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Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Evaluation Report 2015-16

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Contents

EXECUTIVE SUMMARY

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool River System Selected Area in 2015-16. It is the second annual report of the Long Term Intervention Monitoring (LTIM) Project funded by the Commonwealth Environmental Watering Office. This project was undertaken as a collaboration among Charles Sturt University, NSW DPI (Fisheries), Monash University, NSW Office of Environment and Heritage, Griffith University and Murray Local Land Services. Field sampling for the project was undertaken by staff from Charles Sturt University, NSW DPI (Fisheries), and NSW Office of Environment and Heritage.

This report provides details of the Commonwealth environmental watering actions, indicators and an evaluation of the ecosystem responses to environmental watering in the Edward-Wakool Selected Area during the 2015-16 watering year with respect to the objectives set by the Commonwealth Environmental Water Office. Results from monitoring undertaken in 2014-15 were included in some sections to provide context and comparison. This report also evaluates additional water quality data that was collected over thirteen weeks between March and May 2016 during a cyanobacteria bloom that extended throughout the Murray system.

A Commonwealth multi-site environmental watering action in the Murray River contributed to a period of discharge above channel capacity from late July through to early November 2015. The environmental watering actions in the Edward-Wakool system for 2015-16 commenced on 4th September and until 10th November used flows returning from the Barmah-Millewa Forest from the Murray River multi-site watering action. Two Commonwealth environmental watering actions delivered from 4 September 2015 to 30 January 2016 were evaluated in this report: i) A watering action in the upper Wakool River (zone 2), that had an operating range of between 50-100 ML d^{-1} at the Wakool regulator, and ii) A watering action in Yallakool Creek with an operating range of between 450-500 ML d^{-1} at the Yallakool regulator. This action influenced the hydrology of Yallakool Creek (zone 1) and the mid Wakool River (zones 3 and 4).

Indicators monitored in 2015-16 for the Edward-Wakool selected Area evaluation were: river hydrology, water quality and carbon, stream metabolism, riverbank and aquatic vegetation, fish movement, fish reproduction, and fish recruitment (Murray cod, golden perch and silver perch). The fish community was monitored in zone three for the basin-scale evaluation. No selected area evaluation for the fish community was undertaken in 2015-16 as this is scheduled to be monitored in only years 1 and 5 of the project.

The responses to Commonwealth environmental watering observed in 2015-16 were consistent with those observed previously in this system.

There were a number of indicators that showed no detectable response to watering (Table i). Commonwealth environmental water delivered to Yallakool Creek in 2015-16 had the following outcomes (Table i):

- Increase in-channel longitudinal connectivity in zones 1, 3 and 4
- Small increases in lateral connectivity through an increase in wetted benthic area in the Wakool River zones 1, 3 and 4

- Mixed response in hydraulic diversity compared to base flow periods. There was increased hydraulic diversity in zones 3 and 4 but reduced hydraulic diversity in zone 1 due to a reduction in the area of slackwater, which is likely to have an adverse impact on taxa that require slackwater habitat for recruitment and survival while benefiting taxa that require faster flowing water
- Maintained dissolved oxygen levels and ecosystem respiration
- Increased dissolved organic carbon, only during the Murray River multi-site watering action
- Increased taxonomic richness and cover of instream aquatic vegetation, particularly in Wakool River zones 3 and 4, but not consistently in Yallakool Creek zone 1.
- Facilitated fish movement from zone 3 over small distances
- Mixed response in fish spawning, with no detectable difference in Murray cod among zones, but significantly fewer larval carp gudgeon in zone 1 Yallakool Creek than in zones 2, 3 or 4, and significantly fewer flathead gudgeon in zone 1 than in zone 4. The reduced number of these larvae in zone 1 may be due to the smaller area of slackwater and slow water in Yallakool Creek during the environmental watering action compared to the other zones.
- Increased number of silver perch recruits in zone 3 and zone 4 of the Wakool River which received Commonwealth environmental water from the Yallakool Creek environmental watering action. This may be in response to the additional slackwater and slow water habitat and vegetation response in these zones.

Commonwealth environmental water delivered to the upper Wakool River Creek through the Wakool regulator in 2015-16 resulted in almost no detectable responses. The only positive outcome was a slight increase in dissolved organic matter observed during the period when the watering action used flows returning from the Barmah-Millewa Forest from the Murray River multi-site watering action (Table i).

The delivery of environmental water is currently constrained by a limited capacity to deliver larger in-channel flow pulses because of potential impacts on third parties. Although the Commonwealth Environmental Water Office has sought to maximize the flows to a level that is acceptable to third parties in the catchment area, current and previous monitoring in this system suggest that larger in-channel flow events will be required to increase the primary productivity in this system. Although small increases in wetted benthic area can be provided under the current operational flow constraints, the use of return flows from Barmah-Millewa Forest from Murray River multi-site environmental watering actions may result in greater productivity gains than small freshes delivered under current operational flow constraints.

The findings underpin recommendations on the timing, duration and magnitude of flow to help inform the adaptive management of future environmental flows in this system. In summary, the eight recommendations were to:

1. Undertake a comprehensive flows assessment for the tributaries of the Edward-Wakool system to better inform future decisions on environmental watering in this system.

2. Trial the delivery of continuous base environmental flows during winter (no cease to flow) in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.

3. Trial the delivery of a short duration environmental watering action in late winter or spring 2017 at a higher discharge than the current operational constraint of 600 $ML.d^{-1}$ (possibly up to 1000 to 1200 $ML\ d^{-1}$). This would facilitate a test of the hypothesis that larger in-channel environmental watering actions will increase river productivity.

4. Trial the delivery of an environmental watering action in the Edward River downstream of Stevens weir to target golden perch and silver perch spawning.

5. Avoid long periods of constant flows by introducing flow variability into environmental watering actions.

6. Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system.

7. Continue to include a water use option in planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events in the Edward-Wakool system.

8. Continue to include a water use option that enables Commonwealth environmental water to be used to mitigate rapid recessions due river operations in the Edward-Wakool system.

Table i. Summary of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16.

Positive response to environmental watering (green)
Mixed response; some adverse and some positive responses to environmental watering (amber)
Negative response to environmental watering (red)
No detectable response to environmental watering (neither positive nor negative response) (grey)
N/A No evaluation undertaken by this project (white)

Indicators	**Dependant variable**	**Response to Yallakool Creek environmental watering (Aug 2015-Jan 2016)**				**Short-term r esponse to Wakool River environmental watering (Aug 2015-Jan 2016)**			
		Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
Hydrology	Hydrological connectivity		N/A			N/A			
	Coefficient of variation of discharge		N/A			N/A			
Hydraulic modelling	In-channel wetted benthic area		N/A			N/A			
	Hydraulic diversity – zone scale		N/A			N/A			
Stream metabolism, water quality, and organic matter characterisation	Rates of gross primary productivity		N/A			N/A			
	Rates of ecosystem respiration		N/A			N/A			
	Dissolved organic matter	during multisite watering	N/A	during multisite watering	during multisite watering	N/A	during multisite watering		
	Dissolved oxygen		N/A			N/A			
	Temperature		N/A			N/A			
	Nutrient concentration		N/A			N/A			
	Modification of type and amount of DOM	during multisite watering	N/A	during multisite watering	during multisite watering	N/A	during multisite watering		
Riverbank and aquatic vegetation	Percent cover of riverbank and aquatic vegetation		N/A			N/A			
	Taxonomic richness of riverbank and aquatic vegetation		N/A			N/A			
Fish movement	Native fish movement		N/A			N/A			
Fish spawning and reproduction	Larval abundance of 'Opportunistic' (e.g. small bodied fish) species		N/A			N/A			
	Larval abundance of ‘flow-dependent’ spawning species (e.g. golden and silver perch)		N/A			N/A			
	Larval abundance of Murray cod		N/A			N/A			
Fish recruitment	Growth rate of young-of-year (YOY) and age-class 1 (1+) Murray cod, golden perch and silver perch		N/A			N/A			
	Recruitment of young-of-year (YOY) and age-class 1 (1+) Murray cod golden perch and silver perch		N/A	Higher silver perch recritment than zone 1 or 2	Higher silver perch recritment than zone 1 or 2	N/A			
Fish community	Fish condition	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Fish recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. INTRODUCTION

1.1 Purpose of this report

The Commonwealth Environmental Water Office (CEWO) has funded a Long-Term Intervention Monitoring (LTIM) Project in seven Selected Areas to evaluate the ecological outcome of Commonwealth environmental water use throughout the Murray-Darling Basin. The LTIM Project will be implemented over five years from 2014-15 to 2018-19 to deliver five high level outcomes:

1. Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authorities (MDBA) Environmental Watering Plan;

2. Evaluate the ecological outcomes of Commonwealth environmental watering in each of the seven Selected Areas;

3. Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin not monitored;

4. Support the adaptive management of Commonwealth environmental water; and

5. Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. It is the second annual report of the Long Term Intervention Monitoring (LTIM) Project funded by the Commonwealth Environmental Watering Office. This project was undertaken as a collaboration among Charles Sturt University, NSW DPI (Fisheries), Monash University, NSW Office of Environment and Heritage, Griffith University and Murray Local Land Services. Field sampling for this project was undertaken by staff from Charles Sturt University, NSW DPI (Fisheries), and NSW Office of Environment and Heritage.

1.2 Structure of this report

This report provides information on Commonwealth environmental watering actions, LTIM study sites and indicators, and an evaluation of ecosystem responses to environmental watering in 2015-16 with respect to the objectives set by the Commonwealth Environmental Water Office in Water Use Minute 10038 (CEWO, 2015). This introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2015-16 (section 2) and an overview of the monitoring and evaluation undertaken in this system for the LTIM project (section 3). Summaries of the evaluation of responses of each indicator to Commonwealth environmental watering in 2015-16 are presented in in sections four to eleven; Hydrology (section 4), water quality and carbon (section 5), stream metabolism (section 6), riverbank and aquatic vegetation (section 7), fish movement (section 8), fish spawning (section 9), Murray cod, golden perch and silver perch recruitment (section 10) and fish community (section 11). A synthesis of the results (section 12) underpins recommendations to help inform adaptive management of environmental water in this system in the future (section 13). Detailed descriptions of results and analyses are provided in technical appendices: Water quality and carbon (Appendix A), Stream metabolism (Appendix B), Riverbank and aquatic vegetation (Appendix C), and Fish (Appendix D).

Results from monitoring undertaken in 2014-15 will be used to provide context and comparison. Predictive modelling will be undertaken in subsequent annual reports when there are several years of data to include in the models.

1.3 Edward-Wakool Selected Area

The Edward-Wakool system is a large anabranch system of the Murray River main channel in the southern Murray-Darling Basin, Australia. The system begins in the Barmah-Millewa Forest, and travels north and then northwest before discharging back into the Murray River (Figure 1.1). It is a complex network of interconnected streams, ephemeral creeks, flood-runners and wetlands including the Edward River, Wakool River, Yallakool Creek, Colligen-Niemur Creek and Merran Creek.

The Edward-Wakool system is listed as an endangered ecosystem, as part of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment' in New South Wales (*NSW Fisheries Management Act 1994*). This system has abundant areas of fish habitat and historically had diverse fish communities which supported both commercial and recreational fisheries (Rowland 2004).

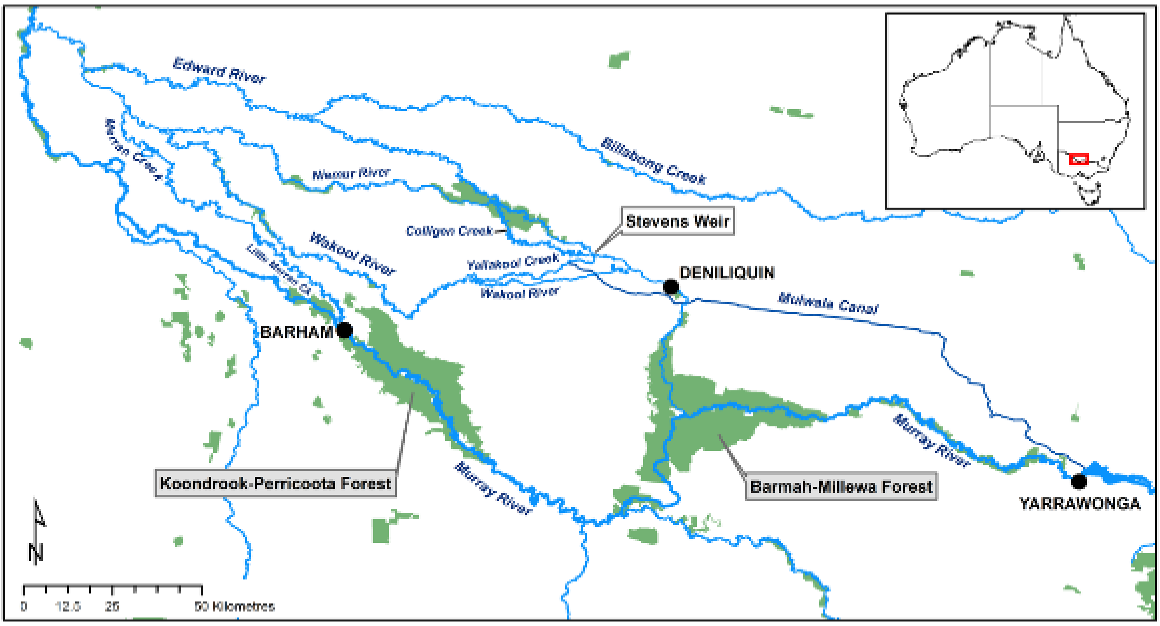


Figure 1.1. Map showing the main rivers in the Edward-Wakool system. (Source: Watts et al. 2013)

Like many rivers of the Murray-Darling Basin, the flow regimes of rivers in the Edward-Wakool system have been significantly altered by river regulation (Green 2001; Hale and SKM 2011). Natural flows in this system are strongly seasonal, with high flows typically occurring from July to November. Analysis of long-term modelled flow data at Deniliquin on the Edward River, showed that flow regulation (post development) has been associated with a marked reduction in winter high flows, including both extreme high flow events, but also average daily flows during the winter period (Figure 1.2) (Watts et al.2015b). There is also an elevated frequency of low to median flows and reduced frequency of moderate high flows (Figure 1.3). These flow changes reflect the typical effects of flow-regime reversal observed in systems used to deliver dry-season irrigation flows (Maheshwari et al. 1995).

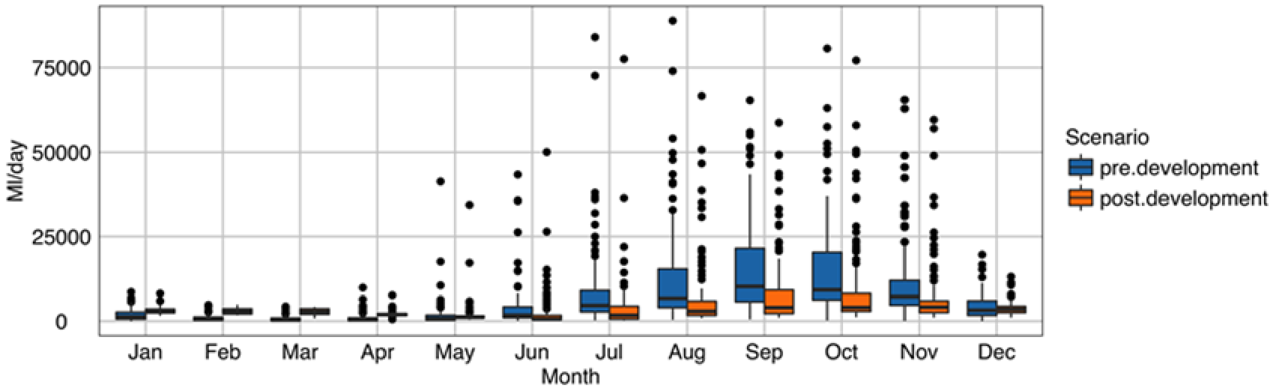


Figure 1.2. Boxplots of mean daily flows by month for the Edward River at Deniliquin. Post-development modelled time-series assumes that all current licensed extractions have been in place for the entire record, and that all licenses are active. (Source: Watts et al. 2015b).

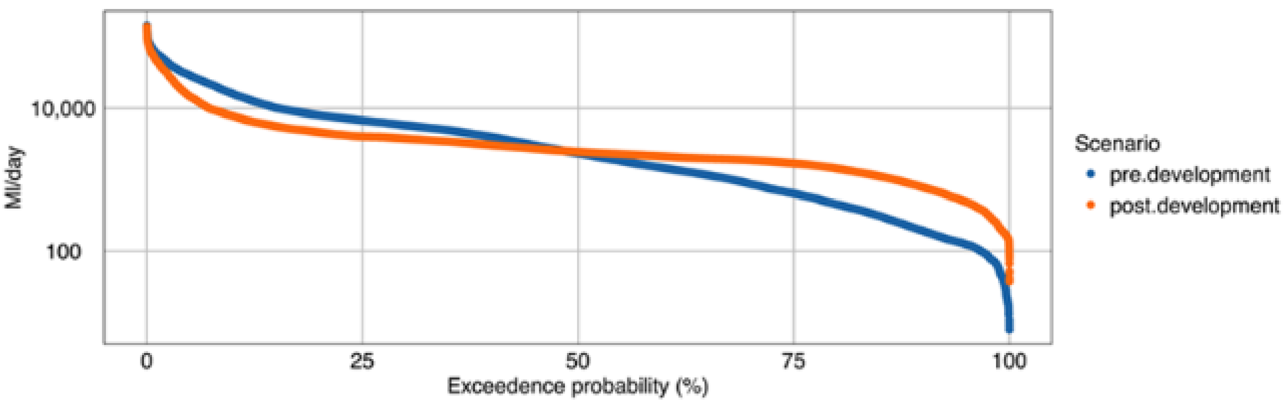


Figure 1.3. Annual flow duration curve for the Edward River at Deniliquin. Post-development modelled time-series assumes that all current licensed extractions have been in place for the entire record, and that all licenses are active. (Source: Watts et al. 2015b).

The Edward-Wakool river ecosystem is recovering from the impact of the Millennium drought in south-eastern Australia, a period from 1998 to 2010 when south-eastern Australia experienced a prolonged drought and flows in the Murray-Darling Basin were at record low levels (van Dijk 2013; Chiew et al. 2014). During the drought there were periods when the regulators controlling flows from the Edward River into tributary rivers such as Yallakool Creek and the Wakool River were closed. For example, between February 2006 and September 2010 there were periods of minimal or no flow (Figure 1.4). At the break of the drought after many years without overbank flows, a sequence of unregulated flow events between September 2010 and April 2011 (Figure 1.4) triggered a hypoxic blackwater event downstream of large river red gum (*Eucalyptus camaldulensis* Dehnh.) floodplain forests (MDBA 2011; Whitworth et al. 2012) (Figure 1.5). These hypoxic blackwater events resulted in the loss of many thousands of native fish, including large individuals of Murray cod (King et al. 2012; Whitworth et al. 2012).

Commonwealth environmental watering actions have occurred in the Edward-Wakool system since 2010 (Figure 1.4). In addition to watering actions specifically targeted for the Edward-Wakool system, water from upstream Commonwealth environmental watering actions that is targeted for downstream watering actions transits through the Edward-Wakool system in some years.

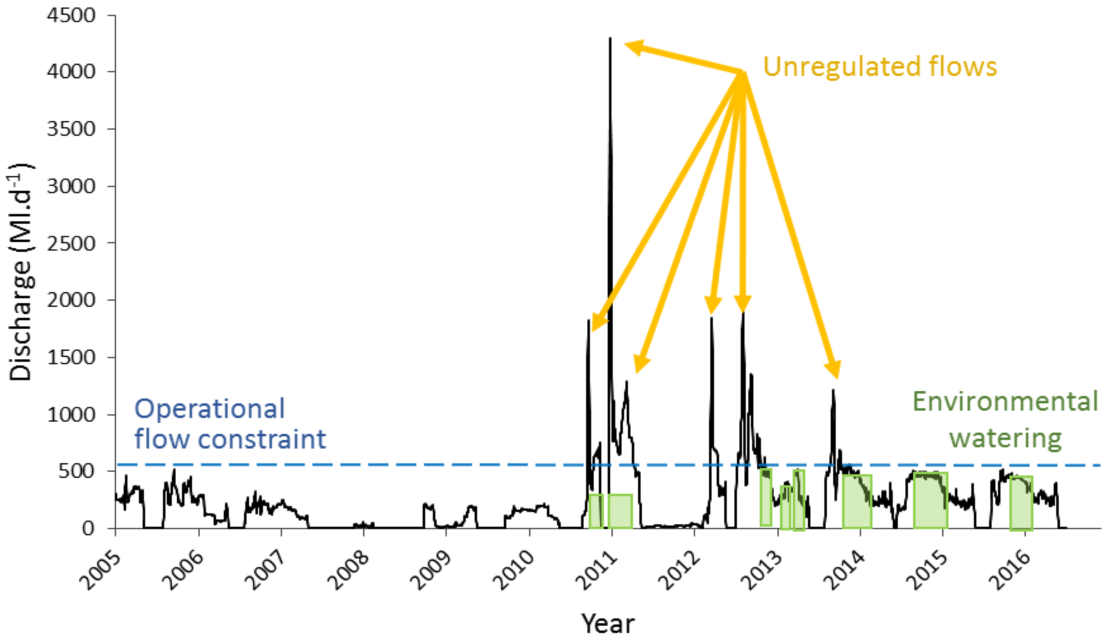


Figure 1.4. Daily discharge (ML.d^{-1}) in Yallakool Creek (gauge 409020 Yallakool Creek @ Offtake) from 1 January 2005 to 30 June 2016, showing period of no flows during the Millennium drought prior to several unregulated flows between 2010 and 2013 and periods of Commonwealth environmental watering between 2010 and 2016 (green shading). There is an operational constraint of 600 ML d^{-1} downstream of the confluence of Yallakool Creek and the upper Wakool River. Daily discharge data was obtained from NSW Office of Water website.

Figure 1.5. Blackwater in the Edward River at Four Posts Reserve in November 2010 (Photo R. Watts).

2. COMMONWEALTH ENVIRONMENTAL WATER USE OBJECTIVES AND WATERING ACTIONS IN THE EDWARD-WAKOOL SYSTEM 2015-16

2.1 Proposed delivery of Commonwealth environmental water and flow objectives in 2015-16

Planning and decision making for Commonwealth environmental water and determining a course of action is influenced by considerations outlined by CEWO (2015) including:

- Environmental water demands and opportunities at specific sites;
- Anticipated environmental demands;
- Climatic conditions across a range of scenarios and current dam storage levels;
- Physical and operational constraints to water delivery;
- Environmental and operational risks;
- Cost versus benefit assessment of each option, within and across catchments; and
- Water account rules and carryover limits.

In 2015-16 the Commonwealth Environmental Water Office considered that there was a moderate to high demand for environmental water in the Edward-Wakool system, particularly to maintain and consolidate the benefits of previous environment watering actions (CEWO 2015). The water resource availability (supply) in the context of meeting environmental demands is contributed by allocations against entitlements held for the environment by the Commonwealth Environmental Water Holder, New South Wales Office of Environment and Heritage, Victorian Environmental Water Holder and The Living Murray, as well as natural and unregulated flows, and planned environmental water provisions (CEWO 2015). Considering carryover of Commonwealth environmental allocations from 2014–15 to 2015–16, the range of potential opening allocations for 2015-16, operational considerations and potential streamflows, it was considered that a moderate resource availability scenario was likely for 2015–16 (CEWO 2015), even though the condition of the Murray–Darling Basin was likely to be dry for the 2015–16 water year (MDBA 2015).

The overall 'purpose' for managing the Commonwealth's water portfolio in the Mid Murray for 2015–16 was to **protect** the floodplain forest areas where demands are high, while **maintaining** ecological health and resilience of other key sites in the system (CEWO 2015). Consistent with the demands and purpose described above, the Office considered supplying environmental water for the following watering actions for Edward-Wakool system and Koondrook-Perricoota in 2015-16 as described by CEWO (2015):

> *Permanent Waterways:* The purpose would be to maintain in-stream habitat, particularly aquatic vegetation and areas supporting the various life stages of native fish. Environmental water use is most likely to contribute to in-channel base flows and freshes. It may also be used to provide a more gradual recession to periods of high

flow (e.g. rain rejection flows) and improve water quality. Environmental water may also be used to assist in the management of natural hypoxic-blackwater events if they occur. Timing: July 2015 to June 2016 (biased late winter to early summer)

Ephemeral waterways and wetlands: The purpose would be to maintain ephemeral in-stream and wetland habitat, particularly water quality, aquatic vegetation and areas supporting the various life stages of native frogs, birds and aquatic invertebrates. Timing: Spring–summer 2015 and/or autumn 2016

Edward-Wakool forests: The purpose would be to maintain vegetation health and to contribute to hydrological connectivity and nutrient/carbon cycling processes. Commonwealth environmental water may be provided to complement the use other flows in Koondrook-Perricoota and Werai forests. Timing: Winter/spring

There were eight proposed environmental watering actions in the Edward-Wakool system in 2015-16 (Table 2.1). As outlined in Water Use Minute 10038, the 2015-16 Commonwealth environmental water use in the Edward-Wakool system expected to achieve the following outcomes:

- maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit
- maintain habitat quality in ephemeral watercourses
- support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity
- support inundation of low-lying wetlands/floodplains habitats within the system
- maintain health of riparian and in-channel aquatic native vegetation communities
- maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH
- maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

Only watering action 4 in the Wakool River and watering action 5 in Yallakool Creek (highlighted) were monitored and evaluated in this 2015-16 Edward-Wakool LTIM report. The expected outcome of watering actions 4 and 5 as described in the Watering Acquittal report for the Edward-Wakool system was '*To compare the spawning response of cod by applying e-flows into the upper Wakool and Yallakool at the same time and to support the ongoing recovery/reestablishment of in stream aquatic vegetation*'(CEWO 2016).

Table 2.1. Summary of proposed environmental watering actions in the Edward-Wakool system as described in Watering Actions Acquittal report (CEWO 2016). Only watering actions 4 and 5 (highlighted) were evaluated in this 2015-16 Edward-Wakool LTIM evaluation report. (Information from CEWO 2016)

	Target asset	Flow component	Timing
1	Edward River	Fresh	June-July
2	Edward River – Stevens Weir	NSW Water to lower and fully open Stevens Weir from 22 June until late July 2015 to facilitate bank drying. Commonwealth environmental water to be used to provide managed flows into the Edward River and refill the weir	June/July
3	Colligen-Niemur	Freshes and recession flows. Flow for early fresh to increase from base flow level to peak of 600 ML/day receding to 400 ML/day. Flow for spring-summer fresh to have a flow range of between a minimum of 400 ML/day and up to 450 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 450 ML/day in 25 ML/day increments every 1-2 weeks.	Spring-summer
4	**Wakool River**	Base flow and Fresh. Flow for spring-summer fresh in upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted.	Spring-summer
5	**Yallakool Creek**	Base flow and Fresh. Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.	Spring-summer
6	Tuppal Creek	Base flow and Fresh. Targeting a release rate of 40-60 ML/day. Flows to remain in channel to minimise third part impacts.	Sept - Nov
7	Tuppal Creek	Base flow and Fresh. Targeting a release rate of 40-60 ML/day. Flows to remain in channel to minimise third part impacts.	Autumn
8	Edward-Wakool River System	Contingency flows to provide refuge habitat and/or slow recessions to high flow peaks	Anytime

2.1 Practicalities of environmental watering in the Edward-Wakool system

The main source of Commonwealth environmental water for the Edward-Wakool system is from the River Murray through the Edward River and Gulpa Creek. Water diverted into the Mulwala Canal can also be delivered into the Edward-Wakool system through “escapes” or outfalls, of which the major escapes discharge to the Edward River, Wakool River and Yallakool Creek (Hale and SKM 2011). The main flow regulating structure within the Edward-Wakool system is Stevens Weir, located on the Edward River downstream of Colligen Creek (Figure 1.1). This structure creates a weir pool that allows Commonwealth environmental water to be delivered to Colligen and Yallakool Creeks, the Wakool River, the Edward River and Werai Forest.

The ability to deliver environmental water to the Edward-Wakool system will depend on water availability and circumstances in the river at any given time. Commonwealth environmental water delivery in this system involves various considerations as outlined by Gawne et al. (2013), including:

- the capacity of the off takes / regulators and irrigation escapes
- channel constraints (e.g. to avoid third party impacts)
- the availability of third party infrastructure to assist in delivering water into the system
- existing flows and other demands on the system.

Delivery of instream flows to the Edward River, Wakool River, Yallakool Creek, Colligen Creek, Niemur River and Merran River system will usually be managed within regular operating ranges as advised by river operators to avoid third party impacts. For example, in the Wakool-Yallkool Creek system the operational constraint is 600 ML d^{-1} (Figure 1.4). Thus, the types of flow components that can be achieved with environmental releases under current operating ranges are in-channel baseflows and freshes (Gawne et al. 2013). Environmental watering may also be constrained due to the limitations on how much water can be delivered into the Edward-Wakool system under regulated conditions. At times of high irrigation demand channel capacity will be shared with other water users. If the system is receiving higher unregulated flows, there may not be enough capacity to deliver environmental water (Gawne et al. 2013). Environmental flows may be delivered to contribute to the slower recession of freshes, delivered during low flow period to provide refuge habitat, or delivered to manage water quality issues, such as algal blooms or hypoxic blackwater events (Gawne et al. 2013).

2.3 Actual delivery of Commonwealth environmental water to the Edward-Wakool system in 2015-16

The delivery of environmental water to the Edward-Wakool system was influenced by natural flows in the Murray River and a multi-site Commonwealth environmental watering action in the Murray River (Figure 2.1).

A hydrograph of the flows in the Murray River downstream of Yarrawonga weir compares the actual release with environmental water to the approximate Yarrawonga modelled natural flow and the actual release without environmental water (Figure 2.1). The overbank flows follow the pattern of modelled natural flows in response to rainfall. Commonwealth environmental watering in the Murray River contributed to a period of discharge above channel capacity from late July through to 5th November. There was a brief period of unregulated flows late July early August.

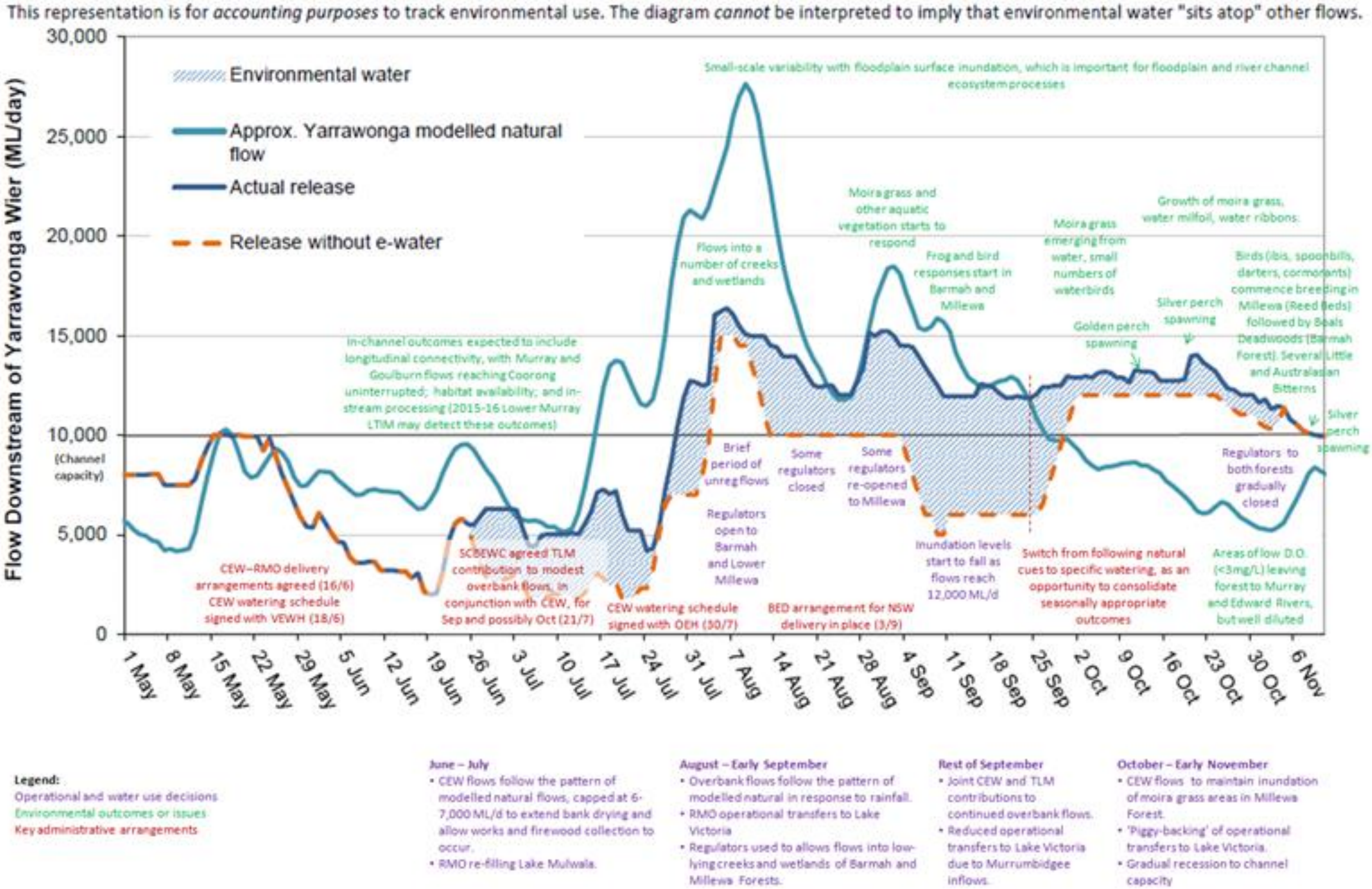


Figure 2.1. Actual flow in the Murray River downstream of Yarrawonga compared to the probable flow in the absence of environmental water**.** (Source CEWO 2016).

The multi-site environmental watering action in the Murray River (Figure 2.1) influenced the use of water in the Edward-Wakool system. There were also a number of key water accounting factors and dates that influenced watering actions in the Edward-Wakool system, including:

- Water accounting arrangements were in place so that when flows for the Barmah-Millewa Forest watering action were above 10,000 ML d^{-1} at Yarrawonga, flows returning from the forest to the Edward River system could be reused for watering actions in the Edward-Wakool River system. This 'return flow period' existed from late July until 10 November.
- From late July until 4 September, flows returning to the Edward River system from the Barmah-Millewa Forest watering action were managed by Water NSW as the River Operator and were not used for Edward-Wakool specific watering actions by the CEWO.
- The environmental watering actions in the Edward-Wakool system for 2015-16 (described in Table 2.2), commenced on 4th September and used flows returning from the Barmah-Millewa Forest watering action until 10th November.
- On 11 November the use of return flows ceased and the environmental watering actions in the Edward-Wakool system for 2015-16 returned to normal water accounting arrangments for the remaining period of these actions.

Of the eight proposed environmental watering actions in the Edward-Wakool system for 2015-16 (described in Table 2.1) only actions 3, 4, 5 and 6 proceeded (Table 2.2). Only environmental watering actions numbers 4 and 5 were monitored by the LTIM Monitoring and Evaluation Project and will be reported on in this report. Targeted environmental watering in the upper Wakool River (proposed action 4, Table 2.1, Figure 2.2) and Yallakool Creek (proposed action 5, Table 2.1, Figure 2.2) occurred from 11th November to 30th January.

Table 2.2. Summary of environmental watering actions in the Edward-Wakool system as described in Watering Actions Acquittal report (CEWO 2016). Only watering actions 4 and 5 (highlighted) were evaluated in this 2015-16 Edward-Wakool LTIM evaluation report. (Information from CEWO 2016)

	Target asset	CEW volume used (ML)	Timing
1	Edward River	0 (action did not proceed)	N/A
2	Edward River – Stevens Weir	0 (action did not proceed)	N/A
3	Colligen-Niemur	15,740 (does not include volume of return flows that were used from start of action until 10 November)	4 Sept to 30 Jan
4	**Wakool River**	**1,444.9 (does not include volume of return flows that were used from start of action until 10 November)**	**4 Sept to 30 Jan**
5	**Yallakool Creek**	**13,004.1 (does not include volume of return flows that were used from start of action until 10 November)**	**4 Sept to 30 Jan**
6	Tuppal Creek	2000	17 Sept to 22 Nov
7	Tuppal Creek	0 (action did not proceed)	N/A
8	Edward-Wakool River System	0 (Contingency flows not required)	N/A

Figure 2.2 shows the proposed versus actual hydrograph for watering action 4 in the upper Wakool River and watering action 5 in Yallakool Creek (CEWO 2016).

Watering Action 4 in the upper Wakool River: As described in the Watering Acquittal report (CEWO 2016) *'Water NSW was given an operating range of between 50-100 ML/day in which to provide variability in the Wakool system for the periods after the September fresh until the recession flows commenced. This was used well by Water NSW early in the watering action (levels reached 100 ML/day over the key spring period) but less so (in terms of providing more variability) towards the end of the watering action. The CEWO originally intended to start this action in early August but delayed the start until 5 September following advice from the Operations Advisory Group, the need to get some baseline vegetation monitoring finished first, and the need for NSW OEH to undertake landholder notifications.'*

Watering Action 5 in Yallakool Creek: As described in the Watering Acquittal report (CEWO 2016) '*Water NSW was given an operating range of between 450-500 ML/day in which to provide variability in the Yallakool system for the periods after the September fresh until the recession flows commenced. It appears that Water NSW opted to deliver most of the planned hydrograph at the lower end of this 'operating range'. This may have been done to ensure that the combined flows of the Wakool and Yallakool did not risk exceeding the 600 ML/day constraint downstream of the confluence of the Wakool and Yallakool. The CEWO originally intended to start this action in early August but delayed the start until 5 September following advice from the Operations Advisory Group, the need to get some baseline vegetation monitoring finished first, and the need for NSW OEH to undertake landholder notifications.'*

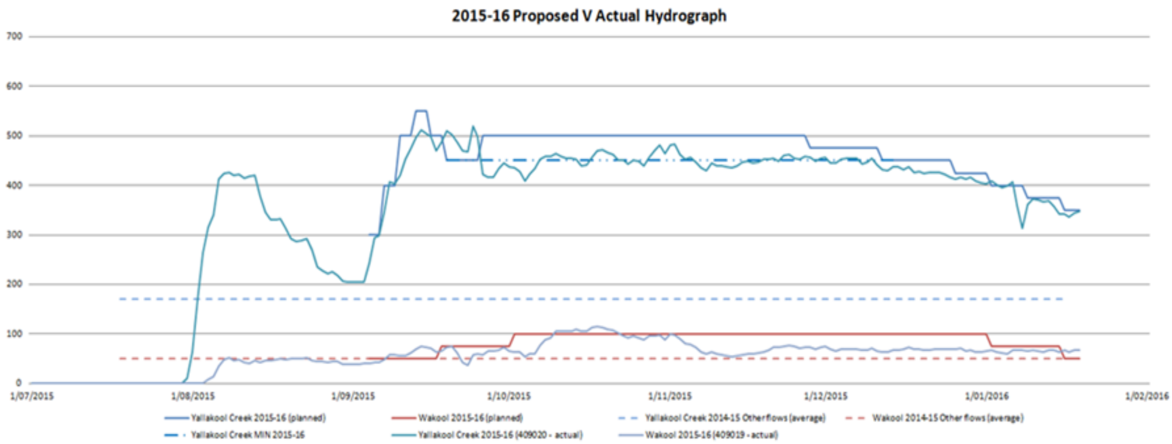


Figure 2.2. Use of Commonwealth environmental water in Yallakool Creek and the upper Wakool River over the primary period using CEW (top hydrograph showing proposed v's actual hydrograph) and the full 2015-16 watering year. (Source CEWO 2016)

3. MONITORING AND EVALUATION

3.1 Monitoring zones and sites

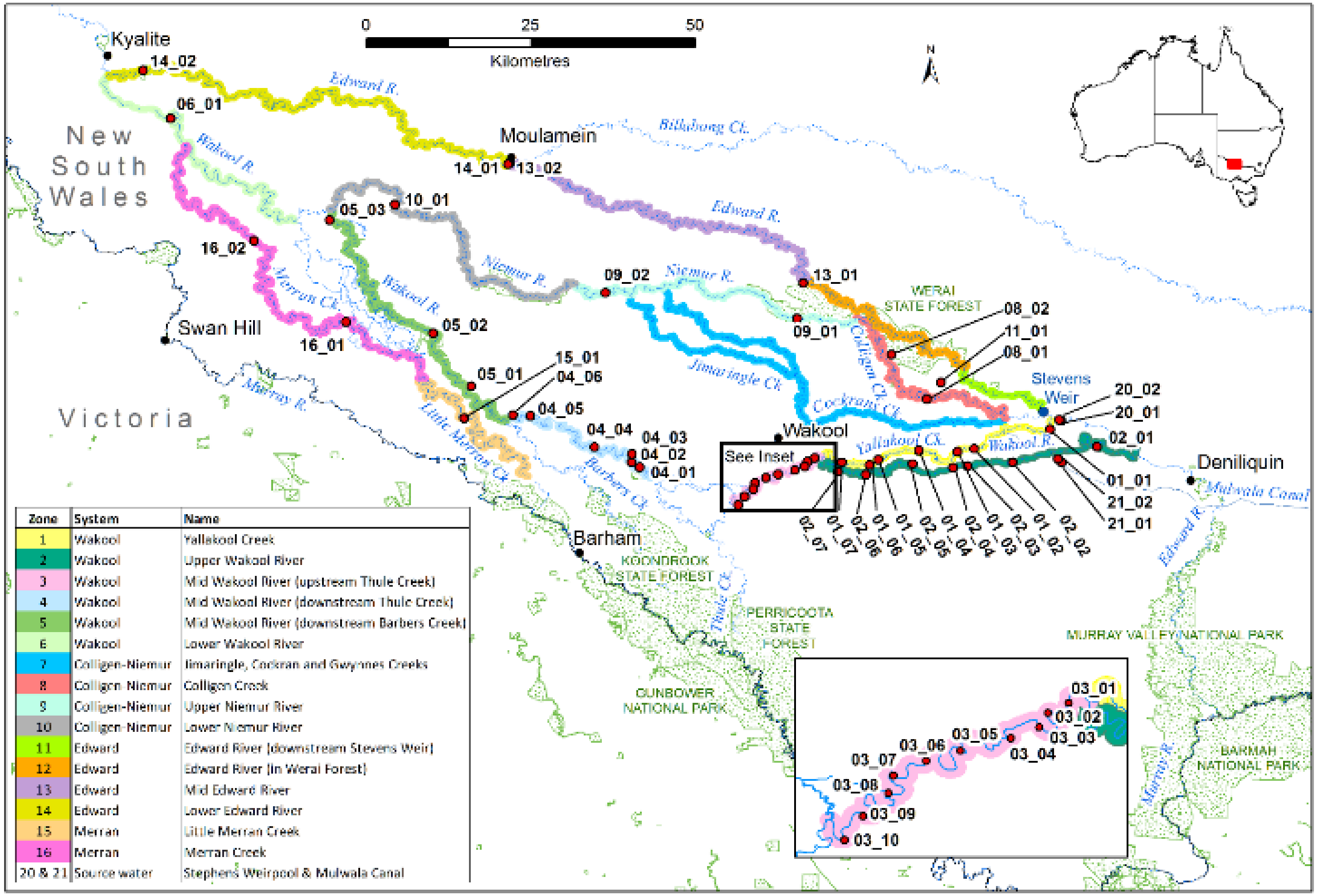
The monitoring of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16 was undertaken as outlined in the Edward-Wakool Long-Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014). The majority of the monitoring in the Edward-Wakool LTIM Selected Area is focussed on four hydrological zones: Yallakool Creek (zone 1), the upper Wakool River (zone 2) and mid reaches of the Wakool River (zones 3 and 4) (Figure 3.1, Table 3.1). Zones one to four are referred to as the focal zone. The reaches in zones 1 and 2 are generally more constrained, have steeper riverbanks and fewer in-channel geomorphic features (e.g. benches) than many of the reaches in zones 3 and 4 (Figure 3.2). In addition to the monitoring undertaken in these four zones, additional sites throughout the Edward-Wakool system will be monitored for fish populations (years 1 and 5), fish movement (years 2 to 5) and for monitoring poor water quality events including the algal bloom monitoring in 2015-16.

3.2 Indicators

The rationale regarding the selection of indicators is outlined in the Edward-Wakool Long Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014). Indicators were monitored to contribute to the Edward-Wakool Selected Area Evaluation and/or the Whole of Basin scale evaluation that is undertaken by the Murray-Darling Freshwater Research Centre (Hale et al. 2014). Some indicators are expected to respond to environmental watering in short time frames (< 1 year), but others (e.g. fish community) are expected to respond over a 2 to 5 year time frame. A summary of monitoring undertaken in 2015-16 is presented in Table 3.3.

There are three categories of monitoring indicators in the LTIM Project:

- **Category I** –Mandatory indicators and standard operating protocols that are required to inform Basin-scale evaluation and may be used to answer Selected Area questions. Category 1 indicators monitored in the Edward-Wakool system (Table 3.2) are: river hydrology, stream etabolism, nutrients and carbon, fish reproduction (larvae) and fish (river).
- **Category 2** –Optional indicators with mandatory standard protocols that may be used to inform Basin-scale evaluation and may be used to answer Selected Area questions. Fish movement (years 2 to 4) is the only category 2 indicator monitored in the Edward-Wakool system.
- **Category 3** – Selected Area specific monitoring protocols to answer Selected Area questions. Category 3 indicators monitored in the Edward-Wakool system (Table 3.2) are: riverbank inundation by 2D-hydraulic modelling (undertaken in year 1), additional water quality and carbon characterisation, riverbank and aquatic vegetation, fish reproduction (larvae), fish recruitment, and fish community survey (years 1 and 5).



Created by Spatial Data Analysis Network, Charles Sturt University, May, 2015

Data Source: NSW "Place Point" & "Hydroline" spatial data: Digital Cadastral Database [CD-ROM], LPMA, 2008, New South Wales; Australian Reserves GEODATA TOPO 250K Series 3, 2006, OEH NSW National Parks 2012

Figure 3.1. Location of monitoring sites for the Edward-Wakool Selected Area for the Long-Term Intervention Monitoring (LTIM) Project. Zones one to four are referred to as the focal zone for the Edward-Wakool project. Hydrological gauges are located in Yallakool Creek just upstream of site 01_01 (gauge 409020, Yallakool Creek at offtake), Wakool River zone 2 just upstream of site 02_01 (gauge 409019, Wakool River offtake), and in the Wakool River zone 4 at site 04_01 (gauge 409045, Wakool River at Wakool-Barham Road). The Wakool escape is located close to site 21_01. Site names are listed in Table 3.1**.**

Table 3.1. List of site codes and site names for sites monitored for the Long term Intervention Monitoring Project in the Edward-Wakool Selected Area.

Zone Name	Zone	Site Code	Site Name
Yallakool Creek	01	EDWK01_01	Yallakool/Back Ck Junction
Yallakool Creek	01	EDWK01_02	Hopwood
Yallakool Creek	01	EDWK01_03	Cumnock
Yallakool Creek	01	EDWK01_04	Cumnock Park
Yallakool Creek	01	EDWK01_05	Mascott
Yallakool Creek	01	EDWK01_06	Widgee, Yallakool Ck
Yallakool Creek	01	EDWK01_07	Windra Vale
Upper Wakool River	02	EDWK02_01	Fallonville
Upper Wakool River	02	EDWK02_02	Yaloke
Upper Wakool River	02	EDWK02_03	Carmathon Reserve
Upper Wakool River	02	EDWK02_04	Emu Park
Upper Wakool River	02	EDWK02_05	Homeleigh
Upper Wakool River	02	EDWK02_06	Widgee, Wakool River1
Upper Wakool River	02	EDWK02_07	Widgee, Wakool River2
Mid Wakool River (upstream Thule Creek)	03	EDWK03_01	Talkook
Mid Wakool River (upstream Thule Creek)	03	EDWK03_02	Tralee1
Mid Wakool River (upstream Thule Creek)	03	EDWK03_03	Tralee2
Mid Wakool River (upstream Thule Creek)	03	EDWK03_04	Rail Bridge DS
Mid Wakool River (upstream Thule Creek)	03	EDWK03_05	Cummins
Mid Wakool River (upstream Thule Creek)	03	EDWK03_06	Ramley1
Mid Wakool River (upstream Thule Creek)	03	EDWK03_07	Ramley2
Mid Wakool River (upstream Thule Creek)	03	EDWK03_08	Yancoola
Mid Wakool River (upstream Thule Creek)	03	EDWK03_09	Llanos Park1
Mid Wakool River (upstream Thule Creek)	03	EDWK03_10	Llanos Park2
Mid Wakool River (downstream Thule Creek)	04	EDWK04_01	Barham Bridge
Mid Wakool River (downstream Thule Creek)	04	EDWK04_02	Possum Reserve
Mid Wakool River (downstream Thule Creek)	04	EDWK04_03	Whymoul National Park
Mid Wakool River (downstream Thule Creek)	04	EDWK04_04	Yarranvale
Mid Wakool River (downstream Thule Creek)	04	EDWK04_05	Noorong1
Mid Wakool River (downstream Thule Creek)	04	EDWK04_06	Noorong2
Mid Wakool River (downstream Barbers Creek)	05	EDWK05_01	La Rosa
Mid Wakool River (downstream Barbers Creek)	05	EDWK05_02	Gee Gee Bridge
Mid Wakool River (downstream Barbers Creek)	05	EDWK05_03	Glenbar
Lower Wakool River	06	EDWK06_01	Stoney Creek Crossing
Colligen Creek	08	EDWK08_01	Calimo
Colligen Creek	08	EDWK08_02	Werrai Station
Upper Neimur River	09	EDWK09_01	Burswood Park
Upper Neimur River	09	EDWK09_02	Ventura
Lower Niemur River	10	EDWK10_01	Niemur Valley
Edward River (downstream Stephens Weir)	11	EDWK11_01	Elimdale
Mid Edward River	13	EDWK13_01	Balpool
Mid Edward River	13	EDWK13_02	Moulamien US Billabong Ck
Lower Edward River	14	EDWK14_01	Moulamien DS Billabong Ck
Lower Edward River	14	EDWK14_02	Kyalite State Forest
Little Merran Creek	15	EDWK15_01	Merran Downs
Merran Creek	16	EDWK16_01	Erinundra
Merran Creek	16	EDWK16_02	Merran Creek Bridge
Edward River, Stevens weir	20	EDWK20_01	Weir1
Edward River, Stevens weir	20	EDWK20_02	Weir2
Mulwala canal	21	EDWK21_01	Canal1
Mulwala canal	21	EDWK21_02	Canal2

Cease to flow (July 2015) **Environmental flow (Dec 2015)** **Operational flow April 2016)**

Figure 3.2. Photos of study sites in the four hydrological zones during the cease to flow(July 2015) and in December 2015 during the Yallakool Creek and Wakool River environmental watering actions. Yallakool Creek (zone 1), Wakool River (zone 2) Wakool River upstream of Thule Creek (zone 3) and Wakool River downstream of Thule Creek (zone 4). (Photos July 2015 Sascha Healy, December 2015 Robyn Watts).

Table 3.2. Summary of indicators to be monitored in the Edward-Wakool system for the Long Term Intervention Monitoring Project from 2014-2019.

Indicator	Method	Zone	Edward-Wakool Selected Area Evaluation	Contribute to whole of basin-scale evaluation	Description
River hydrology	Cat 1	1,2,3,4	✓	✓ (zone 3)	Discharge data will be obtained from NOW website. Water depth monitored using depth loggers and staff gauges.
Hydraulic modelling	Cat 3	1,2,3,4	✓		The extent of within channel inundation of geomorphic features will be modelled for a range of different discharges.
Stream metabolism and instream primary productivity	Cat 1	1,2,3,4	✓	✓ (zone 3)	Dissolved oxygen and light will be logged continuously in each zone between August and March each year.
Nutrients and carbon	Cat 1	1,2,3,4	✓	✓ (zone 3)	Nutrients and carbon samples will be collected monthly and spot water quality monitored fortnightly.
Characterisation of carbon	Cat 3	1,2,3,4	✓		The type and source of dissolved organic carbon will be monitored monthly between August and March.
Water quality and carbon during poor water quality events	Cat 3	1,2,3,4 plus additional zones as required	✓		There is an option for additional water quality and carbon sampling during blackwater or other poor water quality events
Riverbank and aquatic vegetation	Cat 3	1,2,3,4	✓		The composition and percent cover of riverbank and aquatic vegetation will be monitored monthly.
Fish reproduction (larvae)	Cat 1 basin evaluation Cat 3 area evaluation	1,2,3,4	✓	✓ (zone 3)	The abundance and diversity of larval fish will be monitored fortnightly between September and March using light traps and drift nets.
Fish recruitment	Cat 3	1,2,3.4	✓		Young-of-year fish will be collected by back-pack electrofishing and set lines in February and March to develop growth and recruitment indices for young-of-year and age-class 1 Murray cod, silver perch and golden perch
Fish community survey	Cat 1 for basin evaluation Cat 3 for selected area evaluation years 1 & 5	3 (plus 15 sites in year 1 and 5)	✓	✓ (zone 3)	Cat 1 fish community surveys will be undertaken once annually in zone 3 between March and May. An additional 15 sites throughout the system will be surveyed in years 1 and 5 using Cat 3 methods to report on long-term change in the fish community.
Fish movement	Cat 2	1,2,3,4 (plus additional sites funded by Murray LLS)	✓		Movement of golden perch and silver perch will be monitored commencing in spring 2015

3.3 Overview of monitoring undertaken in 2015-16

The monitoring undertaken in 2015-16 is summarized in Table 3.3. The monitoring of for river hydrology, stream metabolism, water quality, riverbank and aquatic vegetation, fish reproduction was undertaken using the same methods as in 2014-15 (Watts et al. 2015). The following outlines the difference between 2014-15 and 2015-16 monitoring:

- No additional hydraulic modelling was undertaken in 2014-15 as the flows delivered were very similar to that in 2014-15.
- Additional monitoring of dissolved organic carbon and nutrients was undertaken fortnightly over a thirteen week period from March to May in 2015-16 during an extended algal bloom in the Murray River system. This included additional samples in Colligen Creek and the Niemur River.
- The fish community survey for the Edward-Wakool Selected Area was not undertaken in 2015-16 as this indicator is monitored only in year 1 (2014-15) and year 5 (2018-19) of the LTIM project.
- Fish movement was not monitored in year 1 (2014-15) of the LTIM project but was established in July 2015 and is evaluated in this report.

