Australian Government
Commonwealth Environmental Water Office

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Water and Society**
Charles Sturt University

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Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool Selected Area Technical Report, 2014-15

October 2015

Watts, R.J.[a], McCasker, N.[a], Thiem, J. [b], Howitt, J.A.[a], Grace, M.[c], Kopf, R.K.[a], Healy, S.[d], Bond, N.[e] (2015). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool Selected Area Technical Report, 2014-15. Institute for Land, Water and Society, Charles Sturt University, Prepared for Commonwealth Environmental Water.

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PROJECT PARTNERS

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), NSW Office of Environment and Heritage, and Murray Local Land Services, with James Abell (CSU) and Chris Smith (NSW DPI) undertaking the majority of the field work. Murray Local Land Services coordinated several community activities so community members were informed about this project and had the opportunity to provide input to the project.

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3	Monitoring and Evaluation	All authors
4	Hydrological responses to Commonwealth environmental watering	Robyn Watts
5	Changes in hydraulic habitat in response to Commonwealth environmental watering	Robyn Watts
6	Response of water quality and carbon to Commonwealth environmental watering	Julia Howitt and Nicole McCasker
7	Effect of Commonwealth environmental water on stream metabolism	Michael Grace
8	Response of riverbank and aquatic vegetation to Commonwealth environmental watering	Robyn Watts, Sascha Healy and Nicole McCasker
9	Response of fish community to Commonwealth environmental watering	Jason Thiem
10	Fish spawning and reproduction responses to Commonwealth environmental watering	Nicole McCasker
11	Murray cod, golden perch and silver perch recruitment and growth responses to Commonwealth environmental watering	Keller Kopf
12	Summary and synthesis	All authors
13	Recommendations and application through adaptive management into 2015-16 use of Commonwealth environmental water	All authors

EXECUTIVE SUMMARY

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2014-15. It is the first 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), NSW Office of Environment and Heritage, and Murray Local Land Services. Murray Local Land Services coordinated several community activities so community members were informed about this project and had the opportunity to provide input to the project.

This report provides details of the watering actions, indicators, methodology, and an assessment of short-term ecosystem responses to environmental watering in 2014-15 with respect to the objectives set by the Commonwealth Environmental Water Office. Evaluation of responses across multiple years will be undertaken in subsequent reports. 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. A synthesis of the results is presented in the LTIM Edward-Wakool Selected Area Synthesis report 2014-15 (Watts et al. 2015).

Commonwealth environmental watering actions in the Edward-Wakool system in 2014-15

Three Commonwealth environmental watering actions were undertaken for the Edward-Wakool System in 2014-15; i) Yallakool Creek-Wakool River watering action between August 2014 and January 2015, ii) Tuppal Creek watering action (partnered with NSW environmental water) in spring (October to November 2014) and autumn (March to April 2015), and iii) Colligen Creek watering action in January 2015.

The Tuppal Creek and Colligen Creek watering actions were not monitored as part of the Edward-Wakool LTIM Project, and hence have not been described or evaluated in this report. The Yallakool Creek-Wakool River environmental watering action is the focus of this technical report and the synthesis report (Watts et al. 2015).

Yallakool Creek Environmental Watering Action (Aug 2014 – January 2015)

A cod maintenance watering option was developed for Yallakool Creek for 2014-15 (CEWO 2014) that was similar to a watering action undertaken in 2013-14 in this system. It was planned that Commonwealth environmental water would contribute about 500 ML/day in Yallakool Creek through to the end of the cod spawning season. In the absence of natural high inflows, it was planned that environmental water would be delivered to provide an early season pulse to 'prime' the channel and contribute to a more natural flow regime (CEWO 2014).

The watering action objectives for this action were defined by CEWO on 22 July. It was expected that this action will:

- support inundation of Murray cod nesting sites and contribute to maximising Murray cod recruitment
- contribute to improved opportunities for movement, condition, reproduction and recruitment of native fish
- increase hydrological connectivity, including inundation of slackwater habitats areas downstream of the Yallakool-Wakool confluence, providing opportunities for recruitment of small bodied native fish, frogs and shrimp
- maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants
- maintain/improve water quality, particularly dissolved oxygen, salinity and pH
- contribute to maximising outcomes in the Wakool from outflows from Koondrook-Perricoota and provide greater volume of receiving water.

Following a series of high unregulated inflow events in July 2014, flows started to pass through the Edward-Wakool system, including overbank flows into Werai Forest and to Colligen and Yallakool Creeks. On the back of these tributary inflows, use of Commonwealth environmental water commenced earlier than planned to synchronise with naturally occurring high flows and the potential that, despite low water temperatures, large bodied native fish may have commenced moving into breeding habitat and nesting sites. The watering action in Yallakool Creek (zone 1) commenced on 12 August 2014 and there was an extended in-channel fresh of approximately 500 ML/day from August until 16 December 2014, followed by a recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day. The action was completed on 15 January 2015. The total Commonwealth environmental water delivery for this action was 34,561 ML.

Monitoring

The monitoring for the Edward-Wakool LTIM Selected Area Evaluation 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). Indicators monitored in 2014-15 were: river hydrology, riverbank inundation by 2D-hydraulic modelling, stream metabolism and instream primary productivity, water quality and carbon, riverbank and aquatic vegetation, fish reproduction, fish recruitment, and fish community.

Outcomes of Commonwealth environmental watering

Commonwealth environmental water delivered to Yallakool Creek in 2014-15 had the following positive outcomes in reaches receiving environmental water (Table i):

- Increased variation in discharge (section 4)
- Increased in-channel longitudinal connectivity (section 4)
- Increased lateral connectivity. There was an increase in wetted benthic area and area of slackwater and slow water in Wakool River zones 3 and 4, but not in Yallakool Creek (section 5)
- Maintained dissolved oxygen levels and ecosystem respiration (section 6)
- Increased cover and diversity of instream aquatic vegetation, particularly in Wakool River zones 3 and 4, but not consistently in Yallakool Creek zone 1 (section 8)
- Potentially contributed to an increase in the diversity of native fish, with one new species, *Galaxias oliros* (obscure galaxias) recorded in Yallakool Creek (section 10).

There was one negative response to Commonwealth environmental watering in 2014-15 (Table i), being a reduction in the area of slackwater in Yallakool Creek during the environmental watering action compared to area of available slackwater during base flows (section 5). This finding was consistent with observations in 2013-14 (Watts et al 2014) of a lower abundance of shrimp larvae in Yallakool Creek during the environmental watering. Shrimp are not monitored as part of the LTIM Project, but it is expected that the increased area of fast flows in Yallakool Creek during the environmental watering action will have had a negative effect on larval shrimp, and the increase in slack water and slow water in zones 3 and 4 will have had a positive outcome for shrimp and other taxa in those zones that require slow flowing water for recruitment and survival.

There were a number of indicators that showed no detectable response to environmental watering (Table i). Although environmental watering increased wetted benthic area in some reaches (section 5), this increase was not sufficient to trigger an increase in gross primary productivity (section 7). 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.

Fish spawning (section 10), and fish recruitment (section 11) indicators did not respond to environmental watering action. Although there is good evidence that fish reproduction occurs in this system (nine species collected as larvae in 2014-15, see section 10; nine species collected as larvae in 2013-14, Watts et al. 2014), the spawning response could not be attributed to the watering action because a similar level of reproduction occurred in the Wakool River (zone 2) that did not receive environmental water. Although there is evidence of some recovery in the fish community in areas impacted by the blackwater events in 2010-2012 (section 9), some of the improvement in the fish community is likely to be due to other factors, such as immigration of fish into the system.

The responses to Commonwealth environmental watering observed in 2014-15 were consistent with those observed previously in this system. The good outcomes for dissolved oxygen and aquatic vegetation will help improve the system for longer term benefits to be realised, providing habitat for invertebrates and small bodied fish and potentially improving riverine productivity. Good dissolved oxygen levels and increased instream habitat are essential for the long-term health of this system and could lead to improved outcomes for fish in the longer term.

The environmental watering that was implemented during the blackwater events of 2010 to 2012 mitigated extreme low dissolved oxygen concentrations (Watts et al. 2013) and created an area of refuge habitat and water quality conditions to avoid critical loss of fish in the upper reaches of the Wakool River and Yallakool Creek. The benefits of those watering actions area still evident, with fish populations in the upper reaches having higher biomass than those in the lower reaches (section 10). The long-term recovery of fish populations in this system is ongoing. Some of the benefits of the Commonwealth environmental watering actions are expected to be realised over a much longer time frame and should not be expected to eventuate from a single flow action or within a single year.

Table i. Summary of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2014-15.

🟩	Positive response to environmental watering (green)
🟥	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	Short-term response to Yallakool Creek e-watering event (Aug 2014-Jan 2015) (< 1 year)	Response to e-watering assessed across 2014-15 watering year (1 year)	Longer-term response to e-watering (assessed across 1-5 years)
Hydrology	Hydrological connectivity	🟩	🟩	N/A TO BE ASSESSED IN YEARS 2 TO 5 OF THE LONG-TERM INTERVENTION MONITORING PROJECT
	Coefficient of variation of discharge	N/A	🟩 zone 3 and 4 only	
Hydraulic modelling	In-channel wetted benthic area	🟩	N/A	
	Area of slackwater	🟩 zone 3 and 4 only	N/A	
	Area of slow flowing water	🟩 zone 3 and 4 only	N/A	
	Area of fast flowing water	🟥 zone 1		
Stream metabolism, water quality, and organic matter characterisation	Rates of gross primary productivity	▨	▨	
	Rates of ecosystem respiration	🟩	🟩	
	Rates of primary productivity	▨	▨	
	Dissolved organic matter	▨	▨	
	Dissolved oxygen	🟩	🟩	
	Temperature	▨	▨	
	Nutrient concentration	▨	▨	
	Modification of type and amount of DOM	▨	▨	
Riverbank and aquatic vegetation	Percent cover of riverbank and aquatic vegetation	N/A	🟩	
	Diversity of riverbank and aquatic vegetation	N/A	🟩	
Fish movement	Native fish survival, dispersal and synchronised movement	N/A	N/A	
Fish spawning and reproduction	Abundance of 'Opportunistic' (e.g. small bodied fish) species	N/A	▨	
	Abundance of ‘flow-dependent’ spawning species (e.g. golden and silver perch)	N/A	▨	
Fish recruitment	Growth rate of young-of-year (YOY) and age-class 1 (1+) Murray cod	N/A	▨	
	Recruitment of young-of-year (YOY) and age-class 1 (1+) Murray cod	N/A	▨	
Fish community	Fish condition	N/A	N/A	
	Fish recovery	N/A	N/A	

Assessment of outcomes against the Commonwealth environmental watering objectives

An assessment of the outcomes against the ecological objectives for 2014-15 in the Edward-Wakool system outlined in the Water Use Minute 10008 (CEWO, 2014) is presented in Table ii and an assessment of outcomes against the specific objectives for the Yallakool Creek environmental watering action in 2014-15 is provided in Table iii. Some of the watering objectives were achieved, some were not achieved and some were not assessed in the Edward-Wakool system in 2014-15. In both of these assessments 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 environmental watering action in 2014-15.

Table ii. Assessment of outcomes of Commonwealth environmental watering in the Edward-Wakool system in 2014-15 against the broad environmental watering objectives outlined in water use Minute 10008. Green shading indicates positive response, red shading indicates negative 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 10008	**Objective achieved or not achieved**
Improve the diversity and condition of native fish and other native species including frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit	Improved diversity of native fish, with one new species detected Diversity and condition of frogs, turtles and invertebrates not assessed
	Improvement in reproduction and recruitment of native fish not achieved
Improve 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. Increased lateral connectivity at some sites
Support inundation of low-lying wetlands/floodplains habitats within the system	Inundation of low lying in-channel features at some sites
Maintain health of riparian, floodplain and wetland native vegetation communities	Floodplain and wetland vegetation not assessed.
	Cover and diversity of riverbank and aquatic vegetation was improved at most sites
Contribute to a more natural wetting-drying cycle for ephemeral wetlands and watercourses	Not assessed
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 most sites receiving environmental water
	Reduced area of slackwater in Yallakool Creek

Table iii. Assessment of outcomes of Commonwealth environmental watering against the environmental watering objectives defined for the Yallakool Creek environmental watering action in 2014-15. Green shading indicates positive response, red shading indicates negative response, grey shading indicates no detectable response (either positive or negative) to environmental watering. White boxes indicate no evaluation was undertaken.

Commonwealth environmental watering objective for the Yallakool Creek environmental watering action	**Objective achieved or not achieved**
Support inundation of Murray cod nesting sites and contribute to maximising Murray cod recruitment	Extent of inundation of Murray cod nesting sites not assessed, but it is expected that the environmental flow inundated nests
	No detectible improvement in Murray cod recruitment
Contribute to improved opportunities for movement, condition, reproduction and recruitment of native fish	Fish movement not assessed in 2014-15
	No detectible improvement in reproduction or recruitment of native fish
Increase hydrological connectivity, including inundation of slackwater habitats areas downstream of the Yallakool-Wakool confluence, providing opportunities for recruitment of small bodied native fish, frogs and shrimp	There was increased longitudinal connectivity. There was increased lateral hydrological connectivity at some sites
	Reduced area of slackwater in Yallakool Creek
Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants	Cover and diversity of riverbank and aquatic vegetation was improved at most sites
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
Contribute to maximising outcomes in the Wakool from outflows from Koondrook-Perricoota and provide greater volume of receiving water	Not assessed, because a planned outflow from Koondrook-Perricoota by NSW Forestry did not occur

Recommendations and application through adaptive management into 2015-16 use of Commonwealth environmental water

The ten recommendations listed below include, where applicable, a note to indicate if the recommendation has been applied (as at 31 October 2015) in the 2015-16 use of Commonwealth environmental water in the Edward-Wakool system (commenced on 4 September 2015). A detailed explanation of these recommendations is provided in Watts et al. (2015).

Recommendation 1. Increase the duration of the recession of Commonwealth environmental watering actions relative to the Yallakool Creek environmental watering actions in 2012-13 and 2013-14.

Adaptive management response in 2015-16: This recommendation has been applied in the 2015-16 use of Commonwealth environmental water in the Yallakool Creek and Colligen Creek-Niemur River watering actions, particularly to maximise outcomes for instream aquatic vegetation. For example, the recession period for 2015-16 flows in Yallakool Creek was over nine weeks compared to four weeks in 2014-15.

Recommendation 2. Avoid long periods of constant flows by commencing the recession of environmental watering actions earlier and introducing flow variability into environmental watering actions.

Adaptive management response in 2015-16: This recommendation has been applied in the 2015-16 use of Commonwealth environmental water in the Yallakool Creek, Wakool River and Colligen Creek-Niemur River watering actions. For example, in 2015-16 the River Operator (Water NSW) was provided with an 'operating range' during the period when constant flows were most likely to occur. This trialled the use of the 'operating range' to improve flow variability at a small scale whilst not risking the ability to achieve other targeted outcomes, such as providing nesting habitat for Murray cod. Colligen Creek is likely to have increased levels of variability compared to other systems due to the River Operator passing rain rejection or other operational flows through the creek. Monitoring and evaluation of 2015-16 watering actions will inform the development of the 'operating range' in future watering actions.

Recommendation 3. Consider a trial of shifting the focus of the delivery of environmental water from Yallakool Creek to the Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system.

Adaptive management response in 2015-16: During 2015-16 environmental water planning this recommendation was considered, and a small volume of Commonwealth environmental water was delivered to the upper Wakool River to maximise outcomes for instream aquatic vegetation and the potential movement of native fish. However, the full recommendation of shifting the focus of environmental watering from Yallakool Creek to the upper Wakool River has not yet been trialled.

Recommendation 4. Consider the delivery of base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat.

Recommendation 5. Continue to include a water use option in environmental water planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events.

Adaptive management response in 2015-16: This recommendation has been applied in the 2015-16 planning for the use of Commonwealth environmental water in the Edward-Wakool River system, especially to contribute to contingency responses to hypoxic blackwater events should they occur.

Recommendation 6. Set watering action objectives that identify the temporal and spatial scale at which the response is expected and are realistic given the magnitude of environmental watering actions proposed.

Adaptive management response in 2015-16: This recommendation has been applied in the setting of objectives for the planned use of Commonwealth environmental water in the Edward-Wakool River system during 2015-16. Objectives now reflect the maintaining/supporting role from the use of Commonwealth environmental water in the Edward-Wakool River system.

Recommendation 7. Consider the implementation of a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/day (possibly up to 1000 to 1200 ML/day). This would facilitate a test of the hypothesis that larger in-channel environmental watering action will result in increased river productivity.

Recommendation 8: Consider the implementation of an environmental watering action in the Edward River to target golden perch and silver perch spawning, as this is a larger system that does not have the same level of delivery constraints as the Wakool-Yallakool system.

Recommendation 9. Undertake comprehensive flows assessment for the smaller creeks and rivers of the Edward-Wakool system.

Recommendation 10. Collaborate with other management agencies and the community to maximise the benefits of Commonwealth environmental watering actions

Adaptive management response in 2015-16: This recommendation has been applied in the use of Commonwealth environmental water in the Edward-Wakool River system during 2015-16. The use of Commonwealth environmental water to provide slower, more natural rates of recessions to high flow events (e.g. rain rejections and other operational flows) is an example of this.

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1. BACKGROUND

1.1 Purpose of this report

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2014-15. It is the first annual report of the Long Term Intervention Monitoring (LTIM) Project funded by the Commonwealth Environmental Watering Office. The 5-year project commenced in 2014 and continues until 2019. 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), NSW Office of Environment and Heritage, and Murray Local Land Services. Murray Local Land Services coordinated several community activities so community members were informed about this project and had the opportunity to provide input to the project.

This report provides details of the watering actions, indicators, methodology, and an assessment of short-term ecosystem responses to environmental watering in 2014-15 with respect to the objectives set by the Commonwealth Environmental Water Office. Evaluation of responses across multiple years will be undertaken in subsequent reports. 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.

This report builds on previous monitoring and evaluation projects undertaken in the Edward-Wakool system since 2010 when a fish monitoring program was established by NSW Department of Primary Industries and the former Murray Catchment Management Authority (Murray CMA, now Murray Local Land Services). Fish monitoring sites were established throughout the Edward-Wakool system and an array of acoustic receivers was installed to monitor behavioural responses of fish to environmental watering. In 2010 Charles Sturt University (CSU) monitored water quality responses to Commonwealth environmental watering and this expanded in 2011-12, when CSU collaborated with Monash University and the Murray CMA to monitor ecosystem responses to environmental watering in the system (Watts et al. 2013a) focussing on Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek. In 2012-13 the fish community monitoring, fish movement and ecosystem monitoring were combined into a single project (Watts et al. 2013b). Monitoring undertaken in 2013-14 continued on from these previous projects (Watts et al. 2014).

1.2 The Structure of this report

This report starts with a background to the hydrology and ecosystem of the Edward-Wakool system (section 1) followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2014-15 (section 2). An overview of the monitoring and evaluation undertaken in this system for the LTIM project is included in section 3, including a map of study sites, summary table of indicators and a conceptual diagram showing the interconnectedness of the indicators. The responses of each indicator to Commonwealth environmental watering in 2014-15 are presented in in sections four to eleven, commencing with hydrology (section 4), hydraulic modelling (section 5), water quality and carbon (section 6) and stream metabolism (section 7) that underpin responses of biota. This is followed by sections on responses of riverbank and aquatic vegetation (section 8), fish community (section 9), fish spawning and reproduction (section 10) and fish recruitment and growth (section 11). A summary and synthesis of the results (section 12) underpins recommendations and application through adaptive management for the use of Commonwealth environmental water into 2015-16 (section 13).

1.3 The Edward-Wakool system

The Edward-Wakool system is a large anabranch system of the River Murray main channel in the southern Murray-Darling Basin, Australia. The system begins upstream of the Barmah choke, and travels northwest through a series of river red gum forests before discharging back into the River Murray downstream of Kyalite (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).

The Edward-Wakool river ecosystem is recovering from the impact of the Millenium drought in south-eastern Australia when flows in the Murray-Darling Basin were at record low levels and the regulators controlling flows from the Edward River into tributary rivers such as Yallakool Creek and the Wakool River were closed. Between February 2006 and September

2010 there were periods of minimal or no flow in the Wakool River (Figure 2). In 2007-08 there was a blackwater event that resulted in the loss of many thousands of native fish, including large individuals of Murray cod. At the break of the drought a number of unregulated flow events occurred in the Edward-Wakool system between September 2010 and March 2011 (Figure 1.2) resulting in another blackwater event. Ecosystem responses to Commonwealth environmental watering in 2014-15 will be influenced by the history of flows in this system.

