH BIODIVERSITY	SITE OF OTHER SIGNIFICANCE	KEY SITE OF HYDRODYNAMIC	THREATENED SPECIES	DRY PERIOD / DROUGHT REFUGE	IN-SCOPE FOR C'TH WATER
Lachlan River – Condobolin to Booligal	*	*	*	*	*	*	Y