Table 3.3. Schedule of monitoring activities For Edward-Wakool Long-Term Intervention Monitoring project for 2015-16 (grey shading). The three categories of indicators are described in section 3.2.

Indicator	Cat	Zones	Schedule of activities											
			J	A	S	O	N	D	J	F	M	A	M	J
River hydrology	1	1,2,3,4	Continuous data from automated gauging stations											
Hydraulic modelling	3	1,2,3,4	Modelling undertaken in 2014-15											
Stream metabolism and instream primary productivity	1	1,2,3,4		Continuous data from loggers										
Nutrients and carbon	1	1,2,3,4		Monthly sampling										
Carbon characterisation	3	1,2,3,4		Monthly sampling										
Additional water quality and carbon characterisation during algal bloom	3	1,2,3,4, 5,8,10								Fortnightly sampling				
Riverbank and aquatic vegetation	3	1,2,3,4		Monthly monitoring										
Fish reproduction (larvae)	1	3					Fortnightly sampling							
Fish reproduction (larvae)	3	1,2,3,4			Fortnightly sampling									
Fish recruitment	3	1,2,3,4												
Fish (river)	1	3												
Fish community survey	3	20 sites	Undertaken in 2014-15 and 2018-19 only											
Fish movement	2	1,2,3,4 (plus additional sites funded by Murray LLS)		Continuous data from acoustic receivers										

3.4 Evaluation of outcomes

Evaluations of the outcomes of Commonwealth environmental watering undertaken in 2015-16 were undertaken for the following indicators:

- Hydrology (Section 4)
- Water quality and carbon (Section 5, Appendix A)
- Stream metabolism (Section 6, Appendix B)
- Aquatic and riverbank vegetation (Section 7, Appendix C)
- Fish movement (Section 8, Appendix D)
- Fish reproduction (Section 9, Appendix D)
- Fish recruitment (Section 10, Appendix D)
- Fish Community data for basin-scale evaluation (section 11, Appendix D).

4. HYDROLOGICAL OUTCOMES OF COMMONWEALTH ENVIRONMENTAL WATER DELIVERED IN 2015-16

4.1 Monitoring

Daily discharge data were obtained from the New South Wales Office of Water website, and data on daily discharge data from the Wakool escape and daily usage of Commonwealth Environmental Water were obtained from WaterNSW. The hydrograph for Yallakool Creek (zone 1) is based on daily discharge data from gauge 409020 Yallakool Creek @ Offtake. The hydrograph for the Wakool River zone 2 is based on discharge data from gauge 409019 Wakool River offtake regulator added to the daily discharge data from the Wakool escape. The daily discharge data for Wakool River zone 3 was estimated by combining daily discharge data from Yallakool Creek regulator, the Wakool offtake and the Wakool escape with an adjustment to account for travel time (4 days) and estimated 20% losses (V. Kelly, WaterNSW pers. comm.) between the regulators and the confluence of Yallakool Creek and the Wakool River. The daily discharge data for Wakool River zone 4 were obtained from gauge 409045 Wakool River at Wakool-Barham Road.

4.2 Main findings

The hydrographs for the four hydrological zones in 2015-16 (Figure 4.1) were very similar to those reported in 2014-15 (Watts et al. 2015). Due to the channel constraints (e.g. to avoid third party impacts) the discharge did not exceed 500 $ML.d^{-1}$ in any of the four zones. This is well below the estimated bankful of 4000 $ML.d^{-1}$ for this system (D. Green, Murray-Darling Basin Authority, pers comm). In May/June of each year there was a sharp rise and fall in discharge in all zones prior to the cease of flow in May/June (Figure 4.1), possibly due to end of watering year operations such as emptying of the Mulwala canal. There was a period of no flow in all four hydrological zones in June and July 2015 (Figure 4.1, Table 4.1, Table 4.2) when the regulators on Yallakool Creek and the upper Wakool River were closed.

In Yallakool Creek zone 1 the hydrograph in 2015-16 was very similar to that in 2014-15 (Figure 4.1). In the upper Wakool River zone 2 there were similar median flows in 2015-16 as in 2014-15, with the exception of the period between April/May 2015 when the MDBA transferred a volume of water via the Wakool escape (Figure 4.1). The Wakool River zones 3 and 4 had a similar shaped hydrograph in 2015-16 to that reported in 2014-15 (Figure 4.1), with the exception that the MDBA water transfer that occurred in April/May 2015 did not occur 2016.

In zones 1, 3 and 4 there was a fresh in August 2015. Section 2.3 of this report provides more detail on the water accounting and use of return flows during this period of time.

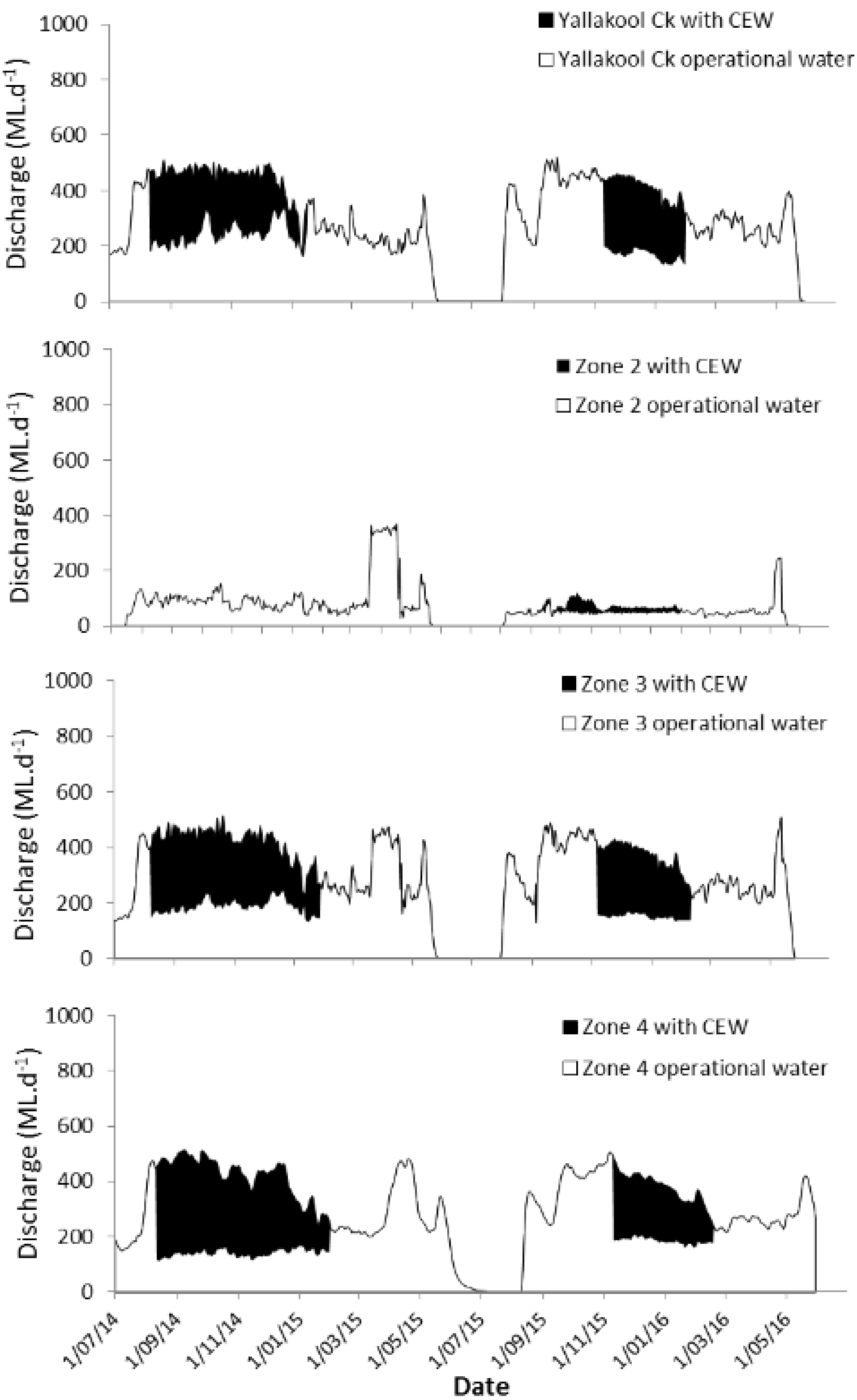


Figure 4.1. Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River for the period from 1 July 2015 to 30 June 2016. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water (CEW) to the Edward-Wakool system for the Yallakool Creek and Wakool River environmental watering actions described in section 2.

The comparison of discharge in the study zones with and without Commonwealth environmental water delivered via Yallakool Creek and Wakool River is confounded because the environmental water returning from Barmah-Millewa Forest watering action is included in the operational water component. That is, prior to 4 September the returning flows were not used by the CEWO as part of Edward-Wakool specific watering actions.

The Yallakool Creek Commonwealth environmental watering action increased the mean and median of discharge in Yallakool Creek, and Wakool River zones 3 and 4 (Table 4.1) While the environmental watering action in Yallakool Creek slightly increased the coefficient of variation in Yallakool Creek, the coefficient of variation in zones 3 and 4 were reduced due to the Commonwealth environmental watering action. At the Yallakool regulator the maximum difference in depth between operational flow (230 ML d^{-1}) and environmental watering (500 ML d^{-1}) was approximately 60 cm (increase from 1.91 m during operational flow to 2.51 m during environmental water).

The small volume of Commonwealth environmental water delivered to the upper Wakool River (zone 2) in 2015-16 had minimal impact on the hydrograph or lateral connectivity in this zone compared to operational flows. The maximum, mean and median discharge in Wakool River zone 2 were all considerably lower than in all of the other zones (Table 4.1). There was very little difference in the mean and median discharge in the Wakool River zone two with and without environmental water, and the coefficient of variation was slightly reduced due to the Commonwealth environmental watering action (Table 4.1). The maximum increase in depth at the Wakool regulator (zone 2) between the operational flow (50 ML d^{-1}) and the environmental watering (100 ML d^{-1}) was approximately 23 cm (increase from 0.56 m during operational flows to 0.79 m during environmental watering).

Table 4.1. Summary hydrological statistics for four hydrological zones in the Edward-Wakool system for the two year period from 1/7/14 to 30/6/2016. Statistics are shown for each zone with and without Commonwealth Environmental Water (CEW). Note that the operational water component includes environmental water returning from the Barmah-Millewa Forest watering action.

Flow variable	Yallakool Creek		Wakool R zone2		Wakool R zone 3		Wakool R zone 4	
	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW
Q_{min} ($ML.d^{-1}$)	0	0	0	0	0	0	0.5	0.5
Q_{max} ($ML.d^{-1}$)	480	520	370	370	508	515	506	514
mean (Q_{mean}) ($ML.d^{-1}$)	231	312	70	74	223	311	217	312
median (Q_{50}) ($ML.d^{-1}$)	240	323	53	64	204	340	197	327
Coefficient of variation	0.42	0.48	0.97	0.91	0.54	0.45	0.55	0.44

The hydrograph for the Wakool River at Gee Gee Bridge (Figure 4.2) was very similar to that for Yallakool Creek and the Wakool River zones 3 and 4 (Figure 4.1). The hydrographs for Coonamit and Stoney Crossing (Figure 4.2) have higher discharge and differ to those for zones 1, 3 and 4. These reaches are more strongly influenced by inflows from the River Murray than flows from Yallakool Creek and Wakool River regulators. At Coonamit and Stoney Crossing there is a period of lower flow in winter, but no cease to flow (Figure 4.2).

The Commonwealth environmental watering action in Yallakool Creek in 2015-16 was very similar to that in 2014-15. Therefore, the instream inundation modelling undertaken in 2014-15 (Watts et al. 2015b) can be applied to the 2015-16 hydrograph. The hydraulic models indicated that the environmental watering action in Yallakool Creek would have resulted in an increase in wetted benthic area in zones 1, 3 and 4 when compared to base flows (Watts et al. 2015b). There was also a reduction in area of slow water (0.02-0.3 $m.s^{-1}$) in Yallakool Creek but an increase in area of slackwater (< 0.02 $m.s^{-1}$),and slow water in Wakool River zones 3 and 4 (Watts et al. 2015b). The environmental watering action resulted in lower hydraulic diversity within Yallakool Creek (zone 1) where there was mainly faster flowing hydraulic habitat, but there was a higher diversity of hydraulic habitats over the whole focal zone.

The instream inundation modelling undertaken in the Wakool River zone 2 in 2014-15 (Watts et al. 2015b) indicated there was minimal difference between the approximate 50 ML d^{-1} base operational flow and the 100 ML d^{-1} discharge with environmental water. Delivery of environmental water to the Wakool River zone 2 is limited by an operational constraint of 600 ML d^{-1} at the confluence of Yallakool Creek and the Wakool River. When the discharge in Yallakool Creek is 500 ML d^{-1} the operational limit in the Wakool River zone 2 is 100 ML d^{-1}.

An evaluation of the outcomes of Commonwealth environmental watering on the hydrology and longitudinal and lateral connectivity in Yallakool Creek and the Wakool River is presented in Table 4.2.

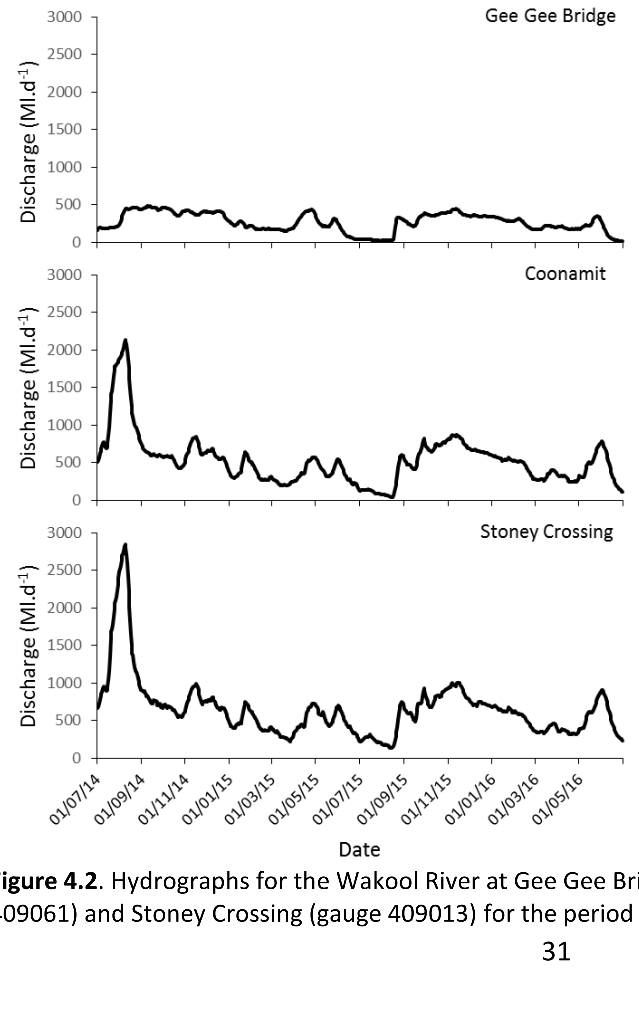


Figure 4.2. Hydrographs for the Wakool River at Gee Gee Bridge (gauge 409062), Coonamit (gauge 409061) and Stoney Crossing (gauge 409013) for the period from 1 July 2014 to 30 June 2016.

4.3 Evaluation

Table 4.2. Expected outcomes of Commonwealth environmental watering on hydrology and connectivity

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Upper Wakool River: Base flow and Fresh Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted. Yallakool Creek: Base flow and Fresh Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity Support inundation of low-lying wetlands/floodplains habitats within the system Maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.	*What is the effect of Commonwealth Environmental Water on the hydrology of the four zones in the Edward-Wakool system that were monitored for the LTIM project?*	CEW had minimal impact on the hydrology of the upper Wakool River zone 2. There were observable differences in hydrological variables in zones 1, 3 and 4 as a result of the Yallakool Creek watering action	Hydrographs comparing reaches with and without CEW	The environmental flow in the upper Wakool River was small magnitude and was not appropriate to achieve expected outcomes due to the flow constraint in the Wakool River. It did not increase lateral connectivity or connect low-lying habitats within the system. The environmental flow in Yallakool creek resulted in an increase longitudinal connectivity and achieved an increase in lateral connectivity in some, but not all reaches.
		What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?	CEW contributed to longitudinal connectivity in Yallakool Ck (zone 1) and the Wakool River (zones 3 and 4). CEW had limited influence on downstream reaches at Coonamit and Stoney Crossing that were more influenced by Murray River flows	Hydrographs comparing reaches with and without CEW.	
		What did Commonwealth environmental water contribute to the in-channel wetted benthic area?	CEW increased wetted benthic area in zones 1, 3 and 4 compared to operational flows. There was considerable variation in the responses in different reaches	In-stream inundation modelling (Watts et al. 2015b)	
		What did Commonwealth environmental water contribute to the area of slackwater, slow flowing water and fast water?	The responses were mixed. CEW increased the area of slackwater and slow water in zone 3 and 4. CEW reduced the area of slow water and hydraulic diversity in zone 1. However, hydraulic diversity was increased over the whole focal zone	In-stream inundation modelling (Watts et al. 2015b)	
		What did Commonwealth environmental water contribute to lateral connectivity	There were small increases in lateral connectivity, in some, but not in all, study reaches	In-stream inundation modelling (Watts et al. 2015b)	

5. SUMMARY OF WATER QUALITY AND CARBON RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

5.1 Monitoring

Water quality parameters were assessed by a combination of continuous logging (temperature and dissolved oxygen) supplemented with spot measurements and collection of water samples (monthly) at two sites within each zone, and from Stevens Weir on the Edward River and the Mulwala Canal for laboratory measurement of: dissolved organic carbon, nutrients and absorbance and fluorescence spectroscopy for organic matter characterisation. Additional weekly monitoring was undertaken at these plus additional sites over thirteen weeks between March and May during a cyanobacteria bloom that extended throughout the Murray system.

5.2 Main findings

This section provides a summary of the main water quality and carbon responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. Detailed findings are presented in Appendix A.

Commonwealth environmental water maintained dissolved oxygen concentrations in zones 1, 3 and 4 during spring and early summer. This was consistent with observations in 2014-15 (Figure 5.1) when the Wakool River zone 2 had lower dissolved oxygen during low flows.

A pulse of dissolved organic carbon (DOC) from the Barmah-Millewa Forest was introduced to the system through the combination of the multi-site watering action and Commonwealth environmental water action in September to December 2015 (Figure 5.2), however no increase in nutrients (nitrogen or phosphorus) was observed over this period (Figure 5.3). The change in DOC concentrations was small and similar to the range observed in 2014-15 but there was a clear increase in all zones that received water from Stevens Weir relative to concentrations in the Mulwala canal, and the pulse of DOC progressed downstream over time.

From late February to May 2016 water quality parameters were influenced by a bloom of the cyanobacteria *Chrysosporum ovalisporum.* This bloom was widespread through the Murray River catchment and originated upstream of these study zones (Figures 5.4, 5.5). The sharp increase in DO observed at the onset of the bloom was a result of the high rates of photosynthesis leading to oversaturation of the water column during the day (Figure 5.1). Hypoxia was not observed following the collapse of the bloom as the bloom decreased gradually in cold water conditions. The high rates of photosynthesis and cell production also increased pH and turbidity. This species of cyanobacteria can fix nitrogen from the atmosphere and a dramatic increase in total N is observed at all sites following the onset of bloom conditions (Figure 5.3). This species is also known to be an efficient scavenger of phosphorus, and total P was also observed to increase slightly in the water column during the bloom event. The bloom contributed substantial quantities of total organic carbon and DOC (Figure 5.2) to the water column and spectroscopic analysis showed that the mixture of compounds making up the DOC (the organic matter profile in the river system) changed considerably during the bloom conditions with a shift to much smaller molecules that absorb light more weakly (less coloured) and are likely to be more readily available to the microbial community in the system.

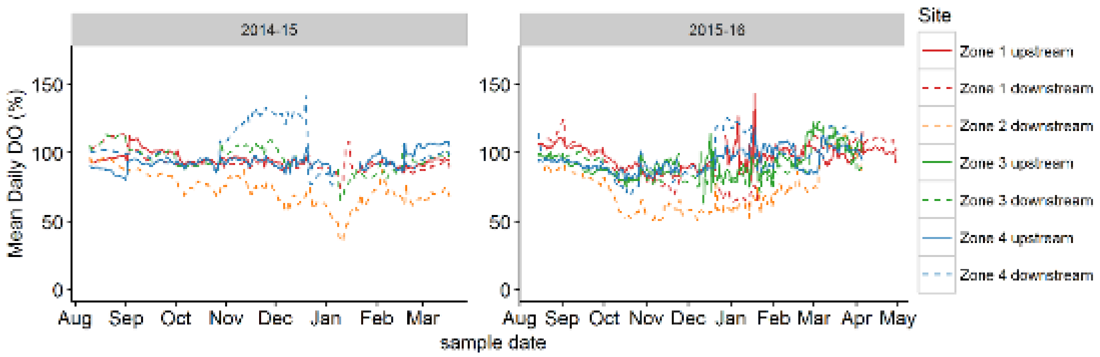


Figure 5.1. Mean oxygen saturation in study zones in 2014-15 and 2015-16. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

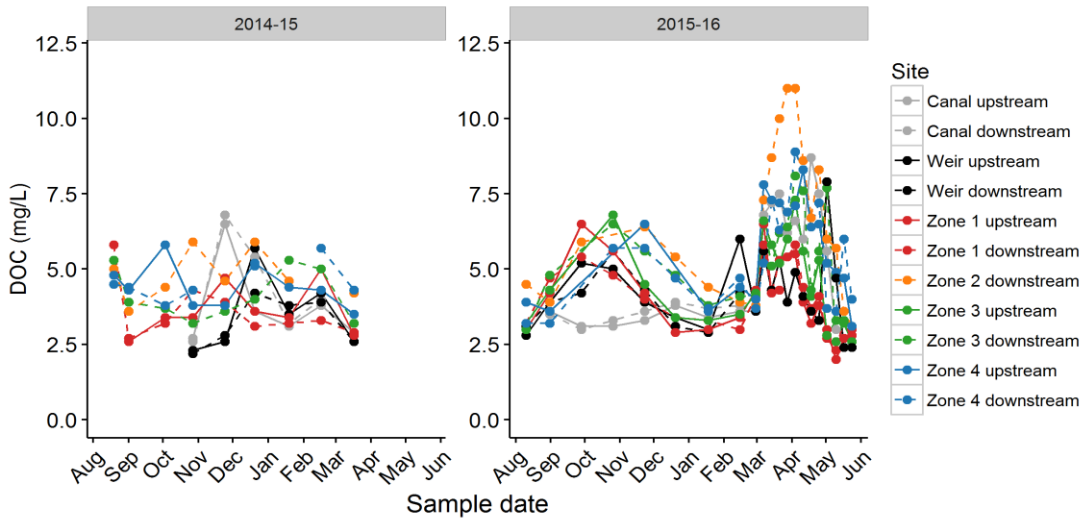


Figure 5.2. Dissolved organic carbon in 2014-15 and 2015-16. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

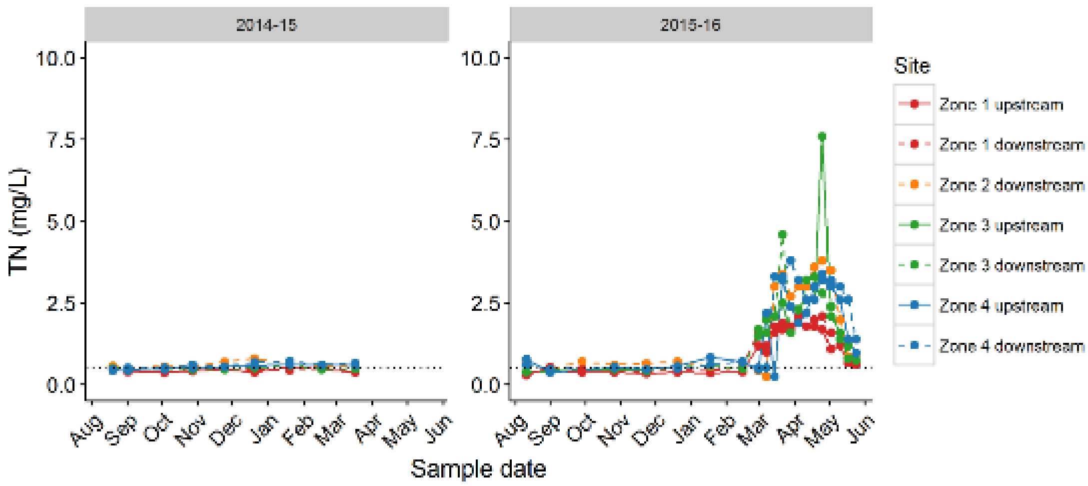


Figure 5.3. Total Nitrogen (mgL^{-1}) in 2014-15 and 2015-16. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

The algal bloom persisted at higher concentrations and for a longer period of time in the Edward-Wakool system than in nearby sites in the Murray River (Figure 5.4). Most sites had more than five times the concentration of blue-green algal cells required to trigger red alert notifications. The bloom started to break down in the Edward River, Yallakool Creek and upper Wakool River prior to the algal bloom break down at sites in the mid and lower Wakool River (Figure 5.4).

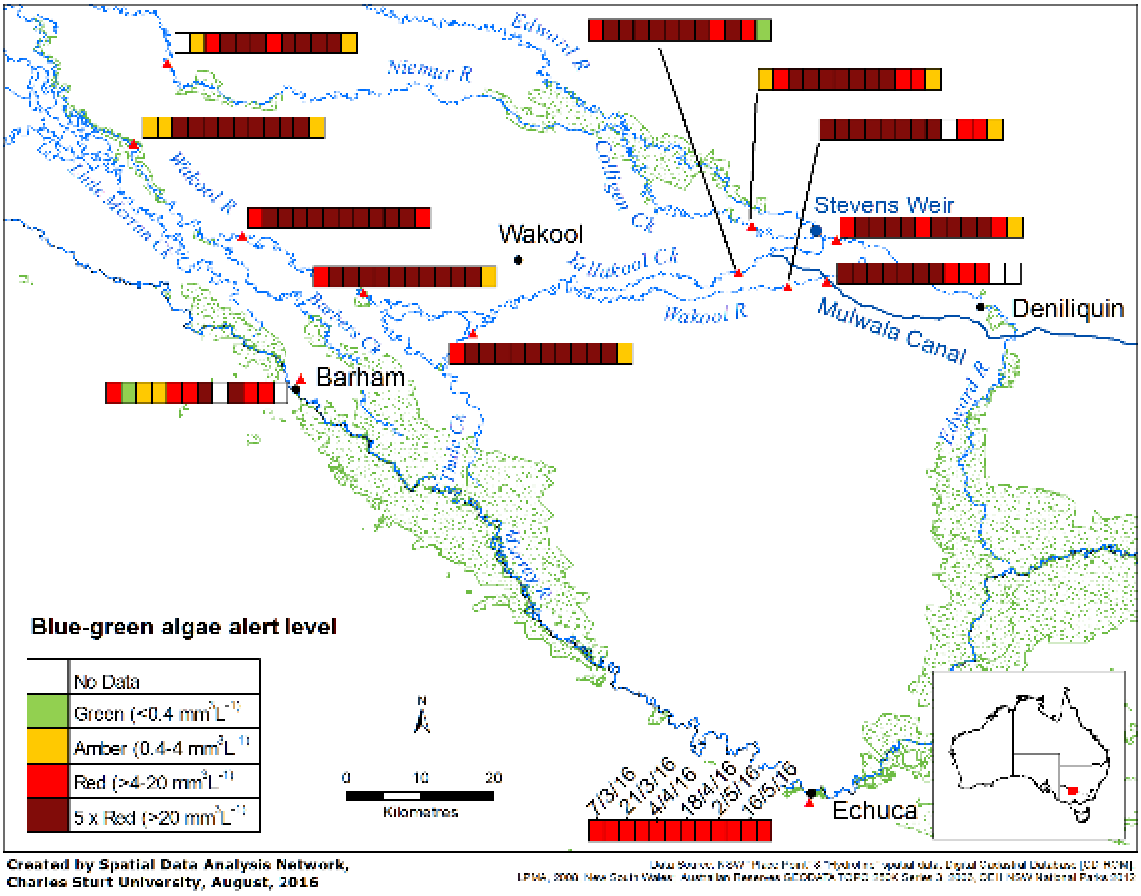


Figure 5.4. Map of bloom conditions in the study region showing weekly blue-green algae alert levels from 7/3/2016 through to 23/5/2016. There were very high biovolumes of blue-green algae in the Edward-Wakool system through to the end of May. The bloom established at much higher biovolumes in the Edward-Wakool system than in the Murray River at Echuca and Barham.

Figure 5.5. Wakool River (Zone 2 site 4) at 'Widgee' on 22/3/16 (Photo J Abell). b) Lower concentration of blue-green algae evident at this site on 17/5/16. (Photo: R Watts).

5.3 Evaluation

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Upper Wakool River: Base flow and Fresh Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted. Yallakool Creek: Base flow and Fresh Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.	To support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity To maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH (Water use minute 10038)	*What did Commonwealth environmental water contribute to temperature regimes?*	Commonwealth environmental water did not influence temperature.	Temperature was similar at all sites regardless of flow.	The environmental flow in the upper Wakool River was small magnitude and was not appropriate to achieve expected outcomes due to the flow constraint in the Wakool River. It did not create additional wetted area of riverbank or provide sufficient flow to maintain DO in the range seen at other sites. Organic matter was influenced by the multi-site watering upstream. The environmental flow in Yallakool creek was sufficient to maintain DO relative to the lower flows seen in the Wakool river (Zone 2). The flow was not sufficient to connect to low-lying floodplain features at this site to introduce additional nutrients to
		What did Commonwealth environmental water contribute to dissolved oxygen concentrations?	Dissolved oxygen concentrations were supported by the Yallakool Creek Base Flow and Fresh	DO was higher in Zones 1, 3 and 4 where the volume of water was higher than in Zone 2.	
		What did Commonwealth environmental water contribute to nutrient concentrations?	Commonwealth Environmental water did not influence nutrient concentrations in 2015-16	Nutrient concentrations were similar across zones and consistent with 2014-15 during the use of Commonwealth environmental water.	
		What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected channel habitat?	Commonwealth environmental water, through the combination of the multi-site watering action and the flows directed specifically at the Yallakool Creek and Wakool River, contributed to the introduction of small amounts of floodplain carbon from upstream in the Barmah-Millewa forest.	DOC concentrations had a small peak that progressed downstream. The organic matter profile over this period reflected input of large, complex humic and fulvic acids which passed through the system from September to December	
		What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?	The timing of the flows through the Barmah-Millewa forest was early enough in the season that carbon inputs were achieved by Commonwealth environmental	Neither very high DOC nor hypoxic DO concentrations were observed.	

			water without causing blackwater in the Edward-Wakool system. Dilution flows from the canal were not required.		the system but some carbon was introduced by the multi-site watering.
		Additional questions for extended algal monitoring			
		Did Commonwealth environmental water contribute to the bloom conditions in the Edward Wakool System?	Commonwealth environmental water did not create conditions responsible for the onset of the bloom of cyanobacteria in February 2016. Nutrient profiles in the system were in the usual range prior to the onset of the bloom, and the bloom was initiated much further upstream than the floodplain connections created by Commonwealth environmental water.	This evaluation was based on data on bloom conditions throughout the Murray system, in addition to water quality parameters before and during the bloom.	
		How did the algal bloom impact water quality in the Edward Wakool system?	The algal bloom caused an increase in Total Nitrogen and Total Phosphorus in the water column through efficient nitrogen fixation from the atmosphere and phosphorus scavenging from the aquatic environment. It dramatically changed the organic matter profile with a shift to much higher proportions of particulate organic matter and the dissolved organic matter became dominated by small molecules. Average dissolved oxygen shifted to supersaturated concentrations and pH moved into the basic region, both with wide diurnal fluctuations during the peak of the bloom. Turbidity was dominated by algal cells during the bloom, limiting the light available for other species.	Water quality parameters changed dramatically during the bloom and all measured parameters were used together to assess the impact of the bloom. Spectroscopic analysis showed a shift in organic carbon type.	

6. Summary of Stream Metabolism Responses to Commonwealth Environmental Watering

6.1 Monitoring

Monitoring of dissolved oxygen concentrations, water temperature and incident solar irradiance was performed at ten minute intervals over the period from mid-August 2015 until early April 2016 at seven sites in four hydrological zones within the Edward-Wakool system. There was a logger at the upstream and downstream end of each of zones 1, 3 and 4, and a logger at the downstream end of zone 2.

Stream metabolism parameters – Gross Primary Production (GPP) and Ecosystem Respiration (ER) - were estimated on a daily basis using the BASEv2 model (Song et al. 2016). Model fits that met LTIM-agreed acceptance criteria were then used for describing stream metabolism, and for assessing effects of watering events and other environmental factors (e.g. season).

6.2 Main findings

This section provides a summary of the main responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. Detailed findings are presented in Appendix B.

A total of 676 separate daily estimates of GPP and ER were obtained from the seven sites. This corresponds to a 45% acceptance rate for daily data – modelled fits to the rest of the data did not meet LTIM acceptance criteria. Figure 6.1 displays the summary of GPP values observed on these 676 days.

Median GPP rates (represented by the horizontal middle line within each 'box') were relatively consistent across 6 of the 7 sites (Figure 6.1). The higher value for Zone 3 upstream was due to that site not having any data during springtime (in contrast to all other sites). Lower GPP rates have been previously observed during spring (Watts et al. 2015). The key point is that GPP rates are at the lower end of the normal range found in river systems throughout the world (typically 3 to 10 mg $O_2.L^{-1}.d^{-1}$)(Lamberti and Steinman 1997). It is highly likely that rates of GPP in the Edward-Wakool system are constrained by the low bioavailable nutrient concentrations. The high 'outliers', shown as circles in the plot, indicate that when conditions are conducive for primary production, rates can be at or above the high end of global normal rates. Ecosystem Respiration showed a similar response (Appendix B).

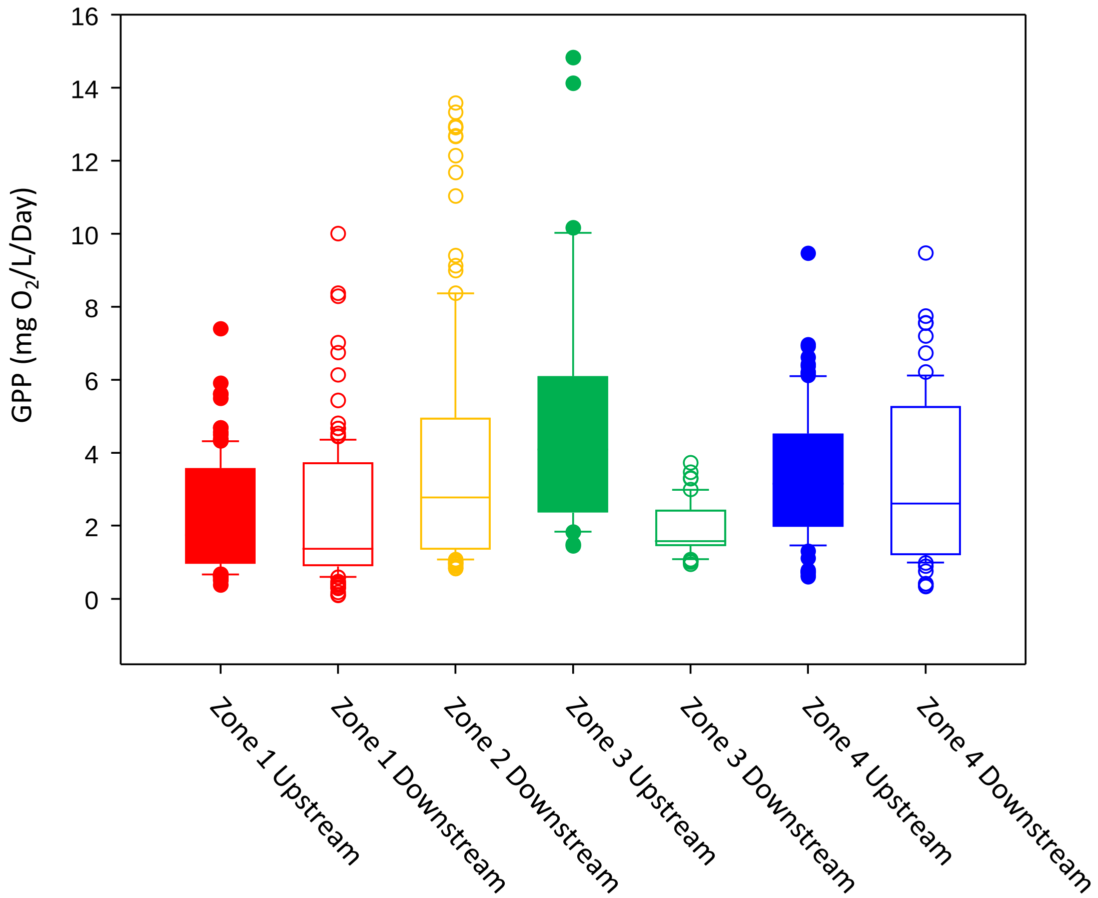


Figure 6.1. Box Plot Summary of Daily GPP rates across all seven sites (4 zones) from August 2015 until April 2016.

There was no consistent effect of Commonwealth environmental water on rates of GPP or ER detected, perhaps largely due to the relatively low variance in discharge through most of the monitoring period. However the absence of a predictable response to environmental watering may be due to other factors, such as variability in wetted benthic area under environmental watering. The Wakool River zone 3 that had the highest median GPP in 2015-16 (Figure 6.1) also had the largest increase in wetted benthic area under the Yallakool Creek environmental watering action (section 4 and Watts et al. 2015b).

The rates of GPP and ER are at the lower end of the normal range observed in river systems throughout the world. More variable in-channel flows, including larger environmental flow events, would result in greater connection with instream features and low lying part of the floodplain and would stimulate these essential processes underpinning aquatic foodwebs. It is therefore recommended that, if possible, there is greater variation in stream flow during subsequent years of the LTIM project.

6.3 Evaluation

CEWO Water Planning and delivery		**Monitoring and Evaluation questions and outcomes**			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Upper Wakool River: Base flow and Fresh Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted. Yallakool Creek: Base flow and Fresh Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.	To support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity (Water Use Minute 10038) *This is related to metabolism but not specifically addressing it*. *No specific targeted outcomes for metabolism* (Watering action acquittal report)	*What did Commonwealth environmental water contribute to patterns and rates of decomposition?*	Changes in ER (ecosystem Respiration) were observed but did not correspond to variation in discharge. Changes were associated with changing season and other instream behaviour (e.g. mid November 2015)	Daily estimates of stream metabolism in seven sites within four zones: one in Yallakool Creek and three in the Wakool River. Measurements were undertaken from mid-August 2015 until early April 2016. All daily estimates of GPP an ER that met agreed acceptance criteria were then assessed for effects of discharge from Commonwealth environmental water (and other flow events)	The environmental flow in the upper Wakool River was small magnitude and was not appropriate to achieve expected outcomes due to the flow constraint in the Wakool River. There was no detected response in GPP and ER to the Yallakool Creek or Wakool River watering actions. Small perturbations in discharge on top of near-continuous daily flow from Oct 2015 through to February 2016 meant that any enhancements in metabolic rates (desired outcome) were masked by daily variability associated with weather and from seasonal changes in these rates (changing temperatures and amounts and intensities of sunlight).
		What did Commonwealth environmental water contribute to patterns and rates of primary productivity?	Changes in GPP (Gross Primary Production) were observed but did not correspond to variation in discharge. Changes were associated with changing season and other instream behaviour (e.g. mid November 2015). Large increases in March 2016 at some sites were associated with the arrival of the algal bloom		
		How does the timing and magnitude of Commonwealth environmental water delivery affect rates of gross primary productivity and ecosystem respiration in the Edward-Wakool River system?	There were no indications of any flow-related changes in these metabolic parameters.		

7. SUMMARY OF AQUATIC AND RIVERBANK VEGETATION RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

7.1 Monitoring

The taxonomic richness and percent cover of aquatic and riverbank vegetation were monitored monthly from August 2015 to May 2016 at four sites in each of four hydrological zones in the Edward-Wakool system. Taxa were classified as submerged, amphibious or terrestrial.

7.2 Main findings

This section provides a summary of the main aquatic and riverbank vegetation responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. Detailed findings are presented in Appendix C. A total of 45 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between August 2015 and May 2016. Only four non-native taxa were recorded and they were all in low abundance. The ten most abundant taxa observed were the submerged Charophyte *Chara spp*., amphibious taxa including floating pondweed (*Potamogeton tricarinatus*), milfoil (*Myriophyllum* sp.), water fern (*Azolla sp*.), mud grass (*Pseudoraphis spinescens*), rush (*Juncus* spp.), sedge (*Cyperus* spp.) and water primrose (*Ludwegia peploides*), and terrestrial taxa including common sneeze weed (*Centipeda cunninghamii*) and grasses (Figure 7.1).

Figure 7.1. Left: Floating pond weed, milfoil, sedge, water fern and rushes in the Wakool River zone 3. Right: Minimal riverbank and aquatic vegetation and high level of leaf litter in the Wakool River zone 2.

There were more taxa recorded in Yallakool Creek zone 1 (36 taxa) and Wakool River zone 3 (30 taxa) and zone 4 (28 taxa) that received the Yallakool Creek environmental base flow and fresh than in the upper Wakool River zone 2 (22 taxa) that received a only a small magnitude environmental watering action (Section 4). The response of riverbank and aquatic vegetation to environmental watering was similar in 2015-16 to that in 2014-15 (Watts et al. 2015b). There was a higher percent cover and taxonomic richness of riverbank aquatic vegetation growing in zones 3 and 4 that has a history of environmental watering compared to that in the Wakool River zone 2 that has received none or very small volumes of environmental water.

The most evident change across years was an increase in the abundance of the amphibious mud grass, floating pondweed and milfoil in zones 3 and 4 and a decrease in cover of spikerush in zone 4 and a slight decrease in rush in zones 1, 3 and 4 (Figure 7.2).

The response of aquatic and riverbank vegetation to environmental watering has been an ongoing process and the differences among zones is not the outcome of a single watering action. There has been a gradual improvement in vegetation observed in zones 1, 3 and 4 that have consistently received Commonwealth environmental water over the past five years.

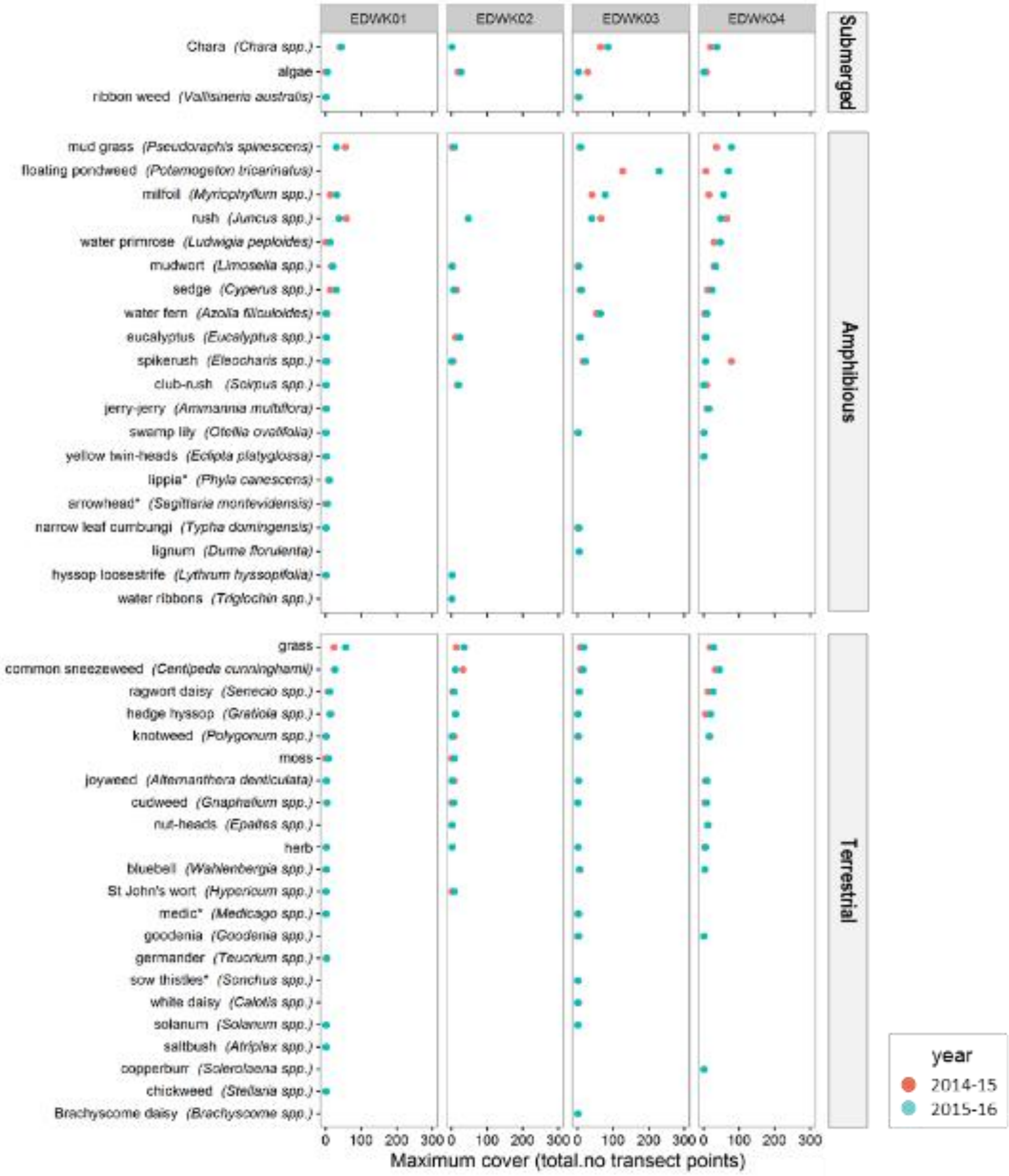


Figure 7.2. Maximum cover of riverbank and aquatic vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between October 2015 and May 2016. Taxa were classified as submerged, amphibious or terrestrial. Red dots indicate maximum cover in 2014-15 and blue dots indicate maximum cover in 2015-16. EDWK01 = Yallakool Creek zone 1, EDWK02 = Upper Wakool River zone 2, EDWK03 = Wakool River zone 3 upstream of Thule Creek, EDWK04 = Wakool River zone 4 downstream Thule Creek. Asterisk indicates introduced taxa.

7.3 Evaluation

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Upper Wakool River: Base flow and Fresh Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted. Yallakool Creek: Base flow and Fresh Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.	To maintain health of riparian and in-channel aquatic native vegetation communities (Water Use Minute 10038) To support the ongoing recovery/re-establishment of in stream aquatic vegetation (Watering action acquittal report)	*What has Commonwealth environmental water contributed to the recovery (measured through species richness, cover and recruitment) of riverbank and aquatic vegetation in Yallakool Creek and the mid and upper Wakool River that have been impacted by operational flows and drought and how do those responses vary over time?*	Commonwealth environmental water has contributed to the ongoing recovery of riverbank and aquatic vegetation in Yallakool Creek zone 1 and the mid-Wakool river zones 3 and 4 through gradual increase in taxonomic richness and maximum percent cover over time.	The taxonomic richness and percent cover of aquatic and riverbank vegetation was monitored monthly from August 2015 to May 2016 at six transects at four sites in each of four hydrological zones	The environmental flow in the upper Wakool River was small in magnitude and was not appropriate to achieve expected outcomes due to the flow constraint in the Wakool River. It did not create additional wetted area of riverbank. There was no evidence of recovery or establishment of riverbank and aquatic vegetation in this zone. Based on hydraulic modelling and the ratings table for the Wakool regulator, a discharge of approximately 220 $ML\ d^{-1}$ (relative to operational flow of 50 MLd^{-1}) would be required to achieve an increase of 60 cm in water level (similar to the rise observed in Yallakool Creek)
		How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones?	Some taxa had higher cover in zones 1, 3 and 4 (environmental water) than in zone 2 (none or minimal environmental water). Recruitment was observed in zones 1, 3 and 4. There was limited recruitment in zone 2 and several taxa were absent or in low abundance in zone 2.	The responses were compared among four hydrological zones	
		What did Commonwealth environmental water delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation in Yallakool Creek and the upper and mid Wakool River?	There was a higher percent cover of riverbank and taxonomic richness of aquatic vegetation growing in zones 3 and 4 that have a history of receiving environmental water compared to that in zone 2 (none or minimal environmental water).	The percent cover of aquatic and riverbank vegetation was monitored monthly from August 2015 to May 2016 at six transects at four sites in four hydrological zones	

		What did Commonwealth environmental water delivered as base flows and freshes contribute to the taxonomic richness of riverbank and aquatic vegetation taxa in Yallakool Creek and the upper and mid Wakool River?	Taxonomic richness was higher in Yallakool Creek (36 taxa), and the mid-Wakool River zones 3 (23 taxa) and zone 4 (28 taxa) that have received environmental water over the past five years than in the upper Wakool River zone 2 (22 taxa) that has received none or very minimal environmental water.	The taxonomic richness of aquatic and riverbank vegetation was monitored monthly from August 2015 to May 2016 at six transects at four sites in each of four hydrological zones	The environmental flow in Yallakool creek was appropriate to achieve expected outcomes in some submerged and amphibious taxa. Shorter duration, higher magnitude flows would be required to achieve outcomes for terrestrial taxa that occur higher up on the riverbank.

8. SUMMARY OF FISH MOVEMENT RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

8.1 Monitoring

A total of 71 acoustic receivers (VEMCO VR2W) (Figure 8.1) were installed in the Edward-Wakool system in August 2015. Of these, 51 constituted the fine-scale acoustic receiver array of approximately 6 km receiver spacing and 20 additional receivers were placed at key entry/exit points and major junctions within the wider Edward-Wakool system to monitor any potential emigration out of the system. Thirty one golden perch and eight silver perch had acoustic telemetry tags surgically inserted from August-October 2015 (Figure 8.1).

Movement responses of periodic fish species golden perch and silver perch were monitored continuously from August 2015 to April 2016 within each of the four focal LTIM hydrological zones in the Edward-Wakool system. Additionally, movements outside of the focal zones were monitored to determine the timing, direction, magnitude and drivers of large scale movements within the entire Edward-Wakool system.

Figure 8.1. Clockwise from left: An acoustic receiver ready for deployment and an acoustic tag for scale, downloading information from tagged fish passing an acoustic receiver and, an anaesthetised golden perch undergoing surgical implantation of an acoustic tag in August 2015.

8.2 Main findings

This section provides a summary of the main fish movement responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. Detailed findings are presented in Appendix D.

All tagged individuals except for one golden perch were detected on acoustic receivers one week or more post-tagging. The majority of movements occurred from late October to late December 2015 (Figure 8.2). The timing of peak movements of both species is consistent with previously reported spawning windows for each species. Commonwealth watering occurred in conjunction with suitable water temperatures, and the volumes of water delivered enabled movement among all zones.

The majority of golden perch movements occurred between mid-September and mid-November 2015 when water temperatures ranged from 20–25 ^{o}C. The majority of golden perch moved very small distances downstream and all of the tagged golden perch remained within the zone 3 throughout the study period (Figure 8.2). The movements of these fish in 2015-16 are less than distances reported for tagged fish 2013-14, where one golden perch were reported to move upstream to Gulpa Creek and another into the upper Edward River (Watts et al. 2014). The largest upstream movement in 2015-16 was into Yallakool Creek where an individual golden perch was detected approximately 12 km upstream of Wakool Reserve on 3/10/15. Of the individuals that moved upstream, more went into the upper Wakool River (zone 2) than into Yallakool Creek (zone 1) during environmental water delivery. This is different to upstream movement patterns of golden perch observed in 2013-14, when more golden perch moved into Yallakool Creek than the Wakool River (Watts et al. 2014). There is no obvious explanation for this preference, however the number of fish and the distances moved upstream are small and are not significant for this species.

Samples sizes of tagged silver perch were low. All of the tagged silver perch remained within the Edward-Wakool selected area during water delivery and only one silver perch was detected outside of the fine-scale array at Gee Gee Bridge, approximately 134 km downstream from Wakool Reserve (Figure 8.2). This movement occurred only for a brief period of time (6th to 10th February 2016) after which the fish returned to zone 3. Another silver perch accounted for the furthest upstream movement, and on 8/10/15 was detected approximately 30 km upstream from Wakool Reserve in the Wakool River. These are very small movements for a species that has the ability to travel long distances.