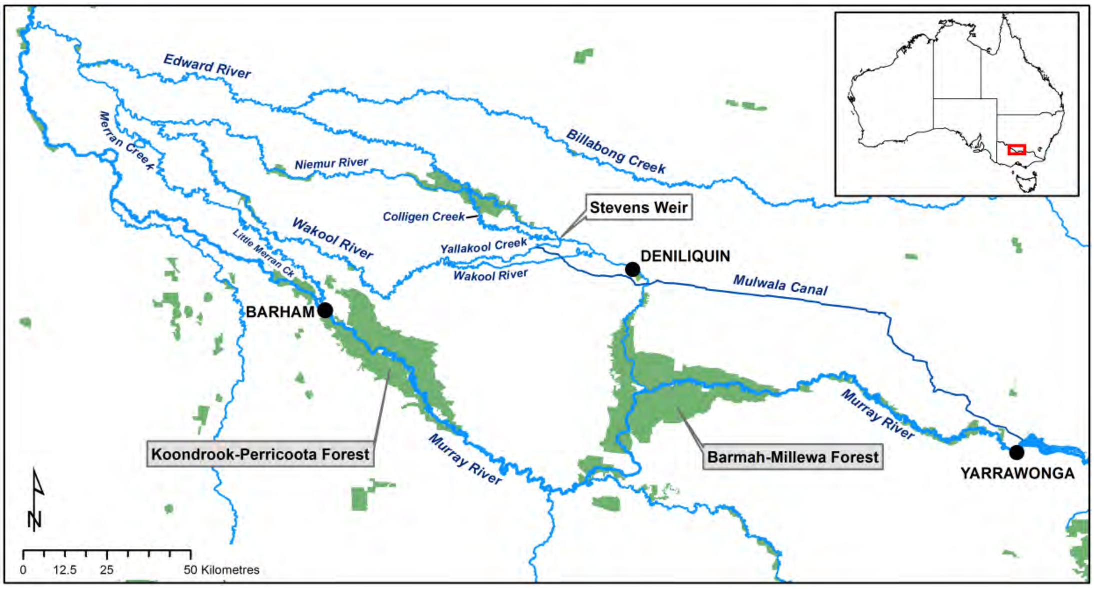

Figure 2.1. Map showing the main rivers in the Edward-Wakool system. (Source: Watts et al. 2013)

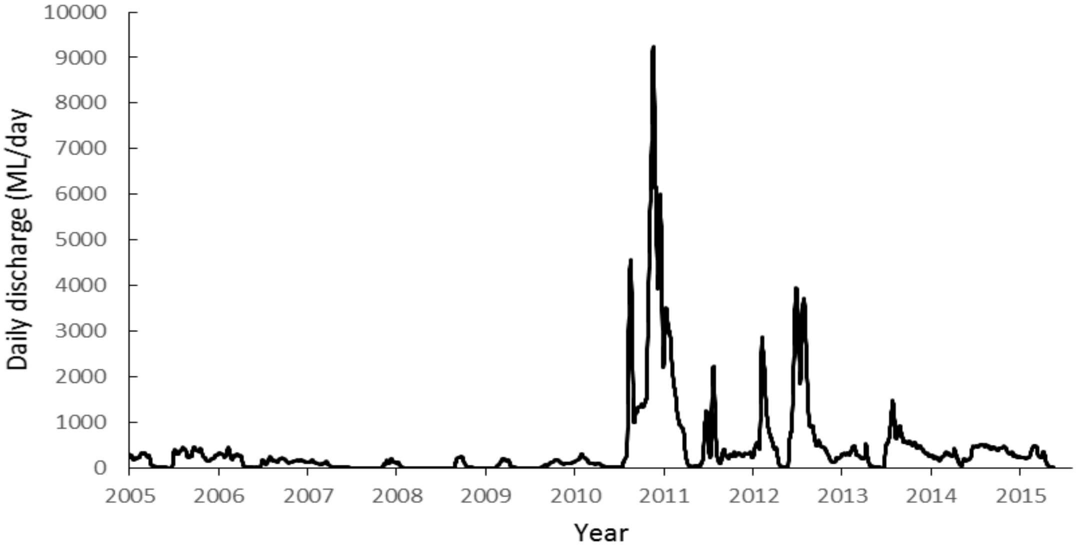

Figure 1.2. Daily discharge (ML/day) between 01/01/05 and 31/06/15 in the Wakool River at the Wakool-Barham Road (Gauge 409045 – see Figure 3.1). Daily discharge data was obtained from NSW Government water information website.

1.3. Hydrological regime of the Edward-Wakool system

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). The hydrology of the Edward-Wakool system is tightly linked with the hydrology of the River Murray and the management of flows at Yarrawonga Weir. Thoms et al. (2000) made the following observations about the mid-Murray River downstream of Yarrawonga Weir when compared with the natural condition;

- flows are much less variable, particularly in winter and spring, because the smaller floods are now stored in Hume Dam;
- flows are held constant, at or near channel capacity, for much of the year;
- the average flow at Yarrawonga has decreased because of water diverted for irrigation;
- the frequency and duration of flooding in winter and spring has been greatly decreased;
- the opportunity for low lying wetlands to dry out in autumn has been greatly decreased; and
- rain rejection events sometimes cause unseasonal flooding in summer and autumn.

Long-term modelled flow data are available from two sites on the Edward River, at Deniliquin and downstream of Stevens Weir. Modelled time-series include both pre-development and post-development scenarios. The latter assumes that all current licensed extractions have been in place for the entire record, and that all licenses are active. In addition to the modelled data, measured flow information was available from Stevens Weir. The hydrostats package (Bond, 2014) within the R statistical environment (R Core Team, 2015) was used to calculate a suite of flow statistics describing various aspects of the flow regime (Table 1.3). In addition, box plots of monthly flow and seasonal flow-duration curves were plotted to illustrate differences between the various scenarios.

Average annual flows, including the mean and median discharge, are similar under the two scenarios, and the post-development scenario closely matches the observed flows. Overall flows at Deniliquin are higher than at Stevens Weir, particularly for high-discharge events (Figure 1.3, Figure 1.4). This is expected given the location of anabranch offtakes and the Wakool Canal, a major irrigation supply channel, between Deniliquin and Steven’s Weir.

Table 1.3. Indices describing the flow regime of the Edward River at Deniliquin and Stevens Weir. Flow series include modelled pre- and post-development scenarios at each site and observed data at Stevens Weir.

	Deniliquin		**Stevens Weir**		
statistic	Pre-development[1]	Post-development[1]	Pre-development[1]	Post-development[1]	Observed[2]
Years of data	113	113	113	113	78
Mean Daily Flow (ML/day)	6453	4605	5111	2824	3031
Median Daily Flow (ML/day)	2329	2462	2311	1100	1010
Mean baseflow index	0.40	0.52	0.43	0.42	0.41
% days zero flow	0	0	0	0	0
High spell threshold (Q10, ML/day)	15796	7757	11515	6202	8327
Number of events (Q10)	134	113	130	119	63
High spell Frequency (events/year)	1.2	1.0	1.2	1.1	0.8
median high spell duration (days)	21	15	21	14	28
Mean return interval (years)	0.8	1.0	0.9	0.9	1.2
Mean Rise rate (ML/day)	2158	1463	1399	897	924
Mean Fall rate (ML/day)	1806	1092	1240	757	713
Mean annual maximum flow	35544	21606	25380	15133	14697
CV annual maximum flow	87	122	89	123	107
Annual Maximum Timing (day of year)	279	332	280	332	5
low spell threshold (Q90, ML/day)	193	783	194	130	161
median low spell duration (days)	24	16	28	7	5
Low spell Frequency (events/year)	0.9	1.3	0.8	4.2	3.8
Low spell Average return interval (years)	2	2	2	2	2
Number of events (Q90)	57	57	57	57	39
2-year ARI flow (ML/day)	52008	28071	35109	18306	18833
2year ARI flood average duration (days)	14	29	14	28	25

[1] Modelled output for the period 1895 – 2008. (Pre-development represents no infrastructure or diversions, Post-development represents current infrastructure and all licenced diversions applied over the full period). [2] Observed data from Stevens Weir for the period 1936-2015.

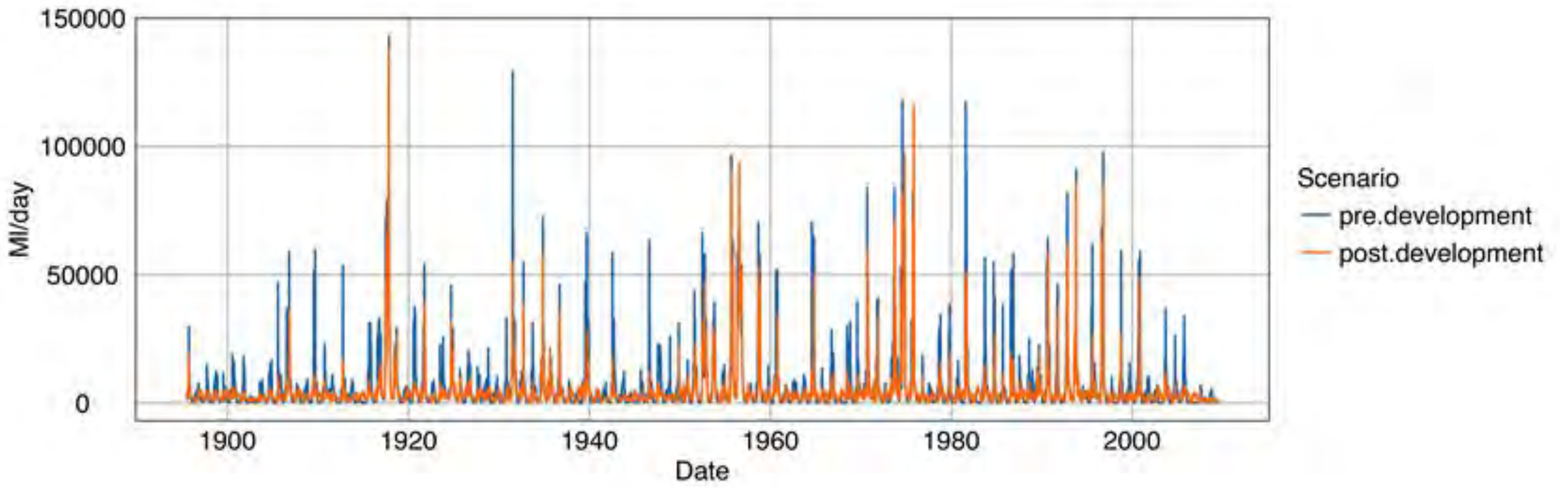

Figure 1.3. Time series plot of flows at Deniliquin.

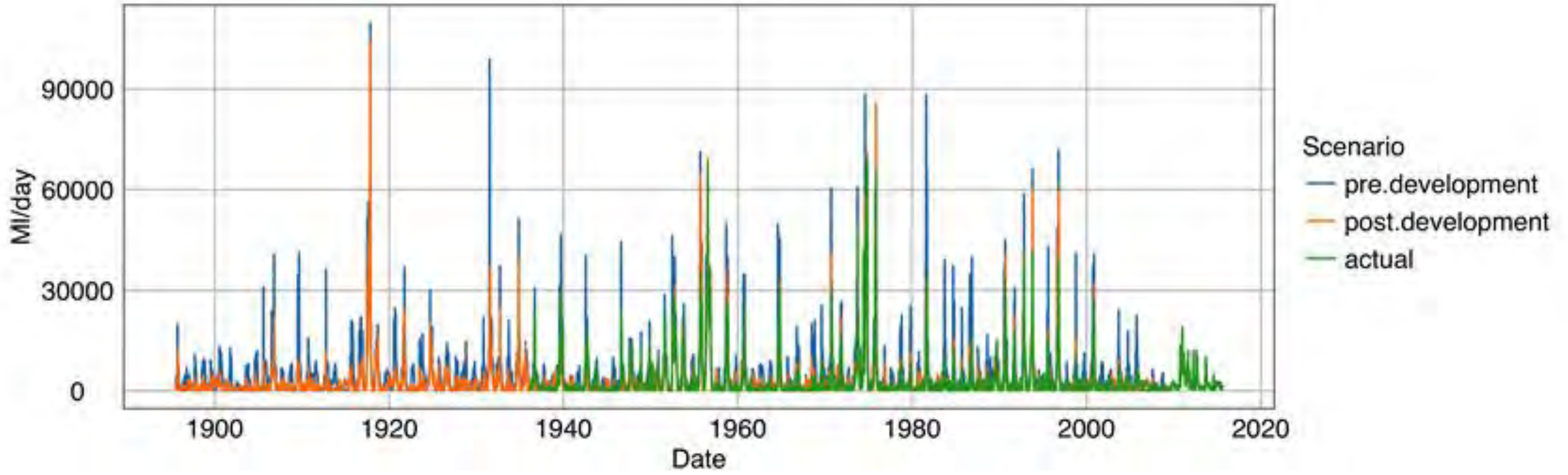

Figure 1.4. Time series plot of flow at Stevens Weir**.**

When examined on a monthly basis, it is apparent that natural flows are strongly seasonal, with high flows occurring typically from July to November (Figure 1.5, Figure 1.6). Flow regulation 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 (Table 1.3, Figure 1.5, Figure 1.6). In addition, there has been an increase in daily flows during the low-flow months (January to March), although these appear to be more pronounced at Deniliquin than at Stevens Weir (Figure 1.5, Figure 1.6). 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, McMahon 2003). This can also be observed in the flow-duration curves, which also show an elevated frequency of low to median flows and reduced frequency of moderate high flows. These effects are more apparent at Deniliquin than Stevens Weir (Figure 1.7, Figure 1.8), as expected due to given the location of several river offtakes and the location of the Wakool Canal upstream of Steven's Weir.

How hydrologic changes manifest themselves at individual sites depends on the interactions between hydrology and channel-geometry (cross-sectional area, slope etc.) and in-stream attributes (e.g. wood and aquatic vegetation), which influence both the in-channel hydraulic environment, and also the frequency of inundation of both in-channel features and the floodplain proper. While no hydraulic analyses have been undertaken thus far, changes in high flow magnitudes indicate potentially large-scale changes in the extent to which flows in the Edward River now interact with floodplain features such as riparian vegetation. For example, the 2-year ARI (average return interval) flow (often used as indicative of the approximate natural bankfull discharge) has been roughly halved at both sites under the current development scenario (Table 1.3). Such changes have the potential to affect a range of ecosystem processes dependent on lateral floodplain connections (Junk et al. 1989, Lake et al. 2006).

River regulation is likely to have altered water velocities, the availability of in-channel habitat types, and ecosystem processes and functions. In subsequent project years further work will be done to integrate the hydrologic data summarised here with information on river hydraulics. There is also a lack of models for the smaller rivers and creeks in the Edward-Wakool system and further investigation of the hydrology of these systems is required.

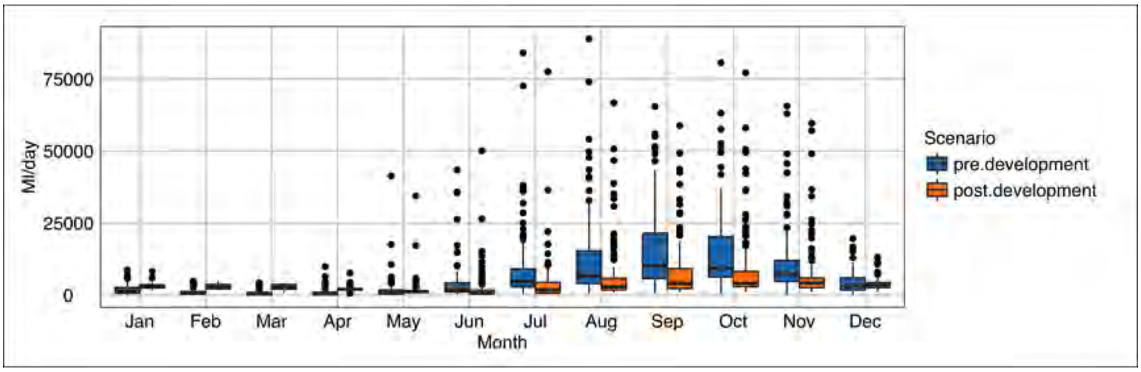

Figure 1.5. Boxplots of mean daily flow by month for the Edward River at Deniliquin.

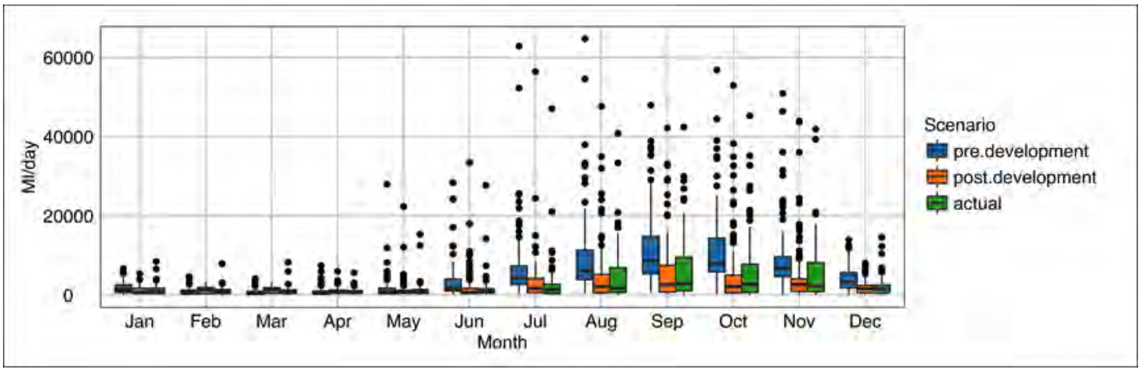

Figure 1.6. Boxplots of mean daily flows by month for the Edward River at Stevens Weir.

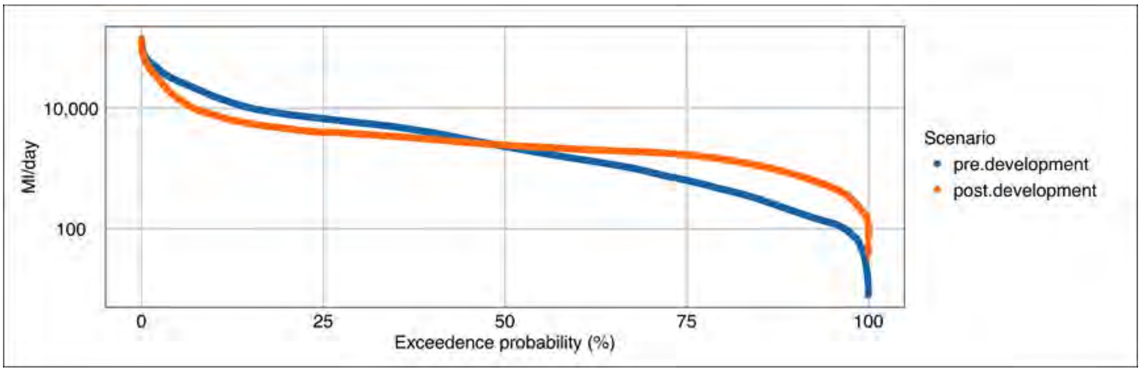

Figure 1.7. Annual flow duration curve for the Edward River at Deniliquin.

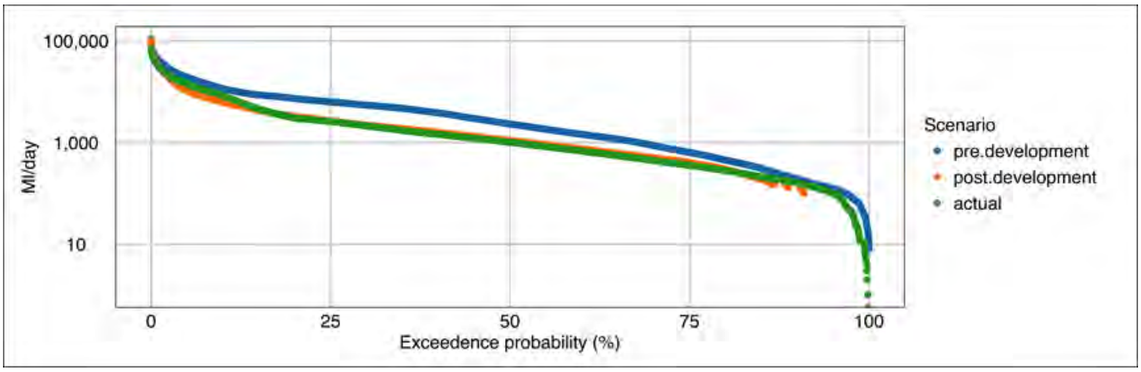

Figure 1.8. Annual flow duration curve for the Edward River at Stevens Weir.

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

2.1 Basin Annual Environmental Watering Priorities

The 2014-15 Basin Annual Environmental Watering Priorities were set in the context of preceding dry conditions throughout the Basin and an average rainfall outlook for June–August 2014, meaning that the status of the Basin was ‘dry’. The Basin Annual Environmental Watering Priorities for 2014–15 were focussed around three themes: connecting rivers and floodplains; supporting in-stream functions; and enhancing and protecting refuge habitat (MDBA 2014). The Basin Priorities for the River Murray (including connected tributaries, anabranches, creeks and wetlands of the River Murray, the Lower Lakes, Coorong and Murray Mouth) was to support in-stream functions and connectivity in the River Murray system (MDBA 2014). In particular, to improve riparian, littoral and aquatic vegetation and native fish populations by increasing ecosystem connectivity through coordinating water delivery in the River Murray system.

2.2 Watering action objectives in the Edward-Wakool system in 2014-15

The 2014-15 Commonwealth environmental watering action objectives for the Edward-Wakool system, as outlined in the Water Use Minute 10008 (dated August 2014), were as follows:

- improve the diversity and condition of native fish and other native species including frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit
- improve 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, floodplain and wetland native vegetation communities
- contribute to a more natural wetting-drying cycle for ephemeral wetlands and watercourses
- maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH
- improve ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

These expected outcomes are consistent with the objectives of the Basin Plan’s environmental watering plan (Table 2.1)

Table 2.4. Table linking expected outcomes for the Edward-Wakool system, as outlined in the Water Use Minute 10008, with the objectives of the Basin Plan's environmental watering Plan.

Expected outcome	Timeframe	Relevant Basin Plan objective
Fish condition and recruitment	<1 year	Biodiversity (Basin Plan S. 8.05)
Vegetation condition and reproduction	<1 year	
Other vertebrate condition	<1 year	
Other vertebrate reproduction	<1 year	
Other vertebrate growth and survival	<1 year	
Landscape vegetation diversity	1-5 years	
Landscape fish diversity	1-5 years	
Fish larval and juvenile recruitment	1-5 years	
Hydrological connectivity	< 1 year	Ecosystem Function (Basin Plan S.8.06)
Biotic dispersal	<1 year	
Nutrient and carbon cycling	1-5 years	
Recovery	1-5 years	Resilience (Basin Plan S.8.07)
Landscape refugia	1-5 years	
Salinity pH Dissolved oxygen	< 1 year	Water quality (Basin Plan S. 9.04)

2.3 Commonwealth environmental watering actions in the Edward-Wakool system in 2014-15

The use of Commonwealth environmental water in the Edward-Wakool system for 2014-15 was assessed based on outcomes from a planning workshop in June 2014, community recommendations and early season system conditions. An initial proposal considered was to provide a repeat fresh watering action in Yallakool Creek that would seek to initiate spawning of golden perch. This proposal was postponed to a future year as the community a) remained concerned about the slow recovery of Murray cod populations in the Wakool River (which were severely impacted by hypoxic blackwater events in 2010-11), and b) requested a more detailed assessment about the type of flows that would be required in Yallakool Creek and Wakool River, particularly the use of in-channel flows, to obtain a spawning response in this species.

Three Commonwealth environmental watering actions were undertaken for the Edward-Wakool System in 2014-15; i) Yallakool Creek-Wakool River watering action between August 2014 and January 2015, ii) Tuppal Creek watering action (partnered with NSW environmental water) in spring (October to November 2014) and autumn (March to April 2015), and iii) Colligen Creek watering action in January 2015. The Tuppal Creek and Colligen Creek watering actions were not monitored as part of the Edward-Wakool LTIM Project, and hence have not been described or evaluated in this report. The effects of the Yallakool Creek environmental watering action will be the focus of this report.

Yallakool Creek Environmental Watering Action (Aug 2014 – January 2015)

A cod maintenance watering option was developed for Yallakool Creek for 2014-15 (CEWO 2014) that was similar to a watering action undertaken in 2013-14 in this system. It was planned that Commonwealth environmental water would contribute about 500 ML/day in Yallakool Creek through to the end of the cod spawning season. In the absence of natural high inflows, it was planned that environmental water would be delivered to provide an early season pulse to 'prime' the channel and contribute to a more natural flow regime (CEWO 2014).

The watering action objectives for this action were defined by CEWO on 22 July. It was expected that this action will:

- support inundation of Murray cod nesting sites and contribute to maximising Murray cod recruitment
- contribute to improved opportunities for movement, condition, reproduction and recruitment of native fish
- increase hydrological connectivity, including inundation of slackwater habitats areas downstream of the Yallakool-Wakool confluence, providing opportunities for recruitment of small bodied native fish, frogs and shrimp
- maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants
- maintain/improve water quality, particularly dissolved oxygen, salinity and pH
- contribute to maximising outcomes in the Wakool from outflows from Koondrook-Perricoota and provide greater volume of receiving water.

Following a series of high unregulated inflow events in July 2014, flows started to pass through the Edward-Wakool system, including overbank flows into Werai Forest and to Colligen and Yallakool Creeks. On the back of these tributary inflows, use of Commonwealth environmental water commenced earlier than planned to synchronise with naturally occurring high flows and the potential that, despite low water temperatures, large bodied native fish may have commenced moving into breeding habitat and nesting sites. The watering action in Yallakool Creek (zone 1) commenced on 12 August 2014 and there was an extended in-channel fresh of approximately 500 ML/day from August until 16 December 2014, followed by a recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day. The action was completed on 15 January 2015. The total Commonwealth environmental water delivery for this action was 34,561 ML.

2.4 References

CEWO (2014) Water Use Minute 10008. Commonwealth Environmental Water Office

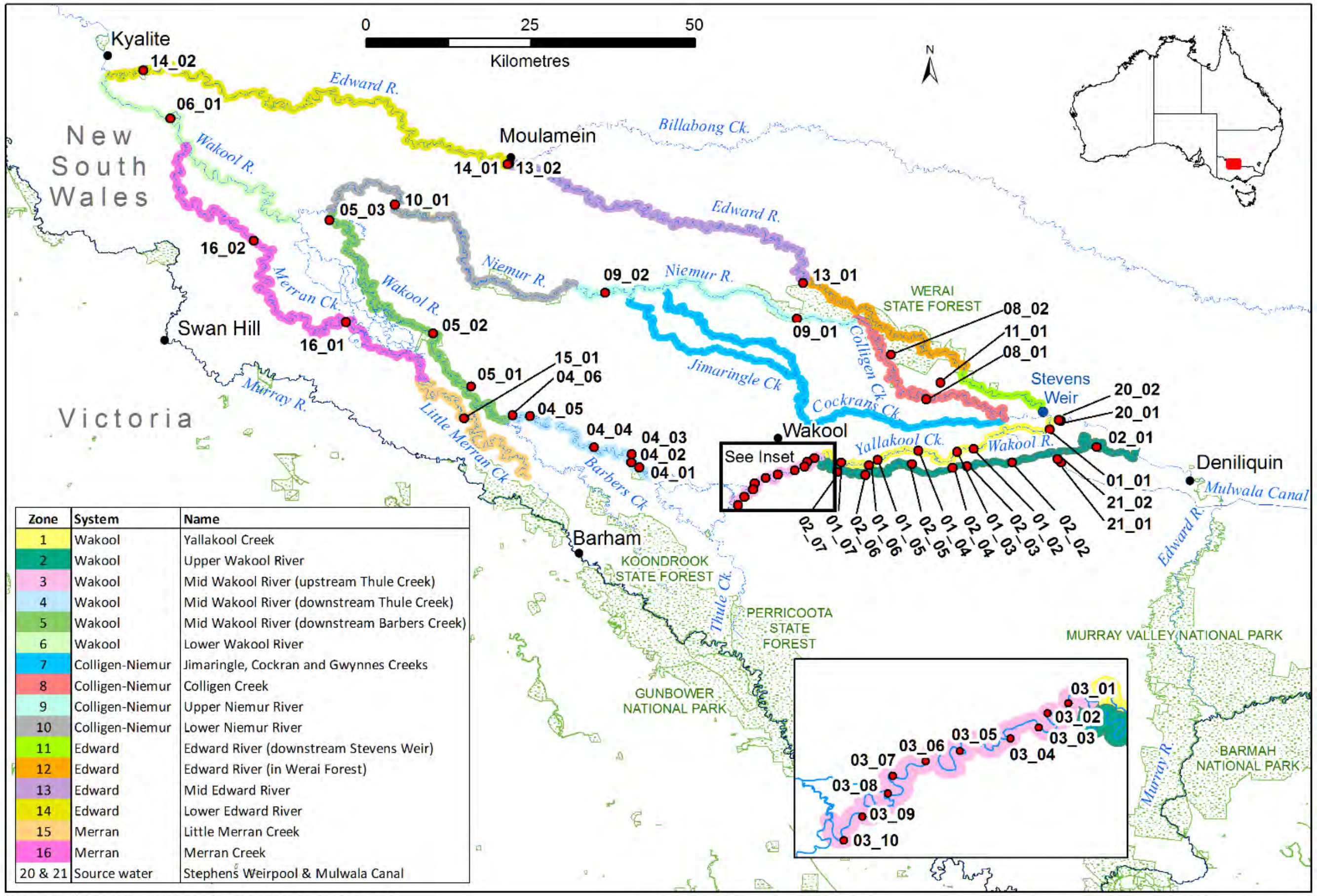
MDBA (2014) 2014–15 Basin Annual Environmental Watering Priorities. MDBA Publication No 24/14

3. MONITORING AND EVALUATION

The monitoring of ecosystem responses to environmental watering in the Edward-Wakool system in 2014-15 was undertaken as outlined in the Edward-Wakool Long-term Intervention Monitoring and Evaluation Plan (Watts et al. 2014). The majority of the monitoring for the Edward-Wakool LTIM Selected Area Evaluation 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)(Figures 3.1, 3.2). Zones one to four are referred to in this report 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. In addition to the fish population surveys undertaken in these four zones, a further 15 sites throughout the Edward-Wakool system will be surveyed for fish populations in years 1 and 5 (Figure 3.1). In addition to water quality sampling in the focal area, water quality is also monitored in Stevens Weir and the Mulwala canal as these sites are the potential source of Commonwealth environmental water in this system. A list of site codes and names is provided in Table 3.1.

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 being undertaken by the Murray-Darling Freshwater Research Centre (Hale et al 2014). Indicators monitored in the Edward-Wakool for the LTIM Project (Table 3.2) are: river hydrology, riverbank inundation by 2D-hydraulic modelling, stream metabolism, water quality and carbon, riverbank and aquatic vegetation, fish reproduction, fish recruitment, fish community, and fish movement (not monitored in 2014-15 but will be monitored from July 2015). Many of the indicators are expected to respond to Commonwealth environmental watering in short time frames (< 1 year), but others (e.g. the fish community) are included as longer term indicators that are expected to respond over 2 to 5 year time frame (Table 2.1).

A conceptual diagram (Figure 3.3) illustrates the linkages among indicators under different types of environmental watering (freshes, overbank flows and low flows). The diagram illustrates how factors such as spawning cues, water quality, availability of habitat and availability of food resources will play an important role in maintaining and/or increasing fish populations.



Zone	System	Name
1	Wakool	Yallakool Creek
2	Wakool	Upper Wakool River
3	Wakool	Mid Wakool River (upstream Thule Creek)
4	Wakool	Mid Wakool River (downstream Thule Creek)
5	Wakool	Mid Wakool River (downstream Barbers Creek)
6	Wakool	Lower Wakool River
7	Colligen-Niemur	Jimaringle, Cockran and Gwynnes Creeks
8	Colligen-Niemur	Colligen Creek
9	Colligen-Niemur	Upper Niemur River
10	Colligen-Niemur	Lower Niemur River
11	Edward	Edward River (downstream Stevens Weir)
12	Edward	Edward River (in Werai Forest)
13	Edward	Mid Edward River
14	Edward	Lower Edward River
15	Merran	Little Merran Creek
16	Merran	Merran Creek
20 & 21	Source water	Stephens Weirpool & Mulwala Canal

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 (LTIM) 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 Creek
Lower Edward River	14	EDWK14_01	Moulamien DS Billabong Creek
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

Yallakool Creek 11/11/2014, 496 ML/day (e-flow) 2/3/2015, 335 ML/day (no e-flow)

Wakool River (zone 2) 11/11/2014, 92 ML/day (no e-flow) 2/3/2015, 69 ML/day (no e-flow)

Wakool River (zone 3) 10/11/2014, 441 ML/day (e-flow) 3/3/2015, 222 ML/day (no e-flow)

Wakool River (zone 4) 10/11/2014, 402 ML/day (e-flow) 2/3/2015, 217 ML/day (no e-flow)

Figure 3.2. Photos of study sites in the four hydrological zones in November 2014 during the environmental watering (zones 1, 3 and 4) and in March 2015 during operational flows. 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).

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

Indicator	Zone	Evaluation of responses to Commonwealth environmental watering in the Edward-Wakool Selected Area	Data will contribute to evaluation of responses to Commonwealth environmental watering at whole of Basin-scale	Notes
River hydrology	1,2,3,4	✓	✓ (zone 3)	Discharge data will be obtained from NOW website. Changes in water depth will be monitored using depth loggers and staff gauges
Hydraulic modelling	1,2,3,4	✓		The extent of within channel inundation of geomorphic features under a range of different discharges will be modelled. Ground truthing of the model and an acoustic doppler survey will be undertaken at selected sites
Stream metabolism and instream primary productivity	1,2,3,4	✓	✓ (zone 3)	Dissolved oxygen and light will be logged continuously in each zone between August and March. Nutrients and carbon samples will be collected monthly and spot water quality monitored fortnightly.
Characterisation of carbon during blackwater and poor water quality events	1,2,3,4	✓		The type and source of carbon will be monitored monthly between August and March. There is an option for CEWO to fund additional sampling during blackwater or other poor water quality events
Riverbank and aquatic vegetation	1,2,3,4	✓		The composition and percent cover of riverbank and aquatic vegetation will be monitored monthly.
Fish reproduction (larvae)	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	1,2,3.4	✓		Targeted capture of young-of-year fish will be undertaken by back-pack electrofishing and set lines in February and March to develop growth and recruitment indices for young-of-year (YOY) and age-class 1 (1+) Murray cod, silver perch and golden perch
Fish community survey	3 (plus 15 sites in yr 1 and 5)	✓	✓ (zone 3)	Fish community surveys will be undertaken once annually in the focal area between March and May. An additional 15 sites throughout the system will be surveyed in years 1 and 5 to report on long-term change in the fish community.
Fish movement	1,2,3,4	✓		Movement of golden perch and silver perch will be monitored commencing in spring 2015

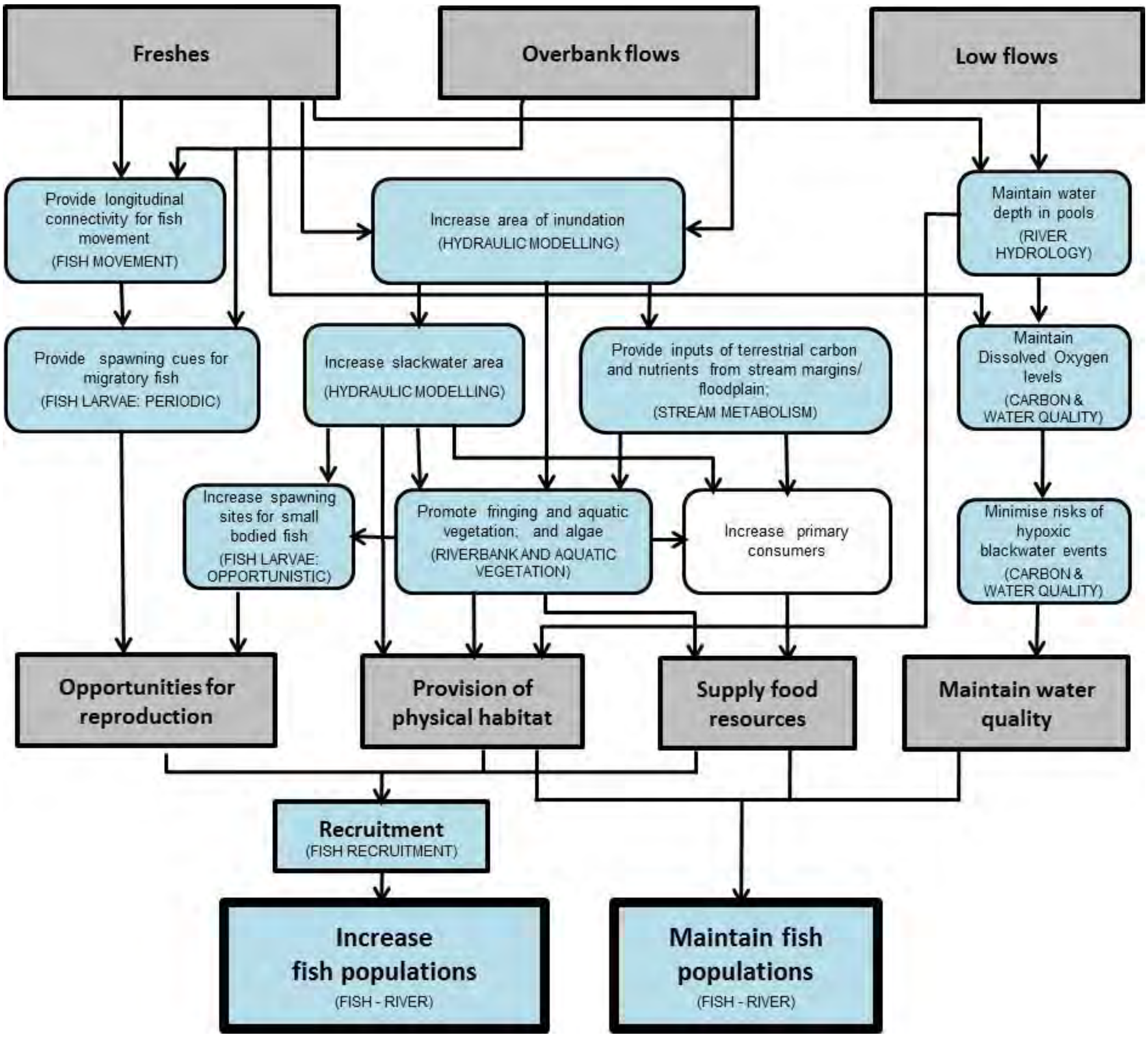


Figure 3.3. Conceptual diagram illustrating the linkages among indicators and links different types of environmental watering (freshes, overbank flows, low flows) to fish populations. Indicators shown in blue are monitored by the Edward-Wakool LTIM Project.

References

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S. and Gawne, B. (2014) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods. Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 29.2/2014, January, 182 pp.

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4. HYDROLOGICAL RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

Weir at the regulator on Yallakool Creek (Photo: Robyn Watts)

Summary

- A Commonwealth environmental watering action undertaken in Yallakool Creek between August 2014 and January 2015 was monitored and is evaluated in this report.
- Daily discharge data for automated gauges in zones 1, 2 and 4 was obtained from New South Wales Office of Water website. Discharge data for the Wakool escape and daily usage of Commonwealth environmental water were obtained from WaterNSW.
- There were three different hydrological regimes observed the focal area in 2014-15:
    i) In Yallakool Creek zone 1 there was extended in-channel fresh of approximately 500 ML/day from August until 16 December 2014, followed by a recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day.
    ii) In Wakool River zone 2 there was an extended period of base operational flows in the range of 50 to 100 ML/day between August and March followed by an operational fresh in March and April 2014 of approximately 300 to 330 ML/day that had both a steep rise and recession
    iii) In zones 3 and 4 in the Wakool River there was an extended in-channel fresh of approximately 450 ML/day from August until the end of December followed by a recession to operational flows in the range of 200 to 240 ML/day. This was followed by an operational fresh in March and April 2014 of approximately 300 to 330 ML/day that had both a steep rise and recession
- The Commonwealth environmental water increased the maximum, mean, median and coefficient of variation of discharge in Yallakool Creek and the Wakool River zones 3 and 4. The watering action achieved the primary hydrological objective set by the CEWO of creating a maintenance flow in Yallakool Creek and the Wakool River zones 3 and 4 of about 500 ML/day through to end of the Murray cod spawning season.
- The Commonwealth environmental watering action in Yallakool Creek contributed to longitudinal connectivity in the upper and mid sections of the Wakool River, influencing the downstream hydrograph as far as Gee Gee Bridge. However the influence of Commonwealth environmental water was diminished at Coonamit and Stoney Crossing gauges, as these

4.1 Background

The hydrological regime of the Edward-Wakool system was described in section one of this report. The natural flow regime of this system is strongly seasonal, with high flows occurring typically from July to November. Flow regulation has resulted in a marked reduction in winter high flows, including both extreme high flow events and average daily flows during the winter period, and an increase in daily flows during the low-flow months (see section 1.3).

Commonwealth environmental water has been delivered to rivers in the Edward-Wakool system since 2010. Over that time instream freshes were delivered to Yallakool Creek and Colligen Creek in 2011-12, 2012-13 and 2013-14 (Watts et al. 2013a; 2013b, 2014). In addition, Commonwealth environmental water was delivered from the Edward River and/or from irrigation escapes on several occasions to improve water quality and create refuge during poor water quality events.

4.2 Questions

Evaluation of hydrological responses to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system at the i) Selected Area scale (Watts et al. 2014), 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 will be evaluated in a separate report. As this is the first year of a multi-year monitoring project, this report will only evaluate short-term response questions specific to the Edward-Wakool selected area.

The effects of the Yallakool Creek environmental watering action (described in section 2) on the hydrology of Yallakool Creek and the Wakool River will be examined in this report.

The following questions will be assessed:

Q1: *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 Long Term Intervention Monitoring project?*

Q2: *What did Commonwealth environmental water contribute to hydrological connectivity*?

4.3 Methods

Daily discharge data for automated gauges was obtained from the New South Wales Office of Water website. 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.

Details of the daily volume of water (ML/day) accounted for as Commonwealth environmental water was provided by WaterNSW and the Commonwealth Environmental Water Office. These data were used to produce the hydrographs that show the overall daily discharge and the proportion of that flow that is Commonwealth environmental water for the four hydrological zones in 2014-15. The maximum, minimum, median, mean and coefficient of variation (SD/mean) of the daily discharge was calculated with and without Commonwealth environmental water.

To evaluate to what extent Commonwealth environmental water contributed to hydrological connectivity the hydrographs for the Wakool River at Gee Gee Bridge site 05_02 (gauge 409062), Coonamit, near site 05_03 (gauge 409061) and Stoney Crossing, site 06_01 (gauge 409013) were plotted and visually compared to the shape of the hydrographs upstream that received Commonwealth environmental water.

4.4. Results

The 2014–15 water year started with a small unregulated flow event in August 2014 that was contained within the channel. The Commonwealth environmental watering action followed on immediately after the unregulated event. There were three different hydrological regimes in the focal monitoring area in 2014-15; a) Yallakool Creek (zone 1), b) Wakool river Zone 2, and c) Wakool

River zone 3 and 4 were similar because there were no inflows to the system from Thule Creek in 2014-15.

In Yallakool Creek (zone 1) there was an extended in-channel fresh of approximately 500 ML/day from August until the end of December 2014, followed by a recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day. In the absence of Commonwealth environmental water there would have been a short-term fresh in early August followed by an extended period of operational flows of approximately 200 ML/day with several small peaks of approximately 300 ML/day (Figure 4.1a).

The Wakool River zone 2 received no Commonwealth environmental water in 2014-15. There was an extended period of base operational flows in the range of 50 to 100 ML/day between August and March. In order to meet downstream demands in the lower Murray River the MDBA delivered an operational flow into the Wakool system via the irrigation channel network (Wakool escape) in March and April 2015. This resulted in a fresh in zone 2 in March and April 2014 of approximately 300 to 330 ML/day that had both a steep rise and recession (Figure 4.1b).

The Wakool River zones 3 and 4 had similar hydrological regimes in 2014-15 because there was no inflow from Thule Creek. The delivery of Commonwealth environmental water to Yallakool Creek resulted in an extended in-channel fresh of approximately 450 ML/day in Wakool River zones 3 and 4 from August until the end of December 2014, followed by a recession to operational flows in the range of 200 to 240 ML/day. These two zones also received a fresh of approximately 450 ML/day in March and April resulting from the MDBA operational flow from the Wakool Escape from the Mulwala Canal (see Figure 3.1). The effect of this operational flow is that the discharge in the Wakool River at Wakool-Barham Road (zone 3) increased from approximately 210 to 240 ML/day in February to approximately 400 ML/day by the end of March (Figure 4.1) and 500 ML/day by mid April 2015. In the absence of Commonwealth environmental water there would have been a short-lived fresh in early August followed by an extended period of flows of approximately 150 to 200 ML/day followed by a fresh of approximately 450 ML/day in March and April (Figure 4.1c and 4.1d).