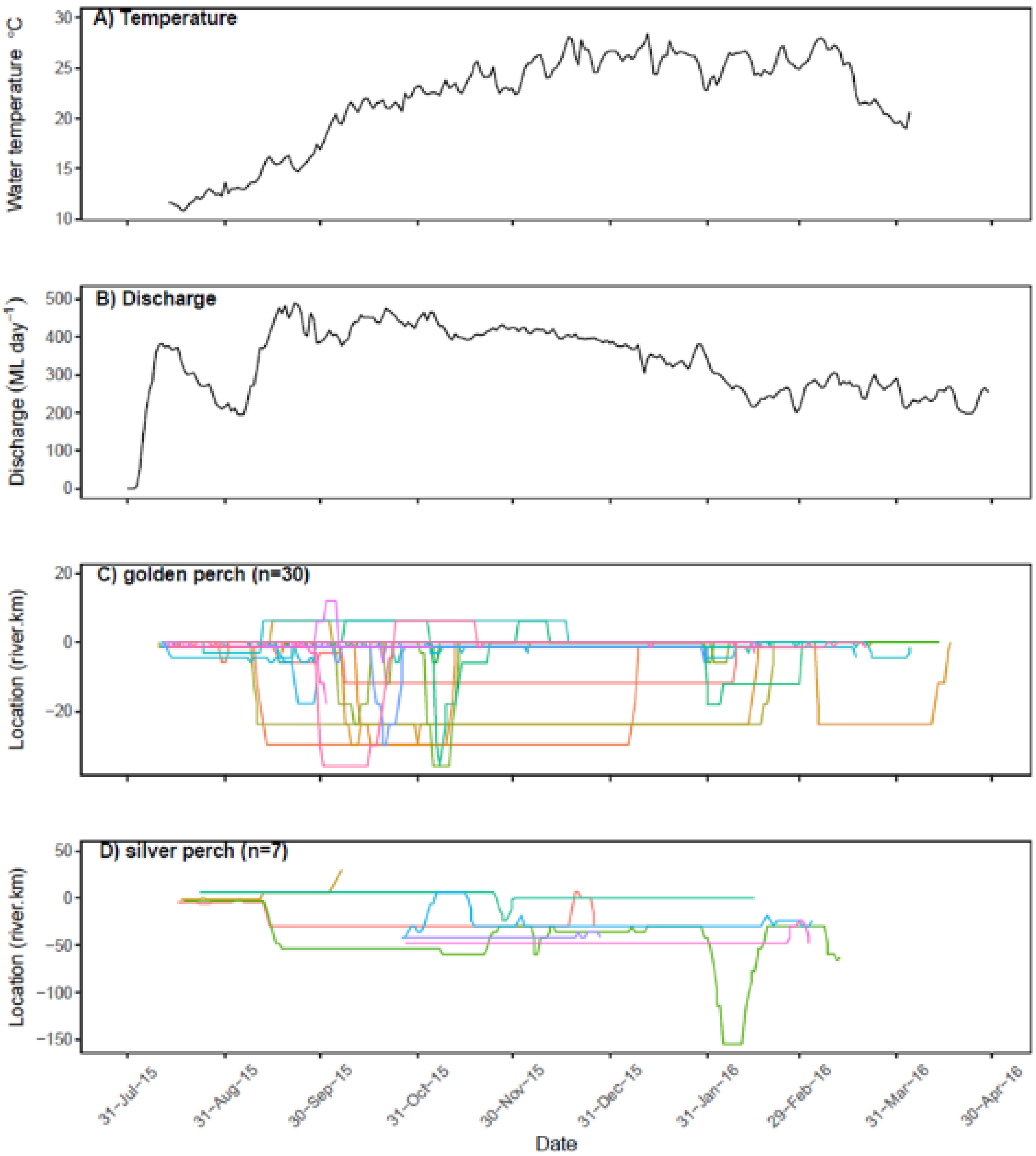


Figure 8.2. A) Mean daily water temperature and B) mean daily discharge at Wakool Reserve (Zone 3) and associated daily location of acoustically tagged C) golden perch and D) silver perch. Different coloured lines represent different tagged individuals and 0 km represents the location of Wakool Reserve, with positive numbers representing upstream locations and negative numbers downstream locations.

8.3 Evaluation

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
<u>Upper Wakool River: Base flow and Fresh</u> Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted. <u>Yallakool Creek: Base flow and Fresh</u> Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability	To maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit (Water Use Minute 10038)	*Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery?*	Both silver perch and golden perch remained within the Edward-Wakool selected area during water delivery. Movements into the upper Wakool River (zone 2) were more common than movements into Yallakool Creek (zone 1) during water delivery. Silver perch exhibited wider ranging behaviour whereas golden perch predominantly occupied zone 3.	The timing of detections on different acoustic receivers (moored within the selected area focal zones) from individually tagged fish	The environmental flows enabled small movements of periodic species throughout the selected area during delivery. These small movements were similar to previous observations under base flows and small fresh flows. As this is the first year of fish movement monitoring, it is unknown whether larger flows would have provided more/greater opportunities for native fish to move.
		Did periodic species remain within the target reaches during Commonwealth environmental water delivery?	Yes. Only one individual left the Selected Area focal zones (silver perch 37201) and this occurred only for a brief period of time.	The timing of detections on different acoustic receivers (moored outside of the selected area focal zones) from individually tagged fish	
		Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour?	The majority of golden perch movements occurred between mid-September and mid-November 2015 when water temperatures ranged from 20–25 ^{o}C. Most movements were to downstream habitats, although were confined to zone 3.	The timing and extent of reconstructed movement paths within the selected area.	

into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.			Samples sizes of silver perch were low, although the majority of movements occurred from late October to late December 2015. The timing of peak movements of both species is consistent with previously reported spawning windows for each species.		
		Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat?	Commonwealth watering occurred in conjunction with suitable water temperatures, and the volumes of water delivered enabled movement among all zones.	The timing and extent of reconstructed movement paths within the selected area.	
		Does Commonwealth environmental water protect periodic species from adverse water quality?	N/A Commonwealth environmental water was not delivered to address adverse water quality issues in 2015-16.	N/A. In future this would be generated from the timing and extent of reconstructed movement paths within the selected area.	

9. Summary of fish spawning responses to Commonwealth environmental watering

9.1 Monitoring

Fish spawning and production responses to Commonwealth environmental watering were assessed by monitoring the presence and abundance of fish larvae throughout the spring and summer of 2015-16. Larval fish were sampled fortnightly from September 2015 to March 2016 using a combination of light traps and drift nets across four study zones: Yallakool Creek (zone 1), Wakool River upstream (zone 2), mid-Wakool River upstream of Thule Creek (zone 3), and mid-Wakool River downstream of Thule Creek (zone 4).

9.2 Main findings

This section provides a summary of the main fish spawning responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. Detailed findings are presented in Appendix D.

Eight of the 10 fish species collected as larvae were native, with small-bodied fish species making up the majority of larvae collected across the 4 study zones. Carp gudgeon (*Hypseleotris* spp., n= 2343), were the most numerically abundant larvae caught in light traps, with flathead gudgeon (*Philypnodon grandiceps*, n = 107) and Australian smelt (*Retropinna semoni*, n= 81) larvae also detected widely across all study zones. Unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*, n= 6), obscure galaxias (*Galaxias oliros*, n=5) Murray River rainbowfish (*Melanotaenia fluviatilis*, n=1), were rare, but showed evidence that spawning had taken place in 2 of the four zones. Carp (*Cyprinus carpio*, n=5) and gambusia (*Gambusia holbrooki*, n=3) were the only non-native species captured as larvae.

Of the large-bodied, native fish species known to the Edward-Wakool River system, two species, Murray cod (*Maccullochella peelii*, n=215), and river blackfish (*Gadopsis marmoratus,* n=18) were collected as larvae. While Murray cod were collected as larvae in all four study zones, river blackfish were only collected in the Upper Wakool River (Zone 2). This is the fourth season that river blackfish larvae have been sampled in the Upper Wakool River, suggesting spawning populations of this species are localised. There were no bony herring (*Netamalosa erebi*), silver perch (*Bidyanus bidyanus*) or golden perch (*Macquaria ambigua*) eggs or larvae collected from light traps or drift nets.

The Yallakool Creek and Wakool River watering actions targeting increased spawning of Murray cod did not result in significantly greater numbers of Murray cod larvae in these study zones (Figure 9.1). These findings concur with results observed during monitoring of similar watering actions in the Yallakool Creek in 2012-13, 2013-14 and 2014-15, and support the body of knowledge that shows Murray cod spawn at peak times in November and December, regardless of flow conditions.

There were significantly fewer larval carp gudgeon in zone 1 Yallakool Creek than in zones 2, 3 or 4 and there were also fewer flathead gudgeon in zone 1 Yallakool Creek than in Wakool River zone 4 (Figure 9.1). This may be due to the reduced area of slackwater and slow water in Yallakool Creek during the environmental watering action compared to the other zones (see section 4).

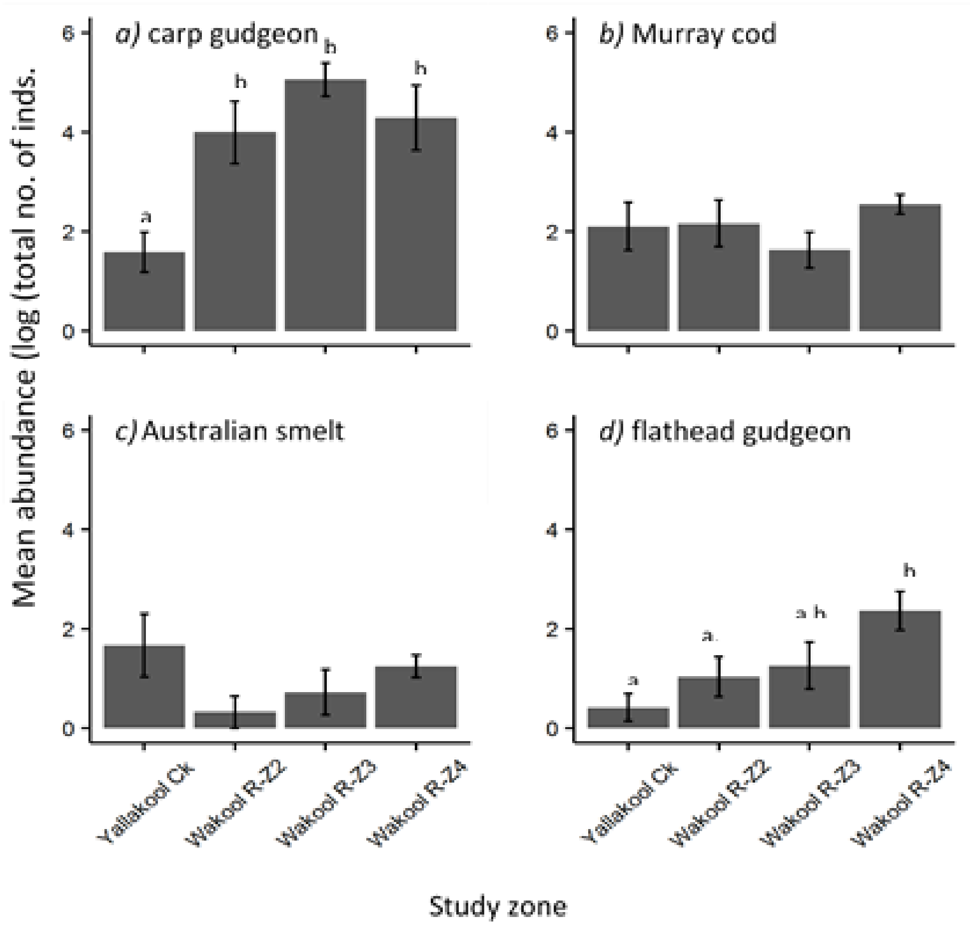


Figure 9.1. Mean total abundance (±SE) of larval sampled in the 2015-16 spawning season in the Edward-Wakool Selected Area, for *a)* carp gudgeon, *b)* Murray cod, c) Australian smelt and *d)* flathead gudgeon. There was a significant difference in carp gudgeon larval abundance across the four study zone.

9.3 Evaluation

CEWO Water Planning and delivery		**Monitoring and Evaluation questions and outcomes**			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Upper Wakool River: Base flow and Fresh Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted. Yallakool Creek: Base flow and Fresh Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.	To provide areas of habitat for Murray cod to move into and spawn, especially where the flows will cover snags that are the preferred spawning and nesting sites of Murray cod.	*Did Commonwealth environmental water contribute to increased spawning activity of Murray cod?*	Environmental flow delivery did not appear to have a significant effect on the spawning magnitude of Murray cod.	The four study zones received varying levels of environmental water during 2015-16, however no difference in the number of Murray cod larvae collected across the 4 study zones was detected, indicating that spawning occurred independently of flow conditions.	The environmental watering actions have had no measurable effect on spawning of Murray cod in the Edward Wakool system for the past three years (Watts et al. 2013, 2014b, 2015b). Flows conditions are not expected to influence spawning of Murray cod and therefore environmental flow delivery objectives should focus on recruitment and growth outcomes required to sustain adult populations.
	To maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit	*What did Commonwealth environmental water contribute to spawning in 'flow-dependent' spawning species (e.g. golden and silver perch?*	No evidence of spawning of golden and silver perch was found.	No eggs or larvae were detected with targeted fortnightly sampling, which involved using drift nets and light traps across the four study zones, from mid November to early January.	The environmental flows did not trigger spawning in golden perch or silver perch

	To maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit	*What did Commonwealth environmental water contribute to the spawning of 'Opportunistic' (e.g. Small bodied fish) species?*	Spawning of all small bodied opportunistic species known to the Edward- Wakool area was detected. Greater numbers of flathead gudgeon and carp gudgeon larvae were found in study zones with increased availability of slow flowing slackwater habitat areas (study zones 2, 3 and 4), so the delivery of environmental flows to Yallakool Creek had a negative impact on somesmall bodied fish species.	Fortnightly light trap sampling from mid September to mid March, across the 4 study zones.	The environmental watering action had mixed responses in small bodied fish.

10. SUMMARY OF MURRAY COD, GOLDEN PERCH AND SILVER PERCH RECRUITMENT AND EARLY LIFE-HISTORY GROWTH RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

10.1 Monitoring

The selected area fish recruitment monitoring was developed specifically for the Edward-Wakool system in order to target juvenile silver perch, golden perch and Murray cod. This monitoring enables comparisons of juvenile growth rates among zones of the Edward-Wakool and is used to determine recruitment variation of these species among years, in response to environmental watering. Fish were sampled by backpack electro-fishing, standardised angling and set-lines to estimate recruitment and growth rates.

10.2 Main findings

This section provides a summary of the Murray cod, golden perch and silver perch recruitment responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16. Detailed findings are presented in Appendix D.

Murray cod recruitment and growth of recruits remained steady in 2015-16, with no positive or negative differences in growth among zones receiving environmental water (Figure 10.1) or between years. The consistent presence of young-of-year and 1+ Murray cod, which are not from hatchery releases, indicates that spawning in the Edward-Wakool, or perhaps nearby rivers, is resulting in successful and wide-spread recruitment of this species within the system.

Zero golden perch recruits sampled for the second year in a row was interpreted as very low recruitment of this species in the system, and possibly in the Edward River upstream, during 2014-15 and 2015-16.

Silver perch 1+ recruits were significantly more abundant in 2015-16, as compared with the first year of monitoring (Figure 10.2). Most recruits were present in the zone 3 and zone 4 of the Wakool River which received Commonwealth environmental water. Two-dimensional hydraulic modelling showed that two zones had the largest increase in area of slackwater ($< 0.02\ m.s^{-1}$) and slow water ($0.02 – 0.3\ ms^{-1}$) during environmental watering actions in Yallakool Creek (Watts et al. 2015b).

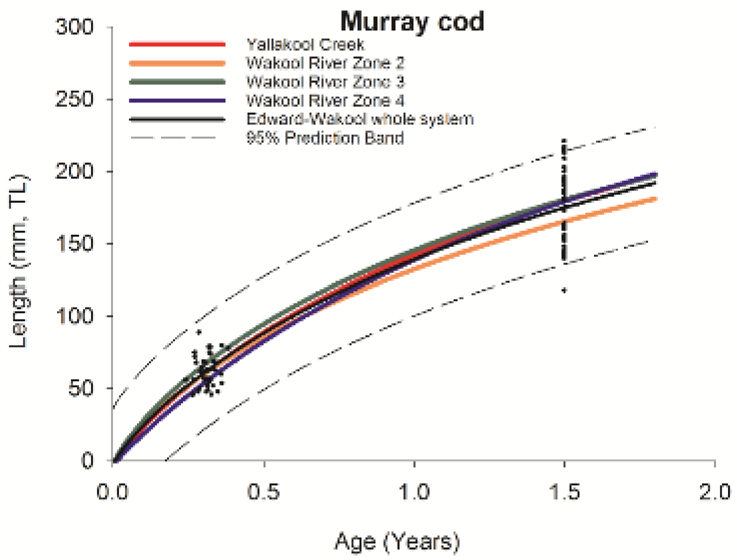


Figure 10.1. Growth curves of Murray cod recruits sampled in the Edward-Wakool system in 2015-16.

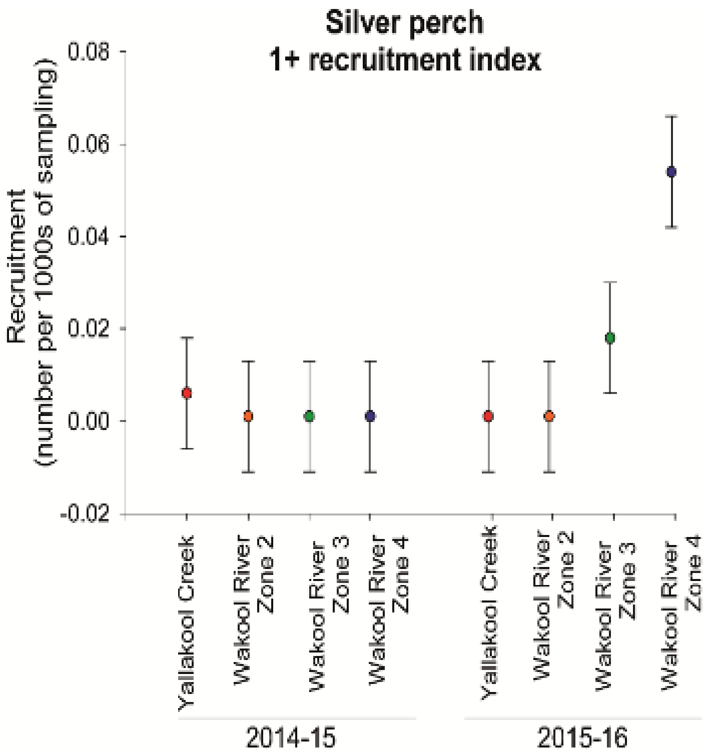


Figure 10.2. Recruitment indices expressed as catch per unit of sampling effort (1000 seconds) for age-class 1 (1+) Silver perch in the Edward-Wakool system in 2014-15 and 2015-16. Values +/- SE.

10.3 Evaluation

CEWO Water Planning and delivery		**Monitoring and Evaluation questions and outcomes**			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Upper Wakool River: Base flow and Fresh Flow for spring-summer fresh in Upper Wakool (above confluence with Yallakool Creek) to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted.	To maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit	Did Commonwealth Environmental Water affect the growth rate of Murray cod, golden perch and silver perch during the first year of life? Did Commonwealth environmental water contribute to the recruitment of Murray cod, golden perch and silver perch?	No differences detected in growth of fish species monitored among zones receiving Commonwealth environmental water in 2015-16. No differences detected in recruitment of fish species monitored among zones receiving Commonwealth environmental water in 2015-16. Silver perch recruitment significantly higher in 2015-16 compared to 2014-15.	Mean total length (mm) of Young-of-Year and age-class 1+ fish determined from otoliths. Relative abundance of Young-of-Year and age-class 1+ fish determined from otolith analyses.	No. Higher magnitude flows in the Wakool River zone 2 during spring which inundate backwater areas may be expected to contribute to recruitment.
Yallakool Creek: Base flow and Fresh Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments.		Did Commonwealth environmental water affect the growth rate of Murray cod, golden perch and silver perch during the first year of life? Did Commonwealth environmental water contribute to the recruitment of Murray cod, golden perch and silver perch?	No differences detected in growth of fish species monitored among zones receiving Commonwealth environmental water in 2015-16. No differences detected in recruitment of golden perch and Murray cod among zones receiving Commonwealth environmental water in 2015-16. Silver perch recruitment significantly higher in 2015-16 compared to 2014-15.	Mean total length (mm) of Young-of-Year and age-class 1+ fish determined from otoliths. Relative abundance of Young-of-Year and age-class 1+ fish determined from otolith analyses.	Mixed responses. No difference in fish growth among zones. Higher numbers of silver perch recruits in zones 3 and 4. Larger magnitude flows during spring which inundate backwater areas may contribute to increased recruitment.

11. Summary of fish community responses to Commonwealth environmental watering

11.1 Monitoring

Category 1 (Basin scale evaluation project) fish (river) monitoring was undertaken in the mid-Wakool River zone 3 in 2015-16 in following methods outlined in Hale et al. (2014). The Category 3 (Edward Wakool Selected Area evaluation project) monitoring of 15 additional sites throughout the Edward-Wakool Selected Area was undertaken in year 1 (2014-15)(Watts et al. 2015b) and is scheduled to be undertaken again in year 5 (2018-19) of the LTIM Project, and thus was not undertaken in 2015-16.

11.2 Main findings

Category 1 fish community sampling identified the same nine native fish species and three alien species in zone 3 during 2016 that were recorded in 2015 (Table 11.1). There were no significant differences in the abundance of the fish assemblage between 2015 and 2016 in zone 3 (Pseudo-$F_{1,18}$ = 2.131, p=0.065). Length-frequency distributions (Figure 11.1) indicate that golden perch (p=0.033) and bony herring (p<0.001) were significantly larger in 2016. There was a significant difference in the size of common carp between years (p=0.048) due to a greater proportion of individuals with a length <200 mm in 2016. There was no difference in the size distribution of Murray cod between 2014-15 and 2015-16 (p=0.375).

The fish surveys were undertaken after the cyanobacterial algal bloom that occurred between March and May 2016 (see section 5). As there were no significant differences in the abundance of the fish assemblage between 2015 and 2016 in zone 3 and there were no reports to NSW DPI Fisheries of stressed or dying fish during the algal bloom this suggests that the bloom has no detecteable effect on the fish community.

Table 11.1 Summary of fish captured during Category 1 sampling in 2015 and 2016 from sites in zone 3 in the Edward-Wakool system. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	2015				2016			
	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**
native species								
Australian smelt	129	2	-	**131**	52	1	-	**53**
bony herring	31	-	-	**31**	27	-	-	**27**
carp gudgeon	47	4302	51	**4400**	68	2367	15	**2450**
flatheaded gudgeon	-	-	1	**1**	-	-	3	**3**
golden perch	107	-	-	**107**	116	-	-	**116**
Murray cod	210	-	-	**210**	333	1	-	**334**
Murray-Darling rainbowfish	339	168	-	**507**	353	77	5	**435**
silver perch	5	-	-	**5**	5	-	-	**5**
un-specked hardyhead	86	64	-	**150**	565	35	-	**600**
alien species								
common carp	167	-	-	**167**	176	-	-	**176**
eastern gambusia	18	175	-	**193**	36	366	1	**403**
goldfish	21	-	-	**21**	38	-	-	**38**

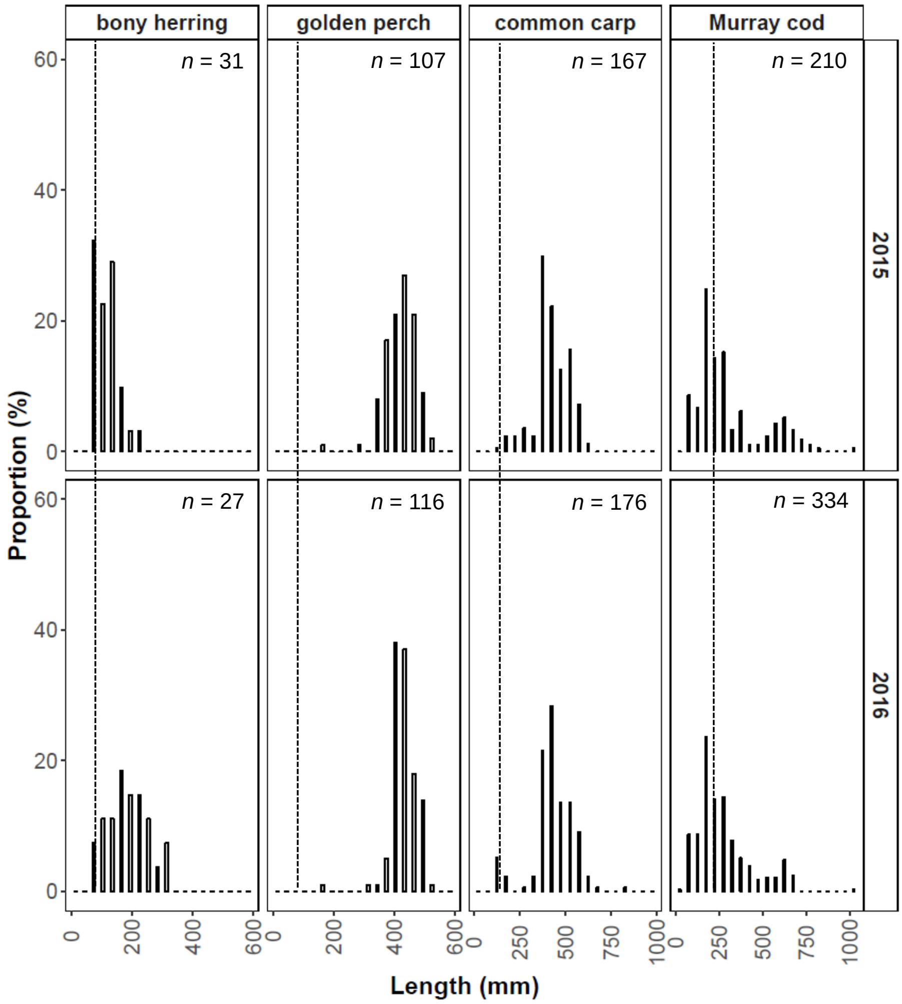


Figure 11.1. Length-frequency histogram of golden perch captured during Category 1 sampling during the Edward-Wakool LTIM project in 2015 and 2016. The dashed line indicates approximate length at one year of age.

11.3 Evaluation

Evaluation of fish community responses to Commonwealth environmental watering in the Edward-Wakool River system for the Long Term Intervention Monitoring Project is being undertaken at the following scales:

i) Selected Area evaluation (Watts et al. 2014) will be undertaken in years 1 (2014/15) and 5 (2018/19) of the LTIM Project, and as such this report will not evaluate response questions specific to the Edward-Wakool Selected Area, and

ii) Basin scale evaluation (Hale et al. 2014) will be undertaken across short term and long term time scales. The Basin Scale evaluation involves the integration of multiple datasets from a number of different catchments, and this will be undertaken by the Murray-Darling Freshwater Research Centre and will be evaluated in a separate report.

12. SYNTHESIS

The responses to Commonwealth environmental watering observed in 2015-16 were consistent with those observed previously in this system (Watts et al 2015b).

Commonwealth environmental water delivered to Yallakool Creek in 2015-16 had the following outcomes (Table 12.1):

- Increased in-channel longitudinal connectivity in zones 1, 3 and 4 (section 4)
- Small increases in lateral connectivity through an increase in wetted benthic area in the Wakool River zones 1, 3 and 4 (section 4)
- Mixed response in hydraulic diversity compared to base flow periods. There was increased hydraulic diversity in zones 3 and 4 but reduced hydraulic diversity in zone 1 due to a reduction in the area of slackwater (section 4), which is likely to have an adverse impact on taxa that require slow flowing water for recruitment and survival while benefiting taxa that prefer faster flowing water
- Maintained dissolved oxygen levels (section 5) and ecosystem respiration (section 6)
- Increased dissolved organic carbon, but only during the Murray River multi-site watering action (section 5)
- Increased taxonomic richness and cover of instream aquatic vegetation, particularly in Wakool River zones 3 and 4, but not consistently in Yallakool Creek zone 1 (section 7).
- Facilitated fish movement from zone 3 over small distances (section 8)
- Mixed response in fish spawning (section 9), with no detectable difference in Murray cod among zones, but significantly fewer larval carp gudgeon in zone 1 Yallakool Creek than in zones 2, 3 or 4, and significantly fewer flathead gudgeon in zone 1 than in zone 4. The reduced number of these larvae in zone 1 may be due to the reduced area of slackwater and slow water in Yallakool Creek during the environmental watering action compared to the other zones.
- Increased number of silver perch recruits in zone 3 and zone 4 of the Wakool River which received Commonwealth environmental water from the Yallakool Creek environmental watering action (section 10) may be in response to the additional slackwater and slow water habitat and vegetation response in these zones.

Commonwealth environmental water delivered to the upper Wakool River Creek through the Wakool regulator in 2015-16 resulted in almost no detectable responses. The only positive outcome was a slight increase in dissolved organic matter observed during the period when the watering action used flows returning from the Barmah-Millewa Forest from the Murray River multi-site watering action (Table 12.1).

There were a number of indicators that showed no detectable response to environmental watering (Table 12.1). Although environmental watering increased wetted benthic area in some reaches (Watts et al. 2015b), this increase was not sufficient to trigger an increase in gross primary productivity (section 6). The delivery of environmental water is currently constrained by a limited capacity to deliver larger in-channel flow pulses because of potential impacts on third parties. Although the Commonwealth Environmental Water Office has sought to maximize the flows to a level that is acceptable to third parties in the catchment area, current and previous monitoring in this system suggest that larger in-channel flow events will be required to increase the gross primary productivity in this system. Although small increases in wetted benthic area can be provided under the current operational flow constraints, the use of return flows from Barmah-Millewa Forest from Murray River multi-site environmental watering actions may result in greater productivity gains than small freshes delivered under current operational flow constraints.

There was no observed increased in Murray cod spawning or recruitment in response to the environmental watering actions. Although this species spawns in this system, there was no detectible increase in spawning in the zones that received the environmental water compared to the Wakool River zone 2 that received only a small environmental watering action. Flows are not expected to influence spawning of Murray cod and future environmental flow delivery objectives should focus on recruitment and growth outcomes required to sustain adult populations.

In 2015-16 one of the objectives of the Commonwealth Environmental Water Office was to trial environmental watering actions in both Yallakool Creek and the upper Wakool River (zone 2) in the same year. The hydrological data analysis showed that the Commonwealth environmental water delivered to the upper Wakool River Creek through the Wakool regulator resulted in almost no detectable responses compared the operational flows and compared to flows delivered in 2014-15. The only positive outcome was a slight increase in dissolved organic matter observed during the period when the watering action used flows returning from the Barmah-Millewa Forest from the Murray River multi-site watering action (Table 12.1).

Concurrent watering actions in Yallakool Creek and the Wakool River is limited by the 600 MLd^{-1} operational constraint downstream of the confluence of Yallakool Creek and the Wakool River. This results from the past 3 years of monitoring in this system suggests that this operational constraint possibly limits a number of ecological processes in this system. The constraint limits lateral connectivity and inundation of inchannel features, resulting in reduced riverine productivity and limited creation of shallow water habitat. This in turn would limit the spawning and recruitment response of many fish and invertebrate and the richness and cover of aquatic vegetation taxa. The constraint also limits the larger-scale movement of flow dependent fish species, such as golden perch and silver perch, which could possibly result in spawning of these species.

The responses to Commonwealth environmental watering observed in 2015-16 were consistent with those observed previously in this system. The good outcomes for dissolved oxygen and aquatic vegetation in zones 3 and 4 will help provide habitat for invertebrates and small bodied fish and could lead to improved outcomes for the whole fish community in the longer term. The long-term recovery of this system from the negative effects of the Millennium drought and subsequent blackwater events is ongoing. Some benefits of Commonwealth environmental watering actions (e.g. recovery of populations of long-lived fish species, recovery of some species of aquatic vegetation) are expected to be realised over longer time frames and should not be expected to eventuate from a single flow action or within a single year.

Table 12.1. Summary of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16.

Positive response to environmental watering (green)
Mixed response; some adverse and some positive responses to environmental watering (amber)
Negative response to environmental watering (red)
No detectable response to environmental watering (neither positive nor negative response) (grey)
N/A No evaluation undertaken by this project (white)

Indicators	Dependant variable	Response to Yallakool Creek e-watering event (Aug 2015-Jan 2016)				Short-term r esponse to Wakool River e-watering (Aug 2015-Jan 2016)			
		Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
Hydrology	Hydrological connectivity		N/A			N/A			
	Coefficient of variation of discharge		N/A			N/A			
Hydraulic modelling	In-channel wetted benthic area		N/A			N/A			
	Hydraulic diversity – zone scale		N/A			N/A			
Stream metabolism, water quality, and organic matter characterisation	Rates of gross primary productivity		N/A			N/A			
	Rates of ecosystem respiration		N/A			N/A			
	Dissolved organic matter	during multisite watering	N/A	during multisite watering	during multisite watering	N/A	during multisite watering		
	Dissolved oxygen		N/A			N/A			
	Temperature		N/A			N/A			
	Nutrient concentration		N/A			N/A			
	Modification of type and amount of DOM	during multisite watering	N/A	during multisite watering	during multisite watering	N/A	during multisite watering		
Riverbank and aquatic vegetation	Percent cover of riverbank and aquatic vegetation		N/A			N/A			
	Taxonomic richness of riverbank and aquatic vegetation		N/A			N/A			
Fish movement	Native fish movement		N/A			N/A			
Fish spawning and reproduction	Larval abundance of 'Opportunistic' (e.g. small bodied fish) species		N/A			N/A			
	Larval abundance of 'flow-dependent' spawning species (e.g. golden and silver perch)		N/A			N/A			
	Larval abundance of Murray cod		N/A			N/A			
Fish recruitment	Growth rate of young-of-year (YOY) and age-class 1 (1+) Murray cod, golden perch and silver perch		N/A			N/A			
	Recruitment of young-of-year (YOY) and age-class 1 (1+) Murray cod golden perch and silver perch		N/A	Higher silver perch recritment than zone 1 or 2	Higher silver perch recritment than zone 1 or 2	N/A			
Fish community	Fish condition	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Fish recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Assessment of outcomes against the Commonwealth environmental watering objectives

An assessment of the outcomes against the ecological objectives for 2015-16 in the Edward-Wakool system outlined in the Water Use Minute 10038 (CEWO, 2015) is presented in Table 12.2. Some of the watering objectives were achieved, some were not achieved and some were not assessed in the Edward-Wakool system in 2015-16. The water quality and vegetation objectives were met. The lateral and longitudinal connectivity objectives were met at some sites, but not consistently throughout all zones. The objectives for reproduction and recruitment of native fish were not achieved by the Yallakool Creek or Wakool River environmental watering action in 2015-16.

Table12.2. Assessment of outcomes of Commonwealth environmental watering in the Edward-Wakool system in 2015-16 against the environmental watering objectives outlined in water use Minute 10038. Green shading indicates positive response, red shading indicates negative response, amber shading indicates mixed response, grey shading indicates no detectable response (neither positive or negative) to environmental watering. White boxes indicate no evaluation was undertaken.

Commonwealth environmental watering objective from Water Use Minute 10038	Objective achieved or not achieved
Maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit	Maintained diversity of native fish
	Diversity and condition of frogs, turtles and invertebrates not assessed
	Opportunities for local movement provided, but operational constraint limits larger watering actions that may trigger larger movements
	Improvement in spawning of native fish not observed
Maintain habitat quality in ephemeral watercourses	Ephemeral watercourses not assessed
Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity	Mobilisation, transport and dispersal not assessed
	Increased longitudinal connectivity
	Some increase in lateral connectivity at some sites in zones 1, 3 and 4
Support inundation of low-lying wetlands/floodplains habitats within the system	Inundation of some low lying in-channel features at some sites in zones 1, 3 and 4
Maintain health of riparian and in-channel native vegetation communities	Cover and taxonomic richness of riverbank and aquatic vegetation was improved at most sites in zones 1, 3 and 4
Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH	Concentration of dissolved oxygen and rates of ecosystem respiration was maintained in reaches receiving environmental water
Improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat	Aquatic habitat (aquatic vegetation, slackwater) was maintained at sites in zones 1, 3 and 4
	Mixed response in hydraulic habitat - reduced area of slackwater in zone 1 but increased slackater in zones 3 and 4

13. RECOMMENDATIONS FOR THE ADAPTIVE MANAGEMENT AND FUTURE USE OF COMMONWEALTH ENVIRONMENTAL WATER

During the 2015-16 watering year seven progress reports on Edward-Wakool LTIM monitoring (Watts and Healy 2015, Watts et al. 2015a, Watts et al. 2016a; Watts and Howitt 2016a, b; Watts, Howitt and Abell 2016; Watts et al. 2016b) were provided to the CEWO to assist environmental watering actions and planning. These reports combined with regular meetings of the Edward Wakool Operations Advisory Group and feedback from local community representatives throughout 2015-16 have informed the planning of Commonwealth environmental water use in the Edward-Wakool system for 2016-17.

The eight recommendations below are underpinned by the 2015-16 Edward-Wakool monitoring and evaluation results and findings from previous monitoring and aim to improve the planning and delivery of Commonwealth environmental water over time. Where applicable, a note has been included to indicate to what extent the recommendation has already been applied (as of September 2016) in the planning or use of Commonwealth environmental water in the Edward-Wakool system.

In summary, the eight recommendations are to:

1. Undertake a comprehensive flows assessment for the tributaries of the Edward-Wakool system to better inform future decisions on environmental watering in this system.
2. Trial the delivery of continuous base environmental flows during winter (no cease to flow) in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.
3. Trial the delivery of a short duration environmental watering action in late winter or spring 2017 at a higher discharge than the current operational constraint of 600 $ML.d^{-1}$ (possibly up to 1000 to 1200 $ML.d^{-1}$). This would facilitate a test of the hypothesis that larger in-channel environmental watering actions will increase river productivity.
4. Trial the delivery of an environmental watering action in the Edward River downstream of Stevens Weir to target golden perch and silver perch spawning.
5. Avoid long periods of constant flows by introducing flow variability into environmental watering actions.
6. Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system.
7. Continue to include a water use option in planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events in the Edward-Wakool system.
8. Continue to include a water use option that enables Commonwealth environmental water to be used to mitigate rapid recessions due to rainfall rejection in the Edward-Wakool system.

Recommendation 1: Undertake a comprehensive flows assessment for the tributaries of the Edward-Wakool system to better inform future decisions on environmental watering in this system.

There is a need for a comprehensive flows assessment to be undertaken for the tributaries of the Edward-Wakool system to inform future decisions on environmental water planning and delivery in this system. A flows assessment has been undertaken for the Edward River (Green 2001; Hale and SKM 2011, Watts et al. 2015) but there are currently no hydrological models available for the smaller creeks and rivers in the Edward-Wakool system. A flows assessment for the tributaries would provide information on factors such as natural rates of recession and rise in flows, short term and long term variability in changes to water height, timing and duration of instream pulses, and periods of low flow that would underpin future planning. This flows assessment would assist the planning of environmental watering to environmental assets of the Edward-Wakool system and contribute to decisions and operating guidelines for future environmental watering actions. The flows recommendations should not be targeted for single species or habitat type, but aim to maximise benefits for the whole ecosystem.

This recommendation was made in the 2013-14 Edward-Wakool short term monitoring report (Watts et al. 2014) and again in 2014-15 LTIM evaluation report (Watts et al. 2015) but has not yet been implemented. The lack of information for the smaller tributaries limits aspects of the planning and delivery of environmental water in this system, particularly decisions on rates of recession and variability of flows.

Recommendation 2: Trial the delivery of continuous base environmental flows during winter (no cease to flow) in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.

Natural flows in the Edward-Wakool system historically reflected strong seasonal patterns in rainfall, with high flows occurring typically from July to November (Green 2001; Hale and SKM 2011; Watts et al 2015b). Low flows would have naturally occurred in this system in summer and early autumn when fish and shrimp larvae are present. Under current operations it is not possible to deliver low flows to this system in summer due to the need to supply consumptive water. Under current river operations the regulators to the Wakool River and Yallakool River are usually shut during cearly winter and there is a period of no flow and some reaches of the river bed are dry (Figure 3.2), with the exception of the larger deeper permanent pools.

Telemetry has shown that during the winter cease to flow period Murray cod, golden perch and silver perch reside in the large permanent pools (Watts et al. 2013, 2014). This period of no flow may be detrimental for the survival and growth of some aquatic animals because they are forced to move to the permanent pools where they may be more vulnerable to predation or experience competition for food and habitat. Similarly, while some riverbank and aquatic plants benefit from, or tolerate, periods of wetting and drying, some submerged aquatic plants can be disadvantaged by a cease to flow in winter. Some aquatic plants can die in a week or so in winter if they are exposed to frost (Roberts and Marston 2011). Exposure during winter also makes roots of aquatic plants more susceptible to damage by wild pigs, and this has been observed to occur in the Edward-Wakool system. Community members report there were beds of submerged aquatic plants, such as ribbon weed (*Valisineria* sp.), in the rivers of the Edward-Wakool system prior to the Millennium drought, but in 2010 after the break of the drought the submerged and amphibious plants were largely absent throughout the system. Aquatic plants in the Edward-Wakool system are still recovering from the effects of this drought and Commonwealth environmental water delivered during winter could assist that recovery.

The recommendation is to trial the provision of continuous base flows in 2017 to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system. A CEWO proposal to maintain a base environmental flow to the tributaries during winter 2017 initially raised concern from some stakeholders who were in favour of continuing the practice of including a period of riverbank drying during winter. However, the proposal to deliver base environmental flows in winter would not jeopardise this drying phase, because under base flows the majority of riverbank would continue to be exposed and experience a period of drying.

There are operational challenges associated with the delivery of base flows during winter. At this time of the year Stevens Weir on the Edward River is usually open and the weir level is often not high enough to deliver water to the tributaries through the regulators. Options such as direct pumping to deliver environmental water to the upper Wakool River, Yallakool Creek and Colligen Creek should be explored and would be technically feasible because the proposed base flow to these tributaries is small. Pumps have been used effectively to deliver environmental water elsewhere in the Murray system (e.g. Hattah Lakes). Guided by catchment conditions and water availability, the winter operation of Stevens Weir could be alternated over a sequence of years and this would also provide more system wide variability. For example, in wetter years Stevens Weir could be maintained at a moderate level to enable low winter base flows to be delivered via regulators to the tributaries, whilst in drier years Stevens Weir could be opened to enable additional bank drying to occur in the weirpool and on these occasions base flows to the tributaries could be delivered by pumps.

The LTIM Monitoring and Evaluation Plan for the Edward-Wakool system includes monitoring of riverbank and aquatic vegetation over the winter months but no other indicators are monitored in winter. If this flow trial were to be implemented additional monitoring may need to be required to assess the outcome of this watering action on other indicators.

There is also a significant opportunity to expore how the provision of environmental flows during winter could be coordinated across multiple catchments. For example, winter environmental flows could be synchronised across the Murray system (including Edward-Wakool), Murrumbidgee, Goulburn and possibly the Darling systems to not only achieve desired outcomes in those catchments but also contribute to outcomes in South Australia.

Adaptive management: This recommendation is similar to recommendation number 4 made in the 2014-15 LTIM evaluation report (Watts et al. 2015) but it has not yet been implemented. However, CEWO and NSW OEH have progressed this recommendation through the facilitation of discussions with various stakeholder groups (e.g. the Murray-Lower Darling EWAG and the Edward-Wakool Environmental Water Reference Group) regarding the implementation of this recommendation in the winter of 2017

Recommendation 3: Trial the delivery of a short duration environmental watering action in late winter or spring 2017 at a higher discharge than the current operational constraint of 600 ML.d^{-1} (possibly up to 1000 to 1200 ML.d^{-1}). This would facilitate a test of the hypothesis that larger in-channel environmental watering actions will increase river productivity.

The flow regime of the Edward-Wakool system has been significantly altered by river regulation, with changes to the timing and volume of flows (see section 2). In the absence of river regulation higher flows would have typically occurred from July to November in winter and spring (Green 2001; Hale and SKM 2011; Watts et al. 2015).

Monitoring undertaken in this system has shown that late winter/early spring unregulated flow pulses that occurred in July/August 2012 (max discharge 1913 ML.d^{-1} in Yallakool Creek), August/September 2012 (max discharge 1360 ML.d^{-1} Yallakool Creek) and August/September 2013 (max discharge 1224 ML.d^{-1} Yallakool Creek) enabled fish to disperse from the refuge pool into new habitats (Watts et al. 2013, 2014). These short-duration (weeks) events in late winter and early spring also brought carbon into the system from flooded upstream forests without causing adverse effects on dissolved oxygen and water quality (Watts et al. 2013, 2014, section 4 this report). Monitoring and evaluation of environmental watering in the Edward-Wakool system from 2011 to 2016 has also shown that environmental watering actions that are constrained to a maximum of 600 ML.d^{-1} in the Wakool-Yallakool Creek system have not increased river productivity and have not triggered spawning of golden perch or silver perch (Watts et al. 2013, 2014, 2015, this report section 7).

If a trial larger magnitude Commonwealth environmental watering action was undertaken in late winter or spring, we would predict it would bring pulses of carbon into the system and enhance opportunities for dispersal, growth and reproduction of fish. A short-duration flow trial in Wakool-Yallakool system at a higher discharge than the current operational constraint of 600 ML.d^{-1} would also facilitate learning and improve future delivery of environmental water to this system. A trial in late winter or spring would minimise disruption to landholders farming activities. A flow trial would also facilitate on-ground validation of hydraulic modelling (see Watts et al. 2015) and facilitate discussion with landholders about third party impacts. Such a trial, involving the use of Commonwealth environmental water, would need the agreement of all potentially impacted landholders.

Adaptive management: This recommendation is similar to recommendation number 7 made in the 2014-15 LTIM evaluation report (Watts et al. 2015) but it has not yet been implemented. Landholders and NSW OEH are continuing to progress a proposal to trial flows in the Edward-Wakool system above current operational constraints through the facilitation of discussions with various stakeholder groups regarding the implementation of this recommendation in the future.

Recommendation 4: Trial the delivery of an environmental watering action in the Edward River downstream of Stevens Weir to target golden perch and silver perch spawning.

Golden perch and silver perch are long-lived, large-bodied fish species whose spawning, or magnitude of spawning, is thought to be associated with flow pulses. Flow-response studies suggest the importance of flow pulses for golden and silver perch spawning and recruitment (Mallen-Cooper and Stuart 2003; Roberts et al. 2008; Zampatti and Leigh 2013). There has been no environmental water used in the Edward Wakool targeting golden perch and silver perch spawning during the current LTIM project, and nor is there any evidence to date that spawning in these species has occurred within the smaller tributaries of the Edward-Wakool system. However monitoring has shown that the Edward-Wakool system does support juveniles and adults of both species (Watts et al. 2014, 2015, this report section 7). Recent evidence suggests that golden perch (and likely silver perch) life-history operates over large spatial scales across the southern connected Murray-Darling Basin (Zampatti et al. 2014). The inter-connectedness of Edward-Wakool golden perch and silver perch populations will be addressed under the fish movement component of the Edward-Wakool LTIM project and through other concurrent collaborations. However, more information on if, and where, these species spawn within the Edward-Wakool system is required.

Environmental watering actions in the Wakool-Yallakool system are currently constrained to a maximum of 600 $ML.d^{-1}$ and actions of this magnitude (whilst not targeting golden perch and silver perch spawning) have not triggered spawning in these species in this part of the system. The Edward River main-stem is a larger river and is similar to other larger river systems (e.g. Goulburn River) where golden perch have been observed to spawn in recent years (Koster et al. 2014). The Edward River can also receive higher flows than the Wakool-Yallakool system as it does not have the same operational constraints as the tributaries. We propose a trial environmental watering action and monitoring program be implemented in the Edward River downstream of Stevens Weir targeting perch recruitment. Stevens Weir could be operated to facilitate the delivery of a managed rise and fall in hydrograph, using results from other river systems or and available hydrological modelling for the Edward River to guide the development of a hydrograph during an environmental flow planning workshop.

This recommendation is similar to recommendation number 8 of Watts et al. (2015) but has not yet been implemented. The current LTIM Monitoring and Evaluation Plan for the Edward-Wakool system does not include monitoring of fish reproduction in the Edward River, so if this trial were to be implemented additional monitoring is recommended in the Edward River to evaluate the effectiveness of this watering action.

Adaptive management: The CEWO has proposed the provision of a perch spawning pulse during 2016-17 targetting the refuge pool at the confluence of the Wakool River and Yallakool Creek, however this will be limited by the 600 MLd^{-1} operational constraint.

Recommendation 5: Avoid long periods of constant flows by introducing flow variability into environmental watering actions.

Rivers in the Murray-Darling Basin have high variability in natural flows. Long periods of constant flow have been shown to have detrimental effects on river productivity, river geomorphology and diversity. One of the key recommendations of Thoms et al. (2000) report of the River Murray Scientific Panel on Environmental Flows was that *"releases at constant discharge should be avoided".*

One strategy to decrease the period of 'constant' discharge during environmental watering actions is to incorporate some of the natural levels of variability by setting bounds for the river operators to work within. This recommendation is consistent with one of the key recommendations of Thoms et al. (2000).

The implementation of this recommendation would be improved through the availability of hydrological models as discussed in recommendation 1, as the analysis of historical flow events and modelled natural flow would provide a basis for establishing the extent of variability to be incorporated into environmental flow actions. The setting of bounds for river operators would be guided by an improved understanding of the natural rate of recession and rise in flows and short term and long term variability in changes to water height.

Adaptive management: This recommendation was applied in the 2015-16 use of Commonwealth environmental water in the Yallakool Creek, Wakool River and Colligen Creek-Niemur River watering actions. The River Operator (Water NSW) was provided with an 'operating range' during the period of the environmental watering action. These operating ranges would be better informed by a comprehensive flows assessment of the tributaries in this system. Operating ranges, where applied, need to complement flow requirements for the environmental outcome being targeted.

Recommendation 6: Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system.

Since 2011 the majority of Commonwealth environmental water in the Wakool-Yallakool system has been delivered via Yallakool Creek, whereas over the same period the delivery of environmental water to the upper Wakool River has been very small due to the operational constraint at the confluence of Yallakool Creek and the Wakool River. The Commonwealth environmental water delivered to the upper Wakool system in 2015-16 (up to total discharge of 100 $ML.d^{-1}$) had minimal effect on the hydrological and ecological outcomes in that system. Hydraulic modelling has demonstrated that the relationship between discharge and wetted benthic area is not linear in this system (Watts et al. 2015b). There is potential to considerably increase the wetted area in some reaches of the upper Wakool River if environmental water was delivered at a higher discharge than in 2015-16 but within the current operational constraint of 600 $ML.d^{-1}$. For example, the total wetted area for modelled reaches in the upper Wakool River increased by an average of 6.1% at discharge of 100 $ML.d^{-1}$ (when compared to discharge of 50 $ML.d^{-1}$), whereas at 250 $ML.d^{-1}$ and 500 $ML.d^{-1}$ the average increase in wetted benthic area in the upper Wakool River increased by 20.2% and 45.5% respectively.

The current operational constraint in this system impedes the concurrent delivery of a significant flow pulse to both Yallakool Creek and the upper Wakool River. Hydraulic modelling has shown that delivering more environmental water via the upper Wakool River has the potential to increase the outcomes in the system. Undertaking a trial whereby environmental water was delivered via the upper Wakool River instead of Yallakool Creek would facilitate understanding of responses to flows in this system by disentangling the confounding factors of river and flow. If flow is a major contributor to the responses in this system then one would expect the positive vegetation and water quality responses observed in Yallakool Creek in 2013-14 (Watts et al. 2014), 2014-15 (Watts et al. 2015b) and 2015-16 (this report) to be observed in the upper Wakool River if it were to receive a larger environmental flow.

Adaptive management: The recommendation in the 2014-15 Edward-Wakool LTIM annual report to deliver water via the upper Wakool River was trialled in 2015-16, and a small volume of Commonwealth environmental water (up to 100 $ML.d^{-1}$) was delivered to the upper Wakool River. However, this watering action did not produce the expected outcomes. Trialling the delivery of higher flows via the upper Wakool may result in better outcomes. This would be difficult to achieve with the current regulator, but could be achieved using a combination of the Wakool escape and Wakool regulator.

Recommendation 7: Continue to include a water use option in planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events in the Edward-Wakool system.

Commonwealth environmental water has been used on several occasions to mitigate the adverse outcomes of blackwater and other poor water quality events. Monitoring has demonstrated that these actions have been successful in maintaining water quality. Rapid action and coordination of information by the Edward-Wakool Environmental Operations Group and the Murray and District Dissolved Oxygen Group plays an essential role in informing management during these events.

Monitoring has shown that the choice of source for delivery environmental water to mitigate adverse water quality events is critical and on each event the quality of water from potential delivery points should be analysed to determine if it is appropriate for the proposed objective. For example, during a blackwater event in 2010 Commonwealth environmental water was released from three Mulwala Canal escapes to lessen the impact of hypoxia and create localised refugia with higher DO and lower organic carbon (Whitworth et al. 2013; Watts et al. in press), because this source water remained well oxygenated and had low DOC. Whereas In 2015-16 it was not possible for environmental water to be delivered from the Mulwala canal to mitigate the effects of a cyanobacterial bloom, because the canal water had very high algal counts (section 4 this report).

Adaptive management: This recommendation was made in previous reports (Watts et al. 2014, 2015) and has been applied in the 2015-16 and 2016-17 planning for the use of Commonwealth environmental water in the Edward-Wakool River system. Contingency flows have continued to be made available to contribute to responses to hypoxic blackwater events or other poor water quality events should they occur.

Recommendation 8: Continue to include a water use option that enables Commonwealth environmental water to be used to mitigate rapid recessions due to river operations in the Edward-Wakool system.

There is sometimes excess water in the system that needs to be managed by river operators. This water is sometimes diverted down the tributaries of the Edward-Wakool system and these flow events typically have fast rates of rise and recession. This type of river operation can cause bank erosion and have negative impacts on ecosystems. While bank erosion and deposition are natural processes, the rate of erosion can be altered under rainfall rejection flows. Commonwealth environmental water was used in 2014-15 and 2015-16 to provide slower, more natural rates of recessions to high flow events (e.g. rain rejections and other operational flows).

The recommendation is that a water use option continue to be included in water planning to mitigate rapid recessions in the Edward-Wakool system and allow for the better management of rates of rise and fall of managed and unregulated flow events. A comprehensive flows assessment of the tributaries (recommendation 1) would help inform decisions regarding of rates of rise and fall.

Adaptive management: This recommendation has been applied in the 2015-16 and 2016-17 planning for the use of Commonwealth environmental water in the Edward-Wakool River system.