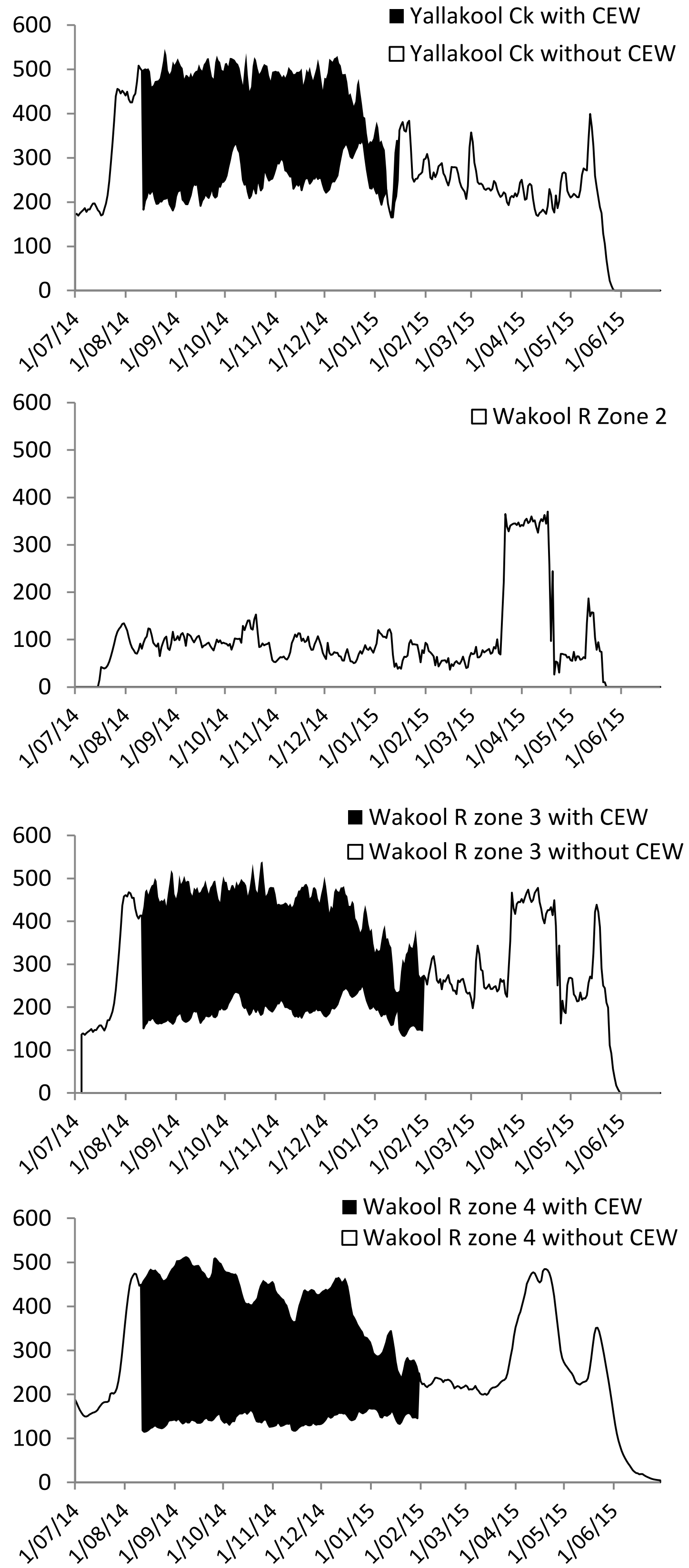

Figure 4.1. Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River for the period from 1 July 2014 to 30 June 2015. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water (CEW). There was an unregulated flow in zones 1, 3 and 4 in August. The MDBA operational flow from the Wakool Escape is evident in the hydrograph of zones 2, 3 and 4 in March.

A summary of hydrological statistics for 2014-15 (Table 4.1) compares hydrological variables for each zone with and without Commonwealth environmental water. The main findings are:

- The Commonwealth environmental water increased the maximum, mean, median and coefficient of variation of discharge in Yallakool Creek, and Wakool River zones 3 and 4 that received the environmental water.
- The maximum, mean and median discharge in Wakool River zone 2 that did not receive environmental water was lower than in all of the other rivers.
- The coefficient of variation of daily discharge was very high in Wakool River zone 2 that did not receive any environmental water but did receive the MDBA operational flow in March/April 2015 that had a steep rise and fast recession.

Table 4.1. Summary hydrological statistics (ML/day) for four hydrological zones in the Edward-Wakool system for the 2014-15 water year (1/7/14 to 30/6/2015). Statistics are shown for each zone with and without Commonwealth Environmental Water (CEW).

Flow variable	**Yallakool Ck**		**Wakool R zone2**	**Wakool R zone 3**		**Wakool R zone 4**	
	Without CEW	With CEW		Without CEW	With CEW	Without CEW	With CEW
Q_{min}	0	0	0	0	0	4.7	4.7
Q_{max}	508.6	546.5	370.2	478.1	539.6	484.6	514.0
mean (Q_{mean})	229.9	323.9	91.0	215.9	335.6	193.9	325.0
median (Q_{50})	231.0	324.6	77.8	197.9	389.5	157.3	336.6
Coefficient of variation (CV)	0.421	0.511	0.912	0.456	0.515	0.426	0.541

The hydrographs for Gee Gee Bridge, Coonamit and Stoney Crossing on the Wakool River are presented in Figure 4.2. It is evident that the hydrograph at Gee Gee Bridge is very similar to that for Yallakool Creek and the Wakool River zones 3 and 4 (Figure 4.1). However, the shape of the hydrographs for Coonamit and Stoney Crossing have considerably higher discharge and differ from those for zones 1, 3 and 4. These reaches were more strongly influenced by inflows from the River Murray than flows delivered via Yallakool Creek and Wakool River regulators from Stevens Weir.

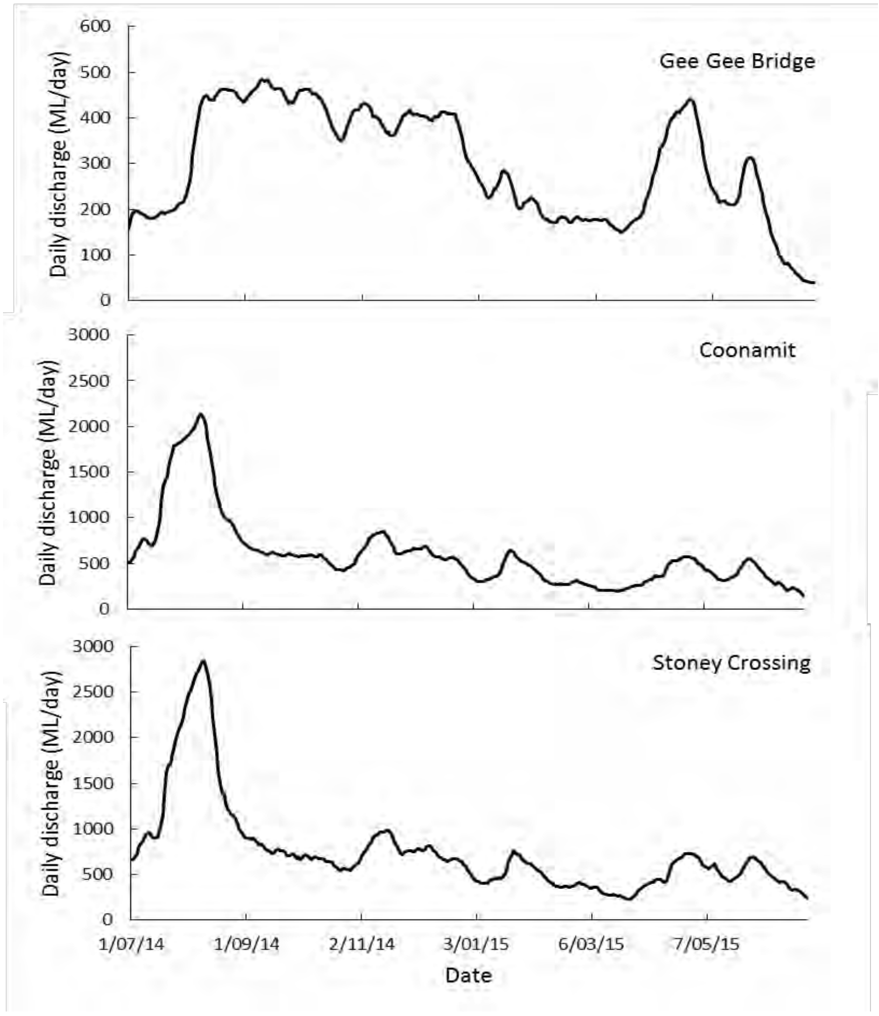

Figure 4.2. Hydrographs for the Wakool River at Gee Gee Bridge (gauge 409062), Coonamit (gauge 409061) and Stoney Crossing (gauge 409013) for the period from 1 July 2014 to 30 June 2015. Note the different y axis units for Coonamit and Stoney Crossing graphs. The Yallakool Creek environmental water action from August through to mid-December and the MDBA operational flow from the Wakool Escape in March and April 2015 is evident in the shape of the hydrograph for Gee Gee Bridge. The Yallakool Creek environmental watering action is not evident in the Coonamit and Stoney Crossing hydrographs, as these reaches are more strongly influenced by flows from the Murray River.

4.5 Discussion

Returning to the two questions associated with the impact of the Yallakool Creek Commonwealth environmental watering action in 2014-15 on the hydrology of the study area.

Q1: *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 Long Term Intervention Monitoring project?*

The Commonwealth Environmental Water increased the maximum, mean, median and coefficient of variation of discharge in Yallakool Creek, Wakool River zones 3 and 4. The watering action achieved the primary hydrological objective set by the CEWO of creating a maintenance flow in Yallakool

Creek and the Wakool River zones 3 and 4 of about 500 ML/day in Yallakool Creek through to end of the Murray cod spawning season. In Yallakool Creek, in the absence of Commonwealth environmental water there would have been a short-term fresh in early August followed by an extended period of operational flows of approximately 200 ML/day with several small peaks of approximately 300 ML/day. Similarly in the Wakool River zones 3 and 4 in the absence of Commonwealth environmental water there would have been a short-lived fresh in early August followed by an extended period of operational flows of approximately 150 to 200 ML/day followed by a fresh of approximately 450 ML/day in March and April that had steep rise and recession. The desired slower recession from 16 December 2014 until the action was completed on 15 January 2015 was also achieved.

Q2: *What did Commonwealth environmental water contribute to hydrological connectivity?*

A secondary objective of the Yallakool Creek watering action was to evaluate the contribution of Commonwealth environmental water to hydrological connectivity. By comparing the hydrographs at downstream gauges (Gee Gee Bridge, Coonamit and Stoney Crossing) with those in the focal study area (e.g. Barham Rd Bridge, Yallakool Creek offtake) it is evident that Commonwealth environmental water contributed to longitudinal connectivity in the upper and mid sections of the Wakool River. The Commonwealth environmental water influenced the hydrograph downstream as far as Gee Gee Bridge. However the influence of Commonwealth environmental water was diminished at Coonamit and Stoney Crossing gauges, as these river reaches were more strongly influenced by flows from the River Murray.

The influence of Commonwealth environmental water on lateral connectivity will be addressed in section 5 of this report where 2D-hydraulic modelling was undertaken to assess the extent of in-channel inundation under a number of flow scenarios.

4.6 References

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5. CHANGES IN HYDRAULIC HABITAT IN RESPONSE TO COMMONWEALTH ENVIRONMENTAL WATERING

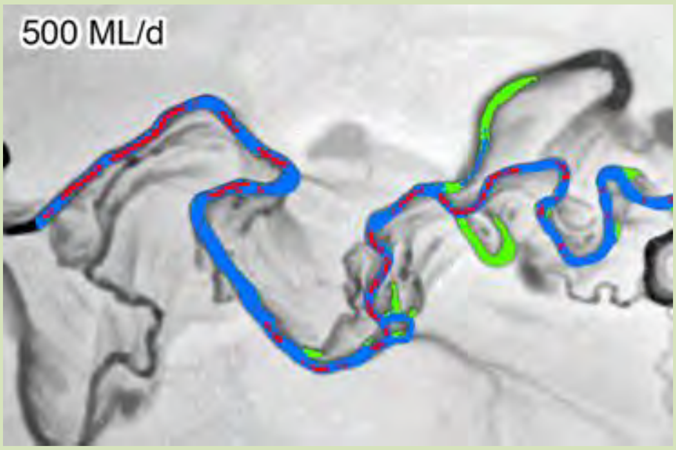

Image: Map showing modelled representation of the spatial coverage of the water surface extent of slackwater (green), slow water (blue) and fast water (red) at 'Cumnock Park' on Yallakool Creek during the 500 MLd^{-1} Yallakool Creek Commonwealth environmental watering action in 2014-15.

Summary

- A two-dimensional hydraulic model was generated for nineteen reaches; five in Yallakool Creek, five in the Wakool River (zone 2), four in Wakool River upstream of Thule Creek (zone 3) and five in the Wakool River downstream of Thule Creek (zone 4). The model was used to estimate the extent of wetted benthic surface area and the area of three velocity zones for seven discharge scenarios, ranging from low flows to bankfull flows.
- There was variation in the extent of in-channel inundation to Commonwealth environmental water among sites, including variation among reaches within the same hydrological zone.
- Commonwealth environmental water increased the wetted benthic area at all sites that received environmental water. The greatest increase was observed at 'Barham Rd Bridge' site in the Wakool river zone 3.
- Commonwealth environmental water increased the area of slackwater (< 0.02 ms^{-1}) and slow water (0.02 – 0.3 ms^{-1}) at some of the reaches, whereas at other reaches there was a reduction in the area of slackwater and slow water and an increase in fast water under Commonwealth environmental watering. Slackwater and slow water patches are important for the survival and growth of some aquatic organisms.
- There was not a strong relationship between discharge and wetted benthic area in these river reaches because river geomorphology has a strong influence on the response to environmental watering actions. The results suggest it may be more appropriate to examine the relationship between inundation area and ecosystem responses to in-channel flows rather than examining relationships with daily discharge.

5.1 Background

Environmental watering actions that are wholly contained within the channel have the potential to inundate riverbanks and other in-channel geomorphic features and can create low flow zones (slackwaters) having low velocities and shallow depths. These habitats are important for river productivity and riverbank plants and can facilitate the survival of organisms, such as larval fish and larval shrimp, through provision of habitat and food.

Modelling is a useful method for comparing estimates of the extent of inundation under different discharge scenarios. In Australia previous studies have modelled river flow and floodplain inundation have been undertaken for wetlands on the Darling River (Shaikh et al. 2001), and floodplains on the Murrumbidgee River (Frazier et al. 2003) and the River Murray (Overton 2005; Overton et al. 2006). These studies have focussed on estimating floodplain inundation during overbank flows. In river systems where environmental watering is contained wholly within the channel, digital elevation models can be used to create flow path assessments to compare the extent of in-stream riverbank inundation under different discharge scenarios. Vietz et al. (2013) used two dimensional hydraulic modelling to examine the impacts of flow regulation on slackwaters in the Broken River, south-eastern Australia. They demonstrated that the area of slackwaters decreased with increasing discharge until inundation of higher-elevation bars and benches.

The aim of this project was to undertake 2D hydraulic modelling of river reaches in the Edward-Wakool system to estimate the extent of wetted benthic surface area and the area of three velocity zones for seven discharge scenarios, ranging from low flows to bankfull flows. Comparison of these parameters at discharges expected during operational flows (no environmental water) and during environmental watering was undertaken to assess the effect of Commonwealth environmental water on benthic wetted area and area of slackwater and slow flowing water. The modelling will assist the interpretation of ecological responses to flows, contribute to decision making regarding the magnitude of environmental watering and will assist the communication of likely outcomes of planned watering events with landholders.

5.2 Questions

Two dimensional hydraulic modelling was undertaken in the Edward-Wakool River system to evaluation the effect of Commonwealth environmental watering at the Selected Area scale (Watts et al. 2014). The following questions will be addressed:

Q1: *What did Commonwealth environmental water contribute to the in-channel wetted benthic area?*

Q2: *What did Commonwealth environmental water contribute to the area of slackwater and slow flowing water?*
Q3: *What did Commonwealth environmental water contribute to hydrological connectivity?*

5.3 Methods

Hydraulic modelling

Discharge scenarios were modelled for nineteen reaches; five in Yallakool Creek (zone 1), five in the Wakool River (zone 2), four in Wakool River upstream of Thule Creek (zone 3) and five in the Wakool River downstream of Thule Creek (zone 4). These are study reaches where water quality, fish reproduction, fish recruitment and aquatic and riverbank vegetation were monitored. Each reach extended over 4km; the upstream end of the modelled reach was 3.2 km upstream of the 400m larval fish study reach and extended 400 m downstream of the larval fish study reach (see section 3).

Each reach was represented within the hydraulic model using a digital elevation model (DEM) supplied under an agreement with the Murray Darling Basin Authority. Several minor artefacts were removed from the DEMs, typically from the areas around the joins between neighbouring DEM tiles. Prior to commencing model runs both the upstream (inflow) and downstream (sink) model boundaries were calibrated to ensure accurate water surface heights and velocities were achieved for each discharge value. For example when calibrating the flow characteristics of the model boundaries a temporary water source was placed ~400m upstream of the proposed boundary and a sink section placed ~400m downstream of the proposed model boundary. The static discharge flow was applied until the inflow rate matched the outflow rate and the river reached stable state flow. Water surface height and velocities at stable state were estimated for each discharge scenario and applied to model boundaries during model runs.

Six discharge scenarios were selected for each reach ranging from low flow to the maximum discharge observed between 2012 and 2015 (Table 5.1). For Yallakool Creek the discharge of 500 MLd^{-1} is similar to the discharge during the environmental watering action in Yallakool Creek between August 2014 and December 2014. This scenario was used to assess the effect of Commonwealth environmental watering on benthic wetted area and area of slackwater.

Each scenario was modelled assuming an initial dry starting condition with no residual water in the system. Surface friction coefficients, representing the amount of instream vegetation, were accounted for in each model using a standard Manning's n value of 0.05. Scenarios were run until stable state flow was achieved whereby the instantaneous flow rate at the downstream boundary condition (sink) stabilised and matched the upstream inflow (source) flow rate. Inflow values were provide to the upstream source as a static value and did not varying over the duration of each model run. Discharge scenarios were modelled using Eonfusion Flood (Myriax Software) with model outputs post-processed using the Eonfusion v2.4.5 (Myriax Software) and Quantum GIS (v2.8.2).

Upon reaching stable state flow the water surface extent was captured in vector format comprised of individual point features, one per m^2, with each point feature containing X/Y/Z geometry and attribute values for water depth, surface elevation (above bed) and velocity. The resulting point cloud allowed a 3D surface to be reconstructed and the wetted benthic surface area to be calculated. The 3D surface was also categorised by water velocity and sectioned into 3 discrete velocity zones to produce a series of water velocity map layers. The three velocity categories were: Slackwater (< 0.02 ms^{-1}), slow water ($0.02 – 0.3$ ms^{-1}) and fast water (>0.3 ms^{-1}). Post-processing, including surface area calculations, was achieved using Eonfusion v2.4.5 (Myriax Software), Quantum GIS and made distributable using the Google Earth KML file format.

Statistical analysis

The wetted benthic area under operational flows was compared among the four hydrological zones using one-way ANOVA (IBM SPSS Statistics v20). The increase in wetted benthic area for the three zones receiving Commonwealth environmental water was compared among the four zones using one-way ANOVA (IBM SPSS Statistics v20). P-values of <0.05 were used to determine the significance of each ANOVA test.

The area of slackwater, slow water and fast water under operational flows was compared among the four hydrological zones using one-way ANOVA (IBM SPSS Statistics v20).

Table 5.1. Summary of discharge scenarios (MLd^{-1}) modelled for 19 reaches across four hydrological zones in the Edward-Wakool LTIM Selected Area; Yallakool Creek (zone 1), the Wakool River (zone 2), the Wakool River upstream of Thule Creek zone 3) and the Wakool River downstream of Thule Creek (zone 4). N/M = not modelled because environmental watering was not undertaken in the Wakool River zone 2. N/A= models for some sites were not achievable because discharge flows resulted in breakout from the main channel and broad-scale overland flows could not be modelled

Zone	Reach Name	Scenario 1 Low flow	Scenario 2 Operational flow	Scenario 3 Yallakool Ck e-flow	Scenario 4 Additional scenario	Scenario 5 Additional scenario	Scenario 6 Additional scenario	Scenario 7 Unregulated flows (max discharge 2012-15)
1	Hopwood	30	240	500		650	800	1913
1	Cumnock	30	240	500		650	800	1913
1	Cumnock Park	30	240	500		650	800	1913
1	Mascott	30	240	500		650	800	1913
1	Windra Vale	30	240	500		650	800	1913
2	Yaloke	25	50	N/M	100	250	500	1439
2	Carmathon	25	50	N/M	100	250	500	1439
2	Emu Park	25	50	N/M	100	250	500	1439
2	Widgee 1	25	50	N/M	100	250	500	N/A
2	Widgee 2	25	50	N/M	100	250	500	1439
3	Tralee	30	170	500		650	800	3352
3	Cummins	30	170	500		650	800	N/A
3	Ramley	30	170	500		650	800	3352
3	Llanos Park	30	170	500		650	800	3352
4	Barham Bridge	30	170	450		600	750	3948
4	Whymoul	30	170	450		600	750	3948
4	Yarranvale	30	170	450		600	750	N/A
4	Noorong1	30	170	450		600	750	3948
4	Noorong2	30	170	450		600	750	3948

5.4 Results

Wetted benthic area under operational flows

There was considerable variation in wetted benthic area under operational flows among reaches (Table 5.2). In general, zones 1 and 2 had significantly lower wetted benthic area under operational flows than the reaches in zones 3 and 4 (df=3, F=6.409, p 0.005).

Contribution of Yallakool Creek environmental watering to in-channel wetted benthic area

There was an increase in wetted benthic area at all reaches that received Commonwealth environmental water during the Yallakool Creek watering action between August 2014 and January 2015. The increase in wetted benthic area as a result of the environmental water ranged from 8.6% increase at 'Noorong1' in zone 4 to 75% increase at 'Barham Bridge' in zone 4 (Table 5.2, Figure 5.1). There was considerable variation in the percent increase in wetted benthic area among reaches in the same hydrological zone receiving the same discharge. Thus, the increase in wetted benthic area was not significantly different among the three zones (df =2, F=0.296, p= 0.749).

Table 5.2. Estimates of wetted benthic area (m^2) for nineteen reaches in the Edward-Wakool Selected Area under the operational base flow and environmental flow in Yallakool Creek where discharge increased to 500 ML/d. The percent increase attributed to Commonwealth environmental water (CEW) is shown. N/A = not applicable because environmental watering was not undertaken in the Wakool River zone 2.

zone	reach	Discharge modelled for operational flow (MLd^{-1})	Wetted benthic area under operational flow (m^2)	Discharge modelled for e-flow (MLd^{-1})	Wetted benthic area under Yallakool Creek e-flow (m^2)	% increase in wetted benthic area under CEW
1	Hopwood	240	99886	500	111,382	11.51
1	Cumnock	240	97018	500	108,005	11.32
1	Cumnock Park	240	102269	500	122,175	19.46
1	Mascott	240	129520	500	144,259	11.38
1	Windra Vale	240	86811	500	113,912	31.22
2	Yaloke	50	94,553	N/A	N/A	N/A
2	Carmarthon	50	87,958	N/A	N/A	N/A
2	Emu Park	50	86,614	N/A	N/A	N/A
2	Widgee 1	50	127,593	N/A	N/A	N/A
2	Widgee 2	50	96,355	N/A	N/A	N/A
3	Tralee	170	173,343	500	203,564	17.43
3	Cummins	170	145,099	500	160,884	10.88
3	Ramley	170	120,924	500	139,757	15.57
3	Llanos Park	170	126,088	500	143,580	13.87
4	Barham Rd Bridge	170	143,854	450	252,502	75.53
4	Whymoul	170	161,121	450	179,224	11.24
4	Yarranvale	170	160,039	450	179,521	12.17
4	Noorong 1	170	122,110	450	132,603	8.59
4	Noorong 2	170	111,210	450	122,067	9.76

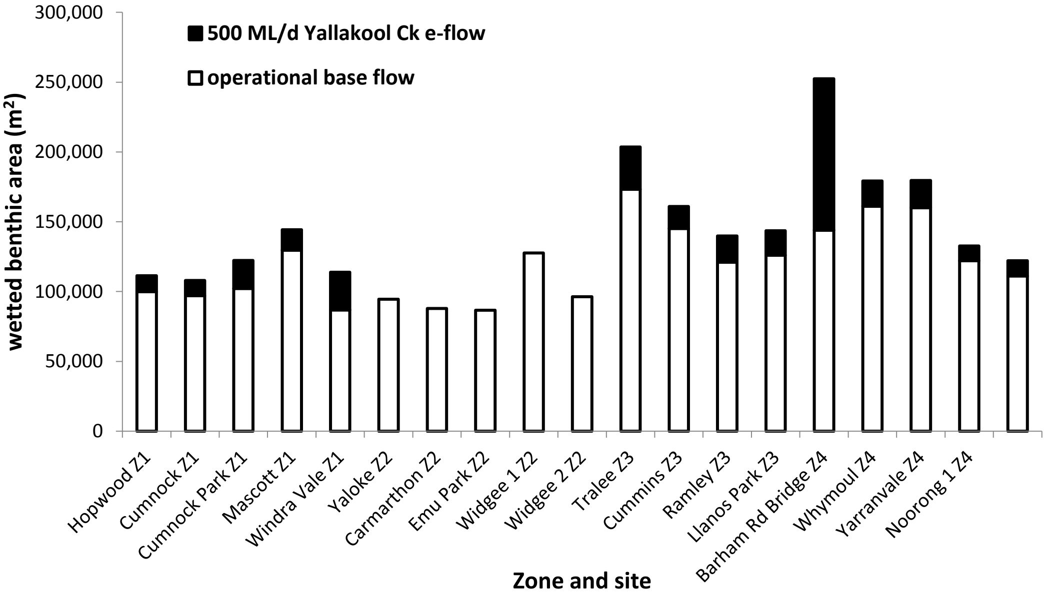

Figure 5.1. Wetted benthic area (m^2) modelled for 19 reaches in the Edward-Wakool Selected Area under a) operational base flow and b) Commonwealth environmental watering in Yallakool Creek where discharge was increased to approximately 500 ML/d between August 2014 and January 2015. Zone 1 = Yallakool Creek, zone 2 = upper Wakool River, zone 3 = Wakool River upstream of Thule Creek and zone 4 = Wakool River downstream of Thule Creek. Discharge levels for operational and environmental flows are provided in Table 5.2.

Area of slackwater, slow water and fast water under operational flows

Under operational flows the area of slackwater ranged from 4,902 m^2 at 'Ramley' to 49,976 m^2 at 'Widgee1' (Table 5.3). The area of slackwater (< 0.02 m.sec^{-1}) varied considerably among reaches and was not significantly different among zones (df=3, F=1.070, p=0.391).

At all reaches the majority of the wetted area under operational flows was slow water (0.02 to 0.3 m.sec^{-1})(Table 5.4). There was a significantly larger area of slow water in zones 3 and 4 than in zone 1 and 2 under operational flows (df=3, F=16.215, p=0.000) and significantly larger area of fast flows in zone 1 under operational flows compared to zones 2, 3 and 4 (df=3, F=7.872, p=0.002).

Contribution of Yallakool Creek Commonwealth environmental water to area of slackwater, slow water and fast water

Under environmental watering the area of slackwater ranged from 2,654 m^2 at 'Llanos Park' in zone 3 to 88,993 at 'Barham Rd Bridge' in zone 4 (Table 5.4). There was a notable increase in area of slackwater (< 0.02 ms^{-1}) during the watering action at 'Tralee' (70% increase) and 'Barham Rd Bridge' (554% increase) (Table 5.4, Figure 5.5). At a few sites there was a small loss in area of slackwater under the environmental watering scenario when compared to operational flows (Figure 5.5). For example, loss of slackwater ranged from as little as 115 m^2 at Cumnock (Yallakool Creek) to loss of 3,323 m^2 at Noorong 1 in zone 4. Due to the large variation in the area of slackwater among sites, it is not surprising there was no overall significant difference in the area of slackwater among zones under environmental watering (df=2, F=1.108, p=0.365).

Table 5.3. Area of wetted benthic area (m^2) of slackwater, slow water and fast water for nineteen reaches in the Edward-Wakool selected area under operational base flow and environmental flow Yallakool Creek**.** N/A = not applicable because environmental watering was not undertaken in the Wakool River zone 2.

zone	reach	area slackwater under operational flow	area slow water under operational flow	area fast water under operational flow	area slack water under e-flow	area slow water under e-flow	area fast water under e-flow
1	Hopwood	11,041	84,252	4,594	12,466	77,545	21,371
1	Cumnock	7,566	84,828	4,625	7,450	79,951	20,604
1	Cumnock Park	13,961	84,700	3,608	18,230	84,958	18,987
1	Mascott	11,355	117,151	1,014	13,782	126,173	4,304
1	Windra Vale	6,001	72,854	7,955	14,706	78,499	20,707
2	Yaloke	25,443	68,928	182	N/A	N/A	N/A
2	Carmarthon	14,892	72,779	286	N/A	N/A	N/A
2	Emu Park	11,966	74,404	244	N/A	N/A	N/A
2	Widgee 1	49,976	76,555	1,061	N/A	N/A	N/A
2	Widgee 2	11,261	84,251	842	N/A	N/A	N/A
3	Tralee	18,696	154,372	275	31,850	168,865	2,848
3	Cummins	23,688	121,410	0	25,302	135,325	258
3	Ramley	4,902	115,148	874	6,973	121,289	11,496
3	Llanos Park	4,115	121,469	503	2,654	138,256	2,670
4	Barham Rd Bridge	13,605	129,316	934	88,993	162,325	1,185
4	Whymoul	35,993	123,874	1,254	35,509	135,634	8,081
4	Yarranvale	34,988	123,914	1,137	34,631	137,655	7,236
4	Noorong 1	6,040	115,230	841	2,717	124,554	5,333
4	Noorong 2	5,528	102,116	3,566	4,349	101,361	16,358

In Yallakool Creek zone 1 there was a loss in area of slow water at 'Hopwood' and 'Cumnock' but an increase in the area of slow water under environmental watering scenario at Mascott and Windra Vale near the lower end of zone 1. In contrast, at most sites in Wakool River zone 3 and 4 (with the exception of Noorong 2) there were substantial increases in the area of slow water under the environmental watering scenario (Table 5.3, Figure 5.2). There was significantly more slow water in zones 3 and 4 than in zone 1 during the environmental watering (df=2, F=8.086, p=0.007).

During the environmental watering action between August 2014 and January 2015 there was a substantial increase in fast flowing water (>0.3 ms^{-1}) in Yallakool Creek. For example, the area of fast water at 'Hopwood' increased from 4,594 m^2 to 21,371 m^2 (Table 5.3), being an increase of 365%. In contrast, the increase in fast water in zones 3 and 4 during the environmental watering action was generally lower, the exceptions being a 200% increase at 'Ramley' and 231% increase at 'Noorong 2'

(Figure 5.2). There was significantly more fast water in zone 1 than in zones 3 and 4 during the environmental watering (df=2, F=5.617, p=0.021).

Maps showing representation of the spatial coverage of the velocity zones for 'Windra Vale' shows the increase in all three velocity types, as backwaters are inundated creating slackwater and the main channel has a mix of slow and fast water (Figures 5.3). The velocity maps of 'Barham Rd Bridge' reach (Figure 5.6) shows the significant increase in slackwater and slow water as backwaters become inundated under environmental watering. In contrast, at 'Noorong2' in zone 4 there is very little slackwater present and the environmental watering resulted in an increase in area of only fast flow.

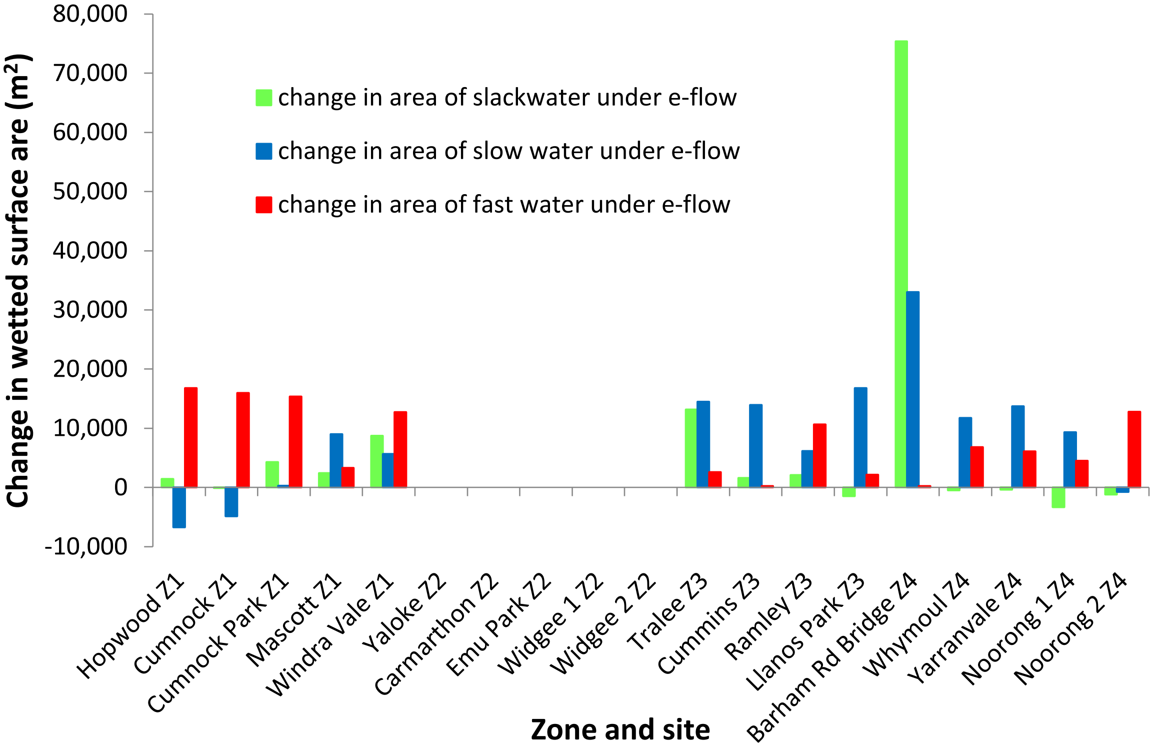

Figure 5.2: Positive or negative change in wetted surface area (m^2) of slackwater, slow water and fast water for nineteen reaches in the Edward-Wakool Selected Area under environmental watering in Yallakool Creek between August 2014 and January 2015 relative to operational base flow. slackwater (< 0.02 $m.s^{-1}$), slow water (0.02-0.3 $m.s^{-1}$), fast water (>0.3$m.s^{-1}$). Hydrological zones: Zone 1 = Yallakool Creek, Zone 2 = upper Wakool River, Zone 3 = Wakool River upstream of Thule Creek and Zone 4 = Wakool River downstream of Thule Creek.

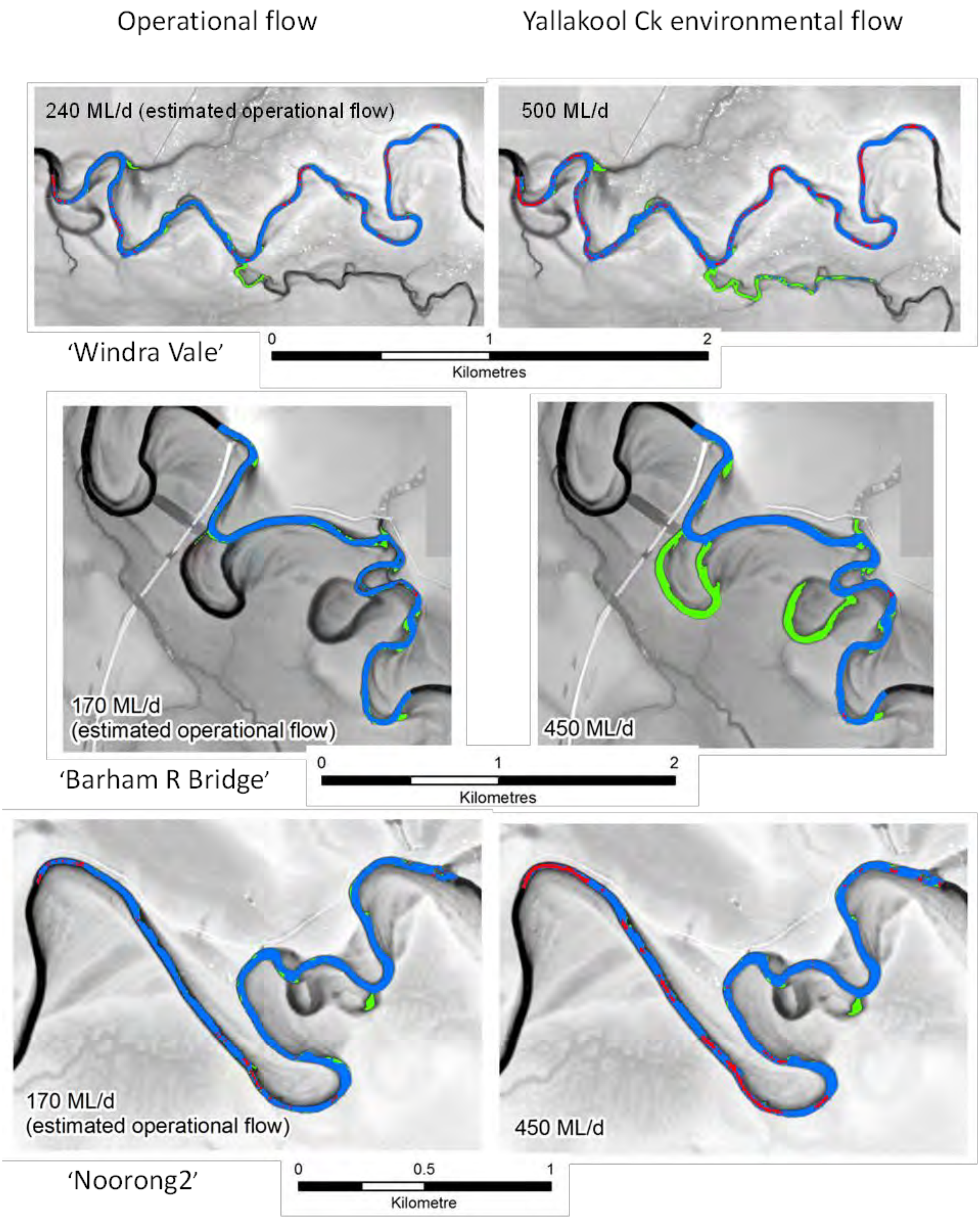

Figure 5.3: Maps showing representation the spatial coverage of the water surface extent for slackwater (green), slow water (blue) and fast water (red) at 'Windra Vale' zone 1, Barham Rd bridge' zone 3, and Noorong 2 in zone 4 under operational flow and Yallakool Creek environmental flow scenarios.

Other modelled flow scenarios

In addition to the operational flow and environmental watering scenarios there were several other scenarios modelled for each reach (Table 5.1) ranging from low flows up to the maximum unregulated flow recorded in these reaches between 2012 and 2015. There is not a tight relationship between discharge and wetted benthic area. There is a broad range of responses for the same discharge (Figure 5.4). Thus, a given discharge can result in vastly different wetted benthic surface area in different reaches.

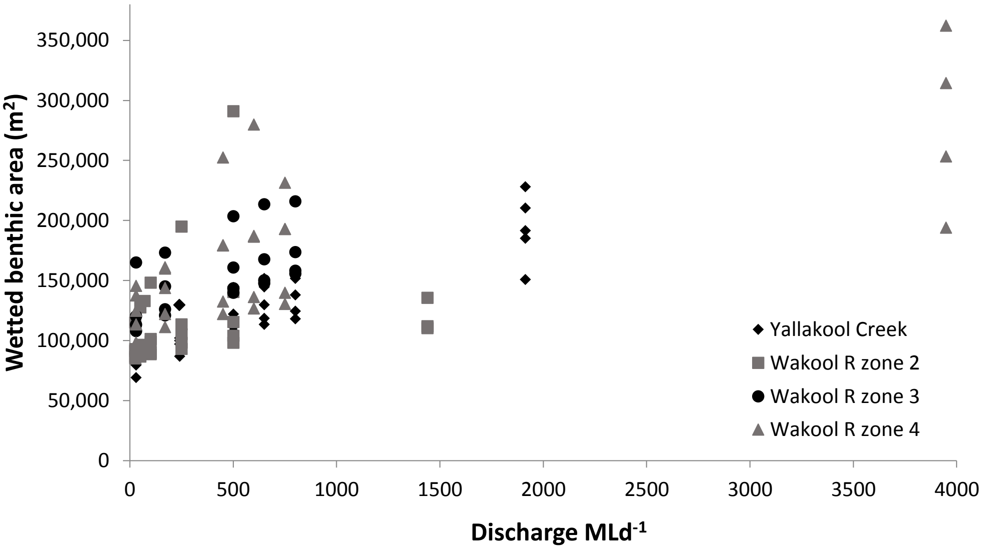

Figure 5.4 Relationship between discharge (MLd^{-1}) and wetted surface area (m^2) for study reaches in Yallakool Creek (zone 1) Wakool River (zone 2), Wakool River upstream of Thule Creek (zone 3) and the Wakool River downstream of Thule Creek (zone 4).

The extent of riverbank inundation under different discharge scenarios differed considerably among reaches. In some cases higher discharge levels did not result in any increase in area of slackwater or slow water, but in other reaches considerable changes were observed under different flow scenarios. For example:

- In the 'Barham Road bridge' reach the backwaters were inundated at 450 MLd^{-1} but there was no additional inundation at 600 MLd^{-1} or 750 Mld^{-1} scenarios (Figure 5.5).
- In the 'Cumnock Park' reach in Yallakool Creek there was additional slackwater formed during the 650 MLd^{-1} scenario when compared to the environmental watering scenario of 500 MLd^{-1} (Figure 5.6).
- In the ''Noorong 2' reach there was no additional slackwater created during the environmental watering. Higher discharges up to 750 MLd^{-1} did not connect any features or backwaters in this reach (Figure 5.7).