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16. Appendix A: Water Quality & Carbon

A.1 Background

Flow plays an important role in the maintenance of water quality in lowland rivers and water quality parameters will often respond to changes in flow regimes very quickly. High flow events can result in exchange of carbon and nutrients between the river and the floodplain, or previously disconnected areas of the channel (Baldwin 1999; Baldwin and Mitchell 2000; Robertson, Burns et al. 2016) and environmental flows have a key role to play in restoring carbon exchange that has been lost due to extensive river regulation and modification of channel and bank features (Baldwin, Colloff et al. 2016). In other instances increased flow may result in lowered concentrations of key water quality parameters as a result of dilution, depending on the source of the water and its immediate history of connectivity with the catchment. Whether changes in flow have positive or negative impacts on water quality depends on the initial water quality as well as the specific flow conditions, time of year and other catchment effects. Dissolved oxygen and temperature are affected by flow through changes in water volume, depth, turbulence and through indirect processes, such as alterations in rates of bacterial metabolism and photosynthesis.

Australian riverine ecosystems can be heavily reliant on both algal and terrestrial dissolved organic matter for microbial productivity and can be limited by dissolved organic carbon concentrations (Hadwen, Fellows et al. 2010). Aquatic environments naturally have quite variable dissolved organic matter concentrations and there are no optimal concentrations or trigger values provided for organic matter (ANZECC 2000).

Dissolved organic matter composition in rivers includes a complex mixture of compounds with very different properties and variable availability to the microbial population. Nonhumic substances include relatively simple compounds belonging to recognised groups such as carbohydrates, proteins, peptides, fats and other low molecular weight organic compounds. However, the much larger molecules that make up the category of humic substances (including humic and fulvic acids) can dominate in many waters and in contrast are poorly characterised (Choudhry 1984). Humic substances are predominantly derived from the processing of plant residues and can involve complex chains and aromatic rings which contribute to their strong yellow-brown colour. Microbial communities do not respond to all types of organic matter in the same way (Baldwin 1999; O'Connell, Baldwin et al. 2000; Howitt, Baldwin et al. 2008) although it has been shown that bacterial communities can respond to changes in organic carbon source quite rapidly (Wehr, Peterson et al. 1999). The very large, complex type of organic matter referred to as humic substances has been shown to be less available to bacterial communities than simpler non-humic carbon (Moran and Hodson 1990) although this can be altered over time with exposure to ultraviolet light (Moran and Zepp 1997; Howitt, Baldwin et al. 2008). These differences in microbial response to different types of organic matter mean that it is important to consider not just the total amount of dissolved organic matter in the rivers but to monitor changes in the type of organic matter present. Both absorbance and fluorescence spectra are used to examine the organic matter in this study. As a general guide, absorbance at longer wavelengths indicates larger, more complex organic matter (Bertilsson and Bergh 1999). Absorbance at a particular wavelength may be increased by increasing concentration of organic matter or a change in the type of organic matter.

In February-June 2016 the sites included in this study were impacted by a bloom of the cyanobacteria C*hrysosporum ovalisporum* (formerly known as *Aphanizomenon ovalissporum*) as part of a much larger bloom impacting the Murray from Lake Hume to the Mildura region. While this species is known in Australia (Shaw, Sukenik et al. 1999; Fergusson and Saint 2003) it is an unusual species to dominate a bloom in Australia and previous studies in the Murray River have focused on *Anabaena* species (Maier and Dandy 1997; Baker 1999) which have dominated a number of large previous outbreaks (Maier, Burch et al. 2001), although very widespread blooms such as occurred in 2009 have involved a mix of species such as *Anabaena circinalis*, *Microcystis flos-aquae*, and *Cylindrospermopsis raciborskii* (Al-Tebrineh, Merrick et al. 2012). *C. ovalisporum* is identified as a species capable of producing toxins, although the presence of toxins within any given bloom will be affected by factors such as temperature, light and nutrient availability (Cirés and Ballot 2016). The species is also identified as potentially invasive (especially under warming climate scenarios) having a preference for warm water temperatures, efficient phosphorus scavenging mechanisms to compete for nutrients in a phosphorus limited environment, can fix nitrogen from the atmosphere and has been reported from sites in the Middle East, Mediterranean , Africa and North America (Cirés and Ballot 2016). The onset of the bloom triggered additional funding under the existing LTIM Edward-Wakool project that had been set aside for an adverse water quality event, and in addition to the regular monthly water quality sampling, this chapter includes data from 12 weeks of weekly monitoring (March-May) with additional sites included on the Colligen Creek, Niemur River and on the Wakool River at Gee Gee Bridge.

This project aims to assess changes to water quality in response to alterations in flow and to consider changes in both the quantity and type of organic matter present in the system. Specifically, this work will be addressing the questions below.

A.2 Selected Area Questions

As described above, the relationship between flow and water quality is complex and can be influenced by how changes in flow influence wetted benthic area, water depth, rate of flow and connectivity to the floodplain. Water quality parameters may be affected in different ways due to the direct effects of changes in flow, or due to interactions between the parameters. In order to obtain an understanding of the impact of environmental water deliveries to the Edward-Wakool system on the water quality in the Wakool River and Yallakool Creek we monitor a number of parameters in each site through a combination of continuous logging, spot readings on site and sample collection for laboratory analysis. Water quality will generally respond very rapidly to changes in flow but trends may also develop over a longer period, so the questions below are considered on a 1-5 year basis. We anticipate that in-channel flows will generally only have very small impacts on the organic matter and nutrient concentrations in the river but that dissolved oxygen may respond more directly to changes in flow.

- *What did Commonwealth environmental water contribute to temperature regimes?*
- *What did Commonwealth environmental water contribute to dissolved oxygen concentrations?*
- *What did Commonwealth environmental water contribute to nutrient concentrations?*
- *What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat?*
- *What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?*

Additional questions for extended algal monitoring

- *Did Commonwealth environmental water contribute to the bloom conditions in the Edward Wakool system?*
- *How did the algal bloom impact water quality in the Edward-Wakool system?*

A.3 Methods

Water temperature and dissolved oxygen were logged every ten minutes with two loggers located in each of zones 1, 3 and 4 and one logger in zone 2. Data were downloaded and loggers calibrated approximately once per month depending on access to survey site (e.g. high rainfall may prevent access). Light and depth loggers were also deployed and data were downloaded on a monthly basis. The data collected by the loggers was used to calculate daily average temperature and dissolved oxygen concentrations for each of the rivers from August

2015 to May 2016. Gaps in dissolved oxygen data were the result of problems with the loggers or due to routine maintenance.

From August to May water samples were collected once per month from two sites within each zone, and from Stevens Weir on the Edward River and the Mulwala Canal, plus a site on the Wakool River at Gee Gee Bridge to monitor downstream effects. Over a thirteen week period between March and May additional samples were collected weekly from all of these sites plus sites on Colligen Creek and the Niemur River were added during the algal monitoring period. On all sample dates water quality parameters (temperature (^oC), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were measured as spot recordings.

Water samples were processed according to the methods detailed in Watts et al. (2014) to measure:

- Dissolved Organic Carbon (DOC)
- Nutrients (Ammonia (NH_4^+), filtered reactive phosphorus (FRP), dissolved nitrate + nitrite (NOx), Total Nitrogen (TN) and Total Phosphorus (TP))
- Absorbance and fluorescence spectroscopy for organic matter characterisation.

Water samples were filtered through a 0.2 μm pore-sized membrane at the time of sampling and then stored on ice until returned to the laboratory. DOC and nutrient samples were frozen and sent to Monash University for analysis. Carbon characterisation samples were sent to CSU Wagga Wagga and analysed within a day of returning from the field. Samples for algal counts and biovolume were sent to ALS Environmental (Canberra) for analysis. All samples for 7/3/16 and half the samples for 14/3/16 were analysed for counts and species only. As the bloom was dominated by cyanophytes (>98% in most samples), counts and biovolumes were highly correlated and missing biovolume data was calculated from count data using the regression:

$$\text{Biovolume} = 4.739 \times 10^5 \text{ counts} - 0.993 \ (R^2 = 0.994)$$

Absorbance scans were collected using a Varian Cary 4000 instrument across a wavelength range of 550 nm to 200 nm (green through to ultraviolet) with a 1 nm step size. Absorbance is a measure of light absorbed by the sample and is a logarithmic scale. An absorbance of 1 indicates that only 10% of the light of that wavelength is transmitted through the sample. Fluorescence scans were collected using a Varian Eclipse spectrofluorometer scanning both emission and excitation wavelengths to give an excitation-emission matrix. Excitation wavelengths were scanned from 200 to 400 nm with a 10 nm step size and for each excitation wavelength, emission of light at 90^O to the source was recorded from 200 nm to 550 nm with a 1 nm step size. Fluorescence results were corrected for sample absorption and plotted as contour plots (Howitt et al. 2008). To correct for drift in the instrument zero position, each contour plot was scaled by subtracting the average emission intensity across the range 200-210 nm for an excitation of 250 nm from all fluorescence intensities (effectively setting this region of the contour plot to zero on all plots).

An example of a fluorescence contour plot is shown in Figure A.1. The contour plots have the excitation wavelength (light shone into the sample) on the y-axis. On the x-axis is the emission wavelength (light given off by the sample). The intensity of the fluorescence (how much light is given off, corrected for absorbance by the sample) is represented by the colours of the contour plot, with more intense fluorescence represented by the blue end of the scale. The two blue diagonal lines are artefacts of the technique and will be present in all samples- key data is found between these two lines.

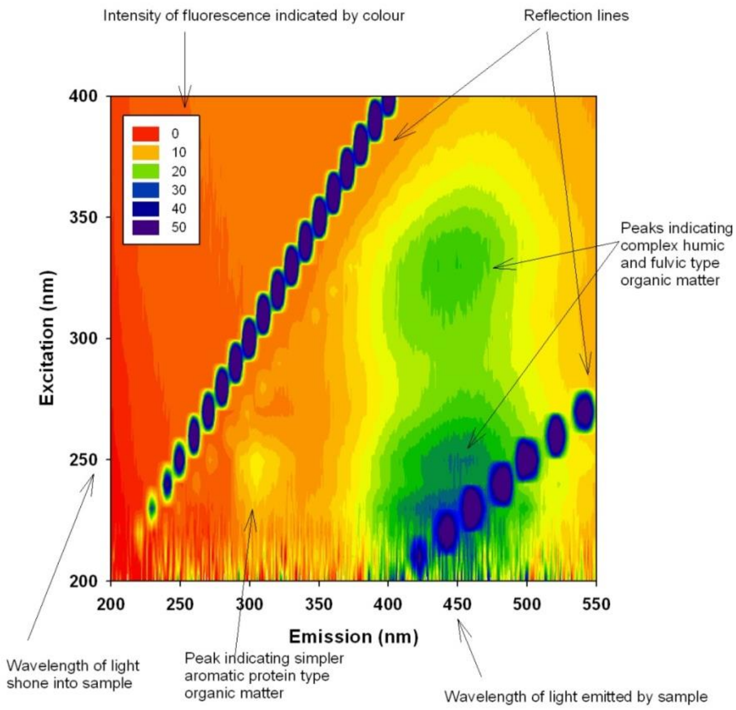


Figure A.1. Sample excitation emission contour plot indicating key features of the data. (Watts et al. 2013)

The monitoring results were assessed against the lowland river trigger levels for aquatic ecosystems in south-east Australia from the ANZECC (2000) water quality guidelines. If the concentration of a particular water quality parameter exceeds the trigger level or falls outside of the acceptable range, the guidelines are written with the intention that further investigation of the ecosystem is 'triggered' to establish whether the concentrations are causing ecological harm. Systems may vary in their sensitivity to various parameters and therefore exceeding a trigger level is not an absolute indicator of ecological harm. The ANZECC water quality guidelines do not provide trigger levels for total organic carbon and dissolved organic carbon, and this reflects the expectation that there will be large variation in the 'normal' concentrations of organic carbon between ecosystems and also in the chemical and biological reactivity of the mixture of organic compounds making up the DOC and TOC at a particular site. Given the variable make-up of organic carbon, and the possible range of ecological responses to this mixture, a trigger level for this parameter would not be appropriate. However, trigger levels are provided for a number of nutrients and these are discussed below.

A.4 Results

Basic Water Quality Parameters

The water temperature was very consistent between sites, as was observed in 2014-15 (Figure A.2), indicating that this parameter is influenced predominantly by seasonal rather than site-specific factors. A persistent heatwave in northeast Victoria and southern NSW exceeded any previous event for March and in this region maximum air temperatures were 10-12 degrees above average during the first 9 days of the month and minimum temperatures were 6-8 degrees above average (Bureau of Meteorology 2016). Overall during the month of March there was a 3-4 degree mean temperature anomaly throughout the Murray region. The prolonged heatwave conditions in March resulted in an extended period of high water temperatures at all sites, with maximum water temperatures (loggers and spot measurements) exceeding 30 ^{o}C into March. Water temperatures in the high-mid teens extended throughout April.

The average daily dissolved oxygen concentration is shown in Figure A.3 as both concentration (mg/L) and as a percentage of the saturated value at that temperature. The Yallakool Creek Environmental Watering Action occurred from 5th September to 30th January and resulted in much higher flows in Zones 1, 3 and 4 than in Zone 2, where a much smaller watering action occurred. The River Murray multi-site watering action contributed flows to Edward-Wakool specific watering actions from 5th September to 10th November with water exiting the Barmah-Millewa Forests. Oxygen saturation results in zones 1, 3 and 4 indicate that there were no detrimental effects of hypoxic water entering the study zones after contact with the Barmah-Millewa floodplain and wetting of the floodplain during these cooler months did not result in hypoxic blackwater in the downstream rivers (likely due to a combination of low temperatures and dilution). Similar to 2014-15 the lower flows in Zone 2 resulted in less DO in the water with concentrations dropping below 5 mg/L regularly between mid-October and January. Sharp increases in DO occurred at each site between mid-February and early March, indicating the onset of bloom conditions and the influence of high rates of photosynthesis. This occurred slightly later in Zone 2 and Zone 4 than at the other sites. During the period of the bloom supersaturation of DO was common (in excess of 150% during daily peaks) but no hypoxia was observed at the end of the bloom, indicating a gradual decline of the population rather than rapid collapse. Commonwealth environmental water was not required to provide a flushing flow for management of DO concentrations during the bloom.

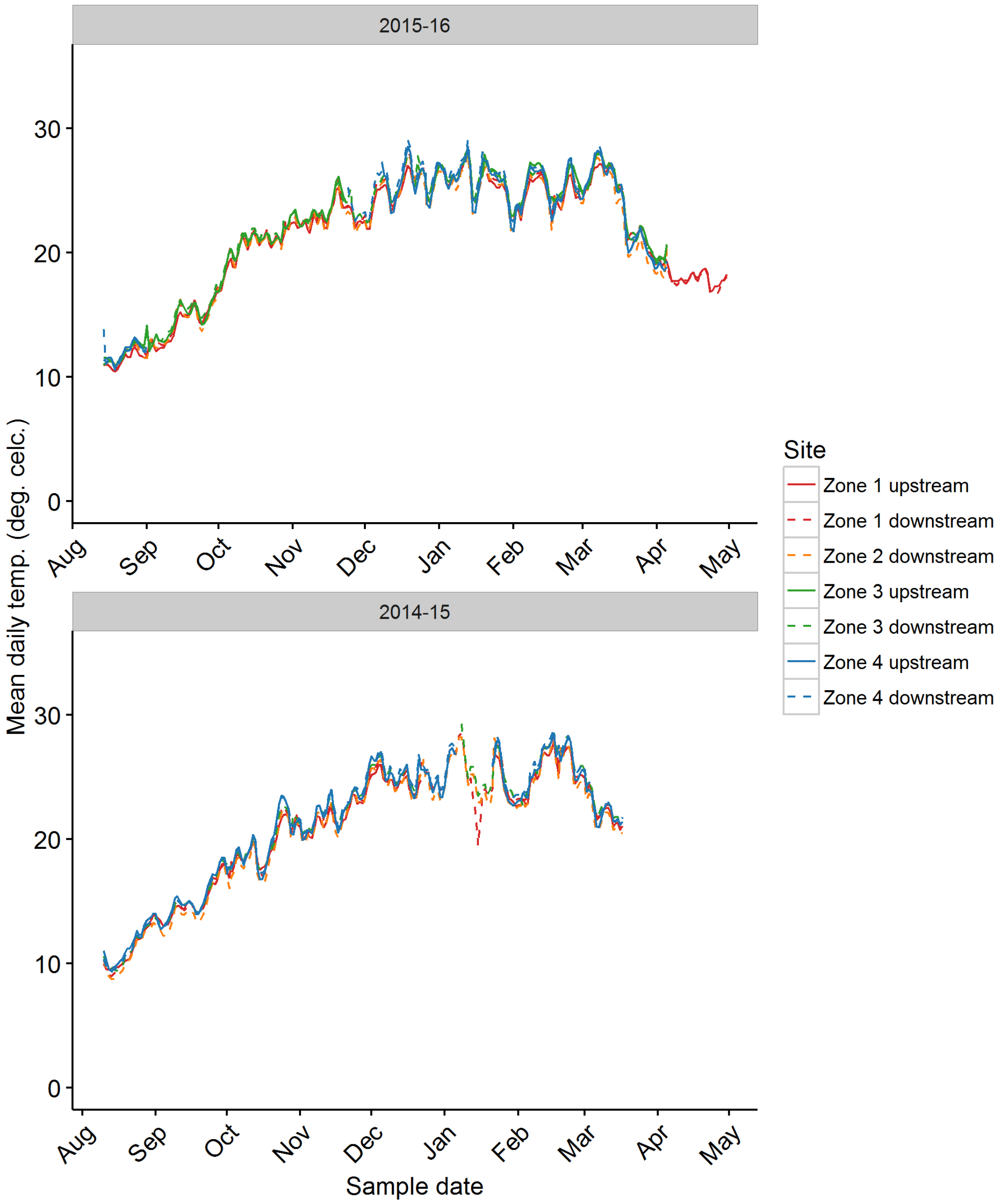


Figure A.2. Mean daily water temperature during the 2015-16 season (above) with the 2014-15 season for comparison (below). Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

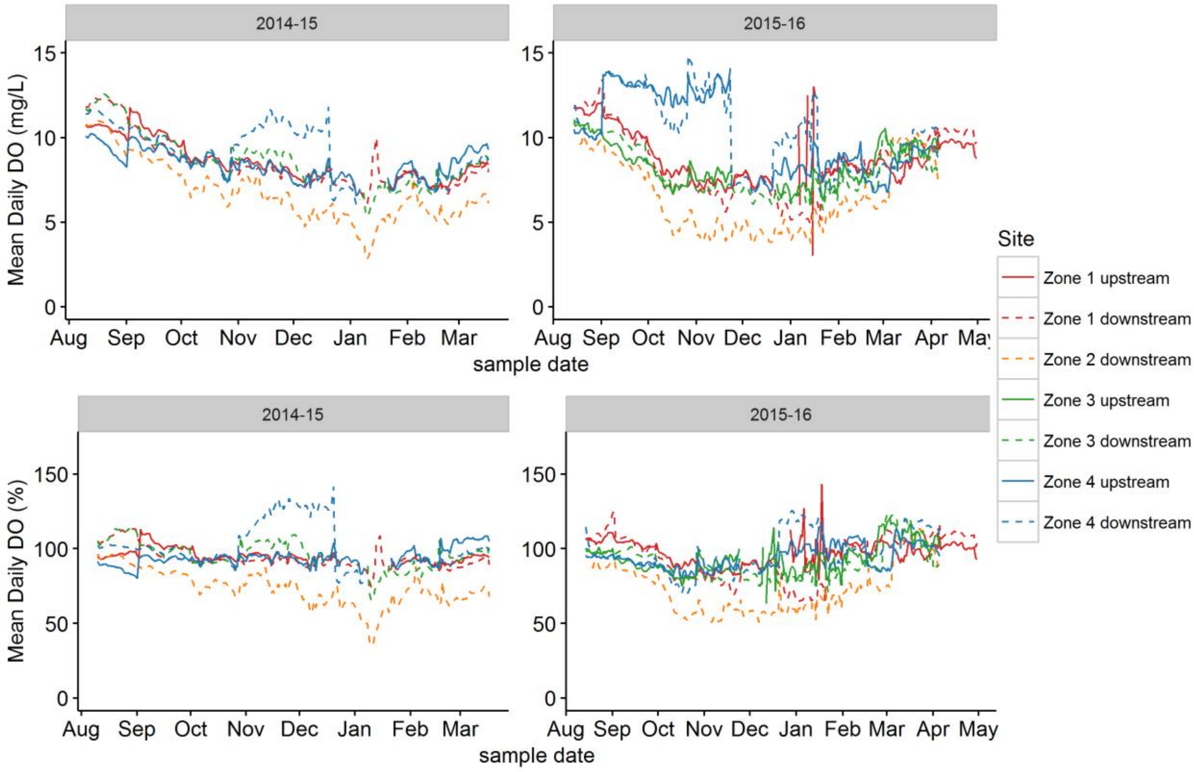


Figure A.3. Average daily dissolved oxygen from loggers at each site in 2014-15 and 2015-16. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

The salinity is low throughout the system, as shown by the electrical conductivity measurements (Figure A.4). The increase in EC in Zone 2 from January-June (Figure A.5) is unconnected to the cyanobacteria bloom and suggests there is groundwater intrusion into the river under the low flow conditions prevalent over this period. The increased salinity is not problematic and simply reflects an additional source of water.

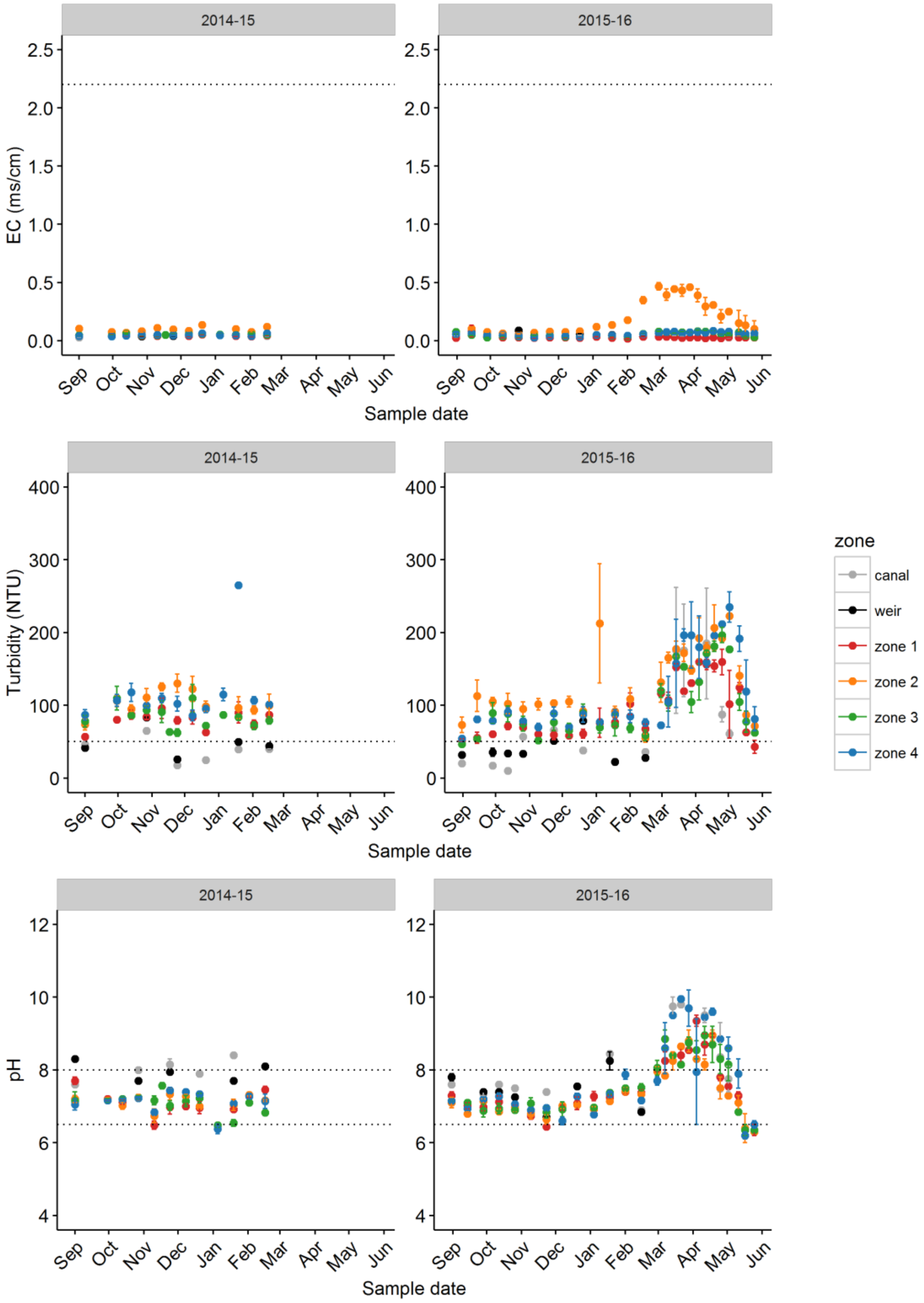


Figure A.4. Spot measurements of electrical conductivity, turbidity and pH at each of the four study zones and in the source waters for 2014-15 and 2015-16. Dotted lines represent the ANZECC (2000) trigger levels (for pH upper and lower trigger levels are given). Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

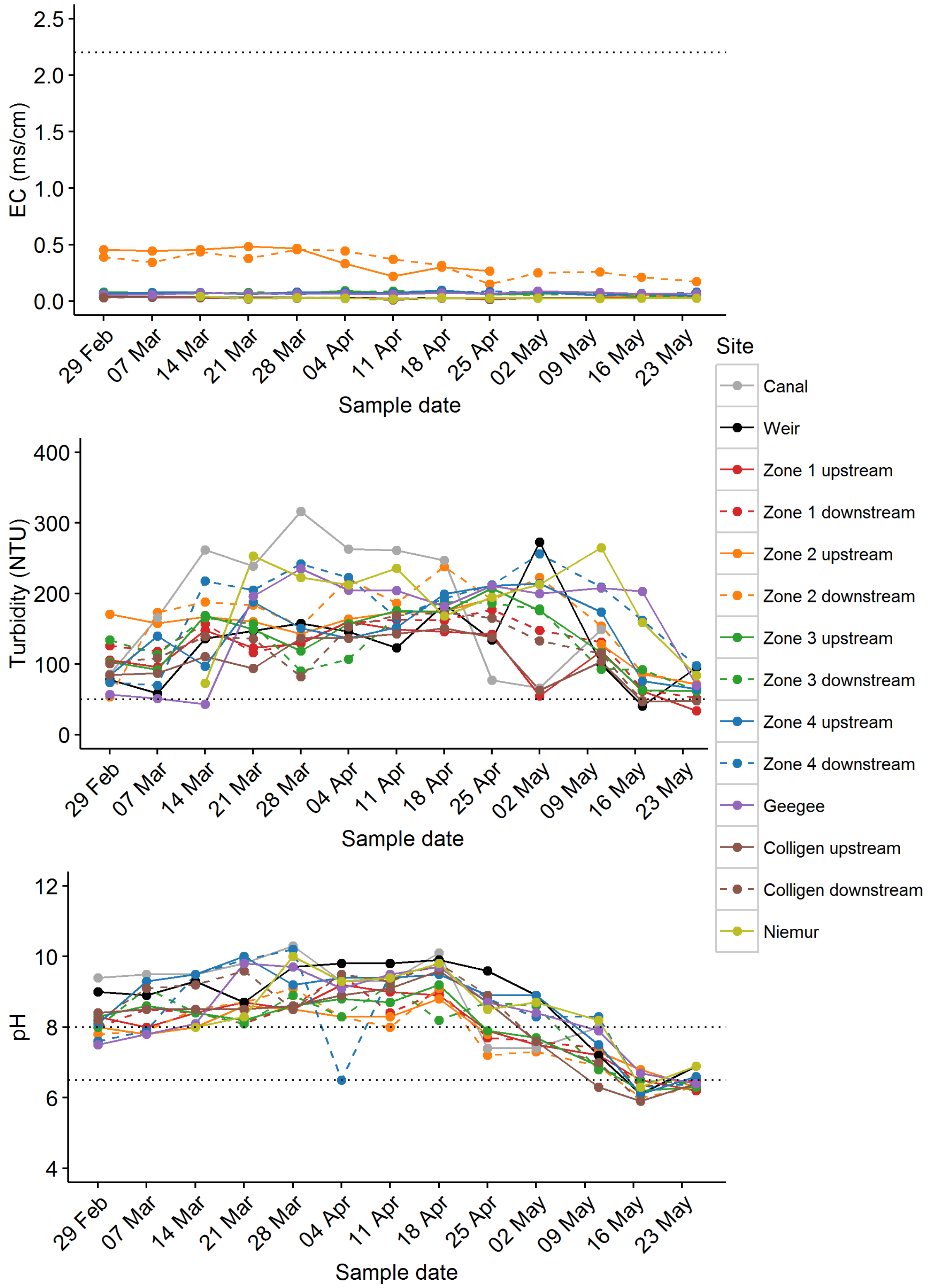


Figure A.5. Weekly spot water quality results for all sites during the cyanobacteria bloom. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

The turbidity of both the Wakool and Yallakool Rivers is generally above the ANZECC (2000) trigger levels but through August-January was consistent with 2014-15 (Figure A.4) and was not impacted by the use of Commonwealth environmental water. The lower turbidity in the weir is to be expected due to settling of particles in the weir pool and shows that there was not an increase in turbidity associated with water having contacted the Barmah-Millewa forests. Turbidity measurements in mid-February are consistent between sites and do not indicate increased particulates (e.g. algal cells) at this time, however the measurements on the 29/02/2016 (Figure A.5) indicate that algal biomass was increasing in all zones except Zone 4, which had also increased by the following week. From March onwards the turbidity is controlled by the presence of the cyanobacteria bloom. Turbidity measurements in the canal indicate an earlier decline in cyanobacteria than at the other sites with a clear decrease between 18/4/2016 and 25/4/2016. There are no results for the canal on the last two sampling dates as the canal had been emptied into the rivers by this time.

The pH of the water in all study zones remained within the ANZECC (2000) guidelines during August-February (Figure A.4) and was not impacted by the use of Commonwealth environmental water. Photosynthesis can change the pH of a water body as dissolved CO_2 behaves as an acid in water, and uptake of CO_2 by cells during photosynthesis will increase the pH. At night when only respiration is occurring, the production of CO_2 will decrease the pH. The extent of the diurnal range and the median pH will be altered by the amount of algal biomass, and during bloom conditions pH may be strongly influenced by the time of day the measurements were made, so care should be taken when comparing between sites during bloom conditions (Figure A.5) as measurements may have been made at different times during the day. The overall effect of the bloom was to increase pH measurements as photosynthetic processes dominated the mechanisms controlling acidity in the water. The pH began to decline back towards the normal range in early May, and slightly earlier than the decrease in turbidity, suggesting rates of photosynthesis declined prior to the decrease in biomass. A decrease in pH in the canal is observed on 25/4/2016, matching the drop in turbidity at this time and suggesting the onset of bloom collapse.

Algal Biovolume

Field teams reported visible signs of cyanobacteria blooms in the study zones during the week of 22/02/2016. Visual assessments suggested that at that time Zone 4 appeared unaffected while Zone 3 was starting to show a green tint and further upstream bloom conditions appeared to be establishing. Algal biomass for the broader system is shown in Figure A.6, for selected study sites in Figure A.7 and detailed results for all sites are given in Table A.1.

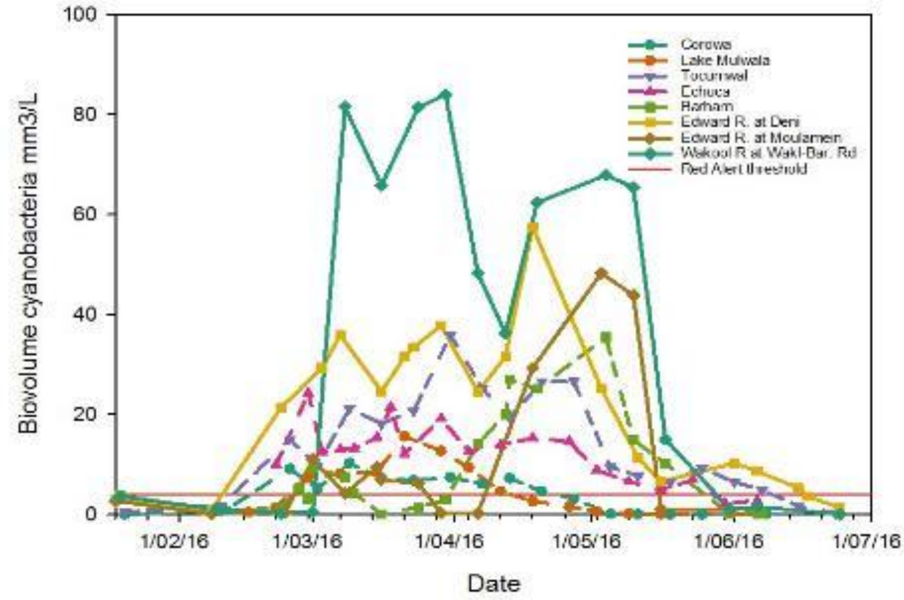


Figure A.6 Total cyanobacteria biovolumes at selected sites in the Murray River (dotted lines) and Edward Wakool (solid lines). Data care of Murray Regional Algal Coordinating Committee.

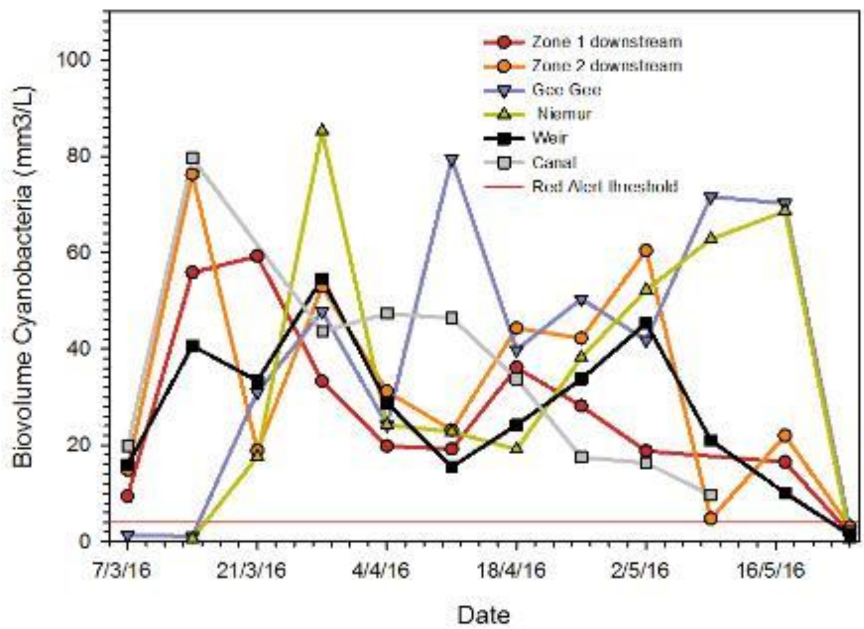


Figure A.7 Biovolumes of cyanobacteria at selected sites over time illustrating the high variability between weeks and the early collapse of the bloom in the canal.

Table A.1. Cyanobacteria biovolume (mm^3/L) at all study sites during the intensive monitoring period (data for 7/3/2016 and some sites on 14/3/2016 have been calculated from counts-reported as whole numbers). Cell shading indicates alert level where red >4, amber 0.4-4 and green <0.4 mm^3/L. Darker red indicates 5 times the red alert level (>20 mm^3/L).

Site	7-Mar	14-Mar	21-Mar	28-Mar	4-Apr	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May	24-May
Zone 1 upstream	16	29.3	31.1	24.4	33.2	40.1	36.1	32.7	13.5	31.5	17.3	0.28
Zone 1 downstream	9	56	59.3	33.3	19.8	19.2	36.9	28.1	18.8	35.3	16.5	1.66
Zone 2 upstream	95	28.9	21.8	44.9	46.0	42.6	34.6	35.8		19.7	13.4	1.61
Zone 2 downstream	15	76	18.9	52.9	31.2	23.1	44.3	42.2	60.4	4.73	22	3.03
Zone 3 upstream	66	30.7	50.7	17.5	45.7	36	33.3	65.4	31.4	27.7	14.9	1.77
Zone 3 downstream	19	26.1	41.7	33.9	31.8	41.1	33.3	35	40	23.3	24.9	1.78
Zone 4 upstream	53	46.3	24.3	43.0	36.8	52.8	32.2	40	39.1	27.2	27.8	0.81
Zone 4 downstream	32	54.0	65.6	55.8	40.6	24.6	23.5	39	42.2	37.3	60.2	13.6
Gee Gee	1	1	31.0	47.8	24.2	79.5	39.8	50.4	41.8	71.6	70.2	2.42
Niemur		0.6	17.6	85.2	24.2	22.8	19.1	38.2	52.2	62.8	68.6	0.56
Colligen Creek upstream	3	16.5	30.0	20.6	35.7	35.2	30.6	36.2	28.1	16.7	7.29	2.58
Colligen Creek downstream	91	30.2	14.8	13.4	36.1	32.6	33.8	58.6	40.1	34.5	7.87	
Weir	16	41	33.4	54.6	28.8	15.5	24.2	33.7	45.3	21	10.1	1.39
Canal	20	80		43.6	47.3	46.4	33.8	17.5	16.3	9.69		

The bloom of C*hrysosporum ovalisporum* was widespread in the Murray River and once established persisted through to winter at many sites (Figure A.6). The bloom is believed to have originated upstream (likely Hume Dam) and seeded through the system from there, although at many sites sampling was sparse prior to the bloom appearing. By late February Red Alert levels (> 4 mm^3/L) were widespread and included the Murray at Corowa, Tocumwal and Echuca and the Edward River at Deniliquin. It is evident from Figure A.6 that once established, the bloom was growing independently in the Edward-Wakool system and not simply flushing through from upstream, as biovolumes in this system considerably exceeded those in the source waters, or equivalent distances downstream on the Murray (e.g. Echuca). Biovolumes decreased dramatically with the combination of rainfall and cold overnight temperatures in late May but the cyanobacteria persisted well into June, especially in the Edward River at Deniliquin, and while below the red alert levels at all sites, non-zero counts are still being recorded at some sites through winter (e.g. 0.61 mm^3/L in the Edward River at Moulamein and 0.43 mm^3/L in the Wakool River at Kyalite in mid July- MRACC).

Within the study zones the bloom was well established at the time of first data collection (7/03/2016) at all sites except Gee Gee Bridge on the Wakool River and the Niemur River, where the cyanbacteria were present but below Red Alert levels (Figure A.7 and Table A.1). Note that the biovolumes may be quite variable at sites within zones, as well as between zones on a given sampling date. This will reflect both site conditions and the variability of cell densities (potentially even at quite small scales). Increases in cell densities were seen at most sites between the 7th and 14th of March (note this was a period of very high temperatures). A similar increase at the Gee Gee and Niemur sites was seen the following week. The bloom persisted at most sites through to May (with a dip in early April) with almost all sites falling to the Amber alert range by the 24th May. The bloom behaviour in the canal was different to the other sites, with steady declines observed from the 18/4/2016 onwards, until the emptying of the canal after 09/05/2016. This is believed to be a case of bloom collapse rather than the bloom flushing through the canal and will be discussed further below. It is important to note that the presence of the bloom in both the Canal and the Weir meant that both sources of water for the Wakool and Yallakool were impacted by the bloom and dilution flows were not an option during this event. While increased flows may have introduced some turbulence into the system, the likelihood of this being advantageous vs the risk of simply spreading the bloom downstream faster meant that in the absence of extreme DO concentrations the use of Commonwealth environmental water in this way would not have been advisable during this event.

Dissolved Organic Carbon

The dissolved organic carbon (DOC) in the study zones and source water is shown in Figure A.8, with all study sites shown in detail for the bloom period in Figure A.9. Total organic carbon was also monitored during April and May to assess the overall impact of the bloom on carbon in the system (Figure A.9). The carbon in these rivers is normally predominantly in the dissolved form with a low particulate fraction, but the additional biomass during the bloom changed the distribution of carbon between these two fractions.

Between August and February the concentration of DOC remained within the range observed during 2014-15 (Figure A.8), however, the influence of the multisite watering event can still be clearly seen in the data with a rise in DOC observed in September and peak in early October for the Weir and upstream sites (Zone 1 and upstream in Zone 2) and slightly later peaks in Zone 3 and 4 as the water which had been in contact with the Barmah-Millewa floodplain made its way down the system. In-channel environmental watering actions in Yallakool Creek and the Wakool River in previous years have not substantially increased the amount of DOC available to support ecosystem productivity. Upstream inputs such as those seen in Figure A.8 may be important sources of carbon to the system within the current flow constraints, and future flow events that aim to reproduce this effect will require arrangements to combine flows greater than 15-18,000 ML/day at Yarrawonga and the use of return flows from the Barmah-Millewa Forest into the Edward Wakool system. Care should be taken to ensure that these flows do not occur when warm water temperatures increase the risk of hypoxic blackwater.

The influence of this water had ended by December for the upstream sites (DOC similar to the Canal where the water bypasses the Barmah floodplain) and all sites were quite similar by January, prior to the onset of the bloom conditions. Input of DOC to the river system is required to support microbial productivity, however, it is not expected to be a contributing factor to the bloom, both due to the effect having ended prior to the bloom, and the fact that cyanobacteria are photosynthetic organisms and capable of producing their own organic carbon, rather than relying on DOC as an energy source.

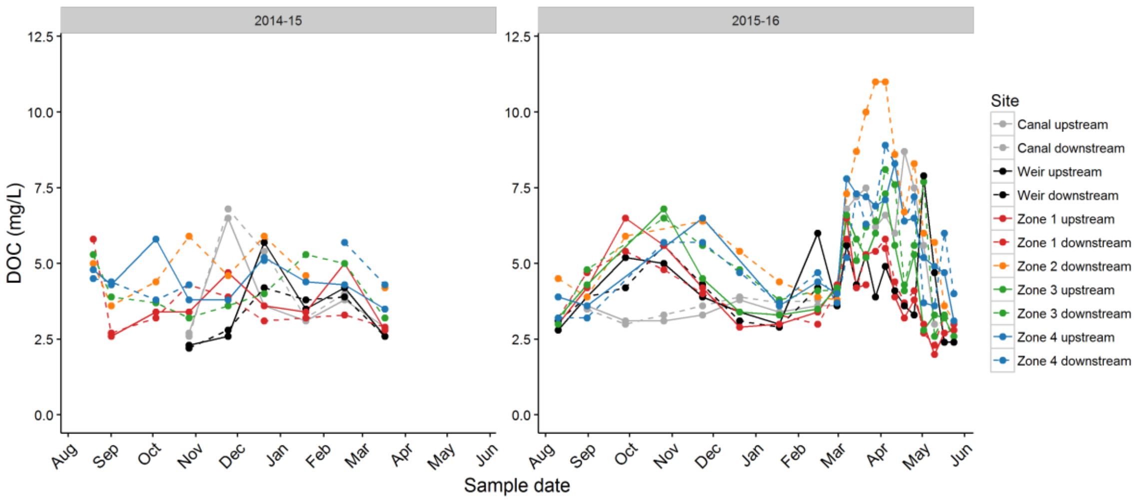


Figure A.8. Dissolved organic carbon in source water and study zones during 2014-15 and 2015-16. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

The input of DOC by the bloom can be clearly seen in Figure A.8, with a sharp rise in DOC in early March. The detailed DOC results for all sites is shown in Figure A.9 for the whole bloom period. Note that there is a lag between the onset of bloom conditions and the increase in DOC, as during the early phases of the bloom the carbon being produced will be contained within the cells of the cyanobacteria and it is only later that extra-cellular exudates and materials released as cells die will start to appear in the dissolved fraction. This impact of the death of cells can be seen in the data for the Canal, where bloom collapse commenced on the 18/4/2016. Total organic carbon peaked at this site on the 11th, and then a steady decline occurred after this date, however DOC peaked the following week, as the degradation of the bloom resulted in the release of dissolved organic compounds into the water, and then the DOC also declined after this period. During the bloom in the region of 50% of the TOC was particulate matter, indicating the proportion of carbon found within cells suspended in the water column. At the end of the bloom this carbon will have been distributed between the DOC in the water column, the sediments (in the form of settled particles) and incorporated into other biomass in the system.

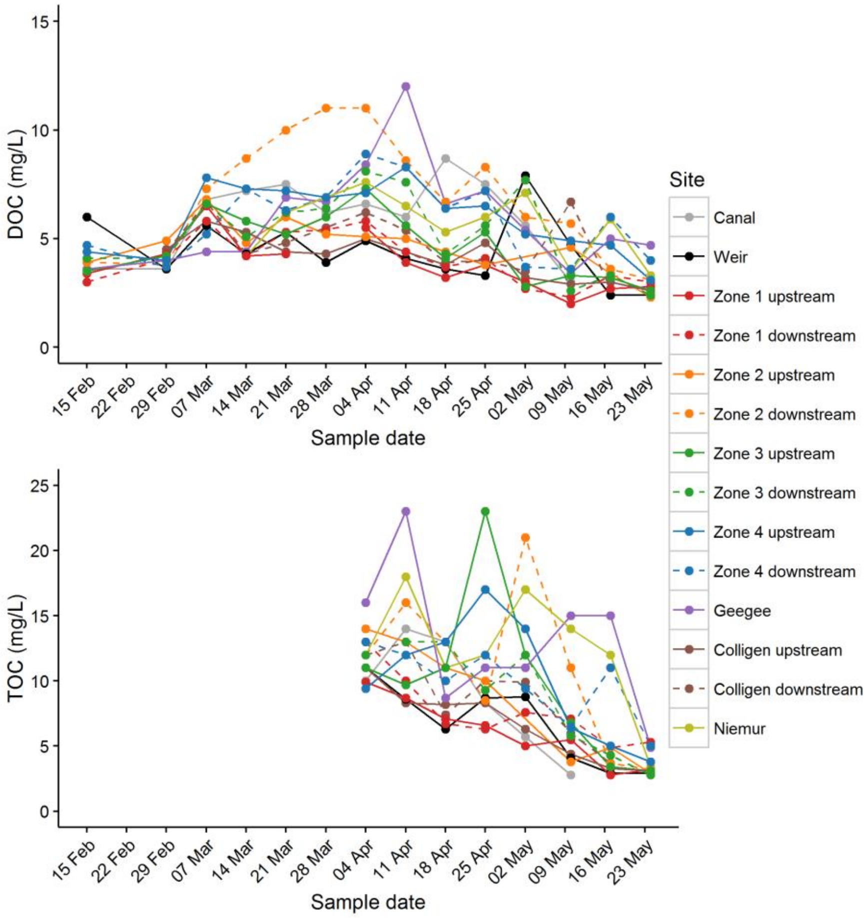


Figure A.9. Dissolved Organic Carbon (top) and Total Organic Carbon (bottom) for all sites during the cyanobacteria bloom.

Nutrients

The nutrient behaviour in the Edward Wakool system was complex in 2015-16 in comparison with that observed in 2014-15, influenced predominantly by the bloom of cyanobacteria (Figures A.10- A.14).

Figure A.10 clearly shows that the nitrogen profiles of the study zones were not impacted by the use of Commonwealth environmental water or the water from the multi-site watering having been in contact with the Barmah-Millewa forest. Any nitrogen inputs from that event have been removed by the system upstream of these sampling sites. Throughout August-February the Total Nitrogen remains around the ANZECC (2000) trigger level, as occurred in the previous year and is normal for this system. Bioavailable forms of nitrogen remain low and well below the trigger levels. Nitrogen concentrations however, are increased dramatically during the bloom period (Figure A.11). Note that TN has increased at the bloom impacted sites by 29/2/2016 but has not increased at the downstream site in Zone 2, Zone 4 or Gee Gee Bridge, consistent with the pH and turbidity data (Figure A.5) indicating that these sites were not yet experiencing bloom conditions.

On 7/03/2016 Zone 2 and Zone 4 had experienced the onset of bloom conditions (Table A.1) but pH, turbidity and TN data suggest that the impact of the bloom was still lower at the downstream sites of Zone 2 and Zone 4. Substantial increases in TN the following week correspond with large increases in biovolume at these sites.

A closer examination of the relationship between TN and the presence of cyanobacteria (Figure A.12) for three key sites also shows that at Gee Gee Bridge and the Niemur, where cyanobacteria were present but below bloom levels at the start of the algal monitoring period, the TN did not increase until the rapid increase in cyanobacteria growth also commenced. In the case of these two sites the nutrient increased slightly faster than the biomass, however the combination of upstream influences and nitrogen fixation at the site make the relationship difficult to tease apart.

It is likely that the majority of the TN increase is associated with algal biomass (note the increase in bioavailable nitrogen in the water column is much later) and that the nitrogen fixing abilities of this species of cyanobacteria are likely to explain the majority of the increase. Bioavailable nitrogen remained below the ANZECC (2000) trigger level at most sites for majority of the bloom period (Figure A.11) with a dramatic increase in ammonia at some sites and NO_x at most sites as the degradation of the bloom released nitrogen from cells into the water column. Note the dramatic spike in ammonia in the canal (Figure A.11) corresponds to bloom collapse and a decrease in TN (Figure A.12). With the decline of the bloom some of the additional nitrogen was released into the water column, some will have been transported downstream and a significant portion will have been incorporated into the sediments and other biomass within the system.

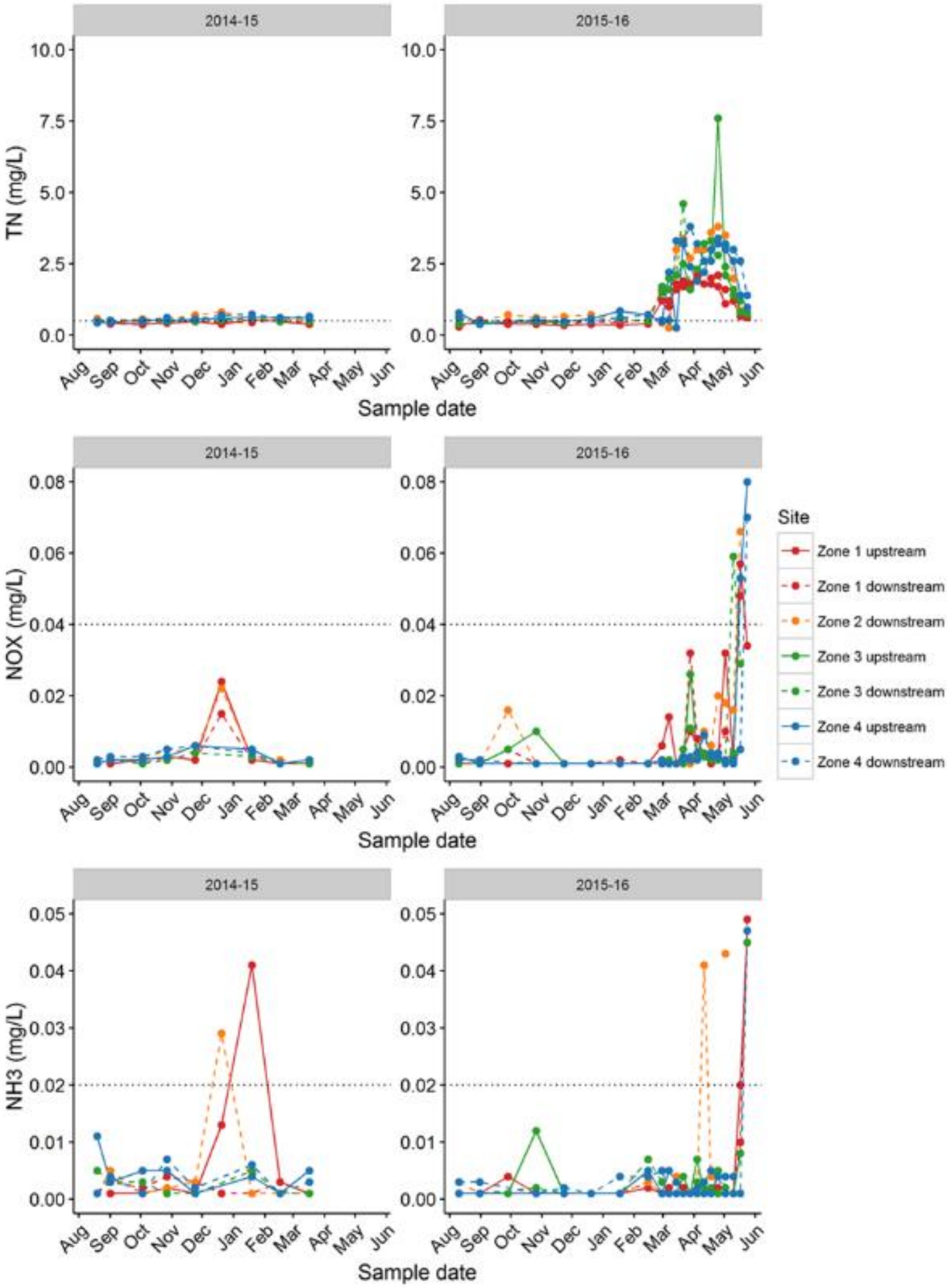


Figure A.10. Total Nitrogen, nitrate + nitrite (NO_x) and ammonia (NH_3) for study zones during 2014-15 (left) and 2015-16 (right). Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

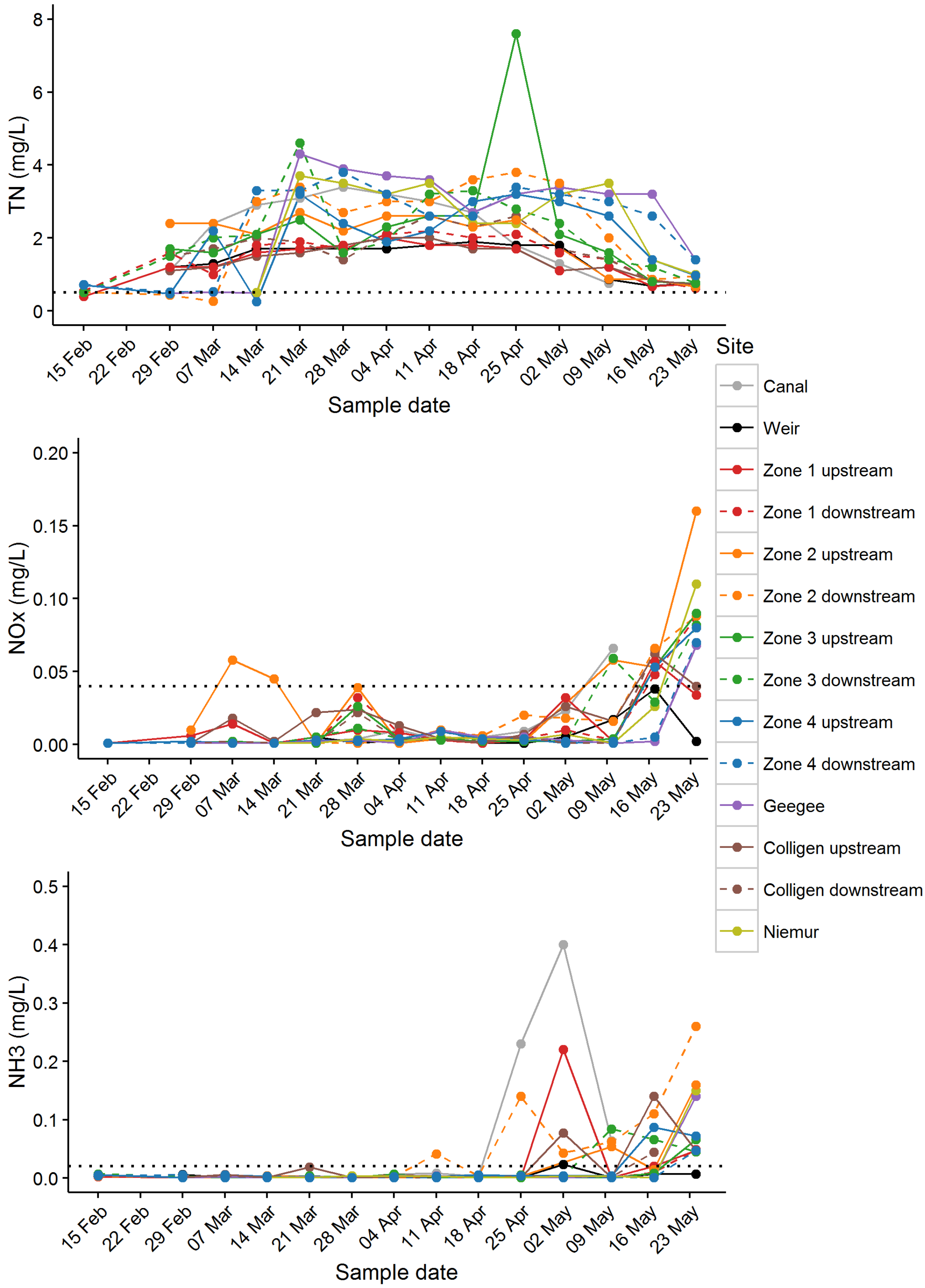


Figure A.11. Total Nitrogen, nitrate + nitrite and ammonia for all sites during the algal monitoring period.

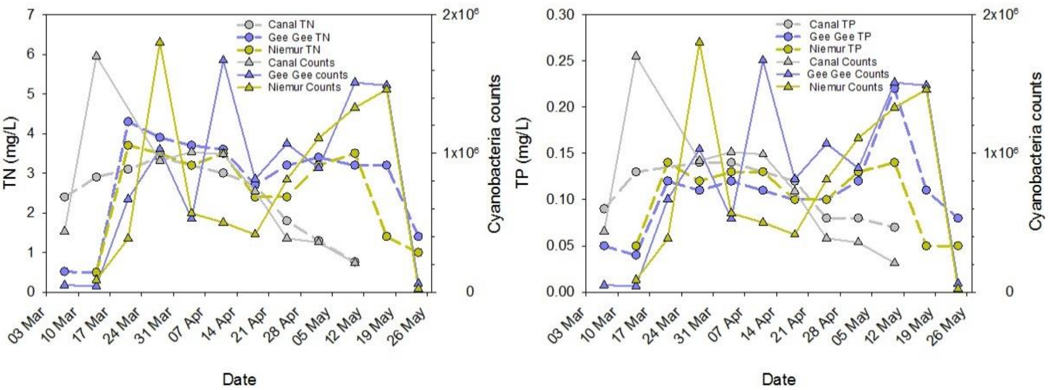


Figure A.12. Comparison of Total Nitrogen (left axis) and cyanobacteria counts (right axis) and Total Phosphorus with cyanobacteria counts for selected sites, showing the nutrients increasing and decreasing with the progression of the bloom.

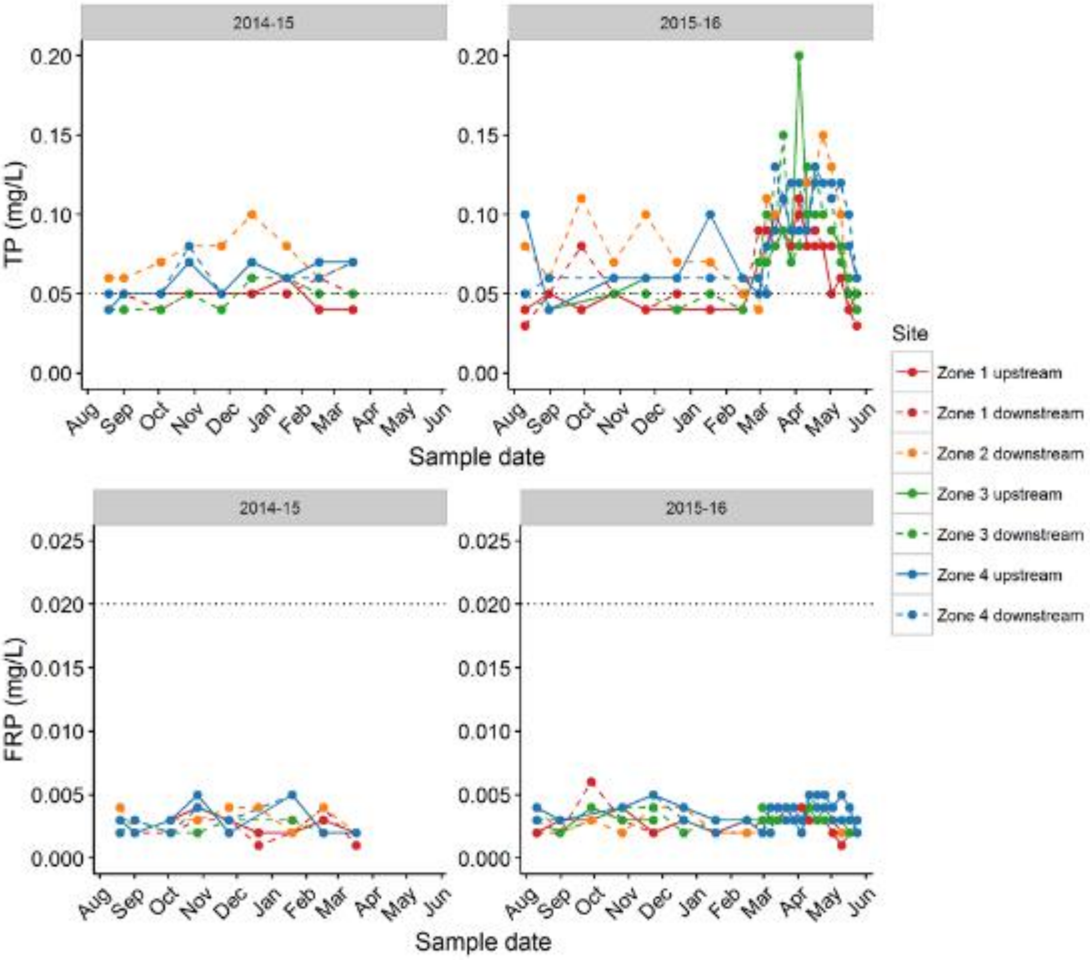


Figure A.13. Total Phosphorus and Filterable Reactive Phosphorus in study zones during 2014-15 and 2015-16. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

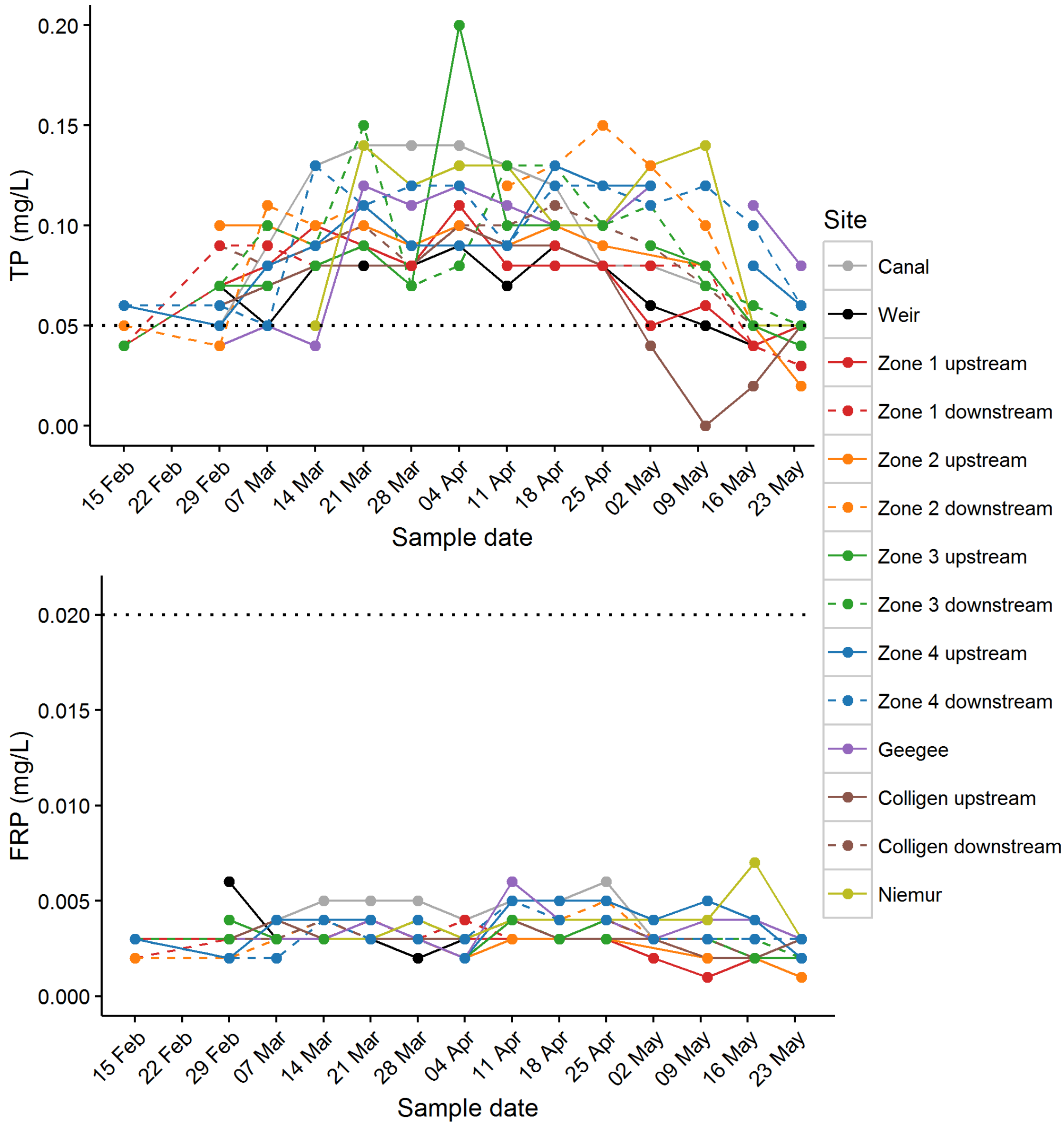


Figure A.14. Total Phosphorus and Filterable Reactive Phosphorus during the algal monitoring period for all sites.

Phosphorus followed a similar pattern to nitrogen (Figure A.12-A.14), although the impact of the bloom conditions resulted in a much smaller change in TP concentrations as, while the cyanobacteria is an efficient phosphorus scavenger from within aquatic environments, the ability to fix nitrogen from the atmosphere effectively allows for importation of that nutrient from outside the aquatic ecosystem. Increases and decreases in TP during the bloom conditions likely reflect the incorporation of P into the biomass keeping material in the water column which may normally settle out in association with particles. Readily bioavailable forms of P remained low throughout the field season and were not impacted by either Commonwealth environmental water or the cyanobacteria bloom.

The influence of the bloom in driving the TN and TP concentrations, rather than a flush of nutrients from upstream driving the bloom is also supported by cases where the downstream sites have higher nutrient concentrations than the sites upstream of them (compare Niemur to Colligen Creek throughout the bloom period and Zone 4 downstream with other Zones in mid March, Figure A.11 and A.14).

Carbon Characterisation

The use of spectroscopic analysis provides key information on how the composition of the dissolved organic carbon changed over the course of the 2015-16 field season and how the algal bloom not only increased the amount of DOC (as was shown in Figures A.8 and A.9) but made important modifications to the types of molecules dominating the carbon dissolved in these rivers.

Absorbance scans of filtered water samples indicate the proportion of ultraviolet or visible light absorbed at each wavelength (measured on a logarithmic scale). Figure A.15 shows the absorbance scans for source water and all four zones in August-December 2015. In August it is clear that all sites are quite similar in both the amount and mixture of dissolved organic carbon (scans are similar in both height and shape). In September the influence of the multi-site watering event can be seen beginning to enter the system but this influence has not yet reached Zone 4 or the downstream sampling site in Zone 2 (where low flow rates result in changes in water quality taking longer to make their way down the zone). By the end of October all zones have very similar carbon profiles, matching those of the source water from the weir, while the difference between these and the canal show the influence of contact with the floodplain. The increase in absorbance across a range of wavelengths suggests DOC of a wide variety of molecular sizes has been added to the system. In November and December the influence of the watering decreases with the effect lingering in Zone 2 (downstream) and Zone 4 and the broader peak around 250 nm suggesting that larger molecules still persist in this system (likely humic and fulvic acids).

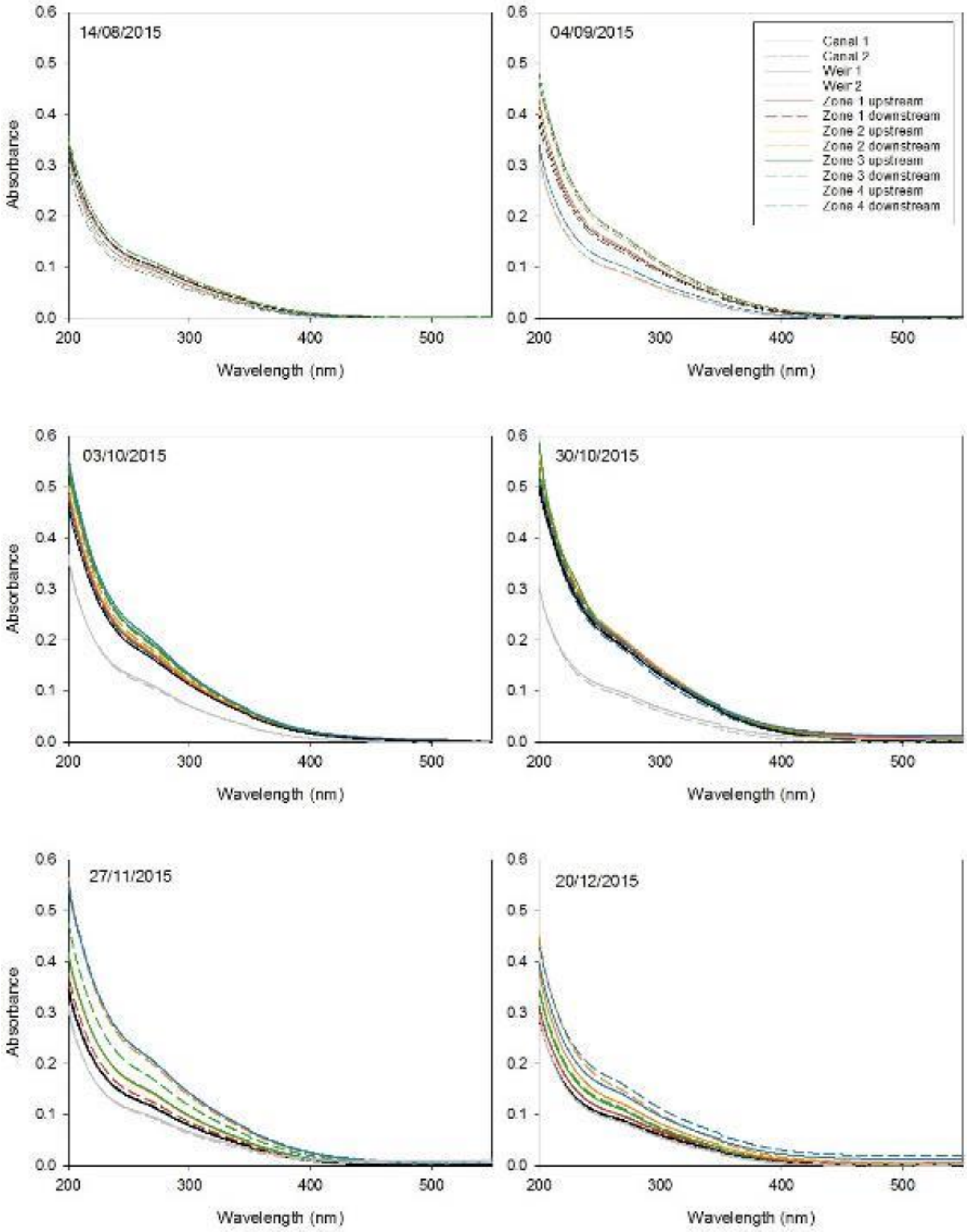


Figure A.15. Absorbance scans for source water and study zones from August-December 2015.

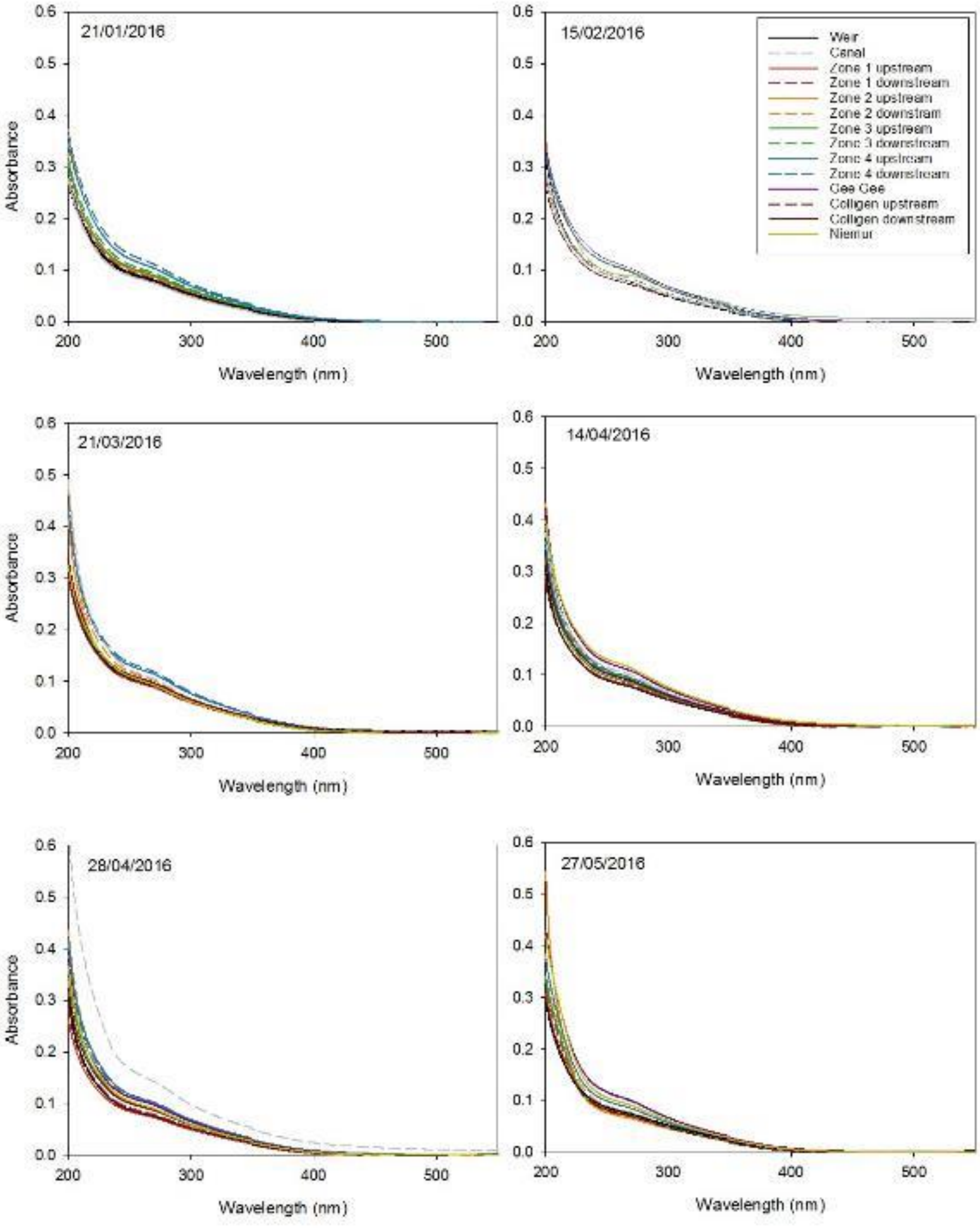


Figure A.16. Absorbance scans for all study sites on selected dates from January-May 2016.

Representative absorbance scans for January-May are shown in Figure A.16. Scans in January and February are broadly consistent with what would be expected in this system in summer under normal in-channel flow conditions. Note that the scans for 15/02/2016 are not all exactly the same shape, suggesting that the mixture of organic molecules differs between sites. The more upstream sites are flatter in the 250 nm region and then steeper towards the left of the graph, which may suggest an increased proportion of smaller molecules. The scans from March and mid-April are much more uniform and the absorbances lower than would have been expected from similar amounts of DOC in the spring. In late April the canal scan suggests a major input of DOC relative to the other sites (this was two weeks after the actual spike in DOC in the canal). At the end of May some sites have very steep scan profiles, suggesting a dominance of small molecules (e.g. Zone 2 upstream), but the height of the absorbance scans would be interpreted to imply that the amount of DOC had remained fairly consistent throughout March-May when it is know that the DOC concentration varied considerably over this period. The amount of light absorbed by a molecule of organic matter varies with the size of the molecule, bonding (presence of double bonds and ring structures) and other structural and water chemistry effects.

The relationship between absorbance and DOC has been used in the Edward-Wakool system as an early warning of high carbon loads (absorbance results are available much more quickly than DOC analyses), and clearly during the multi-site watering the absorbance scans were responsive to changes in DOC. Figure A.17 examines the relationship between absorbance and DOC at two wavelengths in the ultraviolet spectrum. 250 nm (or 254 nm) is often used as a marker of DOC, although establishing a calibration in one catchment is not suitable for predicting DOC concentration in another (Baldwin and Valo 2015). In this field season we have two dominant sources of DOC- floodplain organic matter from upstream (dominant in August-January) and algal DOC (dominant in March-May). Data from mid-February is plotted separately to check for early influence of algal carbon before full bloom conditions. While there is a reasonable amount of scatter in the August-January data (shown in red) there is a clear trend to increased absorbance with increased DOC at both 200 nm and 250 nm. Absorbance at 200 nm is generally more affected by scatter and interference so 250 nm is usually considered a better indicator of DOC. During this period an increase of 2 mg C/L would increase the absorbance at 200 nm by 0.12 and at 250 nm by 0.06. However, during the bloom there is considerably greater scatter in the trend and an increase of 2 mg C/L would be expected to increase absorbance at 200 nm by only 0.03 and at 250 nm by 0.01. In other words, the technique is 4 times more sensitive to floodplain dominated carbon at 200 nm and 6 times more sensitive at 250 nm. This indicates two things- the difference in sensitivity between the wavelengths indicates that the algal carbon is heavily dominated by small molecules with relatively simple structure that absorb only weakly, and that under these circumstances absorbance spectroscopy is a poor early warning technique for high carbon loading in the river.

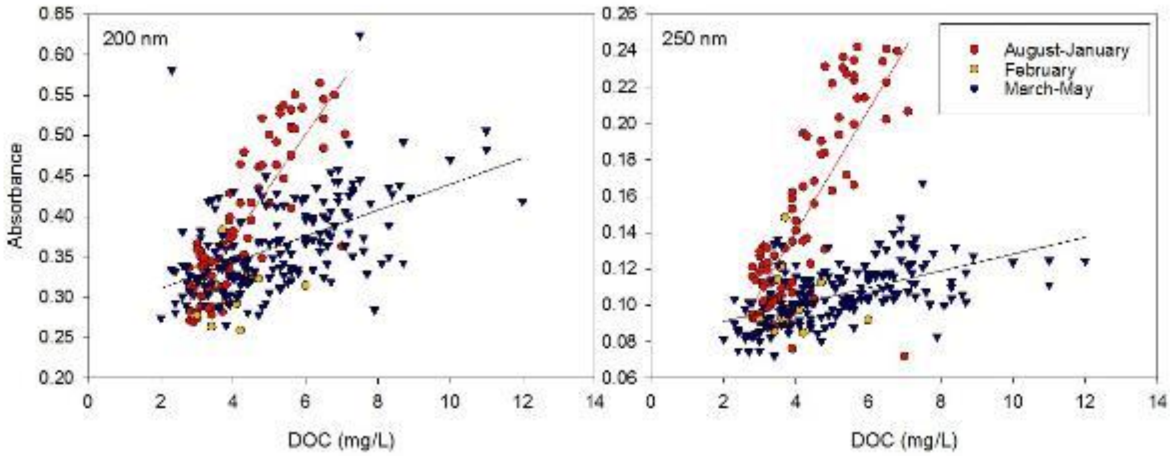


Figure A.17. Relationship between absorbance and dissolved organic carbon concentration at 200 nm and 250 nm showing the dramatic difference in the optical properties of the organic matter during the bloom of cyanobacteria.

Fluorescence

In August the fluorescence of water samples was low and sites were very similar to each other (data not shown). In September the downstream sites were unchanged (see Gee Gee Bridge in Figure A.18 as a representative sample). Water from the weir and as far downstream as Zone 3 (except the downstream site in Zone 2) was showing small increases in fluorescence in the humic and fulvic acid regions (bands of emissions around 450 nm), suggesting a small amount of organic matter from the floodplain upstream had been introduced into the system. The broad nature of these peaks suggest a range of molecular sizes contributing to these peaks. Weak fluorescence was also present in the aromatic protein region (Excitation 250 nm, Emission 300 nm). Note that while increased fluorescence is seen in Zone 3, it is not present at the downstream site in Zone 2, indicating faster transit of the water through the Yallakool Creek.

Fluorescence scans in early October (Figure A.19) clearly show the influence of the multi-site watering, although the effect is less at the downstream end of Zone 4 and minimal at Gee Gee Bridge. The aromatic protein region of the scans is relatively unchanged compared to water in the canal, however the humic and fulvic regions have strong fluorescence, indicating that the carbon exported from the Barmah-Millewa floodplain is dominated by these large complex molecules (smaller molecules may have been consumed further upstream in the system). Late October (Figure A.20) shows a weakening influence of these molecules and the fluorescence is fairly consistent although still slightly lower at the downstream sites. By the end of November (Figure A.21) there is a weak persistence of humic and fulvic fluorescence at downstream zones and at the downstream site of Zone 2, suggesting that complex organic matter is retained longer at this site due to low flows and that water quality in Zone 3 is influenced more strongly by that entering from Zone 1 (due to the higher flow from this zone).

By the 20th of December the fluorescence at most sites was similar and lower than was observed in November. The weir and canal and Yallakool upstream sites were similar to the base levels observed in August and the other sites remained slightly higher, with the downstream site in Zone 2 having marginally higher fluorescence than the other downstream sites (data not shown). In January the pattern was consistent with December, with fluorescence further lowered at all sites.

Figure A.22 shows fluorescence scans for key sampling sites on selected dates throughout the period of intensive monitoring of the bloom of cyanobacteria. Sampling sites and dates are selected based on DOC results to cover the broadest range in DOC over this period. Similar to the trend in the absorbance spectroscopy, the difference in fluorescence measured across these samples is much lower than would normally be expected, reinforcing the evidence for a dramatic shift in the type of organic matter to small molecules that do not fluoresce. Based on DOC concentration the downstream site in Zone 2 should have been separating from other sites throughout March, with a peak on the 28/3/2016, however only very subtle differences are present. On 25/4/2016 the fluorescence properties of water from the canal was dramatically different to other sites, but consistent with the absorbance results. This result may be indicative of changes is DOC chemistry occurring as part of the degradation process of the bloom, which was well underway at that time, but the effect was only found on one sampling occasion. On the same date a peak in fluorescence was observed at the Niemur, suggesting input of larger but relatively bioavailable carbon. Neither of these results correlate with the amount of DOC at the sites relative to the other sites sampled that day, but indicate a transient change in the type of organic matter present.

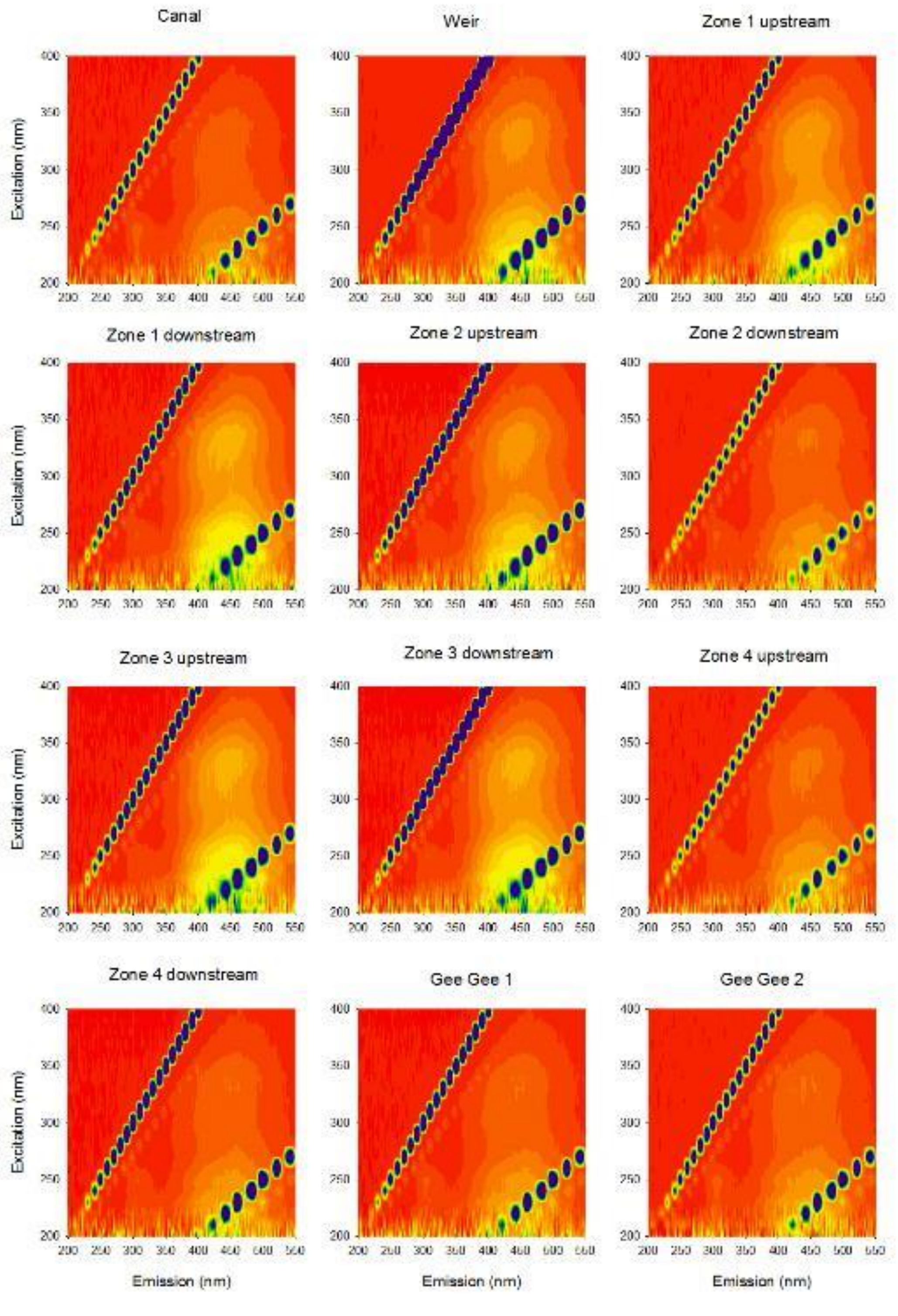


Figure A.18. Fluorescence in source water and study zones 4/09/2015. Gee Gee Bridge is included to track the downstream influence of the water.

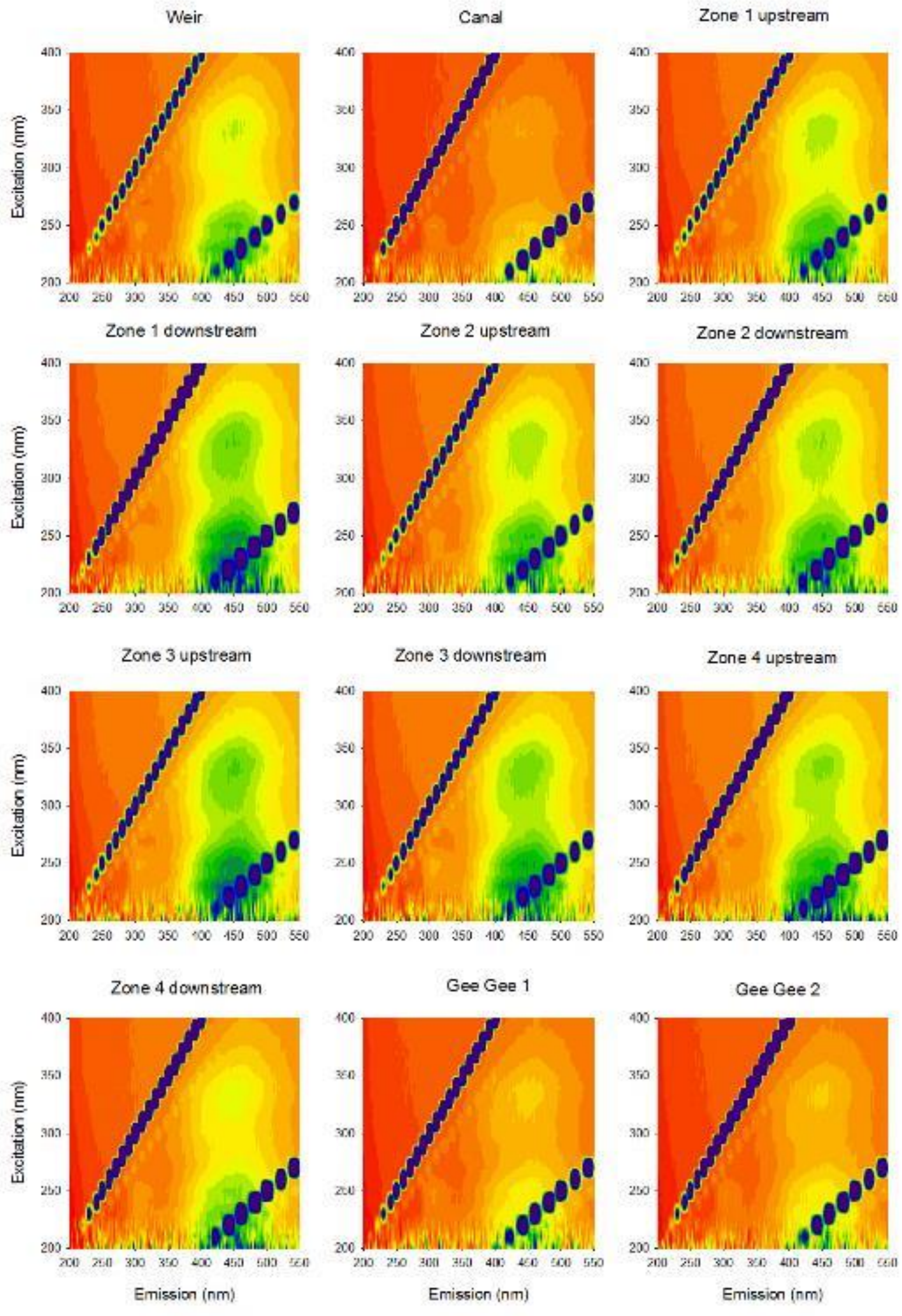


Figure A.19. Fluorescence in study zones and sources 3/10/2015

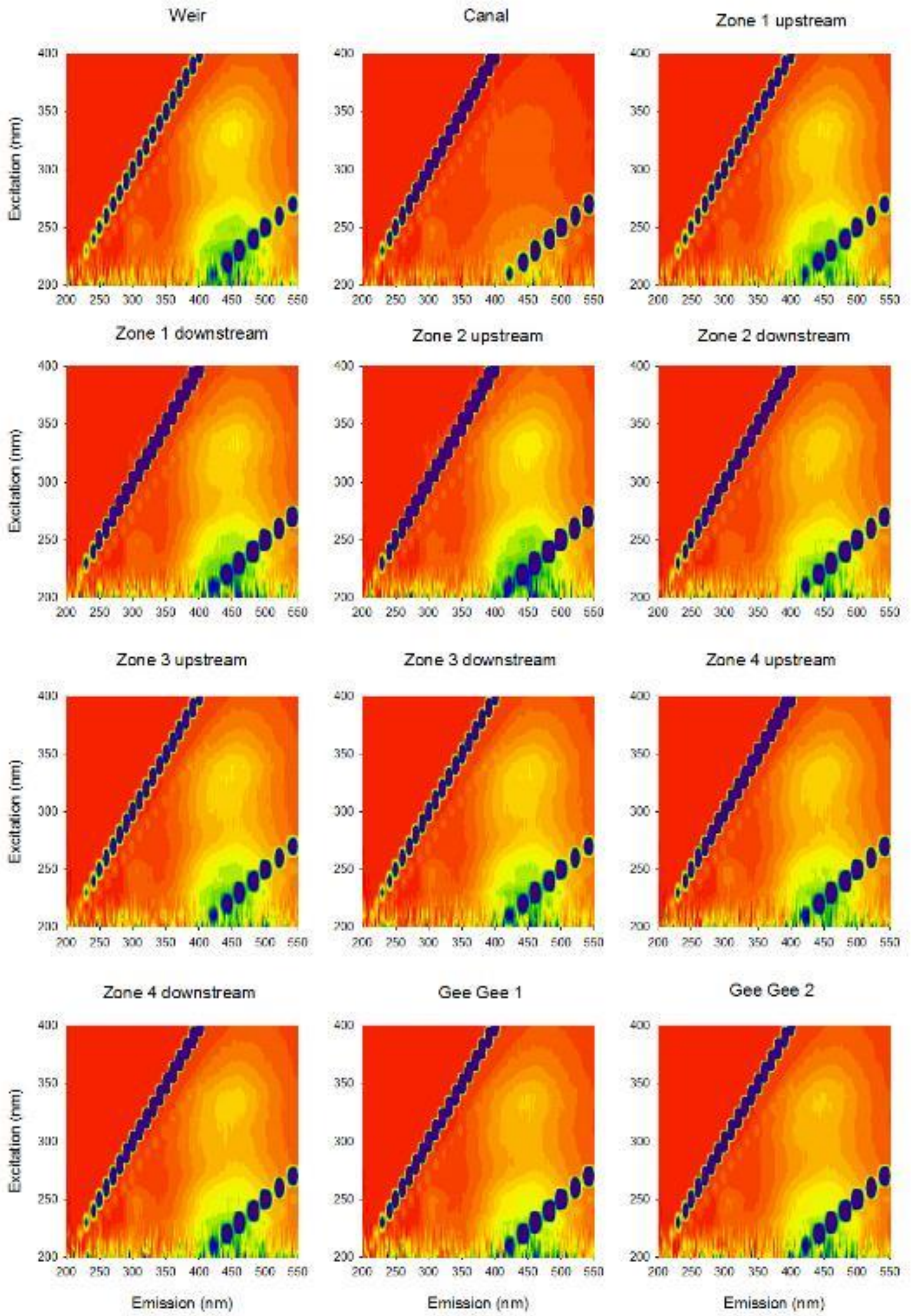


Figure A.20. Fluorescence in study zones and source water 30/10/2015

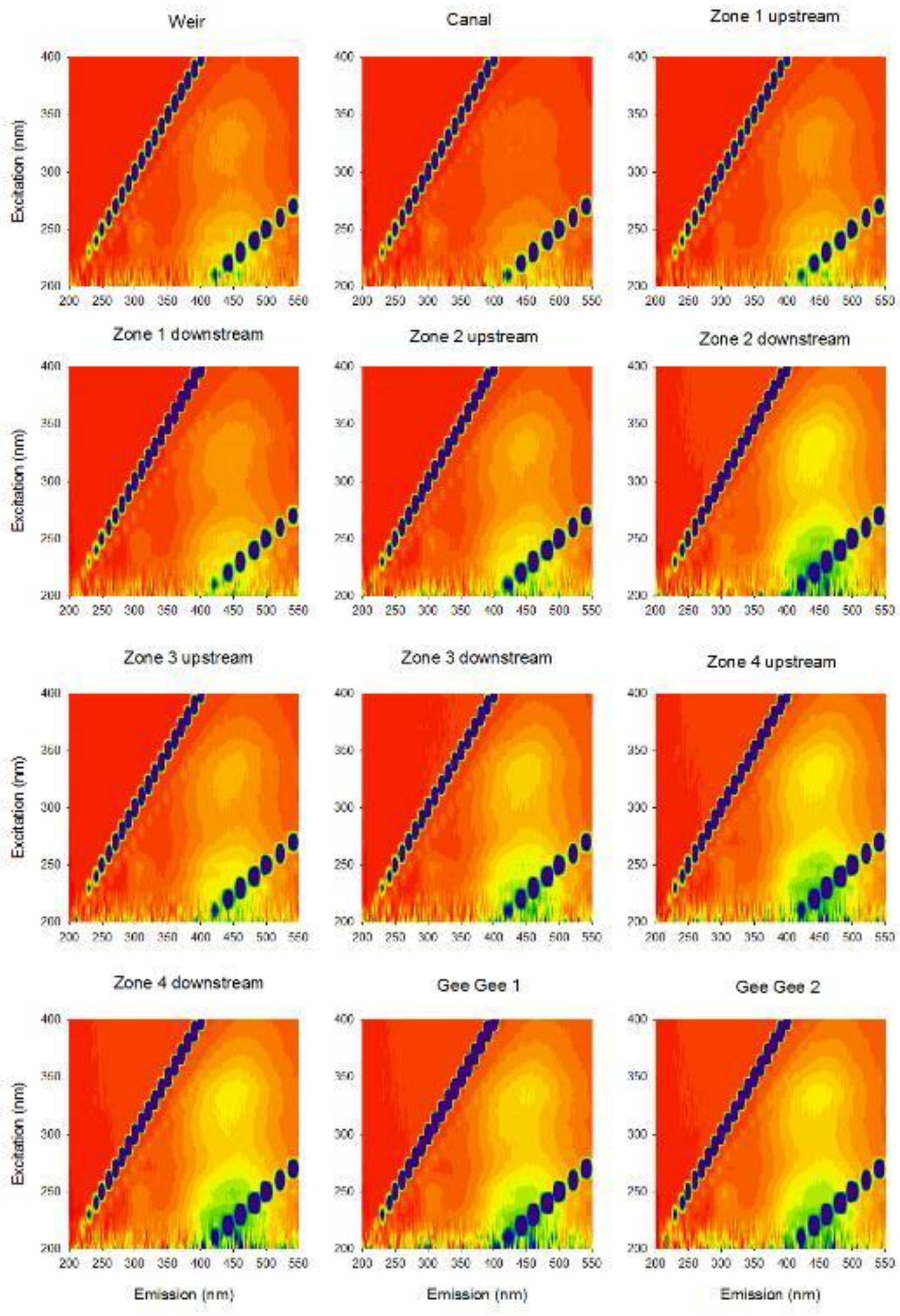


Figure A.21. Fluorescence in study zones and sources 22/11/2015.

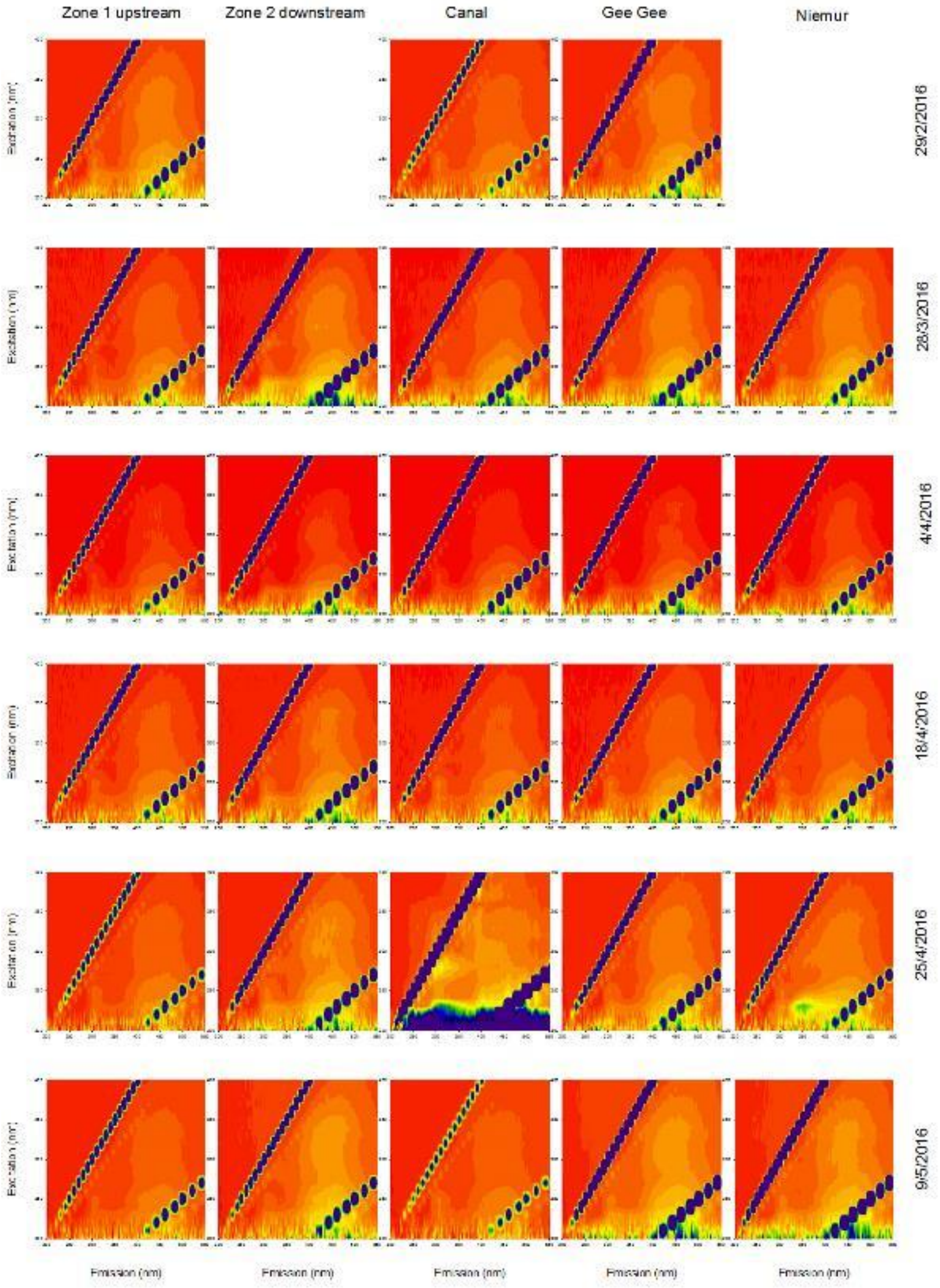


Figure A.22. Fluorescence at selected sampling sites for six sampling dates across the algal bloom. Note: cyanobacteria were present in bloom concentrations from late-February to the end of May 2016.

A.5 Discussion

Returning to the key questions associated with the impact of the Environmental watering actions on the Edward Wakool system as a whole, it is clear that the impact on water quality parameters was variable and in most cases very small.

What did Commonwealth environmental water contribute to temperature regimes?
Commonwealth environmental water did not influence temperature regimes in this system.

What did Commonwealth environmental water contribute to dissolved oxygen concentrations?
Consistent with 2014-15, the Wakool River in Zone 2, which received less environmental water (low flows) had lower dissolved oxygen concentrations in spring and early summer than the other zones receiving larger volumes of Commonwealth environmental water. The environmental water contributes to maintenance of dissolved oxygen in Zones 1, 3 and 4.

What did Commonwealth environmental water contribute to nutrient concentrations?
Commonwealth environmental water did not influence nutrient concentrations in 2015-16.

What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat?
Commonwealth environmental water, through the combination of the multi-site watering action and the flows directed specifically at the Yallakool Creek and Wakool River, contributed to the introduction of small amounts of floodplain carbon from upstream in the Barmah-Millewa forest. The organic matter profile over this period reflected input of large, complex humic and fulvic acids which passed through the system from September to December.

What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?
The timing of the flows through the Barmah-Millewa forest was early enough in the season that carbon inputs were achieved by Commonwealth environmental water without causing blackwater in the Edward-Wakool system. Dilution flows from the canal were not required.

Additional questions for extended algal monitoring

Did Commonwealth environmental water contribute to the bloom conditions in the Edward Wakool system?

Commonwealth environmental water did not create conditions responsible for the onset of the bloom of cyanobacteria in February 2016. Nutrient profiles in the system were in the usual range prior to the onset of the bloom, and the bloom was initiated much further upstream than the floodplain connections created by Commonwealth Environmental Water.

How did the algal bloom impact water quality in the Edward-Wakool system?

The algal bloom was the dominant factor determining water quality during March-May 2016. The algal bloom caused an increase in Total Nitrogen and Total Phosphorus in the water column through efficient nitrogen fixation from the atmosphere and phosphorus scavenging from the aquatic environment. It dramatically changed the organic matter profile with a shift to much higher proportions of particulate organic matter and the dissolved organic matter became dominated by small molecules that absorb and fluoresce light only very weakly. Average dissolved oxygen shifted to supersaturated concentrations and pH moved into the basic region, both with wide diurnal fluctuations during the peak of the bloom, transitioning back into the normal ranges as the bloom slowly degraded in the cold weather. Turbidity was dominated by algal cells during the bloom, limiting the light available for other species.

17. Appendix B: Stream Metabolism

B.1 Background

Whole stream metabolism measures the production and consumption of dissolved oxygen gas (‘DO’) by the key ecological processes of photosynthesis and respiration (Odum 1956). Healthy aquatic ecosystems need both processes to generate new biomass (which becomes food for organisms higher up the food chain) and to break down plant and animal detritus to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic foodwebs. The relationships between these processes are shown in Figure B.1.

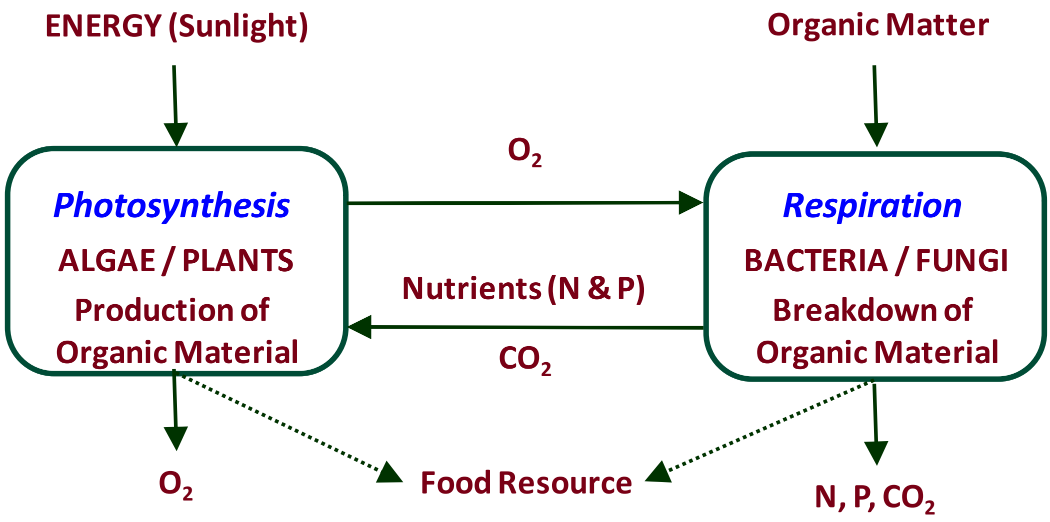


Figure B.1. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of DO concentration over a given time frame; most commonly expressed as (change in) milligrams of dissolved oxygen per litre per day (mg O_2/L/Day). Typical rates of primary production and ecosystem respiration range over two orders of magnitude, from around 0.2 to 20 mg O_2/L/Day with most measurements falling between 2–20 mg O_2/L/Day (Bernot et al. 2010; Marcarelli et al. 2011).

If process rates are too low, this may limit the amount of food resources (bacteria, algae and water plants) for consumers. This limitation will then constrain populations of larger organisms including fish and amphibians. Rates are expected to vary on a seasonal basis as warmer temperatures and more direct, and longer hours of, sunlight contribute to enhancing primary production during summer and into early autumn. Warmer temperatures and a supply of organic carbon usually result in higher rates of ecosystem respiration (Roberts et al. 2007).