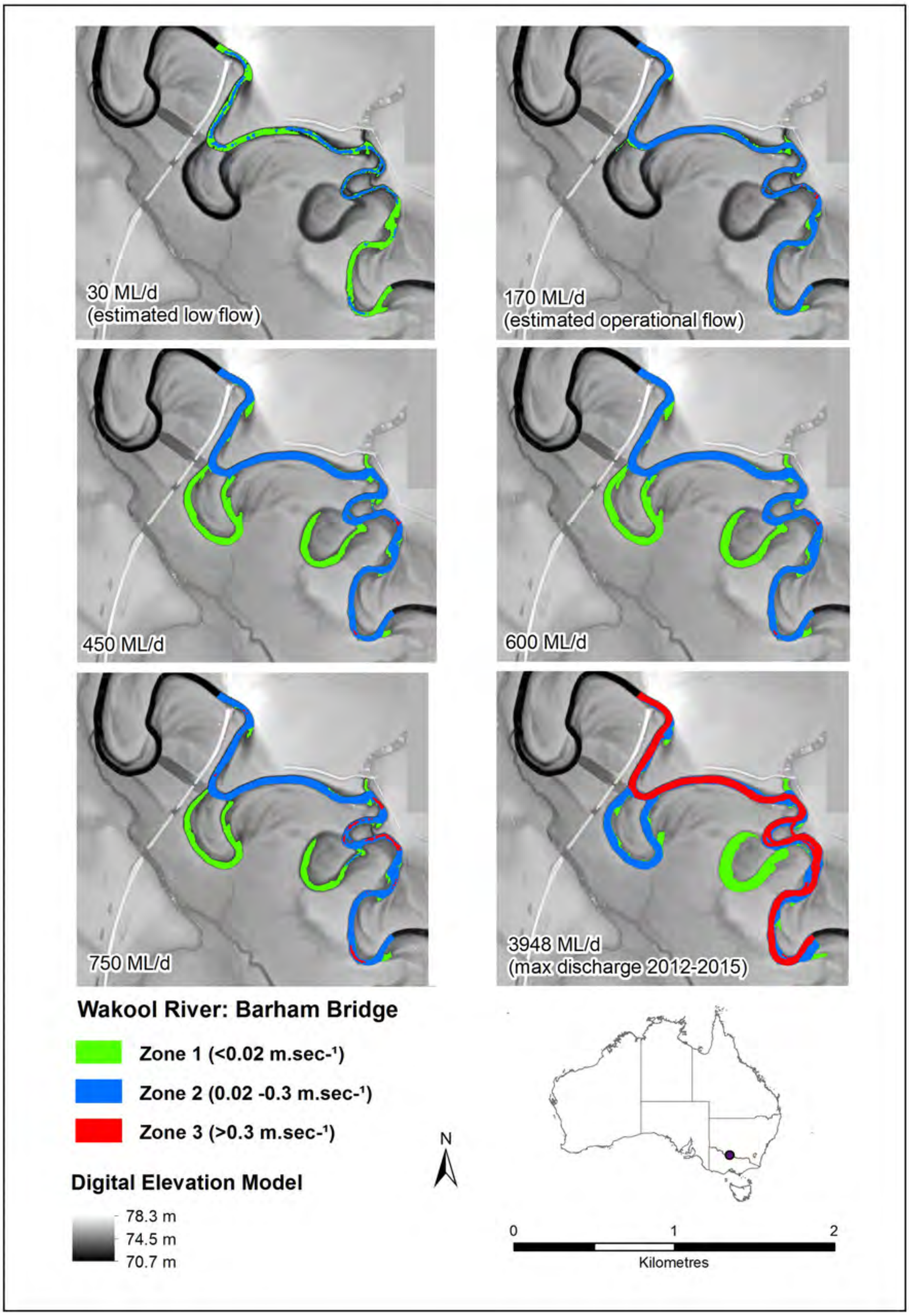

Figure 5.5: Maps showing representation the spatial coverage of the water surface extent for slackwater (green), slow water (blue) and fast water (red) at 'Barham Rd Bridge' zone 4 site 1 under different discharge scenarios. During the environmental watering action in Yallakool Creek the discharge at this site was approximately 450 ML.d^{-1}.

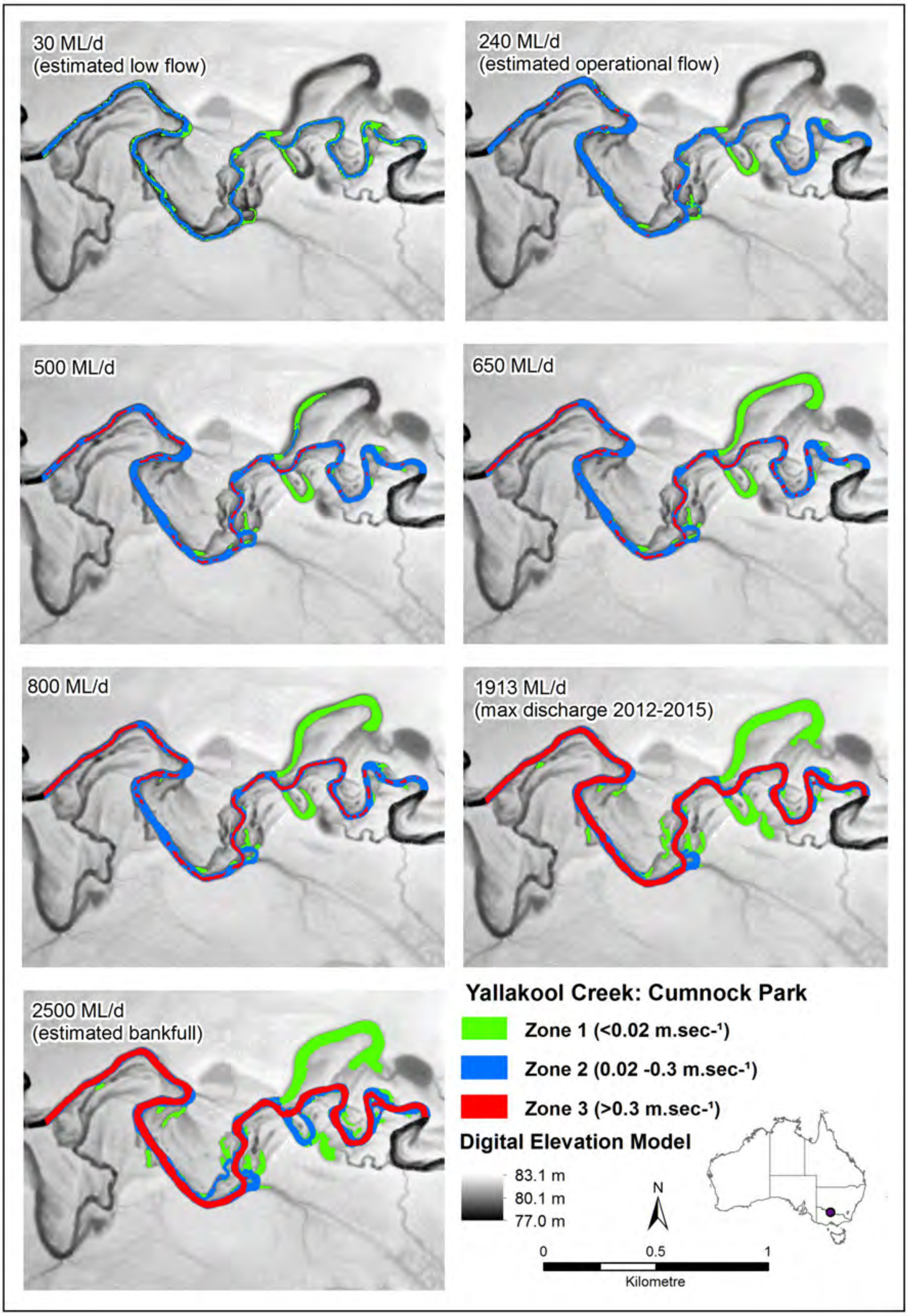

Figure 5.6: Maps showing representation the spatial coverage of the water surface extent for slackwater (green), slow water (blue) and fast water (red) at 'Cumnock Park' zone 1 under different discharge scenarios. During the environmental watering action in Yallakool Creek the discharge at this site was approximately 500 MLd^{-1}.

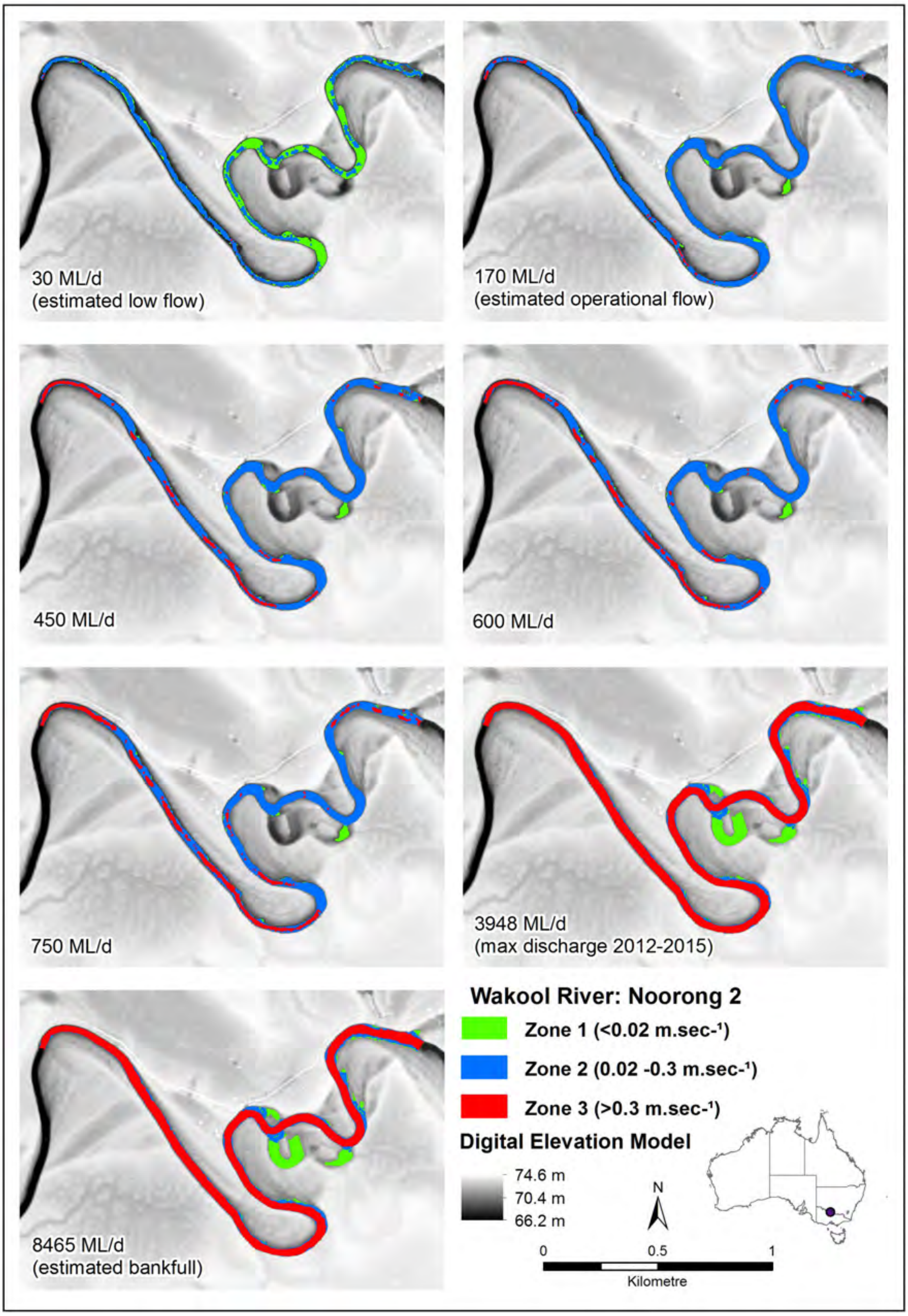

Figure 5.7: Maps showing representation the spatial coverage of the water surface extent for slackwater (green), slow water (blue) and fast water (red) at 'Noorong2' under different discharge scenarios. During the environmental watering action in Yallakool Creek the discharge at this site was approximately 450 MLd^{-1}.

5.5 Discussion

Q1: *What did Commonwealth environmental water contribute to the in-channel wetted benthic area?*

The wetted benthic area under operational flows (no Commonwealth environmental water) was significantly higher in zones 3 and 4 than in zones 1 and 2, being strongly influenced by the geomorphology of the reaches. The delivery of Commonwealth environmental water to zones 1, 3 and 4 significantly increased the in-channel wetted benthic area in reaches in these three hydrological zones. However, as there was considerable variation in the percent increase in wetted benthic area among reaches in the same hydrological zone, it will be difficult to extrapolate these results to other reaches in the Edward-Wakool Selected Area in the absence of information on the geomorphology of those zones.

An increase in wetted benthic area during environmental watering actions is important for river productivity. Later sections of this technical report that evaluate water quality and carbon (section 6) and stream metabolism (section 7) responses to Commonwealth environmental watering will examine whether the increase in riverbank inundation during the environmental watering is sufficient to result in ecosystem responses.

Q2: *What did Commonwealth environmental water contribute to the area of slackwater, slow flowing water and fast water?*

At some of the reaches there was a notable increase in area of slackwater and slow water during the environmental watering action. These increases were particularly notable throughout zone 3 and to a lesser extent observed in the lower reaches of zone 1 and the upper reaches of zone 4. At a few sites there was a small loss in area of slackwater and slow water under the environmental watering scenario when compared to operational flows and in Yallakool Creek. The use of Commonwealth environmental water resulted in a substantial increase in fast flowing water in Yallakool Creek. The response is influenced by the geomorphology of the study reaches. This finding is similar to that of Vietz et al. (2013), who found that in some river reaches of the Broken River the area of slackwaters decreased with increasing discharge until inundation of higher-elevation bars and in-channel benches.

Low flow zones (slackwaters and slow water) having low velocities and shallow depths are important for river productivity and riverbank plants and can facilitate the survival of organisms, such as larval fish and larval shrimp, through provision of habitat and food. Later sections of this technical report that focus on vegetation (section 8) and larval fish (section 10) will examine whether the changes in area of slackwater and slow water have influenced ecosystem responses on these reaches.

Q3: *What did Commonwealth environmental water contribute to hydrological connectivity?*

The effect of Commonwealth environmental water on longitudinal connectivity was assessed in section 4. Commonwealth environmental water increased lateral connectivity between the channel and in-stream geomorphological features, such as backwaters and billabongs, in some of the study reaches but did not increase connectivity in all reaches. As river geomorphology has a strong influence on response to flows, these results suggests that discharge is not a good predictor of hydraulic response.

There is potential to use the modelled results for other discharge scenarios to determine the delivery option at which the greatest number of reaches benefit from the environmental water, in terms of increased lateral connectivity and increased area of slackwater and slow water. For example, there is the potential to split the delivery of environmental, with some water delivered via Yallakool Creek and some via the Wakool River regulator. A discharge of approximately 80 MLd-1 from the Wakool River regulator initiates flow in ‘Black Dog Creek’ that connect the upper Wakool River with Yallakool Creek.

These results have important implications for studies of ecology-flow relationships for in-channel flows. They suggest it may be more appropriate to examine the relationship between inundation area and ecosystem responses to in-channel flows rather than focusing on relationships with daily discharge, as has commonly been the practice.

Acknowledgements

The modelling was undertaken by Dr Hugh Pederson from Marine Solutions. Maps were prepared by Deanna Duffy (Charles Sturt University Spatial Analysis Unit).

5.6 References

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6. RESPONSE OF WATER QUALITY AND CARBON TO COMMONWEALTH ENVIRONMENTAL WATERING

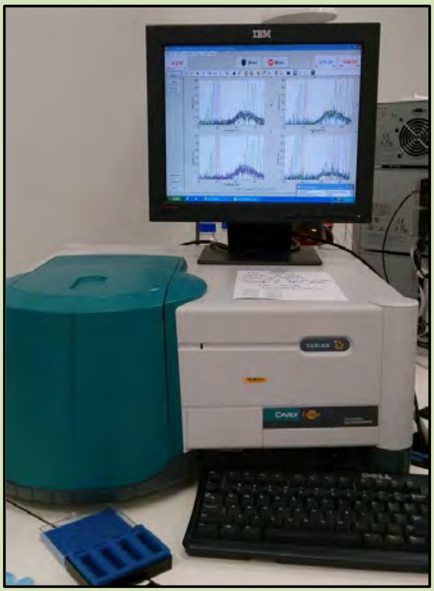

Figure 6.1 Analysis of water samples by fluorescence spectroscopy
(Photo: Julia Howitt)

Summary

- 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) 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.
- Commonwealth environmental water did not influence water temperature, however zones receiving Commonwealth environmental water had higher dissolved oxygen concentrations than the Wakool River in Zone 2 (no environmental water). This difference among zones with and without environmental water persisted beyond the end of the watering action, thus Commonwealth environmental water assisted in the maintenance of dissolved oxygen concentrations over the summer period in the zones receiving the additional flow.
- Total Nitrogen and Total Phosphorus were generally higher in the Wakool River in Zone 2 than in the sites receiving Commonwealth environmental water, however bioavailable nutrients were at similar very low concentrations at all sites.
- A pulse of organic matter was observed passing through the system from upstream during August 2014. Very small differences between organic matter in the Wakool River in zone 2 and the other study sites were measured during the Yallakool environmental watering action. These are unlikely to be ecologically significant.
- Organic matter remained well below concentrations associated with blackwater events.

6.1 Background

Water quality is a key indicator of aquatic ecosystem health and water quality parameters will often respond to changes in flow regimes very quickly. Increases in wetted benthic area can result in inputs of carbon and nutrients from previously dry parts of the channel or floodplain (Baldwin 1999; Baldwin and Mitchell 2000), or increased flow may have a dilution effect on these parameters instead. 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).

Organic matter is made up of a complex mixture of compounds from a diverse range of sources. This mixture contains too many types of compounds to be fully characterised and so the organic matter in natural waters is usually described by the use of broad categories, the most fundamental of which are nonhumic substances and humic substances (Choudhry 1984). 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 humic substances can dominate in many waters and in contrast are poorly characterised, substantially larger (molecular weights ranging from hundreds to tens of thousands) and the group is further classified into two groups (humic acids and fulvic acids) based on their properties rather than chemical structure. Humic acids are the fraction that is soluble in basic solution but precipitates in acid, while fulvic acids are soluble in both acids and bases (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.

Reconnection of the stream channel with backwater areas and dry sections of the floodplain and channel may result in additional nutrients and organic carbon. The majority of these additions are expected to occur in the first day or two after rewetting or reconnection. Inputs of these substances may have a positive influence on the river community through the stimulation of productivity and increased food availability for downstream communities (Robertson, Bunn et al. 1999) and the connection between the river and floodplain has been shown to generate essential carbon stores to sustain the system through drier periods (Baldwin, Rees et al. 2013). However, excessive nutrient and organic carbon inputs can result in poor water quality through the development of algal blooms or blackwater events resulting in very low dissolved oxygen concentrations (Howitt, Baldwin et al. 2007; Hladyz, Watkins et al. 2011). Inputs of large amounts of organic matter and nutrients during hot weather are particularly problematic due to the influence of temperature on the rates of microbial processes and organic matter leaching (Howitt, Baldwin et al. 2007; Whitworth, Baldwin et al. 2014). 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.

6.2 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.

The following questions are addressed in this report to assess the effect of 2014-15 Yallakool Creek environmental watering action:

Q1: *What did Commonwealth environmental water contribute to temperature regimes?*

Q2: *What did Commonwealth environmental water contribute to dissolved oxygen concentrations?*

Q3: *What did Commonwealth environmental water contribute to nutrient concentrations?*

Q4: *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?*

Q5: *What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?*

6.3 Methods

Water temperature and dissolved oxygen were logged every ten minutes with two loggers located in zones 1 and 4 and one logger in each of zones 2 and 3. 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 2014 to March 2015. Gaps in dissolved oxygen data were the result of problems with the loggers or due to routine maintenance.

Water quality parameters (temperature (^{o}C), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were also measured as spot recordings monthly at two sites within each river reach.

Water samples were collected from two sites within each zone, and from Stevens Weir on the Edward River and the Mulwala Canal, and 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 the Water Studies Centre at Monash University for analysis. Carbon characterisation samples were returned to CSU Wagga Wagga and then analysed within a day of returning from the field.

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 (EEM). 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, Baldwin 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 6.2. 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.

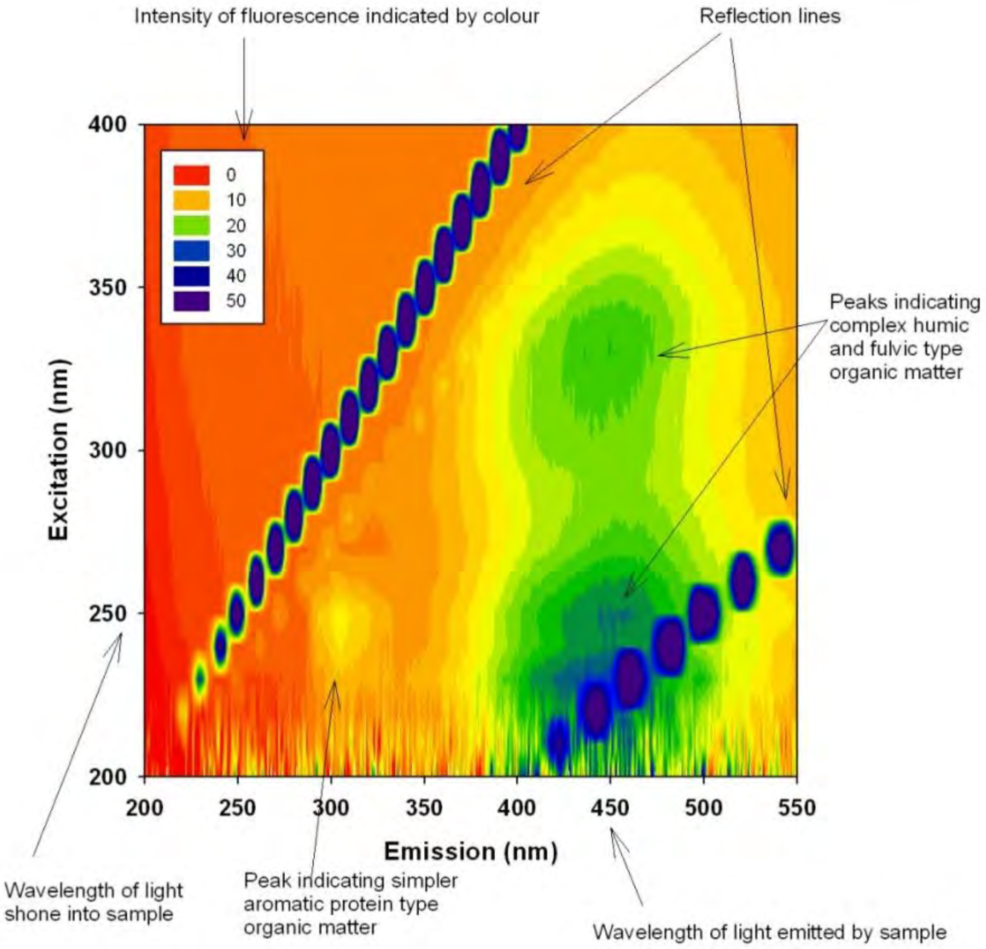

Figure 6.2. Sample excitation emission contour plot indicating key features of the data. (Watts et al. 2013)

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.

6.4 Results

Basic Water Quality Parameters

The water temperature (Figure 6.3) was generally very similar in all study zones with the most downstream zone being fractionally warmer than the upstream zones, as would be expected. There is no discernable effect of Commonwealth environmental water on water temperature, with all sites displaying the same seasonal variation and influence of weather patterns.

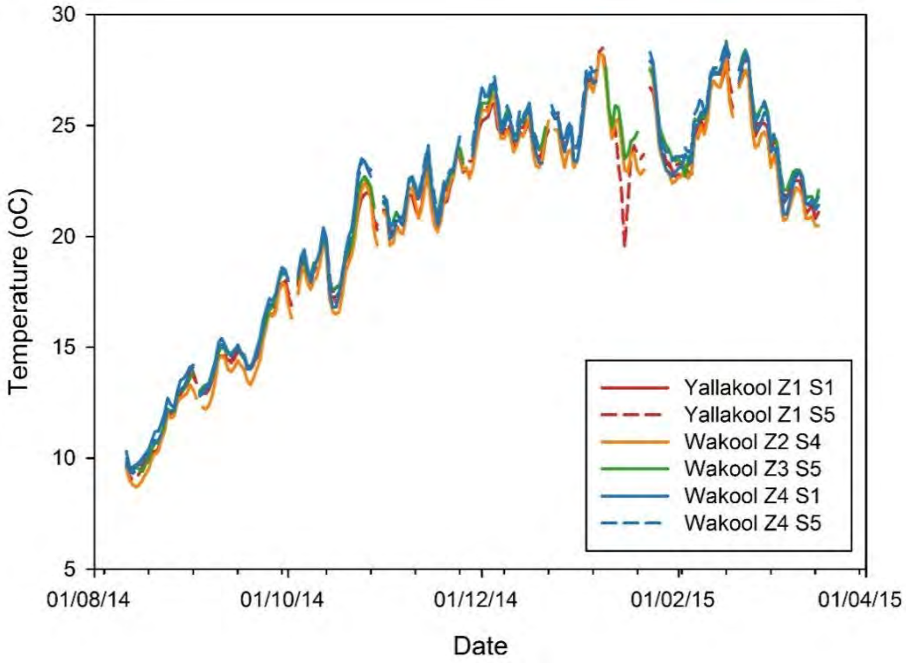

Figure 6.3 Daily average temperature results for six sample sites across four river zones.

The average dissolved oxygen concentration in each zone is shown in Figure 6.4. Yallakool Creek (zone 1) and the Wakool River in zones 3 and 4 (all receiving Commonwealth environmental water) are similar to each other throughout most of the study period, with slightly more variability observed during December and January. Spikes in the data in this period may be indicative of biofilm developing on the sensor between cleanings. The Wakool River in zone 2 (shown in orange) clearly separates from the other sites in mid August, around the time of the commencement of the Yallakool Creek environmental watering action, however the difference between this zone and the three zones receiving Commonwealth environmental water persists beyond the end of this watering action in January. In all cases a decline in dissolved oxygen is observed during the hotter months, as expected with the increased water temperature (which decreases oxygen solubility). However, the difference in dissolved oxygen concentration between zones is not explained by temperature differences and likely reflects differences in input of oxygenated water from upstream and different rates of re-aeration and oxygen consumption associated with flow (see section 7). Concentrations of dissolved oxygen in the Wakool River Zone 2 briefly dropped into the range of concern to fish populations (below 4 mg/L) during mid January and again in mid February.

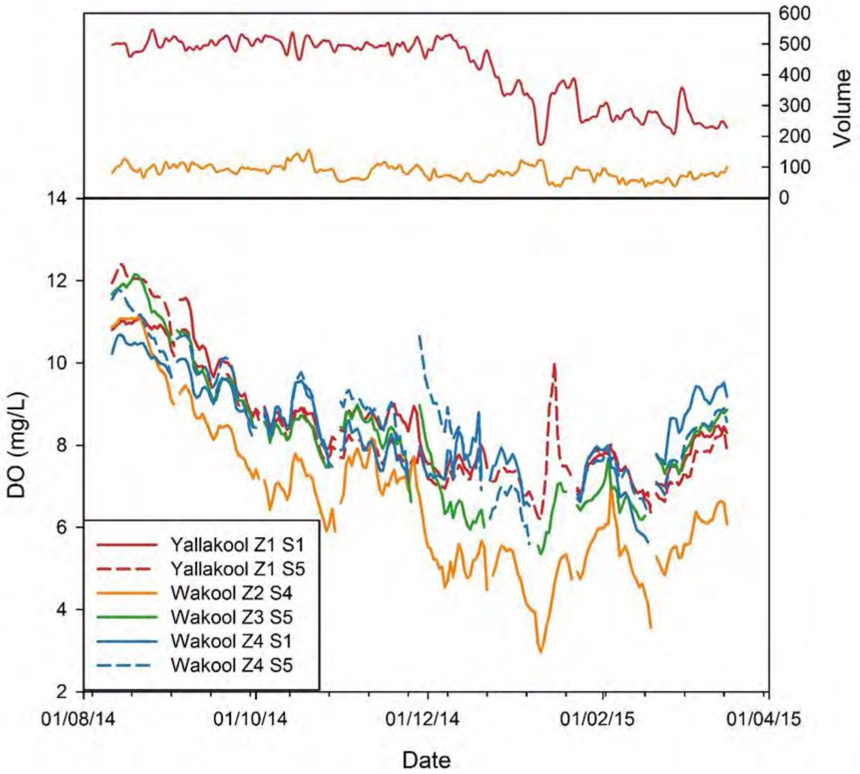

Figure 6.4 Daily average dissolved oxygen concentration in the four zones. Hydrographs for Yallakool Creek Zone 1 (red line) and Wakool River zone 2 (orange line, no environmental water) are shown in the upper portion of the graph to indicate the difference in flow. Zone 3 and 4 have similar hydrographs to zone 1.

DOC

Concentrations of dissolved organic carbon in the four study zones and the source waters are shown in Figure 6.5. Note that two anomalous values have been removed from this figure- a value of 28 mg/L for Wakool River Zone 4 Site 5 in late November and a value of 15 from Wakool River Zone 2 Site 1 in mid February. Neither of these values is consistent with the concentrations for the sites immediately upstream and downstream, or supported by the absorbance and fluorescence data. Sample contamination in the field is the most likely explanation for these high results. The first samples were taken from a reduced number of sites and correspond to the rising hydrograph prior to the onset of the Yallakool Creek Environmental watering action. The data from this small number of samples hints at a trend of decreasing DOC progressively downstream. This pattern is reversed in the following sampling period (although there is some scatter in the data). Throughout most of the study period there is no clear trend in the data and the DOC remains in the low range that is common for this system. It is noted that the upstream site in the Wakool River zone 2 has lower DOC than the downstream site in this zone, however the results remain within the scatter of concentrations observed for the other sampling sites.

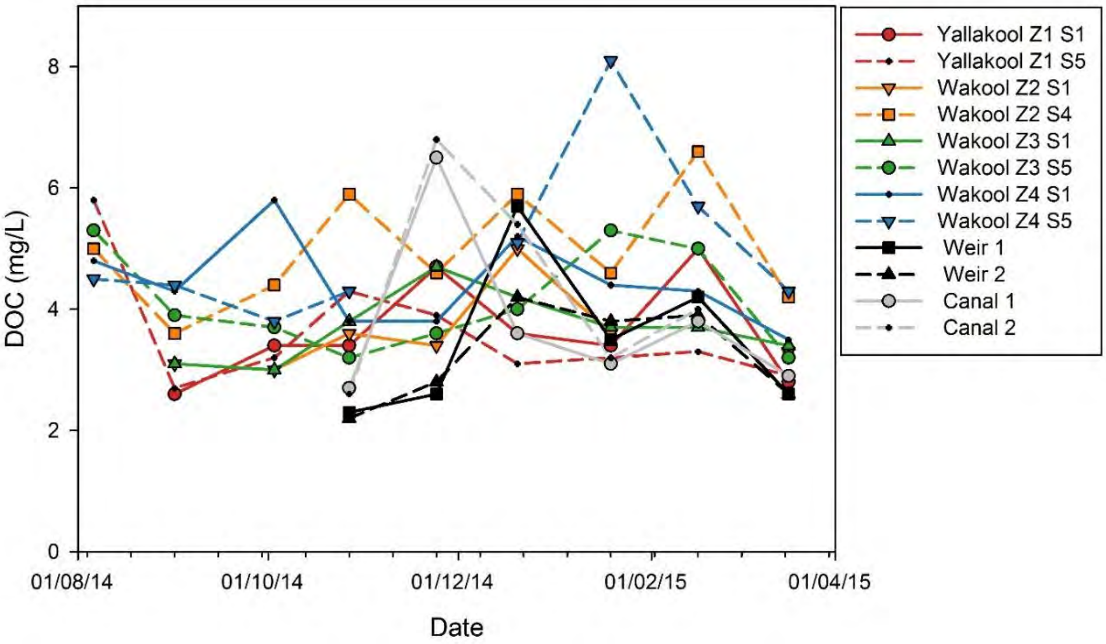

Figure 6.5 Dissolved organic carbon concentrations at study sites and water sources.

Nutrients

Figure 6.6 illustrates the concentrations of nitrogen found in the study zones in the form of a) Total Nitrogen, b) nitrate and nitrite and c) ammonia. Total nitrogen concentrations fluctuate above and below the ANZECC trigger value of 0.5 mg/L with a general trend towards the Yallakool Creek zone 1 having lower concentrations than the Wakool River zone 3 and the Wakool River zone 4, suggesting an increase in total nitrogen as the water progresses through the system. The Wakool River zone 2 site generally has higher total nitrogen concentrations, more similar to zone 4 than zone 1. Total nitrogen at this site gradually increases to a peak in December and then declines to be more similar to the other sites. However, it is known from earlier studies in this system (Watts et al. 2014) that bioavailable forms of nutrients are a more important indicator in this system than total nutrients. Both NO_x and ammonia forms of bioavailable nitrogen are low in all zones. The very high NO_x concentration in the Yallakool Creek in August is unusual and unfortunately, not replicated, so care should be taken with the interpretation of this result. The high ammonia values in the Yallakool on two occasions are only found at the upstream sampling site and either suggest disturbance of the sediments while sampling or ammonia introduced from the source water that dissipates before the water reaches the downstream sampling site.

Total phosphorus and filterable reactive phosphorus (Figure 6.7) have similar patterns to the nitrogen results. Total phosphorus results are scattered above and below the trigger value and the Wakool River zone 2 has the highest concentrations with a peak in December. Bioavailable phosphorus however, is well below the trigger value and similar across zones.

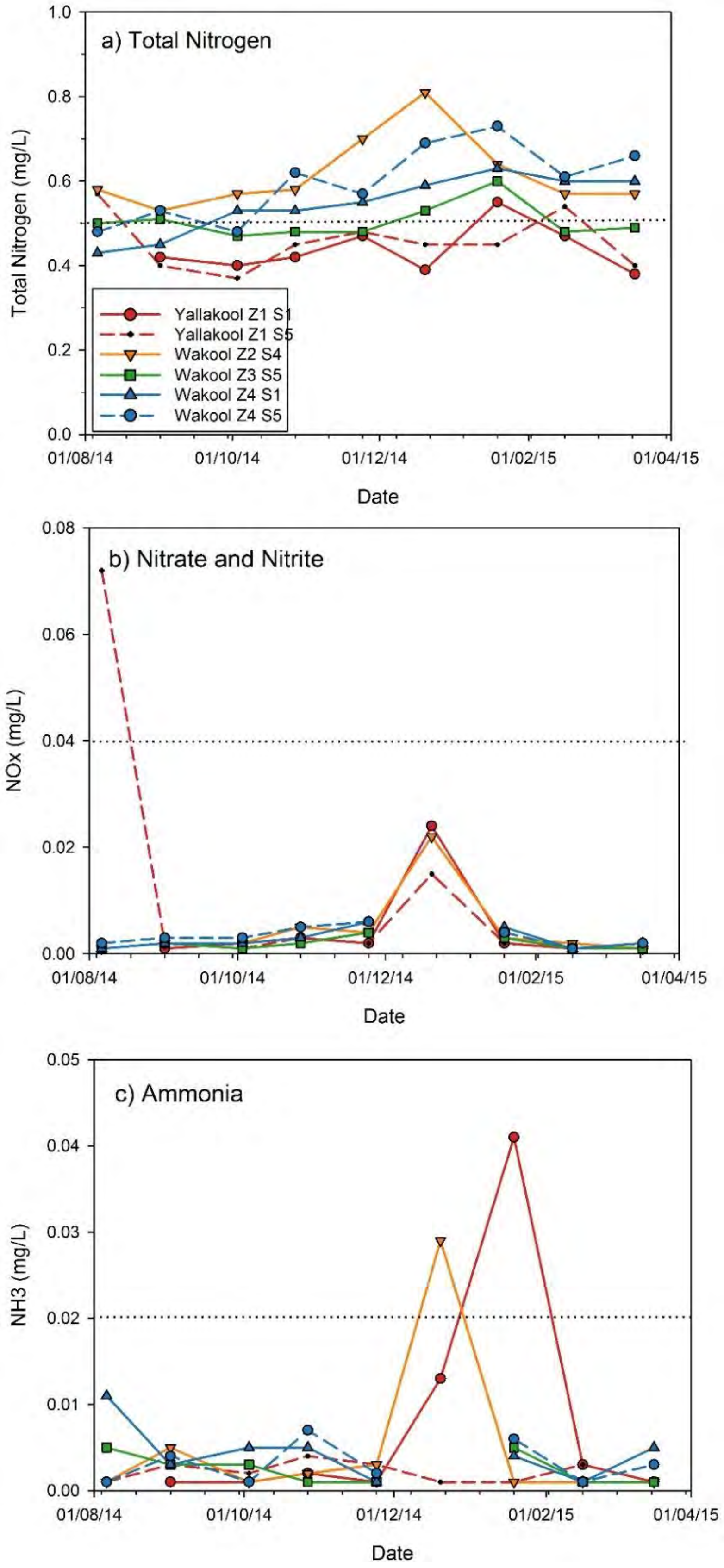

Figure 6.6 Total nitrogen, nitrate + nitrite and ammonia at study sites. ANZECC (2000) guidelines for each parameter are marked as a dotted line.

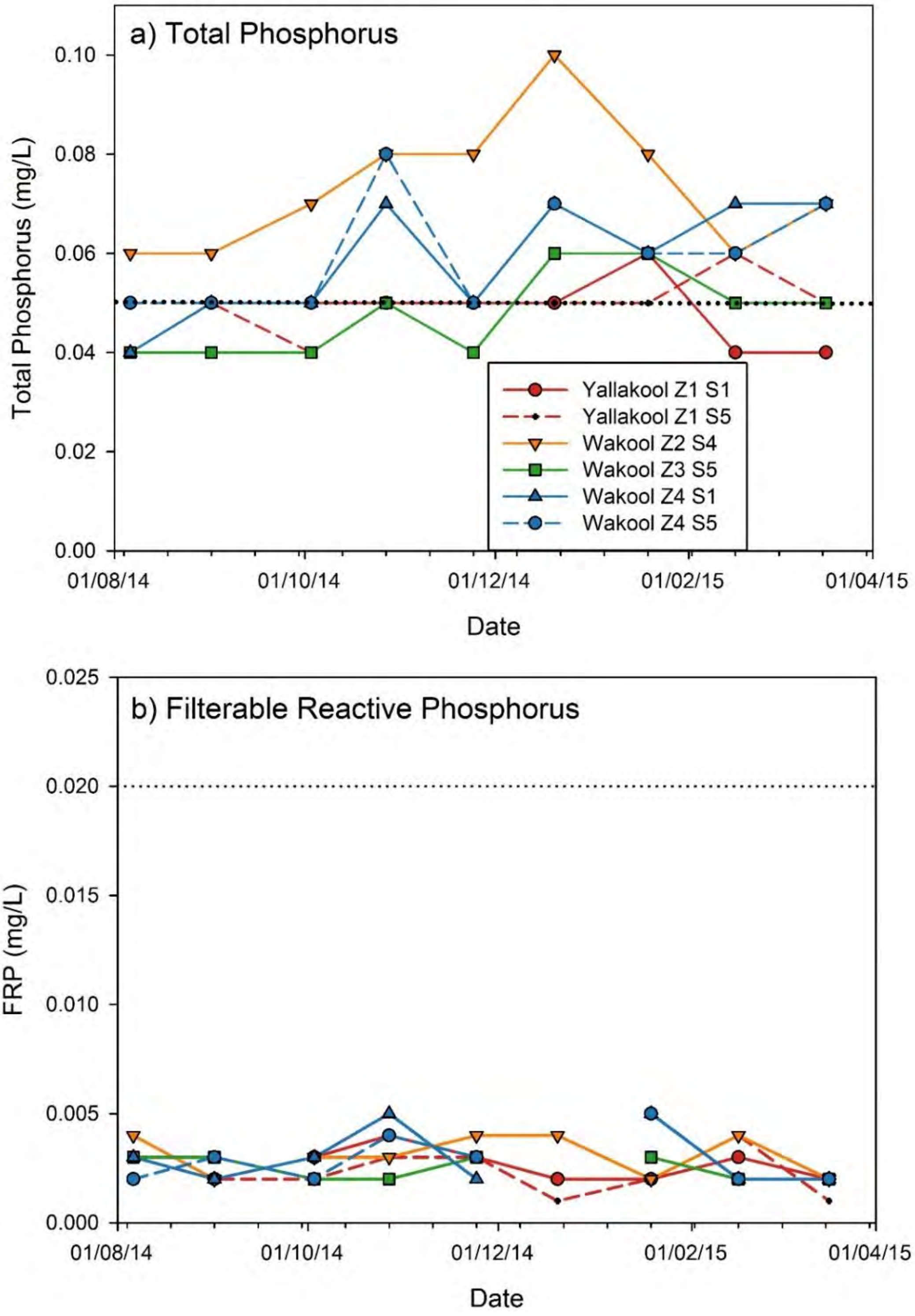

Figure 6.7 Total and filterable reactive phosphorus in the four study zones. ANZECC (2000) trigger values are marked with dotted lines.

Carbon Characterisation

Organic matter composition was studied through UV-visible (Figures 6.8 and 6.9) and fluorescence spectroscopy (Figures 6.10-6.18). Absorbance scans suggest higher organic matter inputs from the Edward River in August, decreasing down the system and in early September the end of this pulse of organic matter is working down the system, with low DOC water measured in the Edward River and upstream sites and slightly elevated absorbance at sites from the downstream zones. Absorbance has declined from the previous month. In late September the Wakool River in zone 2 has slightly higher absorbance than seen for the sites receiving Commonwealth environmental water, but thereafter the absorbances are similar at all sites and decreasing over the season. Note that in February (Figure 6.9), the scans from zones 1 and 2 show signs of slight elevation of measured absorbance due to bubbles forming.

The fluorescence scans for August (Figure 6.10) more clearly show the input of organic matter from upstream, with the pulse of fluorescent organic matter having not spread to the lower study zones at the time of sampling. Note this sampling aligns with the rising hydrograph prior to the onset of the Yallakool Creek environmental watering. Consistent with the absorbance scans, and more clearly demonstrated than in the DOC results above, it can clearly be seen (Figure 6.11) that by early September there is very little fluorescent organic matter in the upper study zones (consistent with the water quality at the source sites), but slightly elevated organic matter remains at the downstream sites. Either material is being collected from low lying surfaces, or clean source water is pushing the last of the earlier pulse through the system. Note in the Wakool zone 3 site 1 is a closer match to Yallakool Creek than the Wakool site upstream (zone 2 site 4).

By late Sept/early October the uppermost site on the Wakool River (zone 2 site 1) shows greatest fluorescence (Figure 6.12), followed by most downstream site suggesting a downstream progression through zone 1, 3 and 4, with zone 2 separating out due to differences in flow. The very slight differences between zone 2 and zones 1 and 3 (which would be expected to be most similar) persist until mid January, with the cessation of the Yallakool Creek environmental watering action (Figures 3.13-3.16) with all sites being very similar in February and March 2015 (Figures 6.17-6.18). Bioavailable carbon appear to be quite low in the upper zones throughout the summer.