In general, there is also concern when process rates are too high. Greatly elevated primary production rates usually equate to algal bloom conditions (or excessive growth of plants, including duckweed and azolla), which may block sunlight penetration, killing other submerged plants, produce algal toxins and large diel DO swings - overnight, elevated respiration rates can drive the DO to the point of anoxia (no dissolved oxygen in the water). When an algal bloom collapses, the large biomass of labile organic material is respired by bacteria, often resulting in extended anoxia. Very low (or no) DO in the water can result in fish kills and unpleasant odors. Bloom collapse often coincides with release of algal toxins; hence the water becomes unusable for stock and domestic purposes as well.

Sustainable rates of primary production will primarily depend on the characteristics of the aquatic ecosystem. Streams with naturally higher concentrations of nutrients (e.g. arising from the geology), especially those with very open canopies (hence a lot of sunlight access to the water) will have much higher natural rates of primary production than forested streams, where rates might be extremely low due to heavy shading and low concentrations of nutrients. Habitat availability, climate and many other factors also influence food web structure and function. Uehlinger (2000) demonstrated that freshes with sufficient stream power to cause scouring can 'reset' primary production to very low rates which are then maintained until biomass of primary producers is re-established. These scouring freshes are normally found in high gradient streams and are considered unlikely to occur in lowland streams such as those in the Edward-Wakool system. However in lowland systems flow variability may drive wetting and drying of biofilms, and this can strongly influence rates of primary production (Ryder 2004; Ryder et al. 2006).

B.2 Selected-area questions

Evaluation of the response of stream metabolism to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system at the i) Selected Area scale (Watts et al. 2014b), and ii) Basin scale (Hale et al. 2014). The Basin Scale evaluation involves the integration of multiple datasets from a number of different catchments, and this will be undertaken by the Murray-Darling Freshwater Research Centre and evaluated in a separate report. The first two questions below relate to the Basin Scale. This Edward-Wakool selected area report will evaluate short-term response questions (Questions 3 and 4 below) specific to the Commonwealth environmental watering action in the Yallakool Creek-Wakool River in 2015-16. These questions arise from the importance of new organic (plant) matter, created through photosynthesis, supplying essential energy to the foodweb and the critical role of respiration in breaking down organic detritus and therefore resupplying nutrients to enable such growth to occur.

Q1. What did Commonwealth environmental water contribute to patterns and rates of decomposition?

Q2. What did Commonwealth environmental water contribute to patterns and rates of primary productivity?

Q3. How does the timing and magnitude of Commonwealth environmental water delivery affect rates of gross primary productivity and ecosystem respiration in the Edward- Wakool River system?

The following hypotheses were developed, partially based on earlier previous work in the Yallakool Creek – Wakool River system (Watts et al. 2014b), to directly explore these evaluation questions:

- Under extended 'cease to flow' conditions of several weeks or more, the responses of GPP and ER will greatly depend on the available nutrient supplies and the time of year. High nutrients and warm conditions may lead to very high rates associated with excessive phytoplankton growth. (Q1, Q2, Q3)
- Under normal 'base' flow, rates of GPP and ER will be constrained to the low-moderate range, typically 1-3 mg O_2/L/Day. (Q3)
- With in-stream freshes, rates of GPP and ER will increase slightly to 3-5 mg O_2/L/Day. Larger increases will occur if significant backwater areas are reconnected to the main channel due to enhanced nutrient delivery. (Q3)
- Inundation and reconnection of backwater areas to the main channel during high flows will result in elevated rates of GPP and ER. (Q1, Q2, Q3)
- Primary production in the Edward-Wakool system will be limited by low phosphorus concentrations. (Q3)

B.3 Methods

The stream metabolism measurements were performed in accordance with the LTIM Standard Operating Procedure (Hale et al. 2014). At least one logger placed in each of four study zones; in zones 1, 3 and 4, loggers were placed at the top and bottom end of these zones. Water temperature and dissolved oxygen were logged every ten minutes from mid-August 2015 until early April 2016. Data were downloaded and loggers calibrated approximately once per month, and more frequently (often fortnightly) during summer time to avoid problems found in previous years with probe biofouling. Downloading also depended upon depending on access. Light and depth loggers were also deployed and data were downloaded on an approximately monthly basis. The data collected by the loggers was also used to calculate daily average temperature and dissolved oxygen concentrations (see Appendix A) for each of the zones from mid-August 2015 to early April 2016. Water quality parameters (temperature (^oC), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were measured as spot recordings fortnightly at two sites within each Zone (and one in Zone 2).

After discussions at the LTIM annual forum in July 2016, it was decided that an updated version of the BASE model (BASEv2) would be used for analysing the 2015-16 metabolism data. This change was a result of the paper published by Song et al. (2016) which showed that our BASE model could be improved by changing from stepwise progression and fitting using each data point to integrated (whole data set) fitting and progression suing modelled data. Thus, the 2014-15 and 2015-16 rates have been determined using related, but different models. Extensive testing of both models (BASE and BASEv2) on the same data sets indicate that the latter typically produces estimates of GPP and ER that are around 5% higher than the model used in 2014-15. Hence parameter estimates across both years are not directly comparable. However, differences of 5% are considered small and almost within the 'noise' of daily parameter estimation.

Acceptance criteria for inclusion of daily results from the BASE model (Grace et al. 2015) in the data analysis presented here were established at the 2015 Annual LTIM Workshop. These criteria were that the fitted model for a day must have both an r^2 value of at least 0.90 *and* a coefficient of variation for the GPP parameter of < 50%. With BASEv2 an additional criterion was also used which stipulated the model fit parameter PPfit must be in the range 0.1 to 0.9. Values of PPfit outside this range indicated that the 'best fit' to the data was still an implausible model.

B.4 Results

Regular maintenance and occasional problems with some loggers meant that there were less than the maximum 232 daily results for each site (Table B.1). Using the acceptance criteria for each day's diel DO curve, the acceptance rate ranged from 67% of all days with data available (144 from 216) for Zone 2 Downstream, down to 14% (31 of 215) at Zone 3 Upstream (Table B.1).

Table B.1 Summary of data availability for the seven data logger sites, August 2015 - April 2016.

Hydrological Zone	Site	Total Number of Days	Days with Acceptable Data	% of Acceptable Days
Zone 1 Yallakool Ck	Upstream	219	130	59
	Downstream	219	136	62
Zone 2 Wakool River	Downstream	216	144	67
Zone 3 Wakool River	Upstream	215	31	14
	Downstream	215	52	24
Zone 4 Wakool River	Upstream	197	106	54
	Downstream	209	77	37

The median GPP values for all seven sites fall within a narrow range of 1.4 to 4.1 mg O_2/L/Day (Table B.2, Figure B.2). This closeness in these median GPP rates is unsurprising given the similarity in the biogeochemical environments as noted in previous years (Watts et al. 2014b, Watts et al. 2015). With the exception of a significantly higher value for Zone 3 upstream (10.6 mg O_2/L/Day), all median ER values fell within the range 3.2 to 6.4 mg O_2/L/Day (Table B.2, Figure B.3). Even though it appears that the median rates are much higher at the Zone 3 upstream site (GPP = 4.09 mg O_2/L/Day, ER = 10.6 mg O_2/L/Day), this is largely an artefact of the data set. This site had by far the least number of days that met the acceptance criteria (Table B.1) and not a single day in the August-October 2015 period. This spring period typically has the lowest rates measured throughout the entire monitoring period, so missing these will elevate the descriptive statistics. These 'low' spring time rates can clearly be seen in Figure B.2.

There was no systematic difference between the daily GPP values measured within the two sites in Zones 1 or 4 (Table B.2). Hence indicating that there are no major changes to metabolism occurring within the reach between upstream and downstream loggers in these two zones. Comparison between the two sites in Zone 3 is compromised by the lack of estimates on the same day.

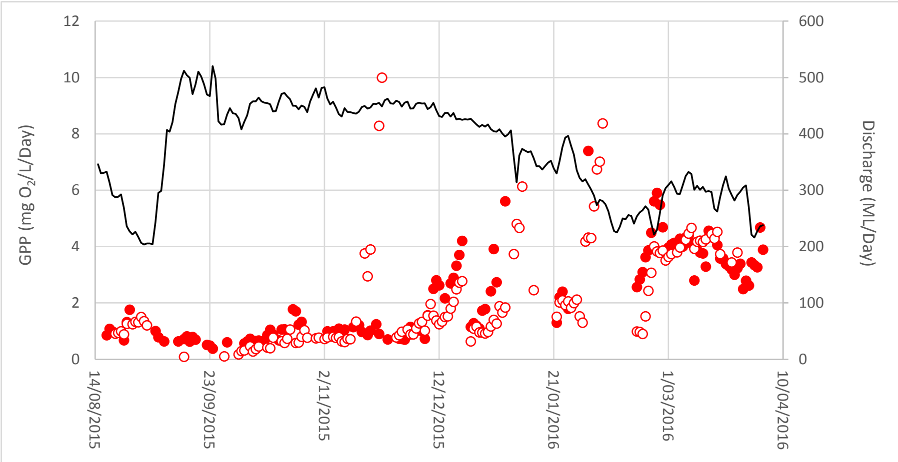
Table B.2 Median, minimum and maximum values of primary production (GPP), ecosystem respiration (ER) rates and P/R ratios for the seven study sites, August 2015 - April 2016. 'n' is the number of days for which successful estimates of metabolic parameters were obtained. The data is separated into the four separate zones.

	Zone 1 Upstream (n =130)			Zone 1 Downstream (n =136)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.75	0.38	7.4	1.37	0.09	10.0
ER (mg O_2/L/Day)	3.19	0.20	10.8	3.18	0.32	31.2
P / R	0.72	0.15	4.4	0.43	0.05	7.2
	Zone 2 Downstream (n =144)					
	Median	Min	Max			
GPP (mg O_2/L/Day)	2.78	0.82	13.6			
ER (mg O_2/L/Day)	6.44	1.97	26.6			
P / R	0.39	0.11	2.5			
	Zone 3 Upstream (n =31)			Zone 3 Downstream (n =52)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	4.09	1.45	14.8	1.57	0.94	3.7
ER (mg O_2/L/Day)	10.59	2.97	52.0	2.73	0.92	7.1
P / R	0.46	0.20	1.1	0.66	0.43	1.2
	Zone 4 Upstream (n =106)			Zone 4 Downstream (n =77)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	3.15	0.60	9.5	2.61	0.33	9.5
ER (mg O_2/L/Day)	4.00	1.02	31.7	2.72	0.18	18.7
P / R	0.62	0.22	1.8	0.70	0.15	18.9

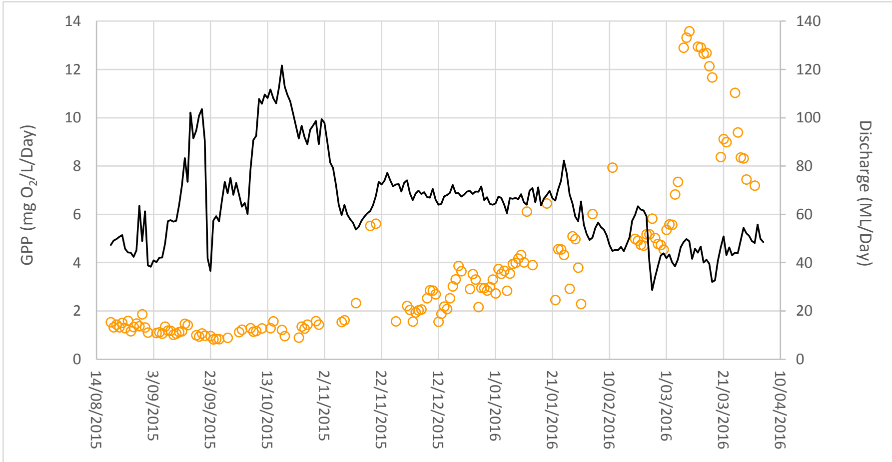
There were sudden increases in metabolic activity during mid-November 2015 at the downstream site at Zone 1 and at sites further downstream (Figure B.2, B.3). Rates of both GPP and ER were rapidly climbing during this period before dropping back to 'normal' levels over a few days. The consistency of this pattern across sites tends to rule out logger failure. Unfortunately there were no data for two sites (Zone 3 and 4 downstream sites) during this period. The origin of this short lived spike in rates is not yet clear but does not appear to be discharge related, as flows were relatively stable in all four zones across this period (and immediately beforehand). Investigations into possible causes (nutrient spikes, altered source water) are continuing.

There was a large increase in GPP in the upper Wakool River (Zone 2) in autumn 2016 (Figure B2). This increase is consistent with the development of the algal bloom (discussed in Appendix A). GPP increased from 7.3 mg O_2/L/Day on the 5th March to 12.9 mg O_2/L/Day on the 7th March and peaked at 13.6 mg O_2/L/Day on the 9th March (Figure B.2b). Daily GPP at this site then gradually declined until LTIM monitoring ceased in early April. Unfortunately the paucity of data from Zone 3 meant this event was not detected in that region of the Wakool River using metabolism measurements. There appears to be an increase in GPP in both Zone 4 sites over this time period too but not as high as the readings for Zone 2. Peak GPP at the upstream site in March 2016 was 7.0 on 7th March which then declined to 4.0 on 4th April (last day of monitoring)(Figure B.2d).

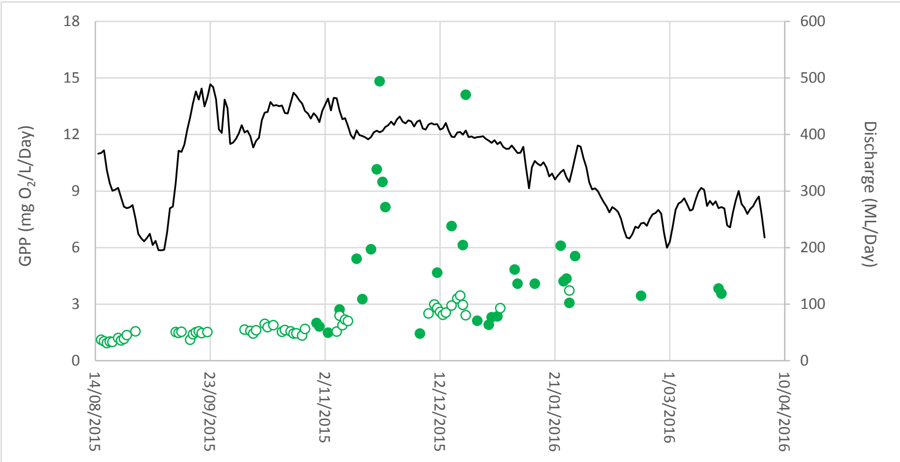
The median ratio of primary production to ecosystem respiration (P/R) at all sites was much less than 1 (Table B.2), indicating that more organic carbon was being consumed within the river channel that was being produced by primary production. This is common for lowland rivers. However all sites had periods where P/R was > 1 suggesting there were occasional periods of high primary production and/or access to organic matter from upstream and outside the stream channel to ensure an adequate supply of organic matter and nutrients to sustain basal growth rates. If physical reaeration is insufficient to counterbalance the oxygen demand through respiration, then dissolved oxygen concentrations can fall to quite low and perhaps problematic levels such as observed in one site in January 2015 (Watts et al. 2015).



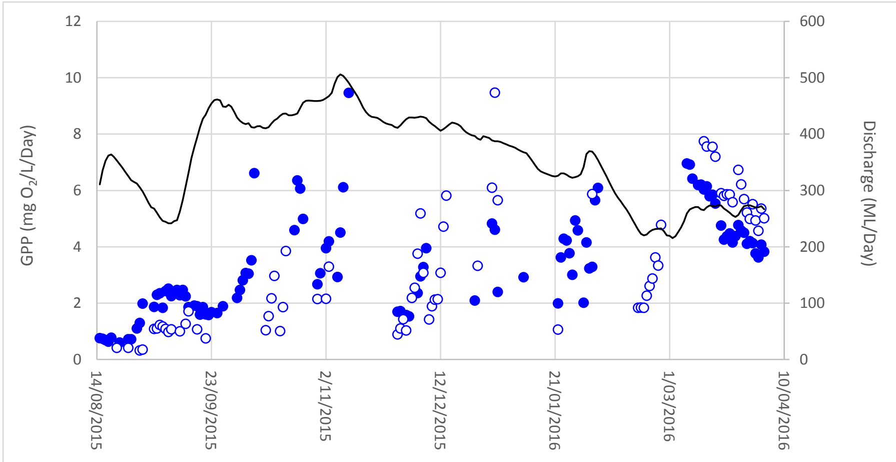
a) Yallakool Creek (Zone 1)



b) Wakool River (Zone 2),

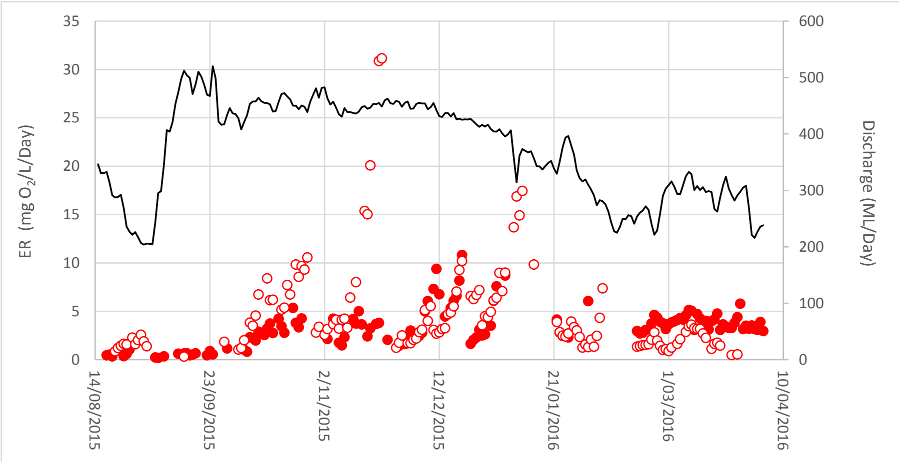


c) Wakool River upstream from Thule Creek (Zone 3),

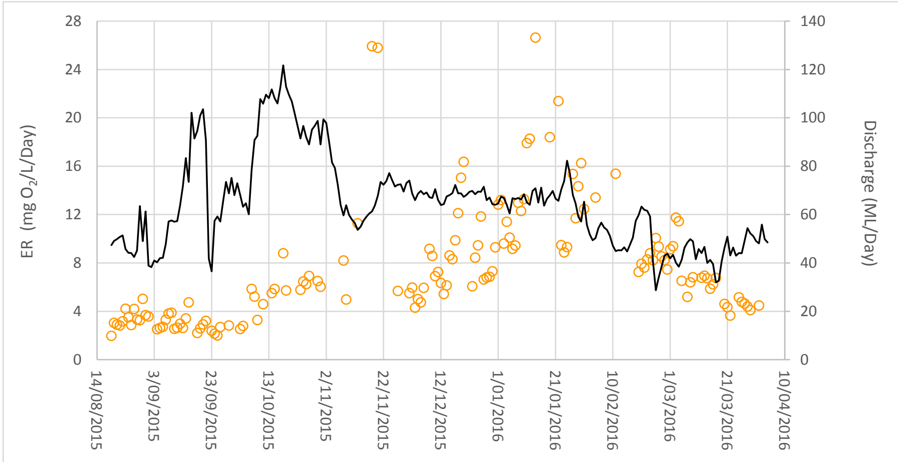


d) Wakool River downstream from Thule Creek (Zone 4)

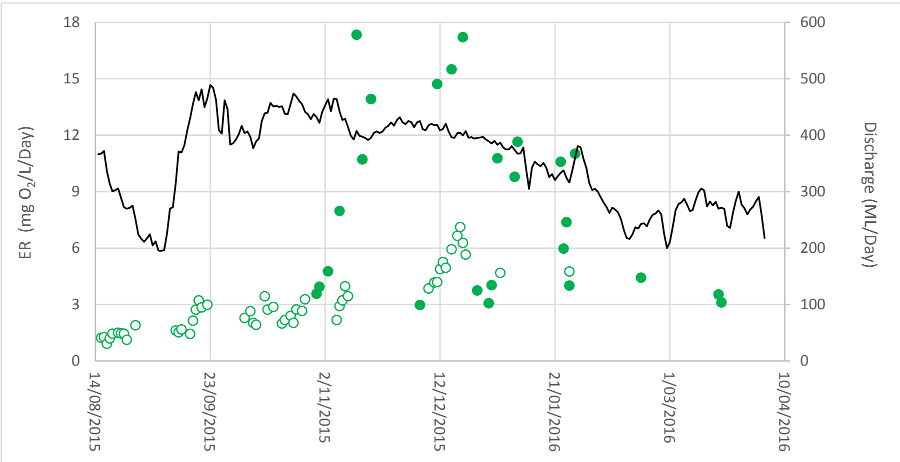
Figure B.2. Relationships between Flow and Gross Primary Production for: a) Yallakool Creek (Zone 1), b) Wakool River (Zone 2), c) Wakool River upstream from Thule Creek (Zone 3), and d) Wakool River downstream from Thule Creek (Zone 4) from August 2015 to April 2016. Full symbols represent the upstream site within each Zone and the hollow symbols the downstream site.



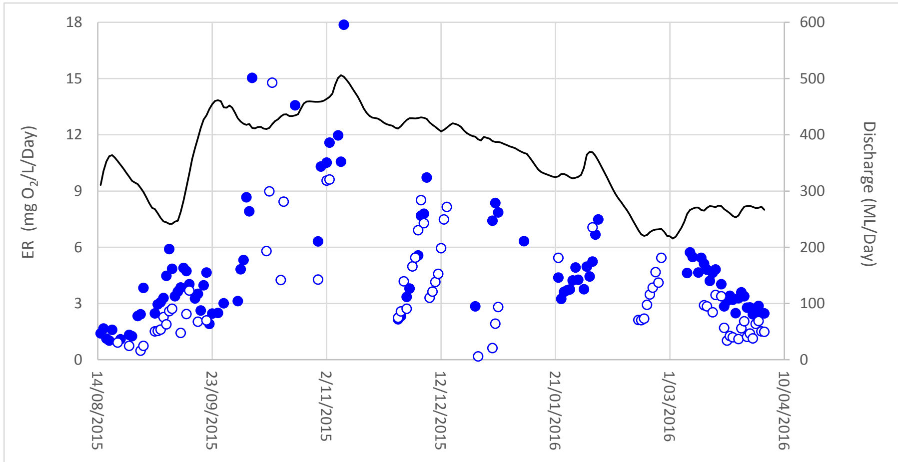
a) Yallakool Creek (Zone 1),



b) Wakool River (Zone 2),



c) Wakool River upstream from Thule Creek (Zone 3)



d) Wakool River downstream from Thule Creek (Zone 4)

Figure B.3. Relationships between Flow and Ecosystem Respiration for: a) Yallakool Creek (Zone 1), b) Wakool River (Zone 2), c) Wakool River upstream from Thule Creek (Zone 3), and d) Wakool River downstream from Thule Creek (Zone 4) from August 2015 to April 2016. Full symbols represent the upstream site within each Zone and the hollow symbols the downstream site.

B.5 Discussion

Despite some differences in GPP across zones, and echoing the findings from 2014-15 (Watts et al. 2015), the GPP rates calculated for the four zones in the Edward-Wakool system are at the lower end of the 'normal' range for freshwater streams and rivers. This normal range is (approximately) 3-10 mg O_2/L/Day (e.g. Bernot et al. 2010; Marcarelli et al. 2011). It is highly probable that these low median rates of GPP and ER are due to a combination of very low bioavailable nutrient concentrations and a water column that inhibits photosynthesis by limiting light penetration. Typically, all bioavailable nutrient concentrations were < 0.005 mg/L (see Appendix A) and most importantly this included FRP – the bioavailable form of phosphorus. Some algae and cyanobacteria can fix nitrogen gas from the water to augment N supply when water column concentrations of nitrate and ammonia are low, but there is no comparable mechanism for easily obtaining bioavailable phosphorus when it is in short supply. Some microorganisms can produce enzymes to convert more complex forms of phosphorus to the bioavailable phosphate form, but measurement of this process is beyond the scope of this LTIM project. Turbidity levels at all seven sites and with all measurements were greater than 50 NTU. This means that light penetration into the water column will be inhibited by the fine suspended particulate matter, which in turn will decrease the PAR available for photosynthesis by benthic algae (and to a lesser extent, phytoplankton).

Overall, there were no strong responses in metabolic rates to changes in river discharge associated with either Commonwealth environmental water or natural flows. Both GPP and ER in the various zones showed substantial increases (and decreases) during periods of relatively constant discharge, yet changes in the hydrograph did not appear to produce any immediate metabolic response.

There was very little flow variability in flow (over a days to weeks time-frame) for the period Aug 2015 to April 2016 when metabolism was measured, especially over the key algal growth period of October through to February. Consequently, it was not possible to discern any flow-related responses in metabolism over this period. *It is therefore recommended that serious consideration be given to providing a more variable flow regime in the Edward-Wakool system over this period in future years*. As noted previously (Watts et al. 2015) an instantaneous response in GPP to discharge is not expected as time (typically weeks) is required for algal populations to increase significantly. More rapid changes in ER may occur as bacterial populations can increase over timeframes of hours to a few days to take advantage of increased concentrations of labile organic carbon.

Despite the general invariance in discharge, some relatively rapid changes in metabolic rates were observed – especially for GPP in mid-November 2015. Rates at several sites climbed rapidly over a few days and then declined again. There were higher nitrate and ammonia concentrations noted at this time in Zone 3 but the origin of this event is still under investigation.

Relatively low dissolved oxygen concentrations was recorded in Zone 2 (see Appendix A) on numerous occasions, which is consistent with observations in 2014-15 (Watts et al. 2015). This low DO may be attributed to the observed accumulation of organic matter which resulted in elevated respiration rates compared to the other sites exacerbated by the lack of adequate reaeration. Reaeration is determined by water velocity and in particular, turbulence (which enhances mixing of air – and hence oxygen – into the water column) and is also determined by the geomorphology of the site. The median reaeration rate at the Zone 2 downstream site (1.7 /Day) was much lower than any of the other sites with the exception of the downstream site in Zone 3. All reaeration rates were typical of slow flowing, low gradient streams with generally only a limited amount of physical structures (e.g. large rocks, riffle zones) generating turbulence. It is unlikely the reaeration rate can be greatly enhanced by flow manipulations due to the flat topography, hence again indicating the importance of sufficient flows above base level to ensure environmentally acceptable DO concentrations simply through dilution.

While the Commonwealth environmental watering actions in 2015-16 did not appear to stimulate gross primary production (and therefore basal food resources for invertebrates and fish), the environmental watering did play an important role in preventing poor water quality (Appendix A). These findings are consistent with the findings from monitoring in the tributaries of the Edward-Wakool system 2014-15 (Watts et al. 2015).

18. Appendix C: Riverbank & Aquatic Vegetation

C.1 Background

Riverbank vegetation and aquatic vegetation play an important role in the functioning of aquatic ecosystems, supporting riverine productivity and food webs and providing habitat for fish, invertebrates, frogs and birds (Roberts and Marston 2011).

Flow management and the water regime in a river system can affect the survival, growth and maintenance of adult plants and strongly influence aspects of reproductive cycles, including flowering, dispersal, germination and recruitment. Riverbank plant survival and growth is affected by the frequency and duration of inundation (Toner and Keddy 1997; Johansson and Nilsson 2002; Lowe et al. 2010). Frequent inundation can delay reproduction (Blom and Voesenek 1996), whilst long duration of inundation can reduce growth or survival (Blom et al. 1994; Johansson and Nilsson 2002; Lowe et al. 2010). Favourable soil moisture and nutrient conditions created by a receding flood can encourage rapid recovery and root and shoot development and many plants, including emergent macrophytes and riparian understorey herbs, often germinate on flood recession (Nicol 2004; Roberts and Marston 2011). However, a high level of sediment deposition during periods of inundation can reduce the survival of some small herbaceous riverbank species (Lowe et al. 2010).

Riverbank and aquatic taxa can be broadly categorised into three groups; submerged taxa, amphibious taxa that respond to or tolerate wetting and drying, and terrestrial taxa that typically occur in damp or dry habitats. The watering requirements of aquatic macrophytes is quite variable. For example, while it is critical that the submerged plant ribbon weed are re-flooded within three to four months to maintain existing plants (Roberts and Marston 2011), many amphibious taxa respond to and tolerate a broad range of wetting and drying regimes.

A long history of operational water delivery in the Edward-Wakool system combined with the prolonged millennium drought when flows in the Murray-Darling Basin were at record low levels (van Dijk 2013; Chiew et al. 2014), had negative impacts on the riverbank and aquatic vegetation in the Edward-Wakool system. Community members report there were beds of ribbon weed (*Valisineria* sp.) within the channels and other plants occurring on the banks of the Edward-Wakool system prior to the drought. In 2010 after the break of the drought the submerged and amphibious plant taxa were largely absent throughout the system, with the exception of the longer lived rush *Juncus sp*.

The CEWO and NSW Office of Environment and Heritage have delivered base flows and freshes in the Edward-Wakool system since 2010 with one of the aims being to maintain the health of riparian and in-channel aquatic native vegetation communities and maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat (CEWO 2015). Environmental watering in this system is expected to increase the area of river bank receiving periods of wetting and drying than under operational flows. This is expected to maintain the health of riparian and in-channel aquatic native vegetation and support ongoing recovery and re-establishment of native aquatic vegetation in this system (water Use Minute 10038).

C.2 Selected-area questions

The river bank and aquatic vegetation in Yallakool Creek and the upper and mid- Wakool River were monitored in four hydrological zones with different geomorphology and flow histories to address the following area-specific evaluation questions:

Long-term evaluation questions

- *What has Commonwealth environmental water contributed to the recovery (measured through species richness, plant cover and recruitment) of riverbank and aquatic vegetation in Yallakool Creek and the mid and upper Wakool River that have been impacted by operational flows and drought and how do those responses vary over time?*
- *How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones*?

Short-term evaluation questions

- *What did Commonwealth environmental water delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation in Yallakool Creek and the upper and mid Wakool River?*
- *What did Commonwealth environmental water delivered as base flows and freshes contribute to the diversity of riverbank and aquatic vegetation taxa in Yallakool Creek and the upper and mid Wakool River?*

We hypothesised that the maximum cover of submerged and amphibious taxa in 2015-16 would be significantly higher in zones 1, 3 and 4 than in zone 2 because zones 1, 3 and 4 a) received more environmental water in 2015-16, thus having a larger area of riverbank that experienced wetting and drying water regime, b) had higher taxonomic richness and cover of vegetation in 2014-15 (Watts et al. 2015) providing rootstock and seed bank, and c) have a history of environmental watering since 2010.

C.3 Methods

Monitoring design and field sampling

Four sites in each of four hydrological zones (Yallakool Creek, Wakool River zone 2, Wakool River zone 3 and Wakool River zone 4) were surveyed monthly between August 2015 and May 2016. Monitoring could not be undertaken in June 2016 because rains limited access to sites. At each site six permanent 20 m long transects were established parallel with the river channel. Star pickets were installed at each end of the permanent transect. The lowest transect on the riverbank was labelled as transect 0 and the other five transects labelled consecutively up to transect 5 highest on the river bank. The transects were surveyed so they were 25 cm apart in vertical height, with the five transects thus covering 1.25 m of vertical height of the bank. Transects zero and one were in the water at base operational flows, and the other four transects further up the riverbank have the potential to be inundated during Commonwealth environmental watering or during unregulated flows.

Vegetation was assessed using the line point intercept method along transects. At each of the transects on each sampling date a 20 m tape measure was laid out running horizontally along the riverbank between two star pickets that had been installed at a known height of riverbank. The taxa at each 50 cm point quadrat along the 20 m transect (40 points on each transect) were recorded. Plants were identified to genus, with the exception of a few common taxa that could be consistently identified to species level. Terrestrial grasses were not identified taxonomically and were recorded collectively as grass. If no vegetation was present at a point, then that point was recorded as bare ground, leaf litter or log/tree trunk. When the transects were in the water the tape measure was laid at the waters edge and a flexible fibreglass pole held from the tape out to the water surface to locate the point on the transect for recording data. Photopoints were established at each site and photos taken on every sample event.

Data analysis

Each species was classified into three broad functional categories using a range of sources including Brock and Casanova (1997), Casanova (2011) and Roberts and Marston (2011). Although there are some limitations of using water plant functional groups to classify taxa, the approach of classifying into these three general groups is sound for common taxa that can be reliably distinguished and can be related to hydrological information on wetting and drying regimes.

The three functional categories were:

a) Submerged taxa, being those that have special adaptations for living submerged in water. These plants grow to, but do not emerge from, the surface of the water.

b) Amphibious taxa, including those that tolerate wetting and drying, and those that respond to water level fluctuations, and

c) Terrestrial taxa, being those that typically occur in damp or dry habitats.

The percent cover of riverbank and aquatic vegetation was calculated for each transect for each sample date. If there were any logs or tree trunks recorded in a given transect, the percent cover for that transect was calculated out of a reduced number of points, being 40 transect points minus the number of points recorded as log or tree trunk. This is because no vegetation would have been able to grow at that point if a log or tree trunk was present. To compare cover of vegetation across years one and two of the LTIM program (2014-15 and 2015-16) the month where there was maximum cover in transects one to five across the months of October to May were identified for each taxa. The period from October to May was used because this is the main growing season and there was no data prior to May in 2014 (Year 1). Transects zero was not used in the comparison across years because it was not surveyed in year one of the program. This comparison used data from 632 transects for 2014-15 and 615 transects for 2015-16.

To test if the percent cover of vegetation was significantly different among the four zones across the entire monitoring period (August 2015 to May 2016) in 2015-16, the total percent cover of all taxa was transformed (square root) and analysed using a one way ANOVA with zone as the treatment factor. Analysis of the percent cover for the eight most common taxa were analysed individually using Kruskal-Wakllis nonparametric test because the data were not normally distributed. Statistical analyses were carried out using the freeware R and the R package MASS (R Development Core Team 2013) and IBM SPSS Statistics v20. P-values of <0.05 were used to determine the significance of each ANOVA test. When significant differences were indicated, post hoc pairwise comparisons were undertaken to determine differences between hydrological zones.

C.4 Results

Comparison of riverbank and aquatic vegetation in the Edward-Wakool system between year one (2014-15) and year two (2015-16) of the LTIM monitoring program

A total of 45 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between August 2015 and May 2016. Three of the 45 taxa recorded in 2014-15 were submerged, 20 were amphibious and 22 were terrestrial (Figure C.1). Only four of the taxa were introduced (lippia, arrowhead, medic and sow thistles) and were all in very low abundance. Seven additional taxa recorded in 2015-16 were in very low abundance, but it is possible they may have been nearby to the study sites in 2014-15 but were not present in the survey transects. The additional amphibious taxa recorded in 2015-16 (all native taxa) were yellow twin-heads, swamp lily, water ribbons and narrow leaf cumbungi, and the additional terrestrial taxa were Brachyscome daisy, copper burr and chickweed (Figure C.1).

Eight of the ten most abundant taxa observed in 2015-16 were classified as submerged or amphibious taxa, as the surveys were undertaken in the active littoral zone of the riverbank (Figure C.1). Of the ten most abundant taxa there was one submerged taxa (*Chara spp*.), seven amphibious taxa including floating pondweed (*Potamogeton tricarinatus*), milfoil (*Myriophyllum* spp.), water fern (*Azolla sp*.), mud grass (*Pseudoraphis spinescens*), rush (*Juncus* spp.), sedge (*Cyperus* spp.) and water primrose (*Ludwegia peploides*), and two terrestrial taxa being common sneeze weed (*Centipeda cunninghamii*) and grass (Figure C.1). Eight of the ten taxa were also in the ten most abundant taxa in 2014-15 (Watts et al. 2015). Water primrose and sedge were among the top ten most abundant taxa in 2015-16 replacing common spikerush (*Eleocharis spp.)* and mudwort (*Limosella spp.*) that were more abundant in 2014-15.

There were some notable changes in the maximum cover of submerged and terrestrial taxa between years one and two of the LTIM program. The most evident change across years was an increase in the cover of three common amphibious taxa, mudgrass, floating pondweed and milfoil, and a slight increase in the cover of water primrose. There was a decrease in cover of spikerush in zone 4 and a slight decrease in rush in zones 1, 3 and 4 (Figure C.1).

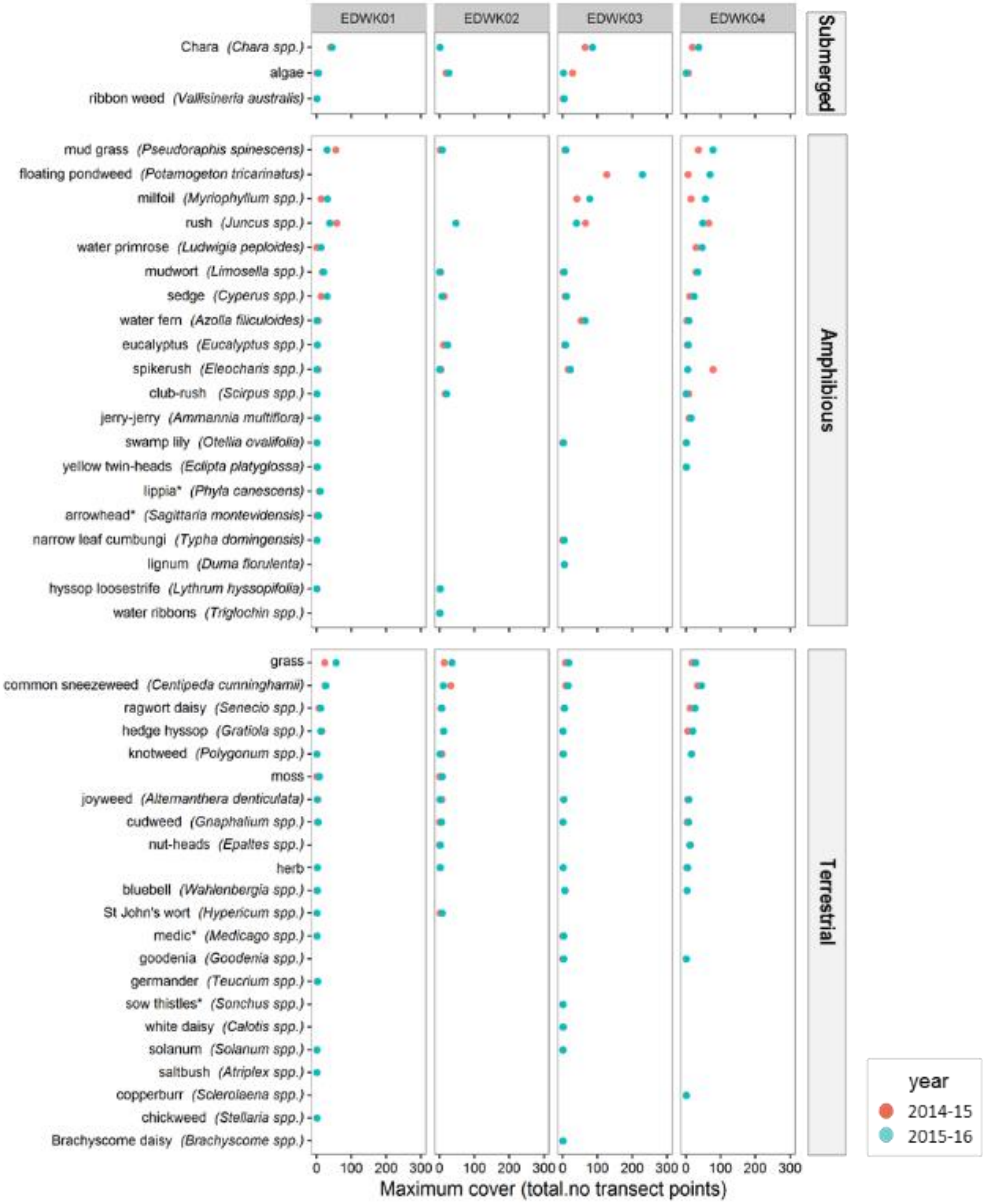


Figure C.1. Maximum cover of riverbank and aquatic vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between October 2015 and May 2016. Taxa were classified as submerged, amphibious or terrestrial. Red dots indicate maximum cover in 2014-15 and blue dots indicate maximum cover in 2015-16. EDWK01 = Yallakool Creek zone 1, EDWK02 = Upper Wakool River zone 2, EDWK03 = Wakool River zone 3 upstream of Thule Creek, EDWK04 = Wakool River zone 4 downstream Thule Creek. Asterisk indicates introduced taxa.

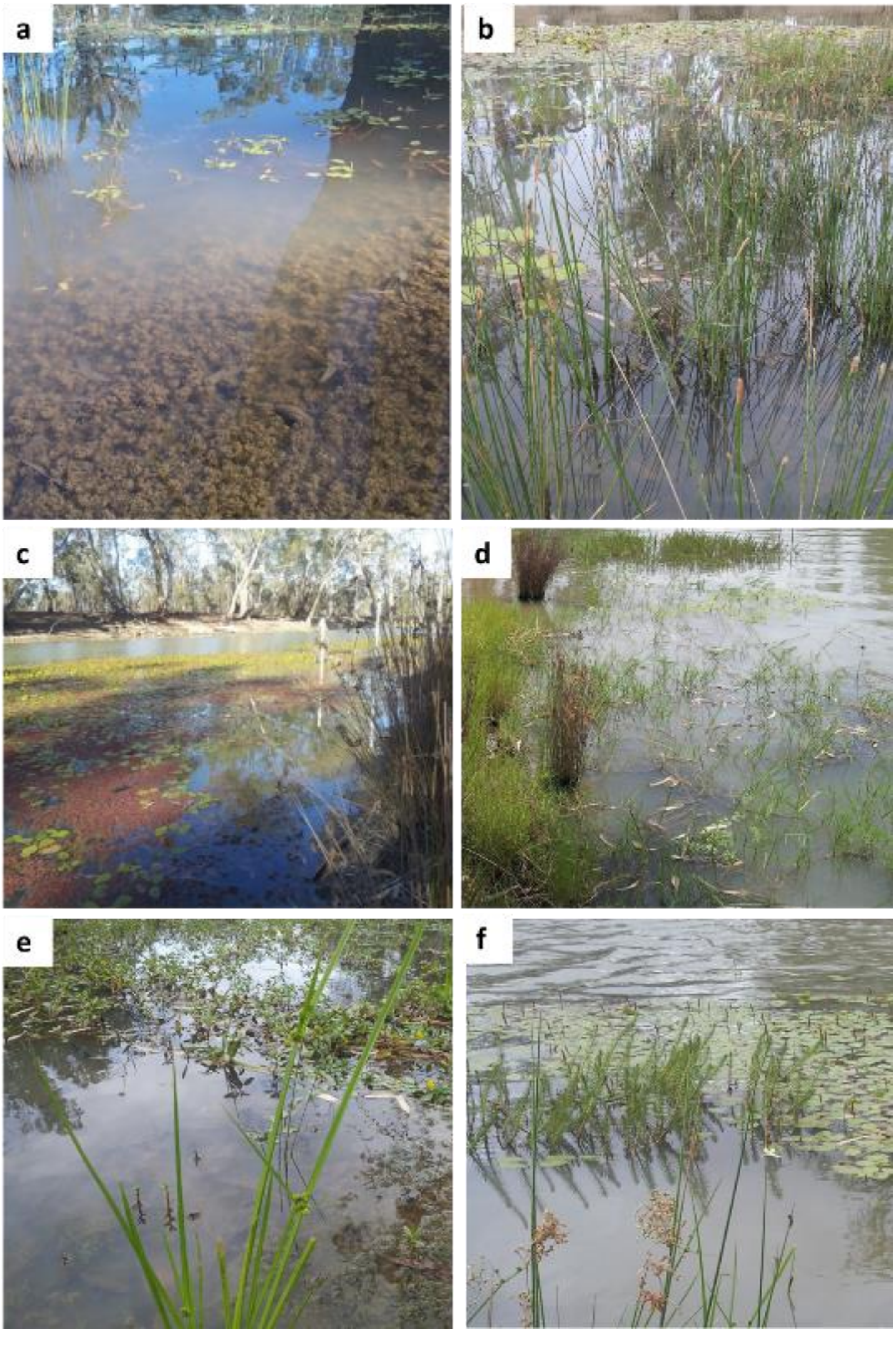


Figure C.2. Photos of abundant aquatic and riverbank vegetation taxa present in the Edward-Wakool system in 2015-16. a) charophyte *Chara* spp. b) *Eleocharis acuta* plants in flower December 2015, c) water fern *Azolla* spp. (red colour) floating amongst *Potamogeton tricarinatus*, d) mud grass (*Pseudoraphis spinescens*), e) water primrose (*Ludwegia peploides*) and sedge (*Cyperus* spp.) in foreground, and f) milfoil (*Myriophyllum* spp.).

Patterns of riverbank inundation in 2015-16

The duration and depth of inundation experienced by vegetation along the river bank between August 2015 and May 2016 was determined by their position along the elevation gradient using data from water depth measurements undertaken on each monitoring trip. In Yallakool Creek (zone 1) and Wakool River (zone 3) transects zero and one were almost continually underwater from August 2015 to May 2016, transects two and three experienced periods of wetting and drying, and transects four and five were dry (entirely out of water for the whole period) (Table C.1). Wakool River zone 4 was similar to this, with transects zero and one continually underwater, transects two and three experiencing periods of wetting and drying (but transect three was mostly dry), and transects four and five were dry (entirely above the water) (Table C.1). In contrast, in the upper Wakool River zone 2, only transect zero was continually underwater, transect one experienced periods of wetting and drying, and transects two to five were dry (entirely out of water for the whole period) (Table C.1).

This pattern of inundation is evident in the hydrograph for Yallakool Creek (Figure C.3) when the depth of each transect is plotted on the hydrograph. Transects in zones one, two and three were influenced by the environmental watering action in Yallakool Creek. The small environmental watering action in the upper Wakool River had minimal effect on the extent of riverbank that was inundated.

Table C.1 Summary of water regime experienced by vegetation transects in Yallakool Creek and the Wakool River between August 2015 and May 2016.

Transect number	Height above transect zero	Yallakool Creek zone 1	Upper Wakool River zone 2	Mid Wakool River zone 3	Mid Wakool River zone 4
0	0 m	Inundated	Inundated	Inundated	Inundated
1	0.25 m	Inundated	Periods of wetting and drying	Inundated	Inundated
2	0.50 m	Periods of wetting and drying	Dry	Periods of wetting and drying	Periods of wetting and drying
3	0.75 m	Periods of wetting and drying	Dry	Periods of wetting and drying	Periods of wetting and drying, but mostly dry
4	1.00 m	Dry	Dry	Dry	Dry
5	1.25 m	Dry	Dry	Dry	Dry

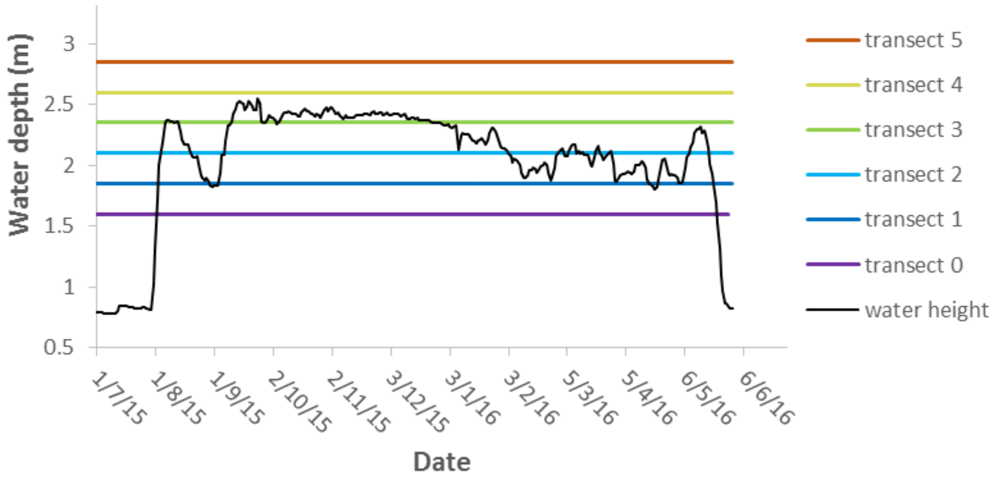


Figure C.3. Hydrograph for Yallakool Creek showing water depth from August 2015 to May 2016 and the depth at which the vegetation monitoring transects become inundated.

Comparison of vegetation among hydrological zones in 2015-16

There were more taxa recorded in Yallakool Creek zone 1 (36 taxa) and Wakool River zones 3 (30 taxa) and zone 4 (28 taxa) that received higher magnitude environmental watering action than in the upper Wakool River zone 2 (22 taxa) that received a small magnitude environmental watering action.

Changes in the cover of several taxa were observed over the year:

- *Chara* spp. (submerged taxa) grew on the sediment in the shallow edges (0 to 40cm) of zones 1, 3 and 4 (Figure C.4), first appearing in the shallow edge of transect 3 during the environmental watering action and then retreating to transects two and then transect one on the recession of the environmental watering action. *Chara* spp. was desiccated following the recession in January 2016 and was essentially absent by March 2016. This was a very similar response to that observed in 2014-15.

- Floating pondweed (an amphibious fluctuation responder species) occurred mainly in zones 3 and 4 in transects zero and one that were inundated from August to May (Table C.1). Floating pond weed was recorded across a range of depths (0 to 100 cm deep) (Figure C.5) and at times comprised up to 70% of the cover in transect zero and one in zone 3 (Figure C.4), but also was recorded in transect 2 in zone 3 that had periods of wetting and drying (Table C.1).

- Milfoil was abundant in zones 3 and 4 and was also present in zone 1, tending to increase in cover in summer after the end of the environmental watering. The count of mifoil was highest at approximately 25cm deep water, but it occurred across a wide range of depths (0 to 100 cm deep) (Figure C.5).

- Water fern was abundant in zone 3 (Figure C.4) and was present in zone 4. The cover of this taxa increased in summer after the end of the environmental watering and dying back in the cooler months. This pattern of distribution is consistent with the ecology of this taxa. It floats at the surface of the water and has a preference for slower flowing or still water.

- The longer lived rush *Juncus* spp. were recorded in all zones and also across all transects, with the highest cover recorded in transect four that has not received environmental water in the past three years and in transect three zone three that experienced wetting and drying (Figure C.4). *Juncus* plants in transects three, four and five were all large plants of similar height, often occurring in one or two narrow bands at a height of the riverbank that possibly corresponds with the height of a previous unregulated flow event or at the water level of the dominant operational flow. In zones 1, 3 and 4 *Juncus* spp. were recorded across a range of sizes, suggesting recruitment has occurred in these zones that were influenced by the Yallakool Creek environmental watering action.

- The terrestrial species common sneeze weed was most abundant in transects 3 and 4 in zones that received environmental water, or in transect 2 in the upper Wakool River (Figure C.4). These transects are at the boundary of the wetting and drying zone and this reflects the preference of this species to grow in damp areas that are subject to flooding. The cover of this taxa was highest in zones 1and 4 that received environmental water and had a larger area of riverbank that was wetted during the environmental watering.

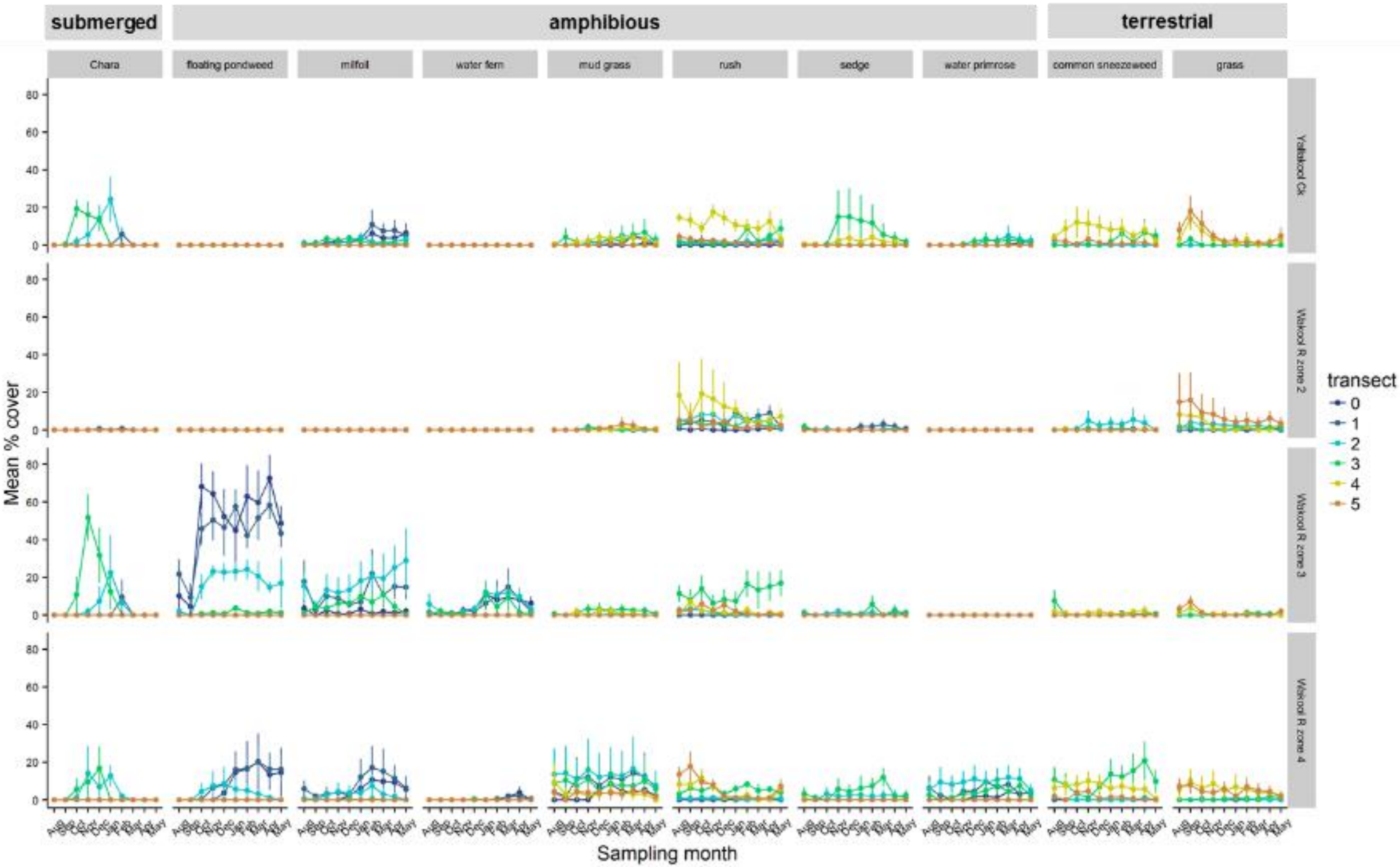


Figure C.4. Mean percent cover (±SE) of ten most abundant riverbank and aquatic vegetation taxa monitored monthly at 16 sites across 4 hydrological zones in the Edward-Wakool system between August 2015 and May 2016. Transect 0 was lowest on the river bank (see Figure C.1).

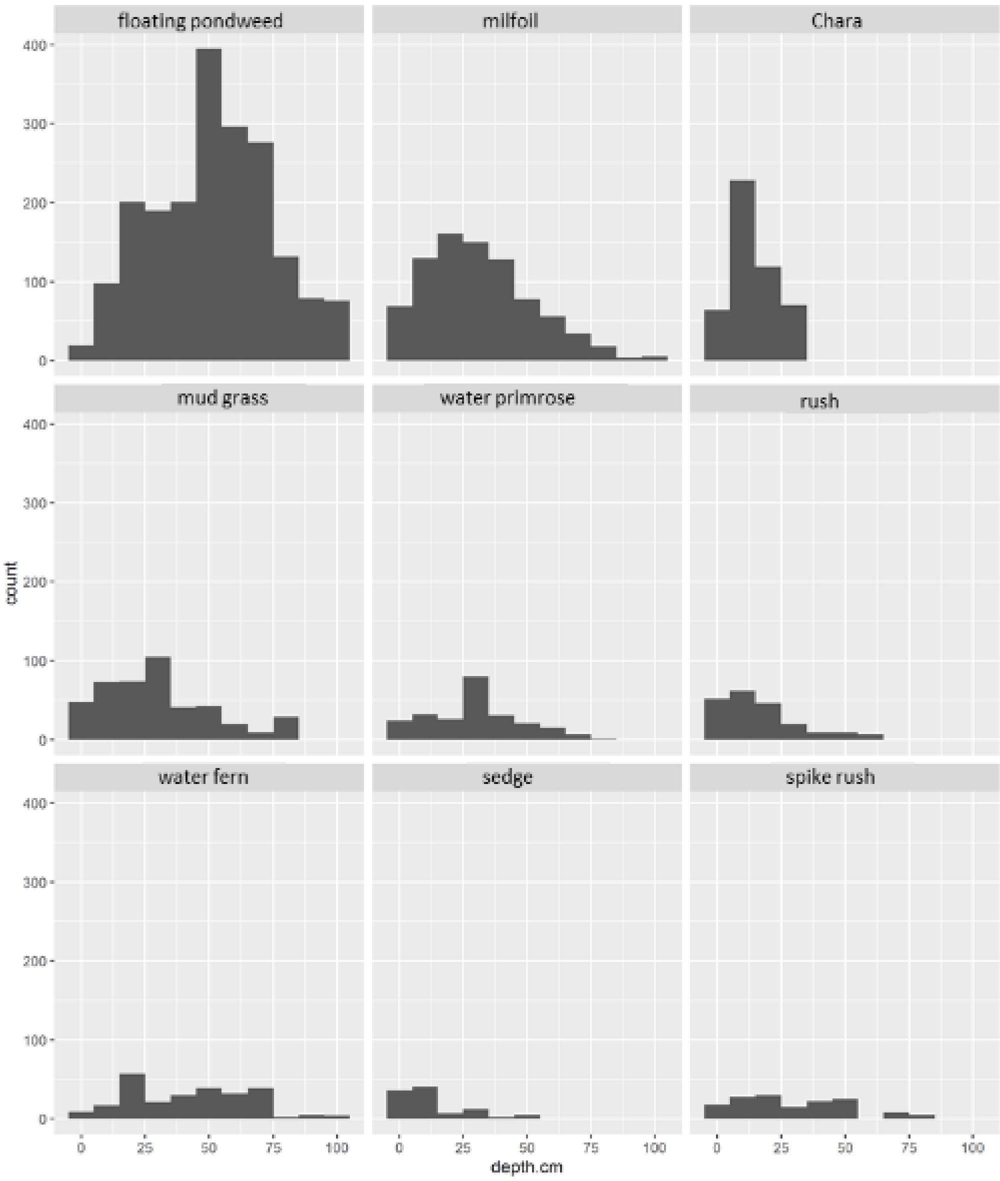


Figure C.5. Range of water depths where nine common amphibious and submerged taxa from the Edward-Wakool system were recorded in 2014-2015.

Change in percent cover of riverbank and aquatic vegetation in response to Commonwealth environmental watering

It was hypothesised that the cover of riverbank and aquatic vegetation in 2014-15 would be significantly higher in zones 1, 3 and 4 that received environmental water compared to the Wakool River (zone 2) that received minimal environmental water. Results of the analysis only partially support this hypothesis (Table C.2, Figure C.6). Although the mean cover of vegetation was higher is zones 1, 3 and 4 than in zone 2, only zones 3 and 4 had significantly high cover than zone 2, as the percent cover of vegetation in Yallakool Creek zone 1 was not significantly different to that in the Wakool River zone 2.

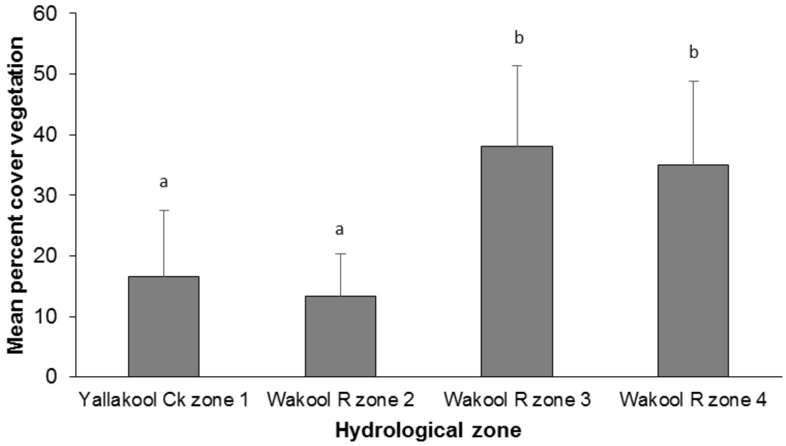


Figure C.6. Mean percent cover (±SE) of riverbank and aquatic vegetation sampled in 2015-16 in the Edward-Wakool Selected Area. Zones 1, 3 and 4 received a greater magnitude of Commonwealth environmental water than the Wakool River zone 2. a and b denotes unique subsets based on posthoc tests.

Results of non-parametric analyses of percent cover of individual taxa and leaf litter among zones produced different groupings of zones (Table C.2, Figure C.7):

- The macroalgae *Chara* (submerged) and mifoil (amphibious) had significantly higher cover in zones 1, 3 and 4, supporting the hypothesis that the cover of riverbank and aquatic vegetation would be significantly higher these zones that received more environmental water than the upper Wakool River (zone 2).

- Floating pondweed (amphibious) and water fern (amphibious) had significantly higher cover only in zone 3.

- Water primrose (amphibious) and common sneezeweed (terrestrial) had higher cover only in zone 4.
- Leaf litter and *Juncus* spp. (amphibious) had significantly higher cover in the upper Wakool River zone 2 that received very little or no environmental water over the past three years.
- Sedge (amphibious) and mud grass (amphibious) showed no difference in mean percent cover among all zones.

Table C.2. Results of Kruskal-Wallis nonparametric tests comparing mean percent cover of aquatic and riverbank vegetation cover for the ten most common taxa and leaf litter across river zones for the sampling period August 2015to May 2016. *P* values <0.05 indicates a significant difference in cover of vegetation among zones.

Analysis	df	p	signif
floating pondweed	3	0.000	***
rush (*Juncus* spp.)	3	0.007	**
milfoil	3	0.000	***
mud grass	3	0.149	ns
grass	3	0.023	*
Common sneezeweed	3	0.000	***
Chara spp.	3	0.000	***
water primrose	3	0.000	***
water fern	3	0.000	***
sedge	3	0.076	ns
Leaf litter	3	0.000	***

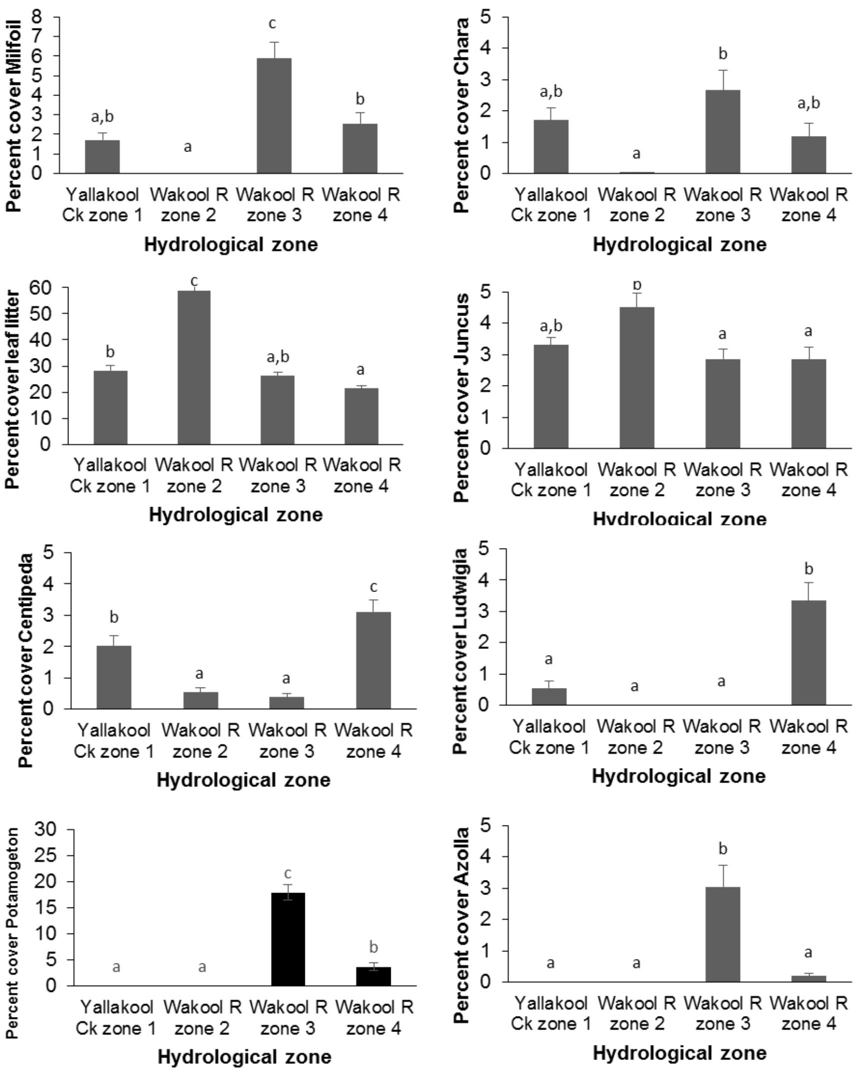


Figure C.7. Mean cover (±SE) of seven abundant riverbank and aquatic vegetation and leaf litter sampled in 2014-2-15 in the Edward-Wakool Selected Area. Significant statistical differences in mean cover across the four study zones are shown using small letters.

C.5 Discussion

There was a significant response of riverbank and aquatic vegetation to Commonwealth environmental watering with higher percent cover observed in two of the three zones that received Commonwealth environmental water.

Some amphibious vegetation taxa had higher cover in the shallow edges of zones 1, 3 and 4 during the environmental watering and contracted to transect 2 and then to transect 1 on the recession of the environmental watering action. Several amphibious taxa such as floating pondweed, milfoil and water fern were absent from the Wakool River zone 2 that has received a very small volume of Commonwealth environmental water, and other taxa such as the macroalgae *Chara* spp., spike rush and mudwort were in low abundance in this zone.

The response of aquatic and riverbank vegetation to the environmental watering action in Yallakool Creek in 2014-15 was not consistent among the three hydrological zones that received Commonwealth environmental water. The response of vegetation to environmental watering was strongly related to in-channel geomorphology, with river reaches having a gentle slope, shallow in-channel benches and a larger area of benthic inundation during environmental watering having a higher percent cover of plants. Thus the larger the area of shallow inundation created during the watering action, in combination with the damp river bank created during the recession of the watering actions, creates opportunities for a range of submerged and amphibious plants to grow and germinate.

The watering action in 2015-16 was managed with a slower rate of recession than in 2013-14 or 2014-15. This management action was based on learning from previous watering events to avoid stranding of biota and enable the aquatic vegetation to persist over an extended period of time. In 2012-13 the recession at the end of the Yallakool Creek environmental watering action was rapid and aquatic vegetation was exposed and desiccated immediately after recession of e-watering (Watts et al. 2014b). The longer recession in this season resulted in longer duration of presence of some taxa, such as the macroalgae *Chara* spp and mudwort. After the recession of the environmental flow these macroalgae desiccate during summer, and this store of nutrients bound to sediment would provide nutrients to help ‘kick-start’ a river productivity response during subsequent inundation events.

The cover of one of the longer lived taxa, *Juncus spp.* was significantly higher in Wakool River zone 2 than in zone three or four. In zone 2 the *Juncus sp.* plants were of similar height and occurred in one or two narrow bands that corresponded with the height of a previous unregulated event or at the water level of the dominant operational flow.

Recruitment of plants was observed in zones 1, 3 and 4 where there has been environmental watering over 2012-13, 2013-14 and 2014-15 and 2015-16. There was very limited recruitment of occurring in the upper Wakool River (zone 2). There was a significantly higher load of leaf litter in zone 2 and it is possible this may supress recruitment of aquatic plants. A higher environmental flow in this system may help shift the leaf litter and expose sections of banks creating opportunities for plant germination.

The most evident change across years was in the cover of common amphibious taxa; there was an increase in abundance of mud grass, floating pondweed, milfoil, and water primrose, and an increase in the submerged macroalgae *Chara* spp.

The response of aquatic and riverbank vegetation to environmental watering has been an ongoing process and the observations in 2015-16 document a continuation of a gradual improvement in vegetation in this system over the past few years.

20. Appendix D: Fish

D.1 Background

The Edward-Wakool system is recognised as a priority area for fish diversity in the Murray-Darling Basin, including threatened and endangered fish, and it is part of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment' in New South Wales (*NSW Fisheries Management Act 1994*). Outcomes for fish have been the main focus of watering actions in the Edward-Wakool system and they are the key environmental asset valued by the Edward-Wakool community. Historically, the Edward-Wakool system had diverse fish communities and supported extensive commercial and recreational fisheries (Rowland 1998). Twenty two native freshwater fish species are thought to have historically occupied the lowland region of the central Murray valley (Table D.1), including the recently described obscure galaxias (*Galaxias oliros*). More recently, fourteen of these native species have been captured in the system.

The overarching principle that underpins the monitoring and evaluation of Commonwealth environmental water for the Edward-Wakool Selected Area is that we are taking an ecosystem approach to evaluate the responses to Commonwealth environmental watering. A suite of questions and indicators have been selected that all have clear linkages to other components of the monitoring and evaluation plan (see Figure D.1). The plan has a strong focus on fish, including fish movement, reproduction, recruitment and adult populations. However, many of the other indicators evaluated in this report (such as water quality, metabolism and aquatic vegetation) are likely to indirectly influence fish population dynamics, and thus a key goal of the long-term intervention monitoring in the Edward Wakool selected area is to improve our understanding and interpretation of these interdependencies.

Table D.1 List of Edward Wakool River system fish community (recorded and expected). Recorded native and alien species are those that have been sampled in the region since 2010, and expected native species are species who were historically likely to have been in the lowland central Murray region. [1]Indicates species have been recorded in the Edward Wakool system, but outside the LTIM focal study zones.

Common name	Species name	Local spawning recorded
Native species - recorded		
Australian smelt	*Retropinna semoni*	*
bony herring	*Nematolosa erebi*	
carp gudgeon	*Hypseleotris* spp.	*
dwarf flathead gudgeon[1]	*Philypnodon macrostomus*	
eel-tailed catfish[1]	*Tandanus tandanus*	
flathead gudgeon	*Philypnodon grandiceps*	*
golden perch	*Macquaria ambigua*	
Murray cod	*Maccullochella peelii*	*
Murray River rainbowfish	*Melanotaenia fluviatilis*	*
obscure galaxias	*Galaxias oliros*	*
river blackfish	*Gadopsis marmoratus*	*
silver perch	*Bidyanus bidyanus*	*
trout cod[1]	*Maccullochella macquariensis*	
unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	*
Native species -expected		
Agassiz's glassfish (olive perchlet)	*Ambassis agassizii*	
flathead galaxias	*Galaxias rostratus*	
freshwater catfish	*Tandanus tandanus*	
Macquarie perch	*Macquaria australasica*	
mountain galaxias	*Galaxias olidus*	
Murray hardyhead	*Craterocephalus fluviatilis*	
shorthead lamprey	*Mordacia mordax*	
southern purple spotted gudgeon	*Mogurnda adspersa*	
southern pygmy perch	*Nannoperca australis*	
Alien species - recorded		
common carp	*Cyrpinus carpio*	*
goldfish	*Carrassius auratus*	
eastern gambusia	*Gambusia holbrooki*	*
oriental weatherloach	*Misgurnus anguillicaudatus*	*
redfin perch	*Perca fluviatilis*	*

Key processes that ultimately shape adult populations; movement, spawning, recruitment and growth, are being monitored and evaluated in response to the contribution of Commonwealth environmental water to native fish outcomes. Monitoring of these key elements are complementary, allowing us to assess contributions of environmental water to key population processes structuring fish assemblages in the Edward-Wakool (Figure D.1). Further, the responses measured across these key fish indicators will also be used in a multiple lines of evidence approach to evaluate competing hypotheses about underlying mechanisms driving or limiting the outcomes from environmental water delivery. For example, if watering achieves increases in production and fish spawning, but not recruitment, it would be possible to identify potential bottlenecks and strategies for overcoming those as part of an adaptive management cycle. A brief description of each of fish indicators being monitored follows.

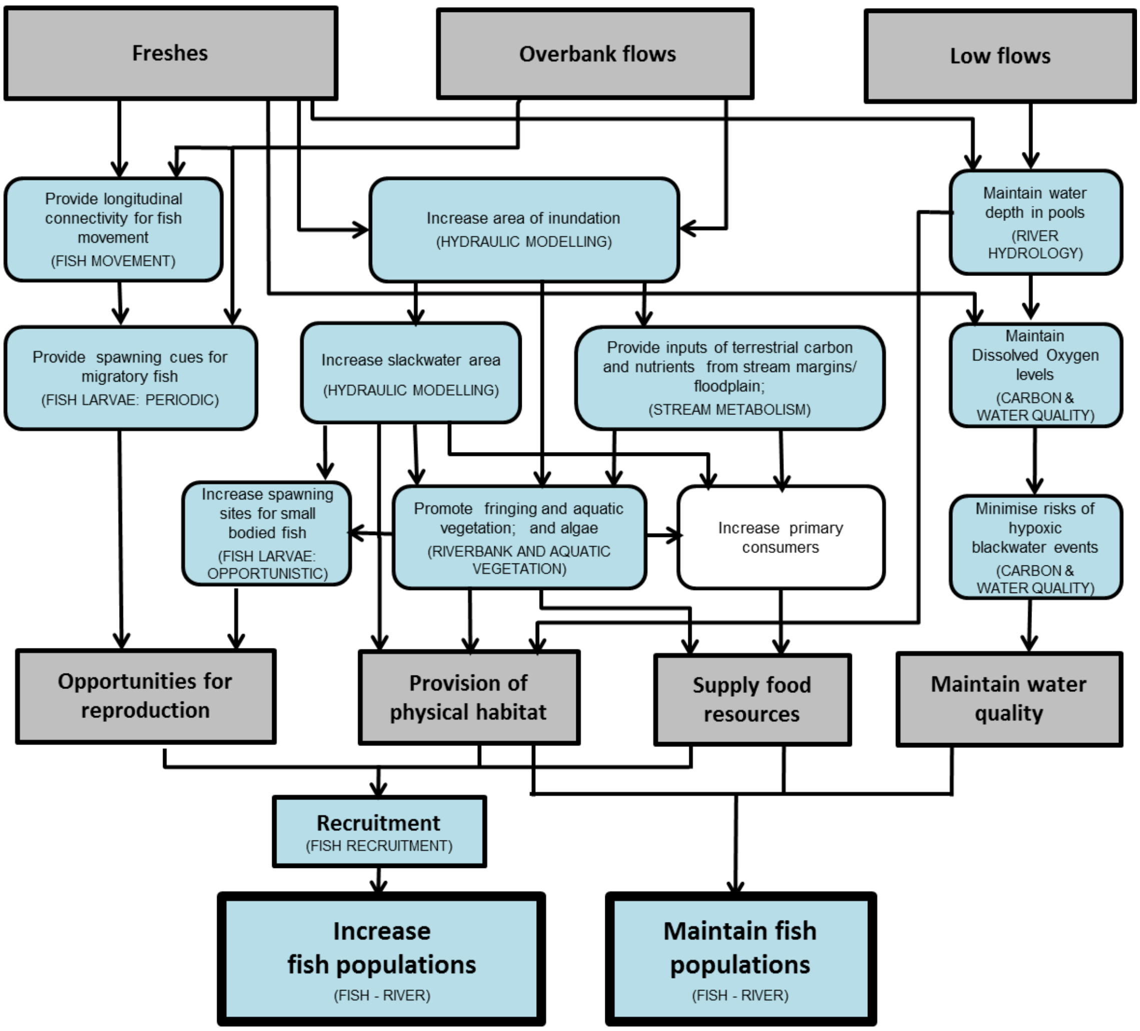


Figure D.1. Conceptual diagram illustrating the linkages among indicators and links different types of environmental watering (freshes, overbank flows, low flows) to fish populations. Indicators included in this monitoring report are highlighted in blue.

Fish movement

We use acoustic telemetry methods for investigating broad-scale and fine-scale fish movement of golden and silver perch adults. This information can be used to quantify large scale dispersal, including movements to and from refuge habitats, and serves as a useful additional line of evidence to infer successful reproduction (e.g. Thiem et al. 2013, Walsh et al. 2013).

Fish spawning and reproduction

Monitoring the abundance and diversity of fish larvae across the spring/summer spawning period is used to identify which fish species have successfully spawned in selected area, and the hydraulic and temperature conditions under which spawning occurred. This provides important information on the flow-spawning ecology relationships of the Edward-Wakool fish assemblage, and will assist in future planning of environmental water delivery for fish population outcomes.

Fish recruitment

Relationships among early life-history growth and recruitment ultimately determine the abundance of many marine fish populations (Pepin et al. 2015), but much less is known about how these factors contribute to populations of freshwater species. It is well-established that many species of fish in the Murray-Darling Basin do not require over-bank flows, or changes in water level, to initiate spawning (Humphries et al. 1999) but nonetheless *recruitment* of all species may be affected by alterations to the natural flow regime, and environmental flows may be able to address elements of this. The selected area fish recruitment monitoring was developed specifically for the Edward-Wakool system in order to target juvenile silver perch, golden perch and Murray cod. This monitoring enables comparisons of juvenile growth rates among zones of the Edward-Wakool and is used to determine recruitment variation of these species among years, in response to environmental watering.

Adult fish community

Evaluation of the adult fish community to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system to determine long-term trajectories in the fish community assemblage in response to Commonwealth environmental watering, and to assess if movement, spawning and recruitment responses ultimately lead to positive responses (condition, biomass, abundance, diversity) in the adult fish community both within and outside of the LTIM focal area. It is anticipated that changes to the fish community assemblage will occur over longer time scales, and as such a broad-scale monitoring program of the fish community is scheduled for years 1 and 5. Additionally, annual fish community censuses are undertaken within a single focal zone 9Wakool River zone 3) to provide data for Basin-scale evaluation of fish communities and these data are incorporated into our selected area evaluation, where relevant.

D.2 Specific flows delivered for fish outcomes

Three Commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2015-16. Two of these were monitored as part of the LTIM project, both of which had primary objectives towards delivering positive outcomes for native fish populations (CEWO 2015).

Primary objectives of Yallakool Creek Environmental Watering Action

- provide areas of habitat for native fish, such as Murray cod, to move into and spawn, especially in areas where the flows will cover snags that are the preferred spawning and nesting sites of Murray cod (CEWO 2015);
- To maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit

Primary objectives for Upper Wakool River Environmental Watering Action

- as per Yallakool Creek action above (CEWO 2015);
- improve knowledge of this part of the system by comparing the responses of Murray cod when environmental flows are provided to both the upper Wakool River and Yallakool Creek systems over the same period of time (CEWO 2015).

D.3 Selected-area questions

Evaluation of the fish community responses to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system to determine long-term trajectories in the fish community assemblage in response to Commonwealth environmental watering. Data from the Edward-Wakool system will be evaluated at the Selected Area scale and contribute to Basin scale evaluation. Basin-scale evaluation involves the integration of multiple datasets from a number of different catchments (Hale et al. 2014), and this will be undertaken by the Murray-Darling Freshwater Research Centre and will be evaluated in a separate report.

This is the second year of a multi-year monitoring project, and as such this report will provide a benchmark which will be used by the LTIM program to determine if there is a system-wide change in the fish community assemblage structure in the Edward-Wakool system with respect to Commonwealth environmental water delivery. The short-term Selected Area evaluation questions, as outlined in the Monitoring and Evaluation Plan for the Edward-Wakool system (Watts et al. 2014a) to be assessed in 2019 are outlined in Table D.2.

Table D.2. Selected-area evaluation questions relating to the effect of CEW on Edward-Wakool fish populations

Indicator	Key components	Selected area-scale evaluation questions
Edward Wakool selected area fish population	Fish movement (acoustic telemetry)	*Short-term and long-term evaluation questions* • Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery? • Did periodic species remain within the target reaches during Commonwealth environmental water delivery? • Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour? • Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat? • Does Commonwealth environmental water protect periodic species from adverse water quality?
	Fish spawning and reproduction (larval fish sampling)	*Short-term and long term evaluation questions* • What did Commonwealth environmental water contribute to the spawning of 'Opportunistic' (e.g. Small bodied fish) species? • What did Commonwealth environmental water contribute to spawning in 'flow-dependent' spawning species (e.g. golden and silver perch?
	Recruitment and growth of young of year (young of year sampling)	*Short-term and long term evaluation questions* • What did Commonwealth environmental water contribute to native fish recruitment to the first year of life? • What did Commonwealth environmental water contribute to native fish growth rate during the first year of life?
	Adult fish population demographics (adult fish sampling)	*Short-term evaluation questions* • Does Commonwealth environmental water contribute to maintain or enhance fish condition in the Edward-Wakool river system? • Does Commonwealth environmental water contribute to the recovery of fish communities following negative conditions within the Edward-Wakool river system? *Long-term evaluation questions* • Does Commonwealth environmental water contribute to maintain or enhance existing levels of fish recruitment in the Edward-Wakool river system? • Does Commonwealth environmental water contribute to maintain or increase native fish diversity and abundance in the Edward-Wakool river system? • Does Commonwealth environmental water contribute to maintain or increase native fish biomass in the Edward-Wakool river system?

D.4 Methods

Fish movement

A total of 71 acoustic receivers (VEMCO VR2W) were installed in the Edward-Wakool system in August 2015. Of these, 51 constituted the fine-scale acoustic receiver array (Figure D.2) of ~6 km receiver spacing, and 20 additional receivers were placed at key entry/exit points and major junctions within the wider system to monitor any potential emigration out of the system. This array can also detect fish that were tagged in other parts of the Murray if they move into the Edward-Wakool system and vice versa. Thirty one golden perch and eight silver perch captured in the Edward Wakool system had acoustic telemetry tags surgically inserted from August-October 2015 (Table D.3). Acoustic tag implantation procedures followed those outlined by Hale et al. (2014).

Acoustic receiver downloads were undertaken in January and April 2016. Downloaded acoustic tag detection data and meta-data were uploaded into a custom SQL database. Data were screened and all duplicates, false detections and orphan tags quarantined prior to storage. Individual movements of fish were recreated over time to determine 1) location within the Edward-Wakool system at any given time and, 2) timing and distance of movements. As receivers were spaced at ~6 km intervals, this represents the minimum distance of movements within the receiver array and detection on multiple receivers is required to determine location and direction of movement. All data were screened to remove any detections one-week post tagging to enable individual fish to adequately recover and resume normal behaviour.

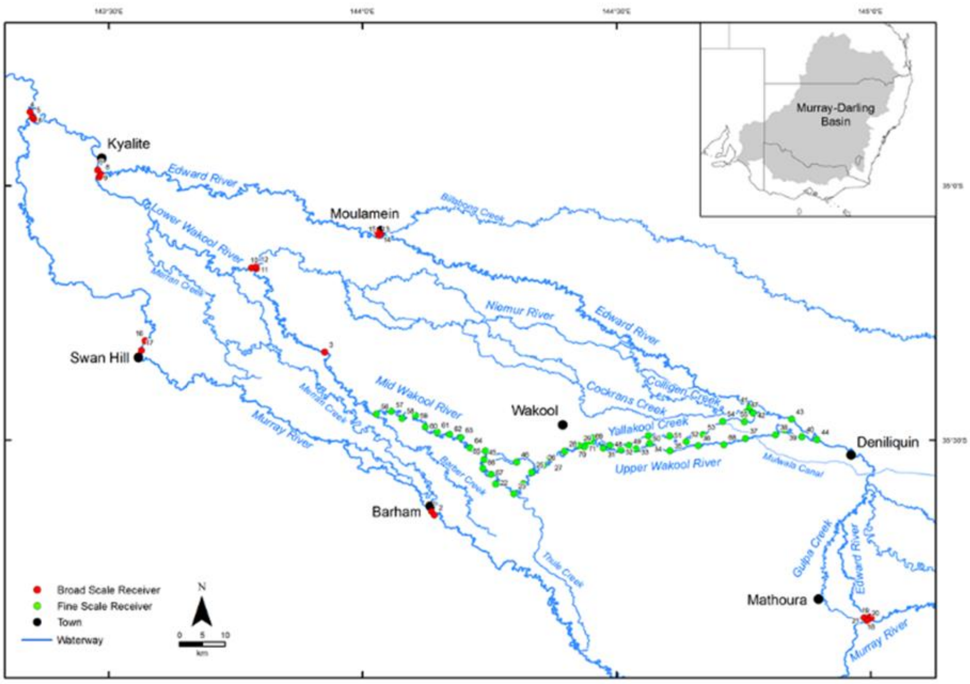


Figure D.2. Location of acoustic receivers in the Edward-Wakool system. Installation and maintenance of receivers in zones 1 to 4 (green dots) (n=51) is funded by the LTIM project and receivers installed at major waterway junctions (red dots) (n=20) is funded by Murray Local Land Services.

Table D.3. Information on individual golden perch and silver perch fitted with acoustic telemetry tags in the Edward-Wakool system in 2015.

Transmitter_ID	Species	Length (mm)	Weight (g)	Sex	Release Date
A69-1601-57291	Golden perch	488	1748	Female	10/08/2015
A69-1601-57290	Golden perch	420	1322	Male	10/08/2015
A69-1601-57292	Golden perch	488	1550	Male	10/08/2015
A69-1601-57293	Golden perch	435	1572	Male	10/08/2015
A69-1601-57295	Golden perch	451	1484	Unknown	10/08/2015
A69-1601-57296	Golden perch	430	1564	Female	11/08/2015
A69-1601-57297	Golden perch	429	1212	Female	11/08/2015
A69-1601-57298	Golden perch	407	1406	Female	11/08/2015
A69-1601-57299	Golden perch	474	2016	Female	11/08/2015
A69-1601-57307	Golden perch	444	1380	Unknown	11/08/2015
A69-1601-57308	Golden perch	525	2438	Unknown	11/08/2015
A69-1601-57309	Golden perch	440	1724	Unknown	11/08/2015
A69-1601-57310	Golden perch	444	1832	Female	11/08/2015
A69-1601-57311	Golden perch	388	952	Female	11/08/2015
A69-1601-57312	Golden perch	426	1188	Male	11/08/2015
A69-1601-57313	Golden perch	456	1410	Unknown	11/08/2015
A69-1601-57314	Golden perch	491	2138	Female	11/08/2015
A69-1601-57315	Golden perch	534	2588	Female	11/08/2015
A69-1601-57316	Golden perch	387	932	Female	12/08/2015
A69-1601-57317	Golden perch	423	1112	Unknown	12/08/2015
A69-1601-57318	Golden perch	460	1628	Female	12/08/2015
A69-1601-57319	Golden perch	414	1062	Unknown	12/08/2015
A69-1601-57320	Golden perch	482	1914	Unknown	12/08/2015
A69-1601-57321	Golden perch	490	2034	Unknown	12/08/2015
A69-1601-57323	Golden perch	515	2338	Female	13/08/2015
A69-1601-57322	Golden perch	451	1548	Female	13/08/2015
A69-1601-57324	Golden perch	374	778	Unknown	13/08/2015
A69-1601-57325	Golden perch	470	1778	Female	13/08/2015
A69-1601-57326	Golden perch	480	1778	Female	13/08/2015
A69-1601-27466	Golden perch	414	1186	Female	13/08/2015
A69-1601-27471	Golden perch	429	1372	Female	13/08/2015
A69-1601-37199	Silver perch	340	534	Female	10/08/2015
A69-1601-37200	Silver perch	352	706	Female	11/08/2015
A69-1601-37201	Silver perch	343	616	Female	12/08/2015
A69-1601-37202	Silver perch	344	515	Unknown	17/08/2015
A69-1601-37203	Silver perch	344	728	Female	21/10/2015
A69-1601-37204	Silver perch	367	862	Female	21/10/2015
A69-1601-37205	Silver perch	292	434	Male	22/10/2015
A69-1601-37206	Silver perch	200	140	Unknown	22/10/2015

Fish spawning and reproduction

Field sampling

Modified quatrefoil light traps were used to sample larval fish, and were deployed every fortnight commencing the week of 15 September 2015 to the 3 March 2015 (n=13 sampling trips) in Yallakool Creek (Zone 1), Upper Wakool River (Zone 2), Mid Wakool River u/s of Thule Creek (Zone 3), and Mid Wakool River d/s of Thule Creek (Zone 4). Three light traps were deployed overnight at five sites in each of the four study zones each trip, and these three light traps were pooled to create one composite light trap sample.

Drift nets were also used for sampling larvae, but over a shorter time, to detect any spawning responses by flow-dependent spawning species during Commonwealth environmental water delivery. Drift nets were deployed fortnightly over 10 weeks (n=5 trips), with sampling occurring from 9 November 2015 to 8 January 2016. Here, three drift nets were deployed overnight at one site at each of the four study zones. The volume of water filtered by the nets was calculated using Oceanic® flow meters positioned at the mouth of each drift net. Volume sampled by the net was estimated as $\pi r^2 \cdot v \cdot t$, where *r* is radius in metres, *v* is mean velocity in m/s, and *t* is time set in seconds.

Laboratory methods and data analysis

All eggs/larvae collected in light trap and drift net samples were identified to species according to Serafini and Humphries (2004), and enumerated. The developmental stage of each individual was recorded as either larvae, or juvenile/adult, according to classifications of Serafini and Humphries (2004), and only abundances in larvae assessed. Carp gudgeon larvae were identified to genus level (*Hypseleotris* spp.) only. Also, Murray cod and trout cod larvae also have similar morphological features, and cannot be easily distinguished visually. Consequently, a sub-sample of ten larvae comprising possible Murray cod or trout cod were submitted to the Australian Genome Research Facility (AGRF). Nucleic acid extraction and subsequent verification of species assignment was based on dual direction sequencing following PCR amplification. Results of the PCR amplification revealed all 10 larvae to be Murray cod, and thus, from here on, we consider all cod larvae collected in the study zone to be Murray cod.

To address the short-term selected area evaluation questions relevant to spawning and reproduction, we tested to see if the total production of larvae (as an indication of the magnitude of spawning across a season) varied significantly between the four study zones. Differences in mean total abundance of larvae for all species (where there was enough data) across the study zones was conducted using a one way ANOVA. We hypothesised that the total production of fish larvae across the 2015-16 spawning season would be significantly higher in the study zones that received an environmental base flow and fresh (Zone 1, 3 and 4) compared to zone 2 that received only a small environmental flow that had minimal impact on the hydrology of that zone (section 4). For light trap data, this analysis was restricted to the four most abundant species, Murray cod, carp gudgeon, Australian smelt and flathead gudgeon. Larval abundances were log-transformed prior to statistical analyses when necessary to normalise data and stabilize variances. Statistical analyses were carried out using the freeware R and the R package MASS (R Development Core Team 2015). P-values of <0.05 were used to determine the significance of each ANOVA test. When significant differences were indicated, *post hoc* pairwise comparisons were undertaken to determine differences between the rivers.

Fish recruitment

Field sampling

Four sites were sampled in each of four river zones within the Edward-Wakool system: Yallakool Creek, Wakool River Zone 2, Wakool River Zone 3 and Wakool River Zone 4. Each of the 16 sites were sampled once in a randomly selected order between February and March 2015. Three sampling methods including backpack electrofishing, standardised angling and baited set-lines were undertaken to target recruits of Murray cod, golden perch and silver perch at each of the 16 sites. A sub-sample of less than 50 fish per zone and species were euthanized and frozen to determine the age and growth rate of recruits, while all other fish were released alive.

Continuous backpack electrofishing, using a 12 V DC battery with a Smith-Root unit, was undertaken at each site by an operator and one person equipped with a 5 mm mesh dip-net. Each site was sampled for a minimum of 3000 seconds of backpack-on electrofishing time, which resulted in a sampling distance of more than 25 times the average wetted-width at each site and 100 times the average wetted width for each zone. Presence of non-target species was recorded at each site, while length measurements and counts were made for all individuals of the three target species and common carp.

Standardised angling was carried out by two anglers with the specific aim of targeting young silver perch and golden perch. Standardised angling at each site consisted of two anglers fishing on the bank for two hours. Angling gear was matched to the specifications commonly used by local fisherman. Species and length were recorded for all individuals caught.

Ten set-lines, each with a 3-10 m (100 lb) monofilament main-line and two 0.5-1.5 m (4 lb) leaders were set at each site. Lines were set, baited and hauled hourly during day-light hours for 5-7 hours at each site. Hook type and bait matched those in the standardised angling section. Species and length were recorded for all individuals caught.

Laboratory methods and data analysis

To determine the annual age and growth rate of recruits, sagittal otoliths from fish were extracted, embedded in a polyester resin and sectioned in the transverse plane to approximately 100 µm thick and mounted on a microscope slide. Final age estimates were based only on samples with matching age readings from three reads given that any bias in annual age estimates of 1+ or 2 year old fish generates a high degree of error unacceptable for the purpose of this study. All otolith sections were checked under a fluorescence stereomicroscope fitted with an excitation filter to identify the presence of Calcein marks to discriminate hatchery released and wild recruits (Crook et al. 2011).

Growth curves derived from annual and daily age estimates were fitted to each zone separately and to the entire Edward-Wakool system. A nonlinear four parameter logistic model was used to describe age-length curves of recruits and the model was weighted to the reciprocal of age. Otolith age-length estimates were used to distinguish all YOY and 1+ Murray cod recruits from other age-classes. The mean length of recruits (YOY and 1+) were compared statistically among zones and years 2014/15 and 2015/16 using a Generalized Linear Mixed Effects Model (GLMM), whereby year, zone and species were fixed effects and site was a random effect.

Recruitment indices of YOY and 1+ Murray cod and silver perch, were calculated from catch per unit effort of backpack electrofishing, set-lines and angling. The GLMM tested whether CPUE of YOY and 1+ recruits varied significantly in relation to the fixed effects of gear type, zone, year and species. Site was incorporated as a random effect.

Adult fish community

A system-wide fish community survey will be undertaken in years 1 and 5 of the Edward-Wakool LTIM project (Watts et al. 2014a). In the absence of fish community data for this current monitoring year we present Category 1 fish community standardised survey data from Zone 3 only. Sampling was undertaken in May 2016, and each site was sampled once using a suite of passive and active gear 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). All captures (fish and other non-target taxa) were identified to species level and released onsite. 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.

To determine differences between years (2015 and 2016) abundance data were analysed 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 $P < 0.05$. To determine whether the size structure of large-bodied fish differed between sampling years (2015 and 2016), thus indicating potential cohorts among years, species-specific pair-wise cumulative distribution functions were compared using Kolmogorov-Smirnov two-sample tests using the Fisheries Stock Analysis package (FSA; Ogle 2015) in R (version 3.2.0; R Core Team 2015).

D.5 Results

Fish movement

All tagged individuals except for one golden perch were detected on acoustic receivers one week or more post-tagging. The majority of movements occurred from late October to late December 2015 (Figure D.3). The timing of peak movements of both species is consistent with previously reported spawning windows for each species. Commonwealth watering occurred in conjunction with suitable water temperatures, and the volumes of water delivered enabled movement among all zones.

The majority of golden perch movements occurred between mid-September and mid-November 2015 when water temperatures ranged from 20–25 ^{o}C (Figure D.4). The majority of golden perch moved very small distances downstream and all of the tagged golden perch remained within the zone 3 throughout the study period (Figure D.4). The movements of these fish in 2015-16 are less than distances reported for tagged fish in 2013-14, when one golden perch moved upstream to Gulpa Creek and another into the upper Edward River (Watts et al. 2014). The largest upstream movement in 2015-16 was into Yallakool Creek where an individual golden perch was detected approximately 12 km upstream of Wakool Reserve on 3/10/15 (Figure D.3c). Of the individuals that moved upstream, more went into the upper Wakool River (zone 2) than into Yallakool Creek (zone 1) during environmental water delivery (Figure D.4). This is different to upstream movement patterns of golden perch observed in 2013-14, when more golden perch moved into Yallakool Creek than the Wakool River (Watts et al. 2014). There is no obvious explanation for this preference, however the number of fish and distances moved upstream are small and are not significant for this species.

Samples sizes of tagged silver perch were low. All of the tagged silver perch remained within the Edward-Wakool selected area during water delivery and only one silver perch was detected outside of the fine-scale array at Gee Gee Bridge, approximately 134 km downstream from Wakool Reserve (Figure D.3d). This movement occurred only for a brief period of time (6th to 10th February 2016) after which the fish returned to zone 3. Another silver perch accounted for the furthest upstream movement, and on 8/10/15 was detected approximately 30 km upstream from Wakool Reserve in the Wakool River. These are very small movements for a species that has the ability to travel long distances.

During this study period no fish tagged as part of other studies from outside the Edward-Wakool system were detected by the array. This report includes movement data until onbly early April 2016, so it is not possible to evaluate a response of fish movement to the algal bloom reported in section 5.

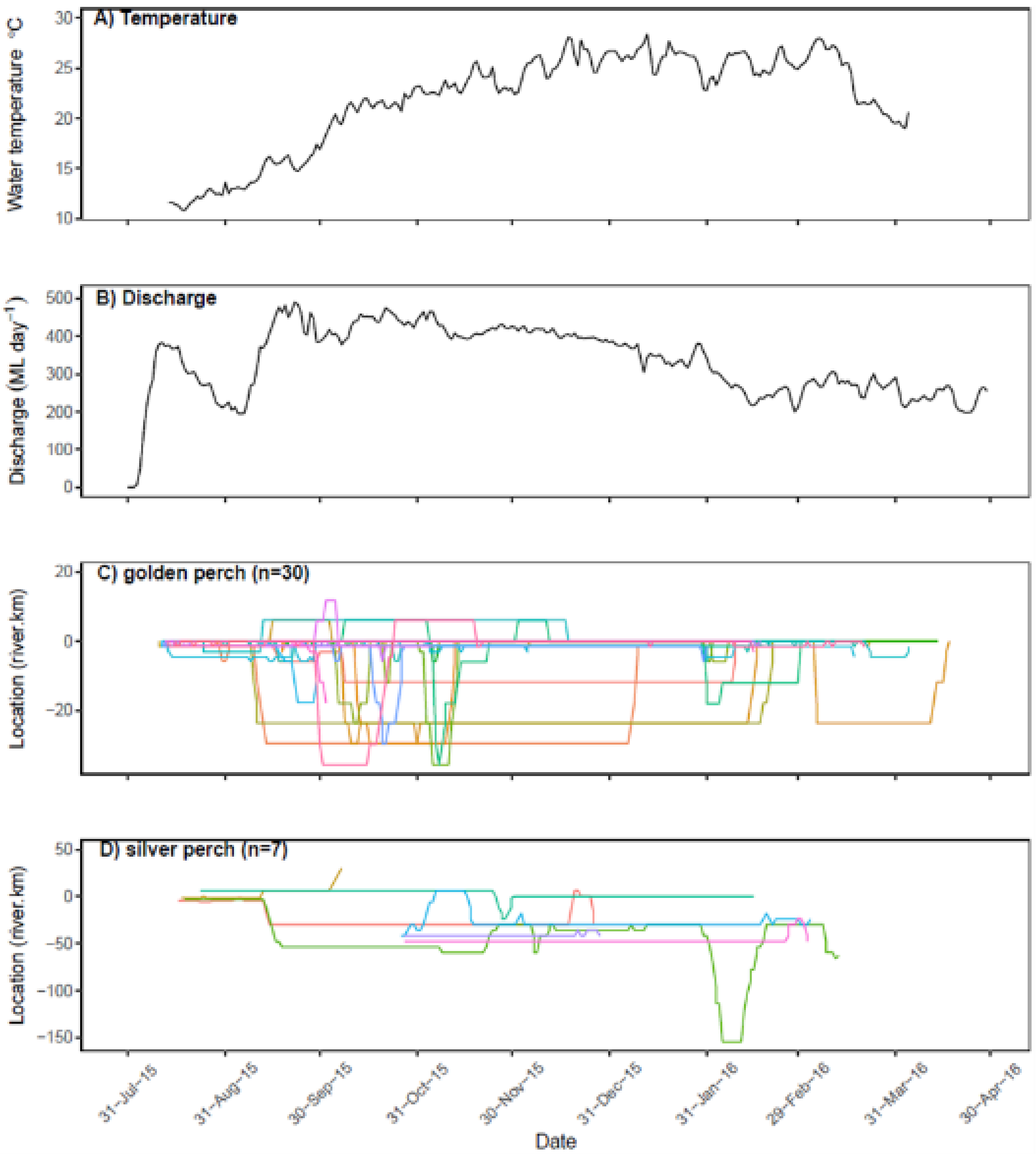


Figure D.3a) Mean daily water temperature and b) mean daily discharge at Wakool Reserve (Zone 3) and associated daily location of acoustically tagged b) golden perch and d) silver perch. Different coloured lines represent different tagged individuals and 0 km represents the location of Wakool Reserve, with positive numbers representing upstream locations and negative numbers downstream locations.

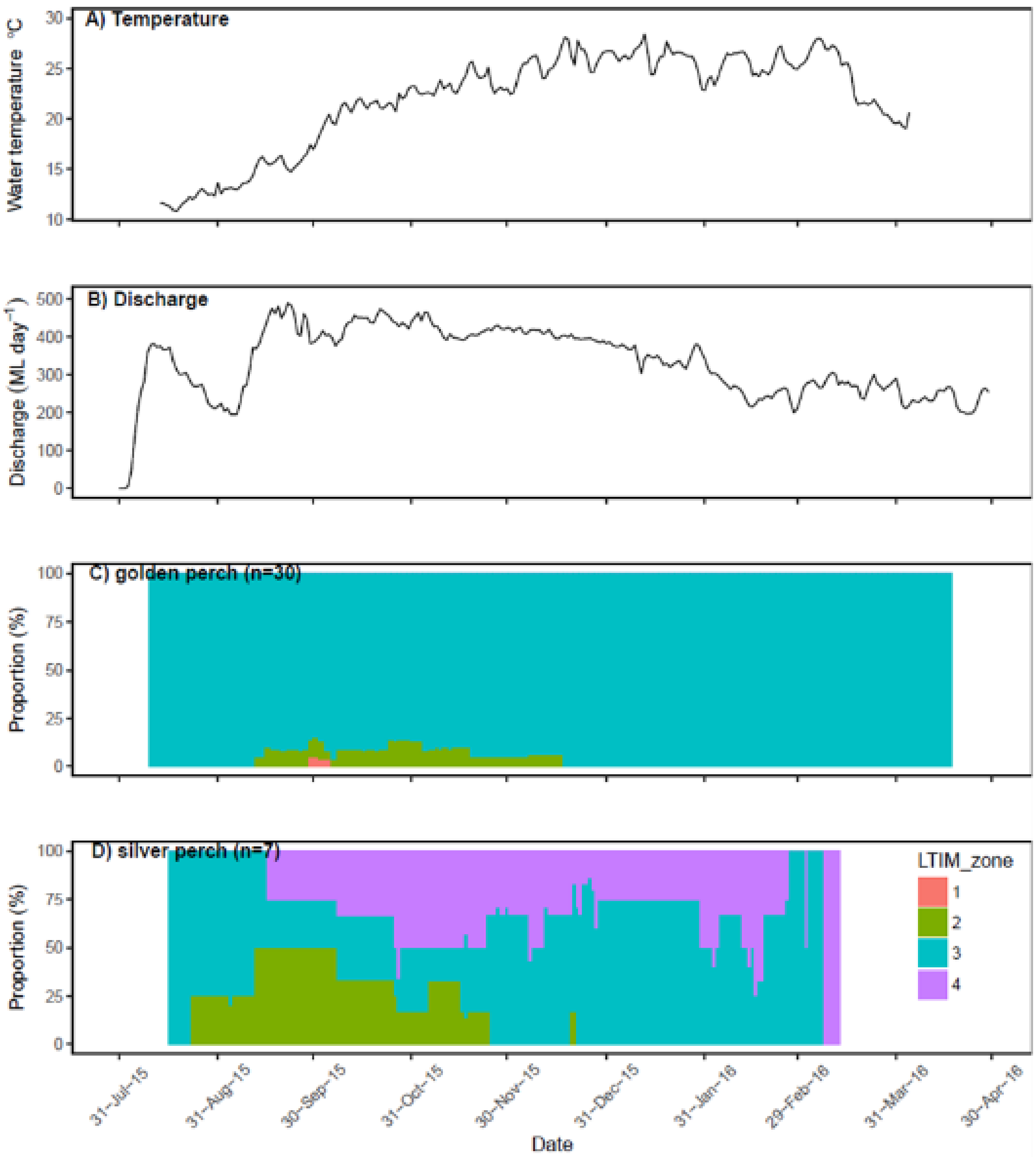


Figure D.4 a) Mean daily water temperature and b) mean daily discharge at Wakool Reserve (Zone 3) and associated daily location within each LTIM focal zone of acoustically tagged b) golden perch and d) silver perch. Different colours represent hydrological zones.

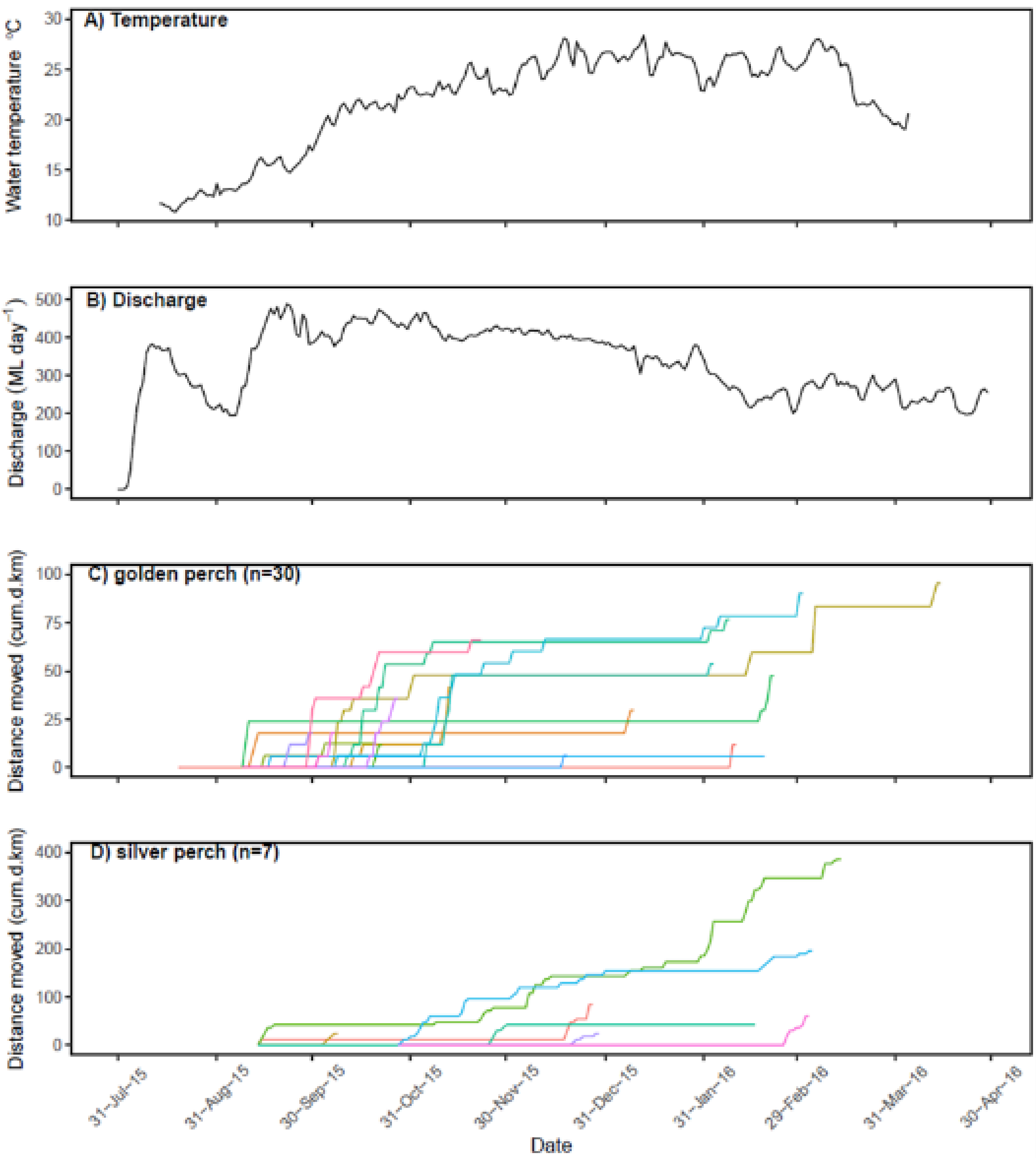


Figure D.5 a) Mean daily water temperature and b) mean daily discharge at Wakool Reserve (Zone 3) and associated absolute cumulative daily distanced moved by acoustically tagged c) golden perch and d) silver perch. Different coloured lines represent different tagged individuals and steeper lines indicate periods of rapid movement.

Fish spawning and reproduction

A total of 3,418 fish larvae, representing ten fish species, were collected in the 2015-16 monitoring study from light traps (*n*=2939) and drift nets (*n*=479) combined. Across the four study zones, Yallakool Creek (Zone 1) comprised 5% of the total light trap catch, with Wakool River Zone 2, Zone 3 and Zone 4 comprising 23%, 38%, and 34% of light trap catch, respectively.

Eight of the ten fish species collected as larvae were native, with small-bodied fish species making up the majority of larvae collected across the 4 study zones (Table D.4). Carp gudgeon (*Hypseleotris* spp., n= 2343), were the most numerically abundant larvae caught in light traps, with flathead gudgeon (*Philypnodon grandiceps*, n = 107) and Australian smelt (*Retropinna semoni*, n= 81) larvae also detected widely across all study zones. Unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*, n= 6), obscure galaxias (*Galaxias oliros*, n=5) Murray River rainbowfish (*Melanotaenia fluviatilis*, n=1), were rare, but showed evidence that spawning had taken place in two of the four zones. Carp (*Cyprinus carpio*, n=5) and gambusia (*Gambusia holbrooki*, n=3) was the only introduced species captured as larvae.

Of the large-bodied, native fish species known to the Edward-Wakool River system, two species, Murray cod (*Maccullochella peelii*, n=215), and river blackfish (*Gadopsis marmoratus,* n=18) were collected as larvae. While Murray cod were collected as larvae in all four study zones, river blackfish were only collected in the Upper Wakool River (Zone 2). This is the fourth season that river blackfish larvae have been sampled in the Upper Wakool River, suggesting spawning populations of this species are localised. There were no bony herring (*Netamalosa erebi*), silver perch (*Bidyanus bidyanus*) or golden perch (*Macquaria ambigua*) eggs or larvae collected from light traps or drift nets (Table D.4). The use of Commonwealth environmental water in the Edward Wakool during 2015-16 did not target a spawning response in silver perch or golden perch.

Numbers of larvae caught were similar to 2014-15, both in terms of total abundance, and for individual species (Figure D.6). There was slightly more Murray cod and Australian smelt captured in 2014-=15 than in 2015-16, while slightly more carp gudgeon were captured in 15-16 (Figure D.6).

Table D.4. Total abundance of fish larvae sampled using light traps (LT) and drift nets (DN) in the four study zones of the Edward-Wakool River system in Spring/Summer 2015-16. Grand totals and percent contribution (%) provided in the far right column. Total amount of water filtered across the nets in each study zone; Yallakool Ck - 14.7 ML, Wakool River Zone 2 - 21.6 ML, Wakool River Zone 3 - 0.1 ML, and Wakool River Zone 4 – 11.3 ML. Fish species listed are those known to occur in the Edward-Wakool river system; however Trout cod are the only species not found in the study zones.

Common name	**Yallakool Ck**		**Wakool R Z2**		**Wakool R Z3**		**Wakool R Z4**		**Total**	
	LT	**DN**	**LT**	**DN**	**LT**	**DN**	**LT**	**DN**	**LT**	**DN**
Native										
Australian smelt	52	-	4	-	11	-	14	-	81	-
carp gudgeon	28	2	530	-	1000	2	785	3	2343	7
flathead gudgeon	4	-	15	-	22	-	66	1	107	1
unspecked hardyead	3	-	-	-	3	-	-	-	6	-
Murray River rainbowfish	-	-	-	-	1	-	-	-	1	-
obscure galaxias	3	-	-	-	-	-	2	-	5	-
bony herring	-	-	-	-	-	-	-	-	-	-
silver perch	-	-	-	-	-	-	-	-	-	-
golden perch	-	-	-	-	-	-	-	-	-	-
river blackfish	-	-	18	-	-	-	-	-	18	-
trout cod	-	-	-	-	-	-	-	-	-	-
Murray cod	56	277	66	42	29	95	64	57	215	471
Introduced										
gambusia	-	-	-	-	3	-	-	-	3	-
oriental weatherloach	-	-	-	-	-	-	-	-	-	-
redfin perch	-	-	-	-	-	-	-	-	-	-
carp	2	-	3	-	-	-	-	-	5	-
goldfish	-	-	-	-	-	-	-	-	-	-

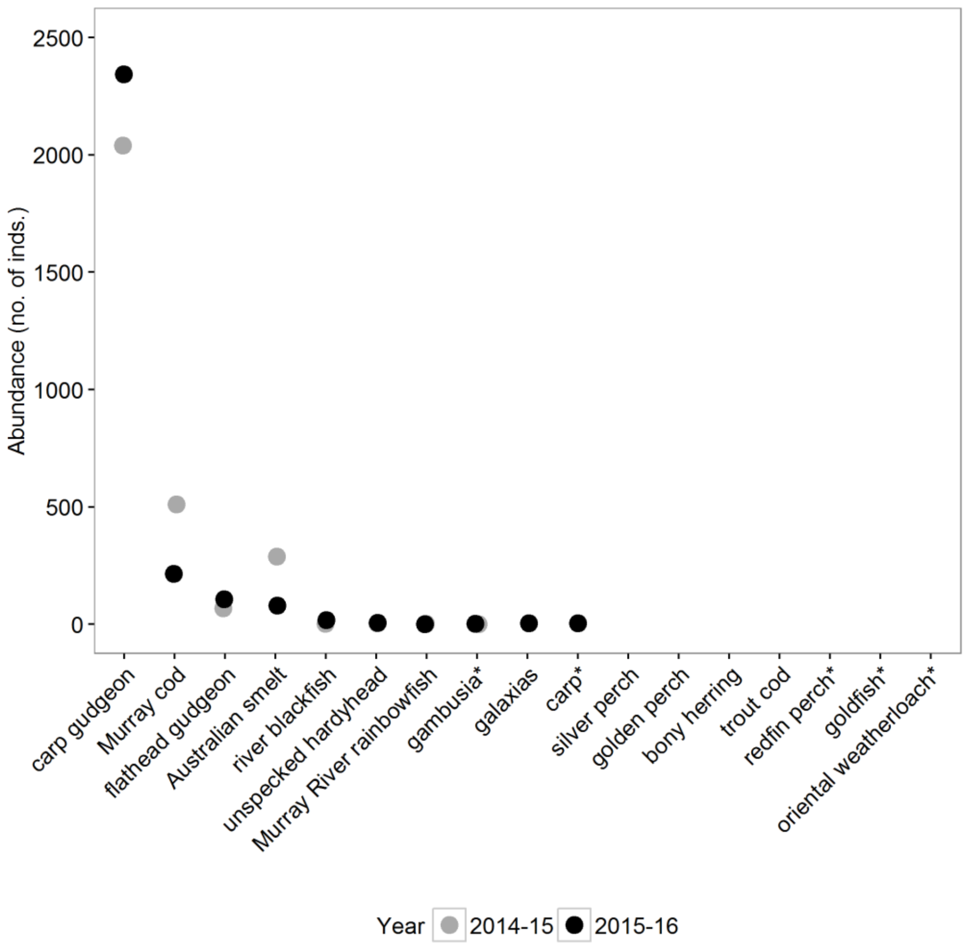


Figure D.6. Comparison of total number of larvae caught in light traps the fish species found in the Edward Wakool River system, in 2014-15 and 2015-16.

Seasonal timing of spawning

The seasonal timing of the appearance of larvae in the Edward-Wakool River System reflected similar patterns to previous years (Watts et al. 2013, Watts et al. 2014b, Watts et al. 2015). Australian smelt larvae were the first species detected as larvae in the 2015-2016 sampling period, occurring from September to early December (Figure D.7). Larval sampling commenced on 15 September, and the appearance of smelt larvae in this first trip suggests the species had probably commenced spawning prior to this date.

Murray cod larvae were found in all four study zones between late October and end of the November 2016. While the spawning window for Murray cod was consistent with trends in the 2012/13 and 2013/14 spawning periods, the duration of the spawning appeared to be shorter compared with the 2014-15 season, which extended through to December (Figure D.7).

Carp gudgeon had the longest spawning period of all fish, with larvae detected over more than four months. Carp gudgeon larvae first appearing first in Wakool River (Zone 3) and Wakool River (Zone 4) in mid October, and by mid November were present in Yallakool Creek (Zone 1) and Wakool River (Zone 2) (Figure D.7). Peak abundance of larval carp gudgeon occurred during the summer months of December and January, as has been previously reported in the Edward Wakool (Watts et al. 2015). Flathead gudgeon had a narrower spawning window than carp gudgeon, detected as larvae in all study zones for 3 months between October 2015 and January 2016 (Figure D.7).

The small numbers of larvae caught for river blackfish, unspecked hardyhead, obscure galaxias and Murray River rainbowfish, make it difficult to generalise spawning patterns (Figure D.7). However, it is worth noting that river blackfish where only collected as larvae from 4 of the 5 sites in Wakool River (Zone 2) between mid October and mid November 2015. In previous years blackfish have been recorded from only two of the five sites in zone 2. Obscure galaxias larvae were also detected at more sites and zones compared to 2014-15, when they were first recorded. In the current year, they occurred in both Yallakool Creek (zone 1) and in Wakool River (zone 4).

Difference in total larval production across rivers

It was hypothesised that the total production of fish larvae across the 2015-16 spawning season would be significantly higher in the study zones that received an environmental base flow and fresh (Zone 1, 3 and 4) compared to zone 2 that received only a small environmental flow that had minimal impact on the hydrology of that zone (section 4). Statistical analyses did not support this hypothesis, we found no significant difference in the mean total number of larval fish for Australian smelt and Murray cod (Table D.5, Figure D.8), which is the same result as in 2014-15 (Watts et al. 2015). There was a significant difference in abundance of carp gudgeon larvae among hydrological zones ($p<0.01$, Table D.5), however in contrast to our hypothesis, there was no consistent pattern in larval abundance with the amount of environmental water delivered. Instead, we observed a significantly greater number of larvae in the slower flowing river sections of zone 2, zone 3 and zone 4, than in Yallakool Creek (Figure D.8) that had reduced area of slackwater and slow water (Section 4). In 2014-15 there was a slightly lower mean abundance of carp gudgeon in zone 1 than the other three hydrological zones, however this pattern was not statistically significant (Watts et al 2015).

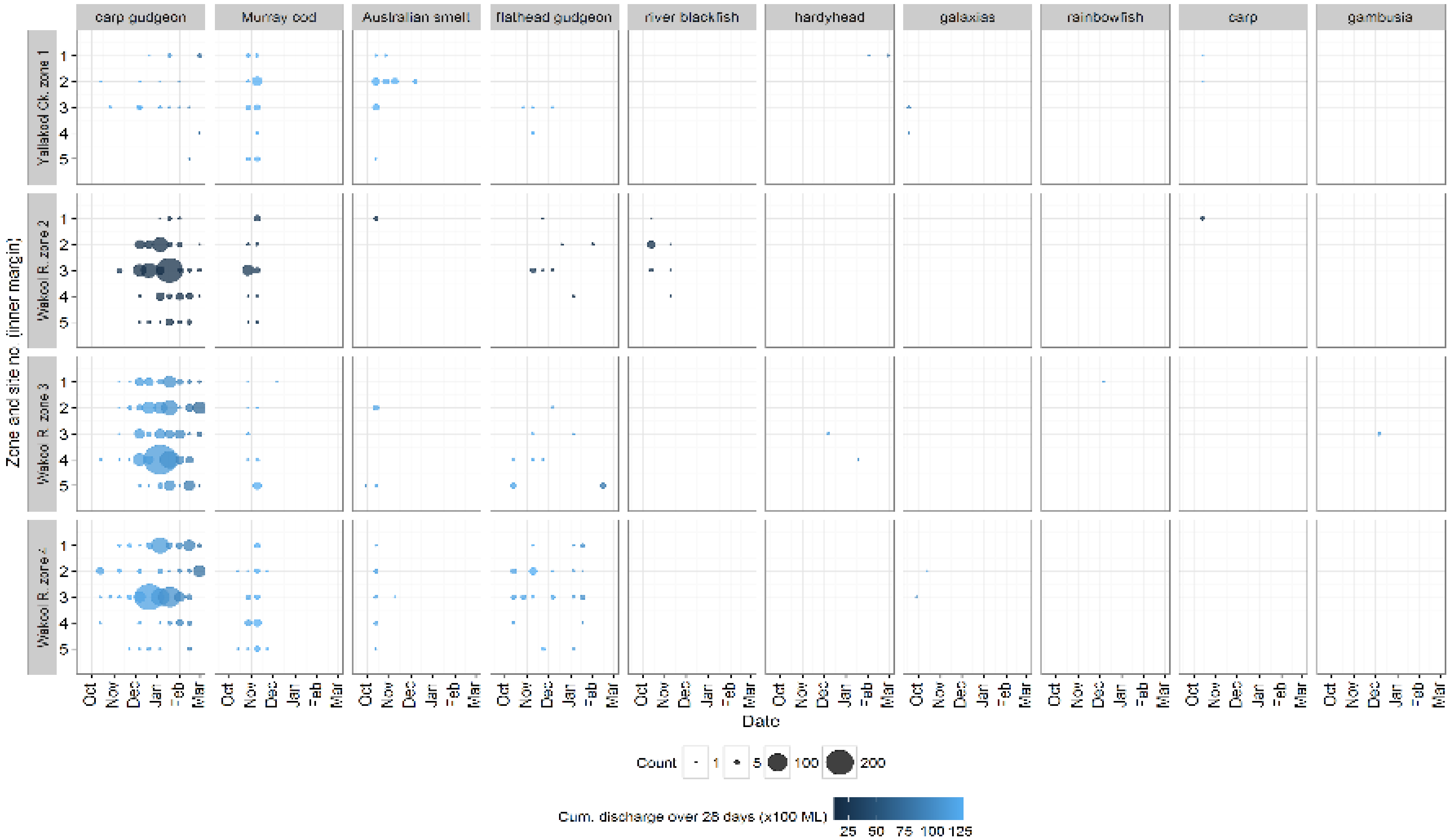


Figure D.7. Bubble plots representing relative abundance of larval fish collected in light traps from each site across the 2015-16 sampling period. Bubble size (count) represents relative abundance based on maximum number of individuals collected. Bubble colour (flow28) represents cumulative discharge over the 28 days prior to sampling.

Table D.5. One-way ANOVAS comparing total mean larvae abundance for carp gudgeon, Murray cod, Australian smelt and flathead gudgeon across zones for the entire sampling period. *P* values <0-05 used as significance threshold. * denotes significance.

Fish species	d.f	deviance	f-statistic	*P* value	
carp gudgeon	3,16	33.787	8.224	0.0015	*
Murray cod	3,16	2.133	0.929	0.4493	
Australian smelt	3,16	5.221	1.807	0.1865	
flathead gudgeon	3,16	9.892	4.335	0.0204	*

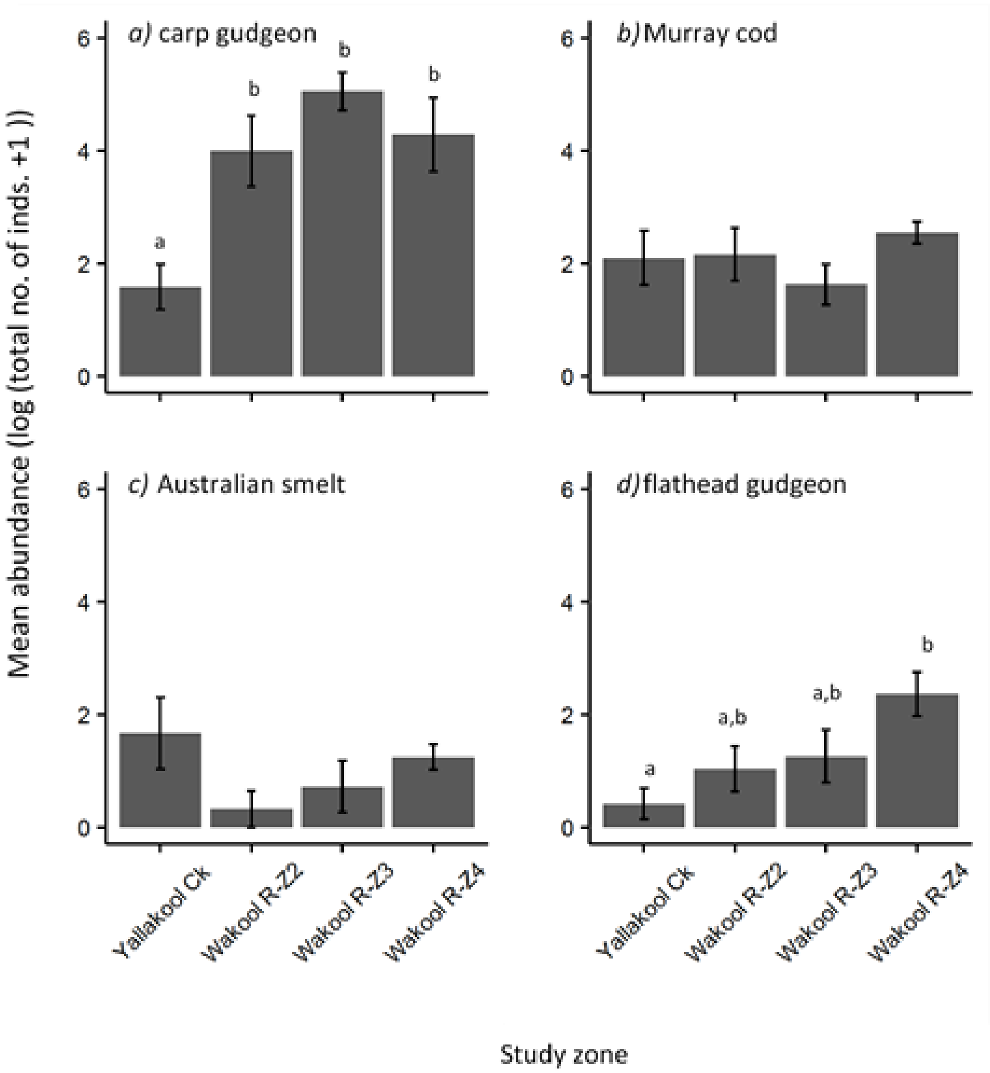


Figure D.8. Mean total abundance (±SE) of larval sampled in the 2015-16 spawning season in the Edward- Wakool Selected Area, for *a)* carp gudgeon, *b)* Murray cod, c) Australian smelt and *d)* flathead gudgeon. There was a significant difference in carp gudgeon larval abundance across the four study zones.

Fish recruitment

A total of eight native fish species and five alien species were sampled in the 2015/16 fish recruitment monitoring and this result was not different to the previous year of monitoring. A notable difference in 2015/16 was the increase in relative abundance of juvenile silver perch, particularly in the Wakool River Zones 3 and 4 (Table D.6 see *Recruitment silver perch*). River blackfish remained present for the second year of monitoring—again only in Wakool River Zone 2, site 2. Golden perch recruits were again not present, or were not detected by our monitoring, for the second year of sampling in the Edward-Wakool and therefore growth and recruitment statistics could not be reported for this species.

Table D.6. Number of Young-of-Year (YOY), age-class 1 (1+) recruits and older juvenile and adults of the three target species sampled in recruitment and growth monitoring in the Edward-Wakool system in 2014-15 and 2015-16.

	2014-15 Stage of development			2015-16 Stage of development		
Zone	YOY recruit	1+ recruit	Other Juvenile or Adult	YOY recruit	1+ recruit	Other Juvenile or Adult
Murray cod						
Yallakool Creek	5	15	17	20	8	10
Wakool River Zone 2	5	11	11	9	16	19
Wakool River Zone 3	3	14	13	7	9	16
Wakool River Zone 4	7	6	14	4	17	11
Silver perch						
Yallakool Creek	-	1	6	-	1	5
Wakool River Zone 2	-	-	2	-	-	3
Wakool River Zone 3	-	1	5	-	4	9
Wakool River Zone 4	-	1	1	5	15	14
Golden perch						
Yallakool Creek	-	-	-	-	-	-
Wakool River Zone 2	-	-	-	-	-	-
Wakool River Zone 3	-	-	1	-	-	3
Wakool River Zone 4	-	-	2	-	-	1

Recruit growth

Sections of otoliths from Murray cod and silver perch resulted in clearly discernible alternating patterns of opaque and translucent zones that were used to distinguish recruits and other age-classes. Only 5/73 and 4/31 annual otolith ages from Murray cod and silver perch respectively were not consistent among all three readings and otoliths with these discrepancies were not used in further analysis.

Murray cod YOY ranged from 46 to 89 mm TL, while 1+ recruits ranged from 140 to 221 mm TL. The logistic growth model provided a significant (DF=90; F = 744; P<0.001) fit to describe

Murray cod age-length data (Figure D.9). Differences in growth curves among zones were not significant, so a single growth curve for the entire Edward-Wakool system was used to describe the age-length relationship in 2015/16 (Figure D.9). The growth index parameter for 2015/16 Murray cod recruits was not notably different to the previous year (Table D.7). There were no significant differences in YOY growth rate (Figure D.10) or length of 1+ recruits among zones (Figure D.11) in 2015/16. The fitted growth index parameters provide an overall index of recruit growth that can be compared among years in order to evaluate the long-term effects of Commonwealth environmental water delivery.

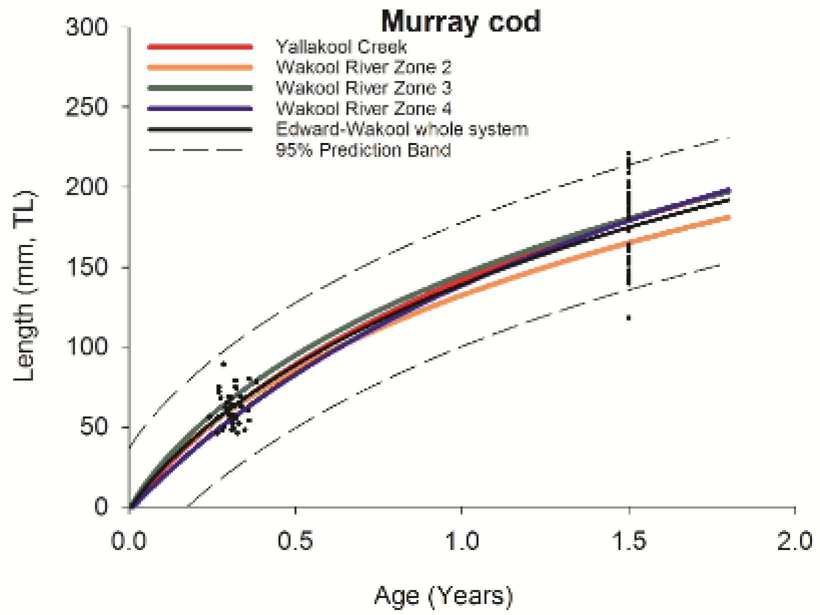


Figure D.9. Growth curves of Murray cod recruits sampled in the Edward-Wakool system in 2015-16.

Table D.7. Logistic model growth index for Murray cod recruits sampled in the Edward-Wakool system in 2014-15 and 2015-16.

Year	Growth parameters	Estimate	Std. Error	t value	P value
2014-15	Growth index	1.02	0.14	7.29	<0.0001
2015-16	Growth index	0.86	0.04	22.16	<0.0001

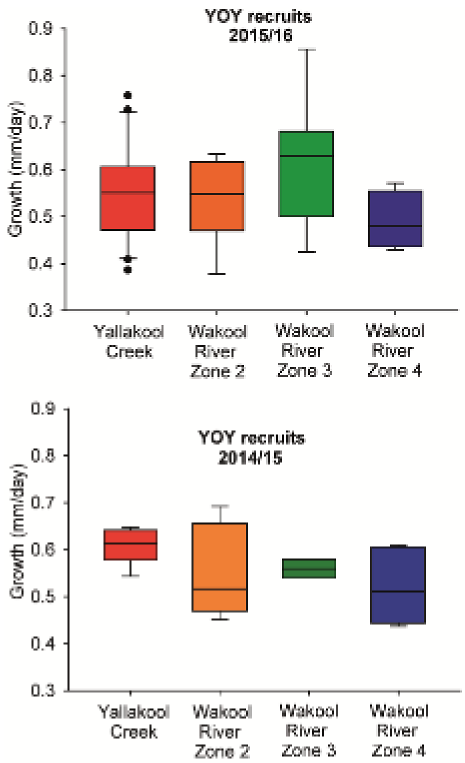


Figure D.10. Daily growth rate of Murray cod young-of-year (YOY) recruits sampled in the Edward-Wakool system in 2014-15 and 2015-16. Box plots illustrate the median, upper and lower quartiles and 95% confidence intervals.

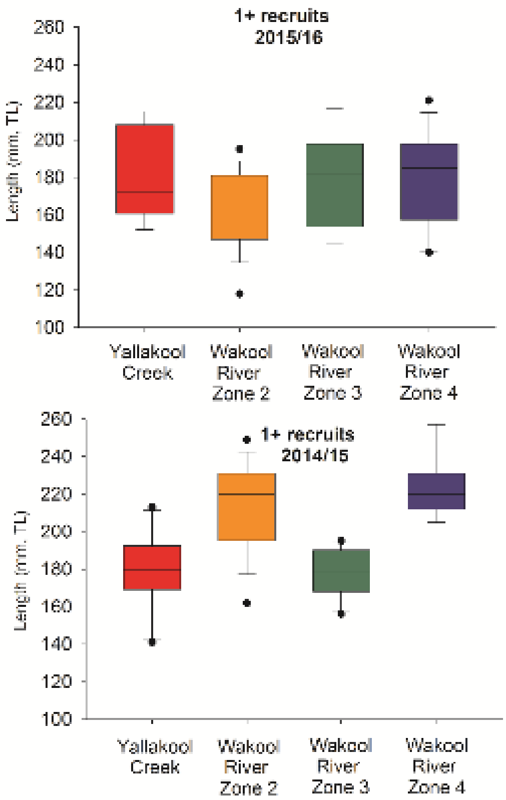


Figure D.11. Length of Murray cod 1+ recruits sampled in the Edward-Wakool system in 2014-15 and 2015-16. Box plots illustrate the median, upper and lower quartiles and 95% confidence intervals.

Silver perch YOY ranged from 63 to 101 mm TL, while 1+ recruits ranged from 123 to 195 mm TL (Figure D.12). Age-length curves were not developed for silver perch because sampling permit restrictions for this threatened species limited the number fish that could be euthanized; resulting in no samples retained for daily age estimation. However, the length distribution (Figure D.12) of YOY (median = 72 mm) and 1+ (median = 164) silver perch recruits in 2015/16 can be compared statistically to future monitoring years—when silver perch recruits are present—in order to evaluate the long-term effects of Commonwealth environmental water delivery on the growth rate of recruits. Zone-specific comparisons of silver perch recruit growth rates could not be made since fewer than 5 recruits were sampled in 3 out of 4 zones.

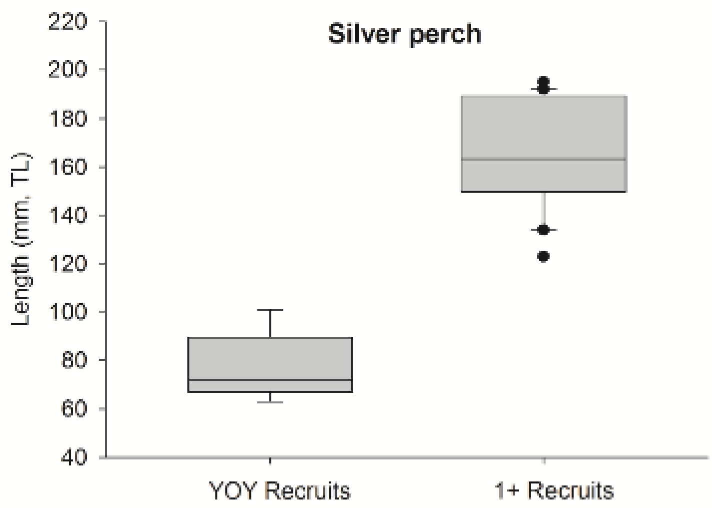


Figure D.12. Length distribution of Young-of-Year (n = 5) Silver perch and 1+ recruits (n = 20) sampled in the Edward-Wakool system in 2015-16. Box plots illustrate the median, upper and lower quartiles and 95% confidence intervals.

Recruitment

Murray cod were the most abundant of the three species being targeted as part of fish recruitment monitoring (Table D.6). The same as in 2014/15, Murray cod recruits were sampled consistently in all zones in 2015/16, including 40 YOY, 50 1+ recruits and 56 fish in older age-classes.

Indices of YOY and 1+ recruitment of Murray cod (Figure D.13) were developed for the Edward-Wakool system and compared among zones and years, taking into account differences in sampling gear catchability (Table D.8. The recruitment index values for YOY and 1+ Murray cod have been relatively consistent in the Edward-Wakool (Figure D.13) with no significant differences detected across monitoring years or zones (Table D.8.). Per 1000 seconds of sampling, backpack electrofishing was the most effective method of sampling Murray cod recruits and based on the recruitment index values (Table D.8), 1+ recruits were sampled more efficiently than YOY.

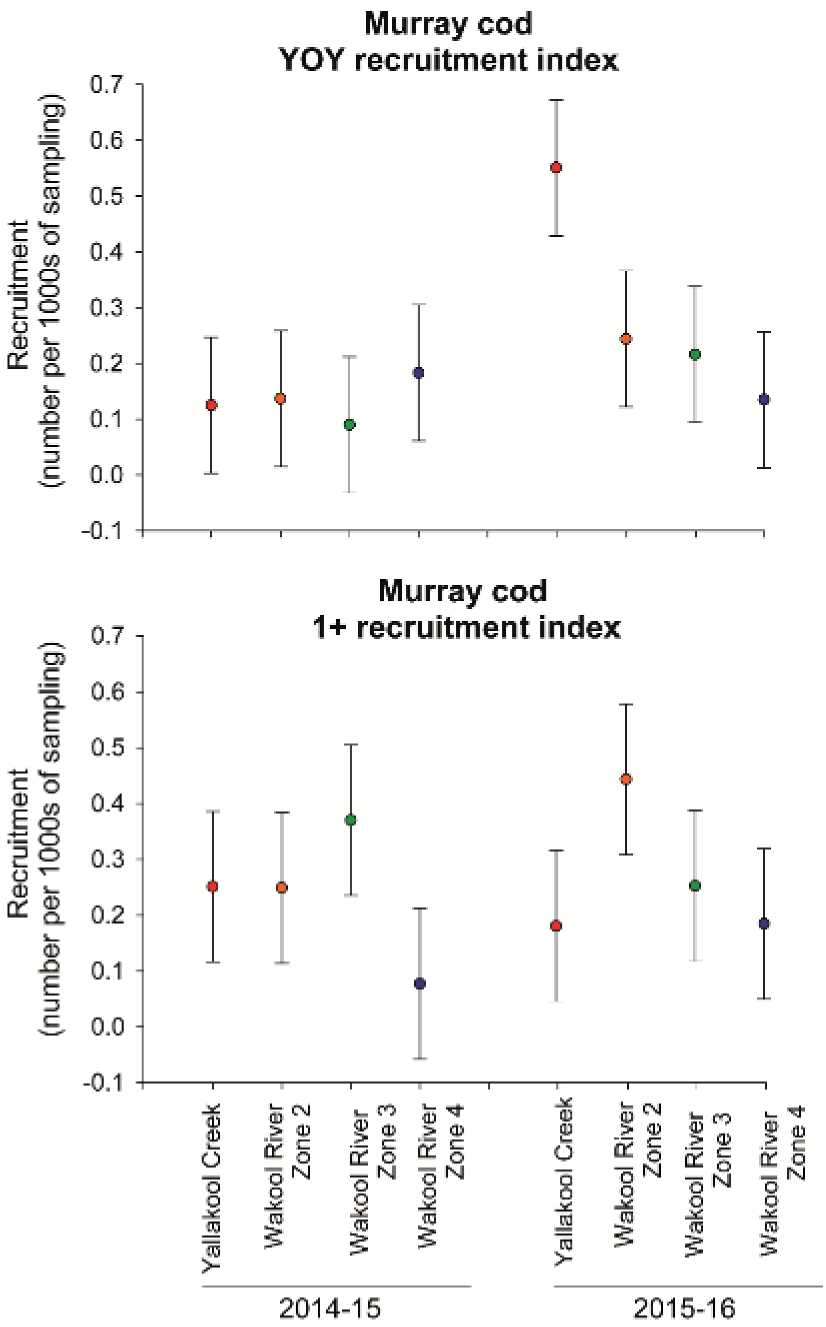


Figure D.13: Recruitment indices expressed as catch per unit effort (1000 seconds) of Young-of-Year (top) and age-class 1+ (bottom) Murray cod sampled in the Edward-Wakool system in 2014-15 and 2015-16. Values +/- SE represent the fitted estimates of a Generalized Linear Mixed Model including all fixed effects in Table D8.

Table D.8. Recruitment indices for Young-of-Year (YOY) and age-class 1 (1+) Murray cod in the Edward-Wakool system in 2014-15 and 2015-16. Differences among zones and years were not significant. Values are reported only for significant (P<0.05) effects.

	YOY recruitment index			1+ recruitment index		
Fixed effects	value	Std. Error	p-value	value	Std. Error	p-value
Gear			p<0.001			p<0.001
Angling	0.00	0.08		0.01	0.08	
Backpack EF	0.64	0.08		0.74	0.8	
Setlines	0.00	0.08		0.01	0.08	

Silver perch 1+ recruits (n = 20) were significantly (Table D.9) more abundant in 2015/16, as compared with the previous sampling year where only three individuals were sampled (Figure D.14). Five YOY recruits and 32 older silver perch were sampled in 2015/16, as compared with a total of 3 and 14 respectively the previous year (Table D.6). Due to the low sample size of YOY silver perch, recruitment statistics were only calculated for 1+ recruits. Angling and setlines (Table D.9) were significantly more effective at sampling 1+ silver perch, which is different to Murray cod recruits that were most effectively sampled using backpack electrofishing. The increase in recruitment of silver perch in 2015/16 was attributable primarily to more 1+ silver perch sampled in Wakool River Zones 3 and 4 (Figure D.14) but there were no significant differences among zones, or their interaction with year, in the overall model (Table D.9). Two-dimensional hydraulic modelling showed that two zones had the largest increase in area of slackwater (< 0.02 $m.s^{-1}$) and slow water (0.02 – 0.3 ms^{-1}) during environmental watering actions in Yallakool Creek (Watts et al. 2015b).

Table D.9. Recruitment indices for age-class 1 (1+) Silver perch for the Edward-Wakool system comparing years 2014-15 and 2015-16 and sampling gear. Differences among zones were not significant but year and sampling gear were significant factors. Values are reported only for significant (P<0.05) effects.

	1+ recruitment index		
Fixed effects	value	Std. Error	p-value
Gear			p<0.05
Angling	0.028	0.007	
Backpack EF	0.000	0.007	
Setlines	0.002	0.007	
Year			p<0.05
2014-15	0.002	0.006	
2015-16	0.018	0.006	

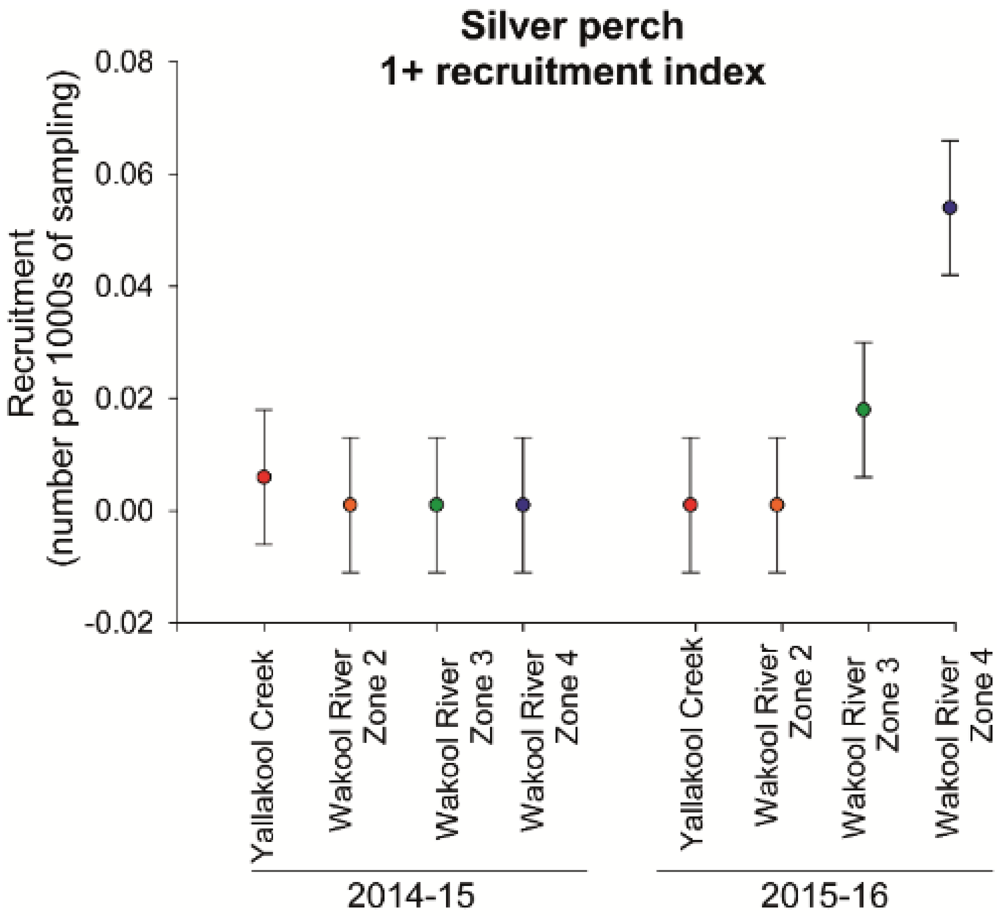


Figure D.14. Recruitment indices expressed catch per unit effort (1000 seconds) of age-class 1 (1+) Silver perch in the Edward-Wakool system in 2014-15 and 2015-16. Asterisks denote zone which received environmental water. Values +/- SE represent the fitted estimates of a Generalized Linear Mixed Model including all fixed effects in Table 10.5.

Adult fish community

Category 1 fish community sampling identified the same nine native fish species and three alien species in zone 3 during 2016 (Table D.10). No silver perch or golden perch (Figure D.15) new recruits were captured in 2016. Few bony herring and common carp recruits were captured in 2015 or 2016, although Murray cod new recruits represented the predominant catch in both years (Figure D.15). There were no significant differences in the abundance of the fish assemblage between 2015 and 2016 in zone 3 (Pseudo-$F_{1,18}$ = 2.131, p=0.065). Length-frequency distributions indicate that golden perch (p=0.033) and bony herring (p<0.001) were significantly larger in 2016. There was a significant difference in the size of common carp between years (p=0.048) due to a greater proportion of individuals <200 mm in 2016. No differences in the size distribution of Murray cod were observed (p=0.375).

Table D.10. Summary of fish captured during Category 1 standardised sampling in 2015 and 2016 in the Edward-Wakool LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	**2015**				**2016**			
	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**
native species								
Australian smelt	129	2	-	**131**	52	1	-	**53**
bony herring	31	-	-	**31**	27	-	-	**27**
carp gudgeon	47	4302	51	**4400**	68	2367	15	**2450**
flatheaded gudgeon	-	-	1	**1**	-	-	3	**3**
golden perch	107	-	-	**107**	116	-	-	**116**
Murray cod	210	-	-	**210**	333	1	-	**334**
Murray-Darling rainbowfish	339	168	-	**507**	353	77	5	**435**
silver perch	5	-	-	**5**	5	-	-	**5**
un-specked hardyhead	86	64	-	**150**	565	35	-	**600**
alien species								
common carp	167	-	-	**167**	176	-	-	**176**
eastern gambusia	18	175	-	**193**	36	366	1	**403**
goldfish	21	-	-	**21**	38	-	-	**38**

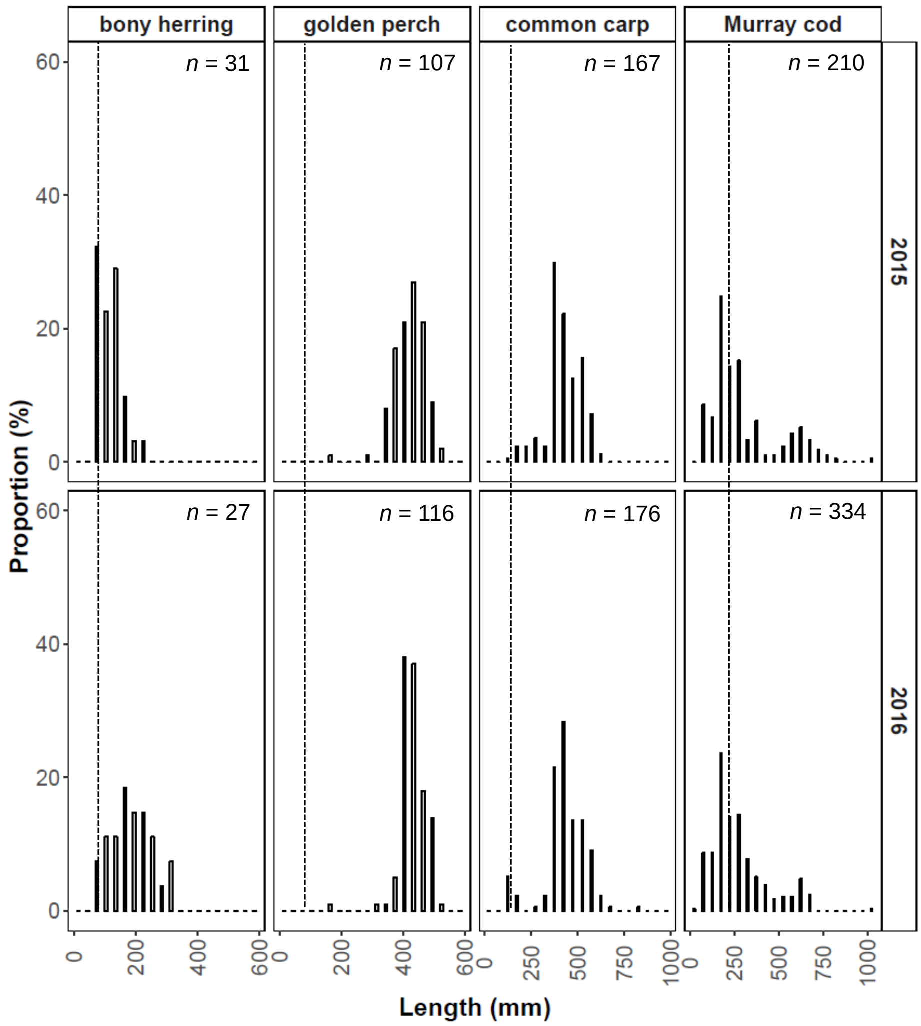


Figure D.15. Length-frequency histogram of golden perch captured during Category 1 sampling during the Edward-Wakool LTIM project in 2015 and 2016. The dashed line indicates approximate length at one year of age.

D.6 Discussion

Periodic species (e.g. golden perch, silver perch)

Periodic species are characterised as relatively large, long-lived species that have high fecundity and low investment in offspring (i.e. a lot of small eggs and no parental care) (King et al. 2013). Within the Edward-Wakool system, bony herring, golden perch and silver perch are representatives of this group. Spawning and recruitment in all three species is thought to benefit from higher flow events and even over-bank flooding (King et al. 2013), and as such the group represents an excellent target for environmental water delivery. However, it should be noted that existing flow-ecology relationships aren't definitive and substantial flexibility has been documented through all species' distributional ranges (e.g. Mallen-Cooper and Stuart 2003; Balcombe et al. 2006; Balcombe and Arthington 2009). Regardless of the conjecture, there is a general agreement that substantial reductions in populations, particularly of golden perch and silver perch, have resulted from alteration of the seasonal timing and magnitude of river flows as a result of water resource development within the Murray-Darling Basin (Lintermans 2007).

During the 2015-16 water delivery period both golden and silver perch adults remained present within the Edward-Wakool system, mainly within zone 3. Previous monitoring has documented that the system supports adult populations of all three periodic species. Despite the presence of golden and silver perch in the focal areas during water delivery, there was no evidence from our larval fish monitoring to confirm a spawning response of either species (or bony herring) to water delivery. Environmental watering actions in the Wakool-Yallakool system are currently constrained to a maximum of 600 $ML.d^{-1}$ and actions of this magnitude (whilst not targeting golden perch and silver perch spawning) have not triggered spawning in these species in this part of the system. In some cases, large-scale rapid pre-spawning movements are thought to precede spawning in golden and possibly silver perch. Indeed, Koster et al. (2014) demonstrated downstream pre-spawning movements of golden perch in the Goulburn River, Victoria. O'Connor et al. (2005) identified both downstream and upstream pre-spawning movements in Murray River golden perch, including the relocation of a number of fish to an area near the junction of the Wakool and Murray rivers. The majority of movements exhibited by both golden and silver perch in this study are consistent with existing literature regarding the timing of spawning. For example, golden perch movements in this study were earlier than silver perch movements, and this is consistent with a generally earlier spawning window for golden perch (King et al. 2013, 2016). However, the distances that golden perch moved during 2015-16 were very small, with almost all fish remaining within zone 3.

The results from the recruitment monitoring over two years has indicated an absence of 0+ and 1+ golden perch within the Edward-Wakool system. This result conforms with our lack of evidence of localised spawning in this species and more generally with our lack of captures of small sizes classes of golden perch throughout the broader system (this study; Watts et al. 15, Watts et al. 14b). Similarly, Thiem et al. (in press) captured few juvenile golden perch at hypoxic blackwater affected sites within the system and identified that immigration into the system was the most likely explanation for the presence of older golden perch (i.e. pre-blackwater events). Indeed, Zampatti et al. (2014) recently identified large scale movements of juvenile golden perch, with fish spawned in the Darling River in 2009 later immigrating into the lower Murray (South Australia) during overbank flooding as 1+ juveniles. A similar result has been observed for fish captured in the Edward-Wakool as adults (i.e. Darling River origin; Thiem *Unpublished data*), although additional research is required to identify whether this result is consistent among years or a one-off event. Regardless of the source of immigrants, the collective results of recent monitoring including during 2015-16 indicate that the Edward-Wakool system sustains an adult population of golden perch. It appears however, based on multiple lines of evidence, that golden perch 1) did not spawn in the focal zones in 2015-16 and 2) localised spawning has not occurred in this system the past 5+ years and contributed to recruitment.

Unlike golden perch, the results from the past two years of LTIM monitoring are not as easy to interpret for silver perch. There was a population of adult silver perch present within the system during environmental water delivery, so we could reasonably expect to capture eggs or larvae if a spawning response had occurred (typically October-January with a December peak; King et al. 2013). However no eggs or larvae were collected. Despite this result, both 0+ and 1+ silver perch were captured in 2015-16 and a smaller number of 1+ individuals were captured in 2014-15. There was a significant increase in the number of 1+ silver perch captured in 2015-16 compared with the previous year. The possible explanations for this result are 1) 0+ recruits were present in 2014-15 and were under sampled, 2) recruits have immigrated into the Edward-Wakool system, or 3) or silver perch larvae from upstream sites may have drifted into and settled in the study area. While the former explanation cannot be ruled out, the latter two explanations appears more likely as regular spawning has been observed in the nearby Murray River (see King et al. 2016). Regardless of the source population, it appears that the Edward-Wakool system is an important nursery area for silver perch, and a broad range of size and age classes occupy the system (Watts et al. 2014b). It may be that spawning in this species could be triggered in future flow delivery years through the provision of large volumes of water as the probability of spawning in the species increases with increasing discharge (King et al. 2016). Most recruits were present in the zone 3 and zone 4 of the Wakool River which received Commonwealth environmental water and these two zones had the largest increase in area of slackwater (< 0.02 m.s-1) and slow water (0.02 – 0.3 ms-1) during environmental watering actions in Yallakool Creek (Watts et al. 2015b). This monitoring program is well placed to report on such a response through the combined monitoring of adult movement, capture of eggs or larvae and subsequent capture of juveniles via the multiple indicators employed.

Equilibrium species (e.g. Murray cod)

Murray cod spawning, as measured by the abundance of larvae, was consistent among all zones in 2015-16, which was the same as results from the previous three years of monitoring and evaluation in this system (Watts et al. 2013, Watts et al. 2014b, Watts et al. 2015). Irrespective of differences in hydrology and environmental flows in 2015-16 and in all previous years, Murray cod spawning started in mid-October, peaked in November and ended by mid- to late December. The steady seasonal and yearly spawning time and relatively large larvae of Murray cod aligns it with the 'equilibrium' life-history strategy of many medium to large and long-lived fish species (Winemiller and Rose 1992; Humphries et al. 1999). Results from the Edward-Wakool agree with previous monitoring and research on Murray cod which has demonstrated spawning in this species is associated with rises in temperature up to and above 20°C during spring (Humphries 2005; Koehn and Harrington 2006; King et al. 2009b).

Murray cod recruitment and growth of recruits in the Edward-Wakool remained steady in 2015-16, with no differences among zones or between years (Watts et al. 2015). The consistent presence of young-of-year and 1+ fish, which are not hatchery releases, indicates that spawning in the Edward-Wakool system or perhaps nearby rivers, is resulting in successful and wide-spread recruitment of this species within the region. Zone-specific differences in growth detected in the previous monitoring year (Watts et al. 2015) were not detected in 2015-16, suggesting no discernible pattern or relationship with environmental watering. Although it is well-established that many species, including Murray cod, do not require high flows to initiate spawning (Humphries et al. 1999), recruitment may be affected by alterations to the flow regime, and environmental watering may be able to influence this.

The size distribution of adult Murray cod in the Edward-Wakool was the same in 2015-16 as it was the previous year. Two clear size-classes around 200 mm TL and 650 mm TL appear to be stable across years and, based on size-at-maturity estimates from elsewhere in the Murray-Darling (Forbes et al. 2015), the largest size-class is most likely contributing to a majority of the spawning and recruitment of the species in Edward-Wakool system. As demonstrated by monitoring over the past two years, the current abundance of spawning adult Murray cod in the Edward-Wakool system appears to be generating consistent and wide-spread production of larvae which are supporting stable recruitment.

In conclusion, the spawning, recruitment and adult populations of Murray cod in the Edward-Wakool system have been steady, across years, and across zones sampled, regardless of differences in hydrology. The consistency of larval production, recruits and spawning-size adults is generally indicative of a sustainable population within the Edward-Wakool. Environmental flows have had no measurable effect (positive or negative) on spawning of Murray cod in the Edward Wakool system for the past three years (Watts et al. 2013, Watts et al. 2014b, Watts et al. 2015), although it remains less clear whether recruitment or growth of older age-classes may be affected by changes in hydrology. Environmental flow delivery objectives should focus on recruitment and growth outcomes required for early life-history survival needed to sustain adult populations.

Small bodied opportunistic species

Opportunistic fish species are characterised by being small bodied and having fast growth rates, small eggs and frequent reproduction over an extended spawning season (Winemiller and Rose 1992). There are six native small bodied opportunistic species known to the Edward-Wakool selected area: Australian smelt, carp gudgeon, flathead gudgeon, unspecked hardyhead, Murray River rainbowfish and obscure galaxias. These species will spawn under a range of flow conditions, however the early life stages of these species are commonly found in slow flowing slackwater waters, suggesting that shallow, low flow environments are important nursery areas for this group of fish (Humphries et al. 1999, Lyon et al. 2010, Bice et al. 2014). Instream submerged vegetation is also considered to be important for many opportunistic species (Bice et al. 2014).

Populations of small bodied species from 2015-16 were similar to 2014-15, as evidenced by similar numbers of adults (collected under Category I basin-scale methods), and larvae collected for each species. For small bodied opportunistic species we had hypothesised that watering actions that provide a significant increase in low flow habitats (such as inundated slackwaters, backwaters and off channel wetlands) were likely to result an increase in habitat for both larvae and adult life stages (Humphries et al. 1999, Lyon et al. 2010). The consistent result across years is likely to be attributable to the similar flow delivery patterns which occurred throughout the study zones during the 2015-16 and 2014-15, and thus the availability of slackwater habitat would have not have increased significantly this year. However, in 2015-16 there were significantly fewer larval carp gudgeon in zone 1 Yallakool Creek than in zones 2, 3 or 4. There were also fewer flathead gudgeon in zone 1 Yallakool Creek than in Wakool River zone 4. This may be due to the increased area of slackwater and slow water in zones 3 and 4 than in Yallakool Creek during the environmental watering action, and the increasing abundance and cover of aquatic vegetation in these two zones over the past two years.

We had hypothesised that the increased instream vegetation observed in 2014-15 and 2015-16 throughout the study zones would benefit species such as unspecked hardhead and Murray River rainbowfish because of its importance as a spawning substrate and refugia. We did not observe increases in the number of larvae caught of either of these species in 2015-16, although more unspecked hardyhead were collected under basin-scale surveys compared with 2014-15. Previous studies have found abundance of Murray River rainbowfish to be positively associated with *Potamogetan tricarinatus* and *Nicotiana galuca* (Bice et al. 2014). It may be possible that positive responses to improved habitat conditions may take several spawning seasons to be detected, especially if adult populations of these species were occurring in low numbers to begin with. Continued monitoring of the larval and adult populations of these species in coming years will be important in identifying the role of instream vegetation for small-bodied species.

21. APPENDIX E: REFERENCES FOR APPENDICES

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