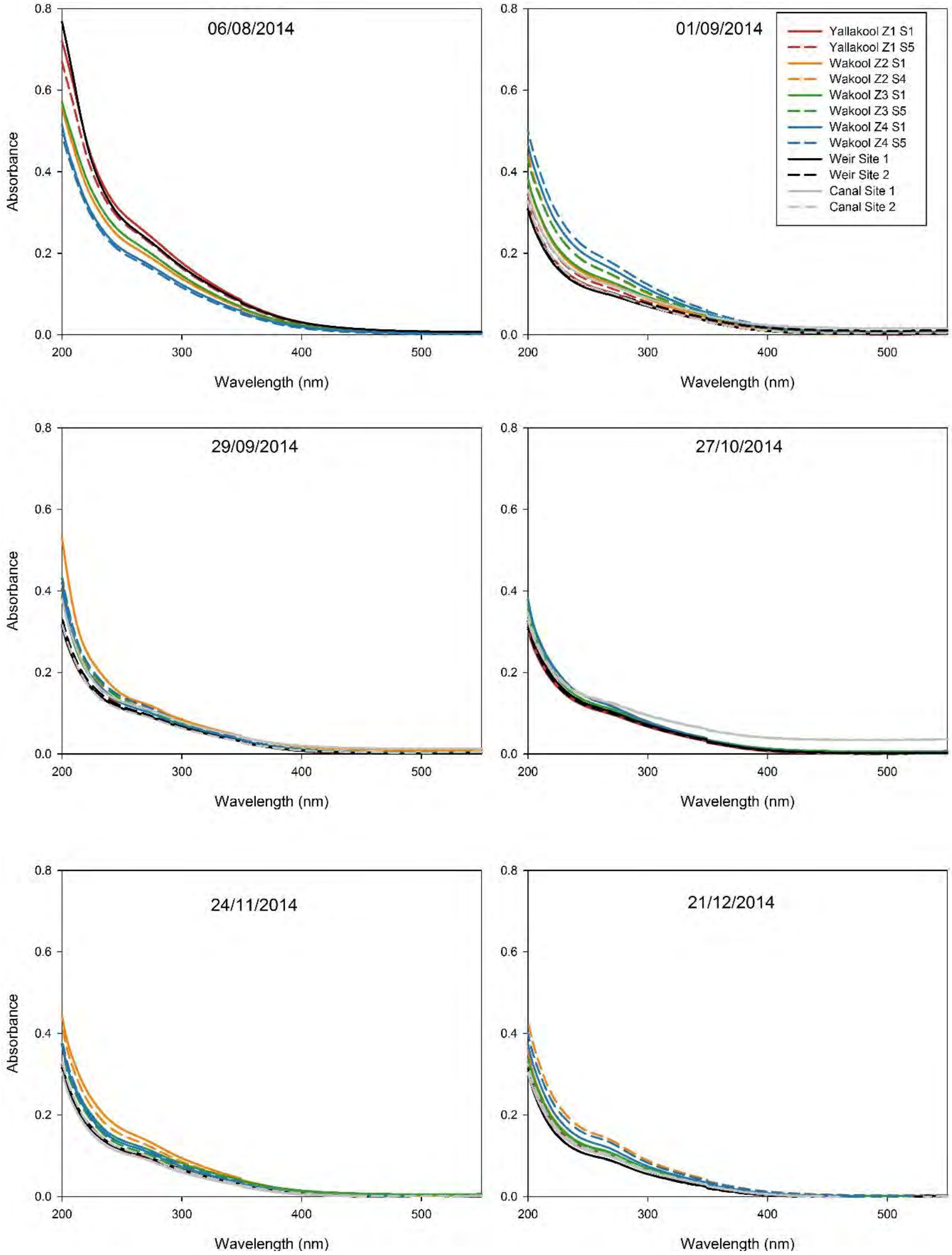

Figure 6.8 Absorbance scans representing two study sites in each zone, plus source waters from August to December 2014.

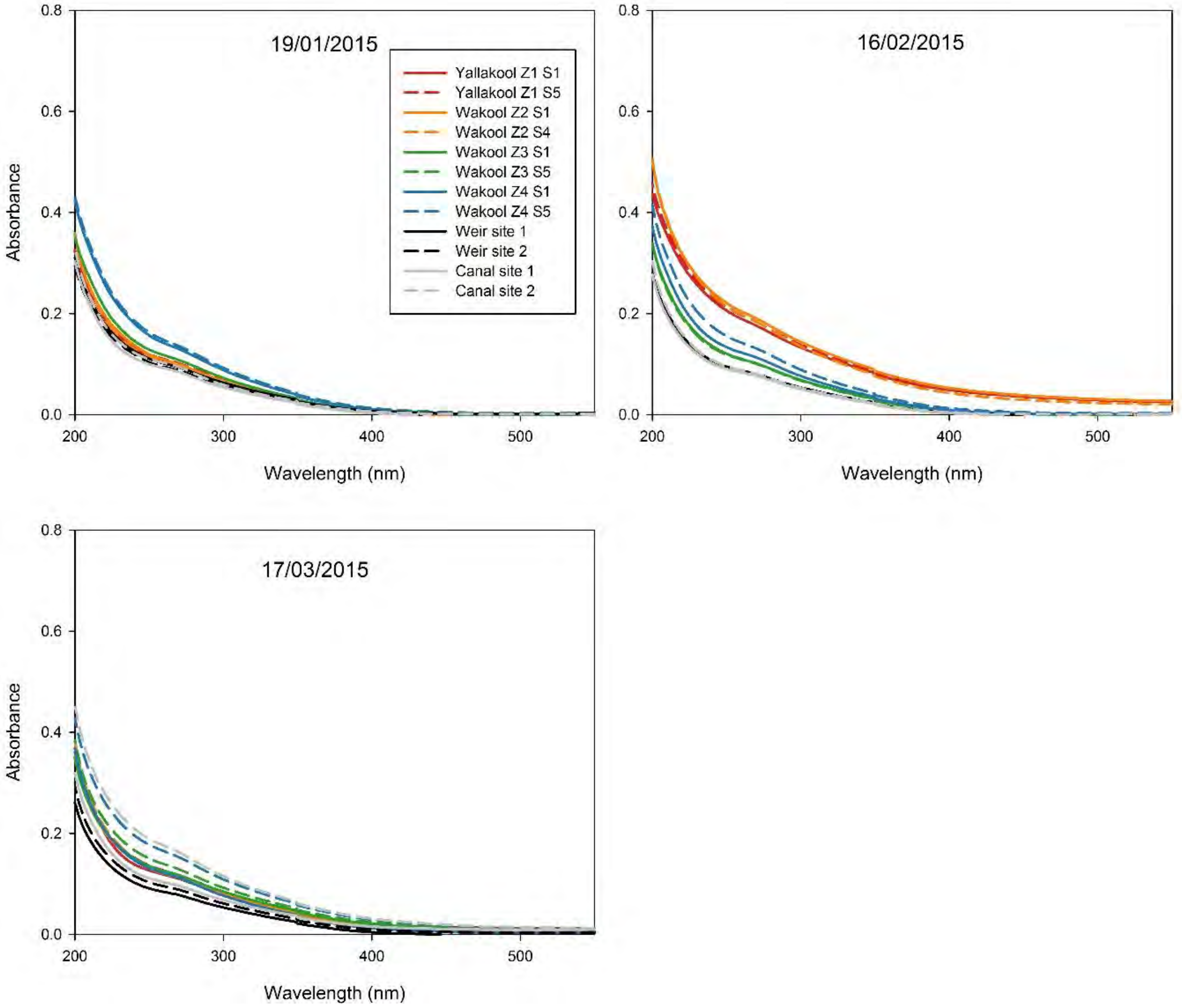

Figure 6.9 Absorbance scans for four study zones and two water sources from January to March 2015.

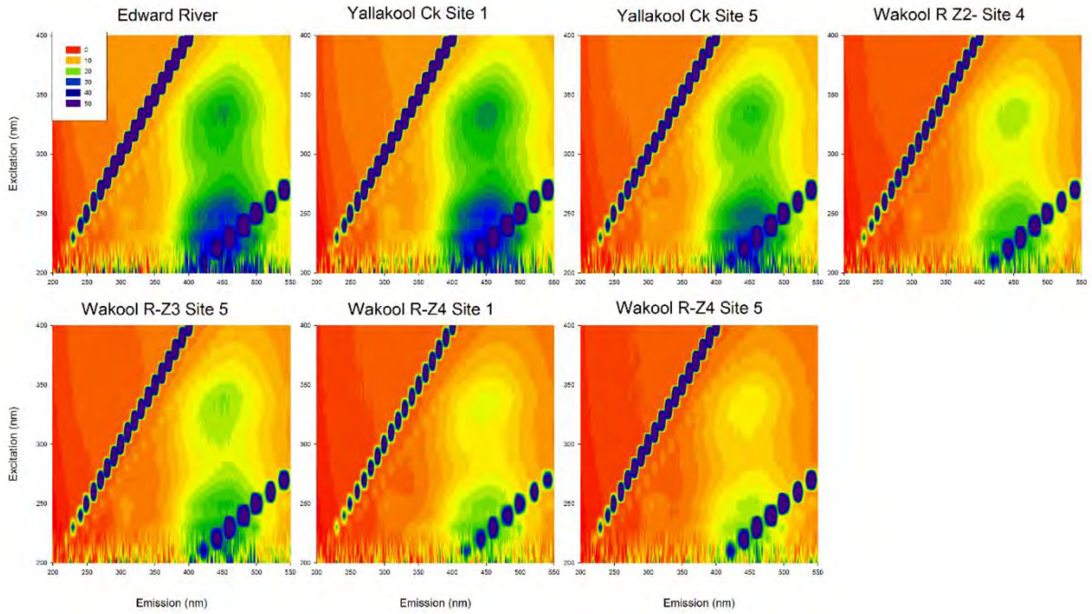

Figure 6.10- Fluorescence scans of water samples collected 06/08/14 showing decreasing organic matter as samples are taken further from the source water.

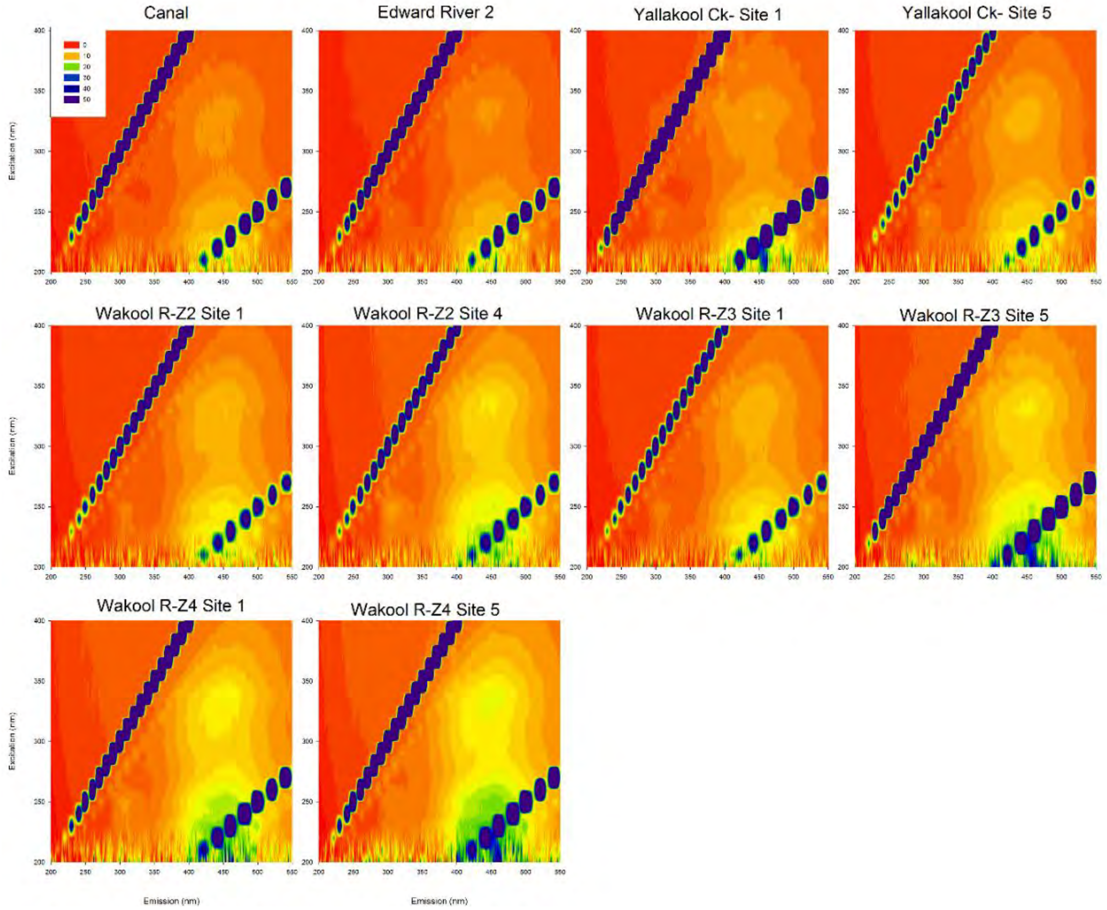

Figure 6.11 Fluorescence spectra for water samples collected 01/09/14 showing higher concentrations of fluorescent organic matter in downstream sites, with upstream sites more closely matching the source water.

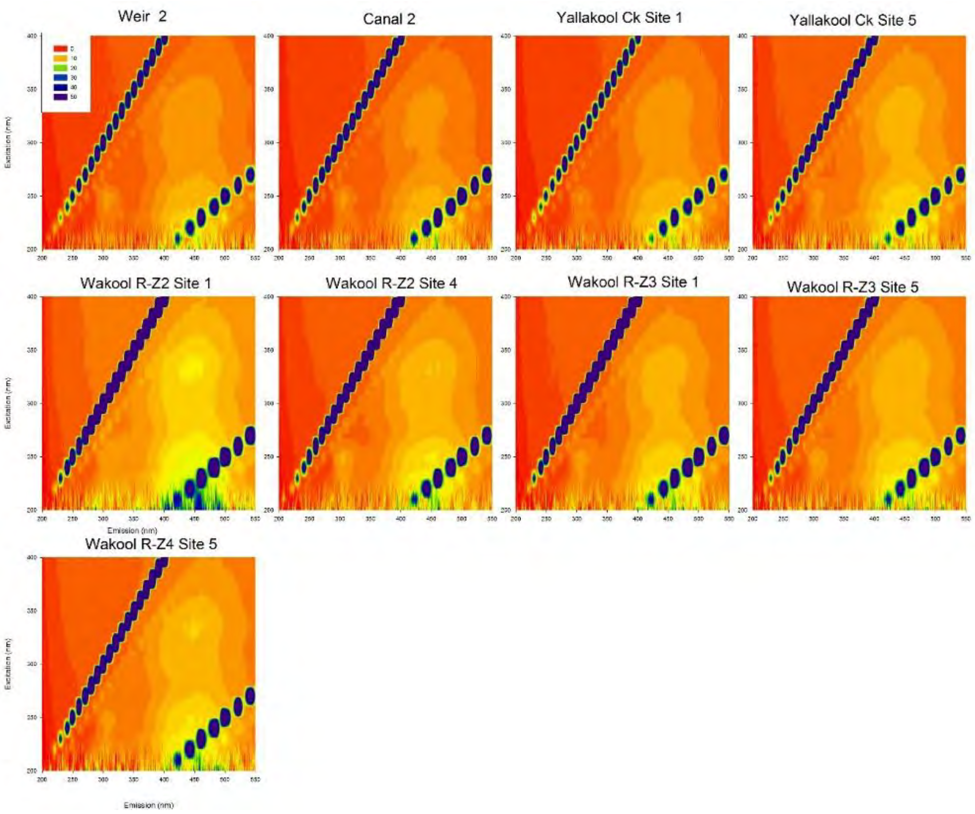

Figure 6.12 Fluorescence Scans for water samples collected 29/09/14 indicating fairly consistent organic matter across sites but slightly higher concentrations of fluorescent organic matter in zone 2.

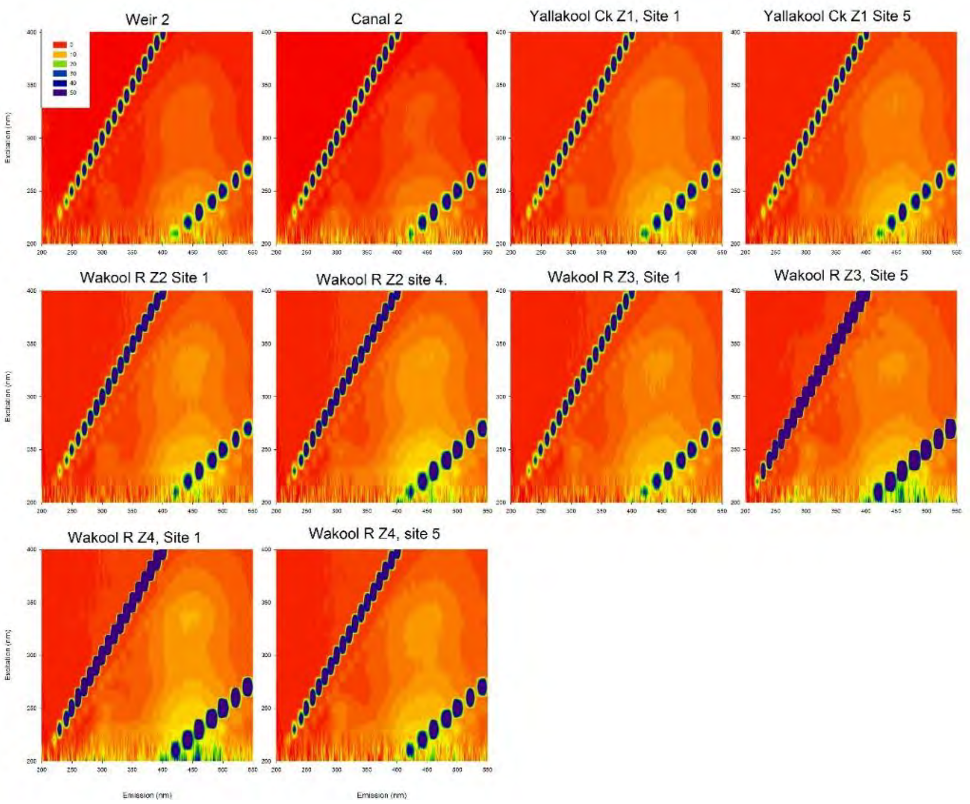

Figure 6.13 Fluorescence scans for water samples collected 27/10/14 indicate decreased concentrations of fluorescent organic matter compared to the previous month, but with similar patterns among sites.

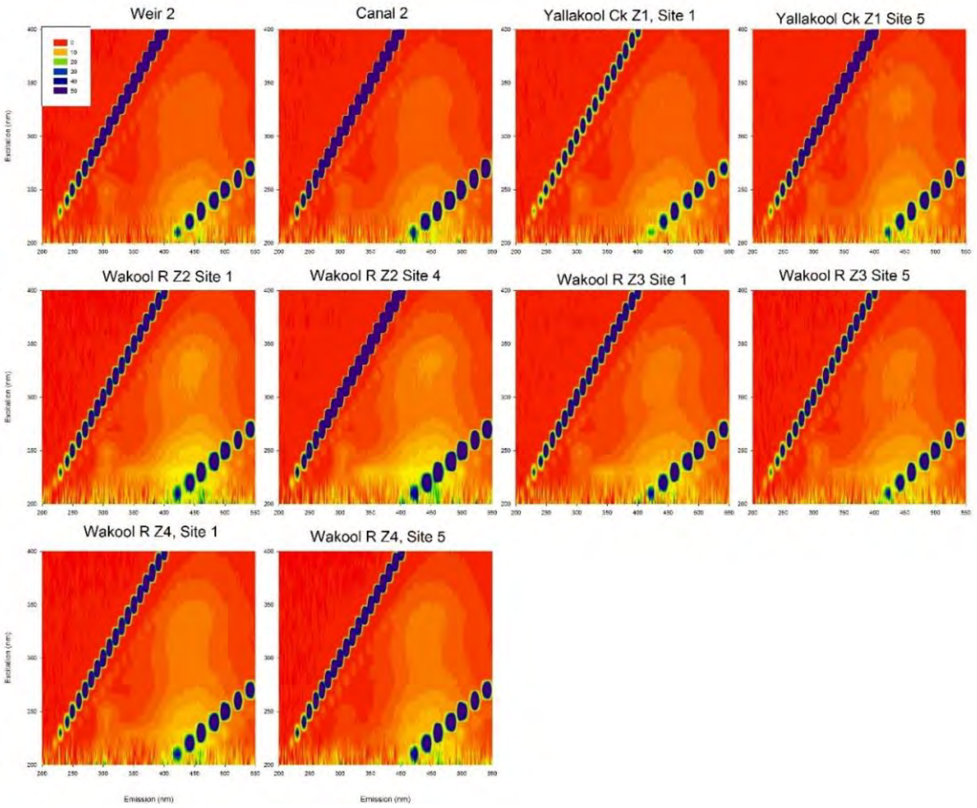

Figure 6.14 Fluorescence scans for samples collected 24/11/14.

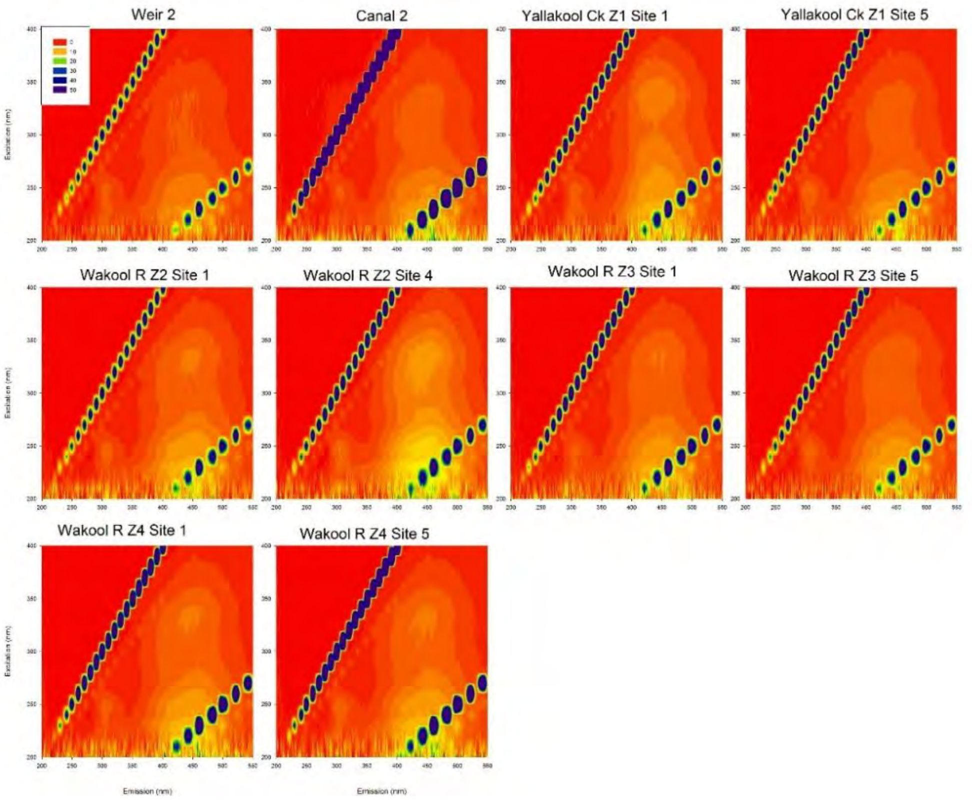

Figure 6.15 Fluorescence Scans for samples collected 21/12/14

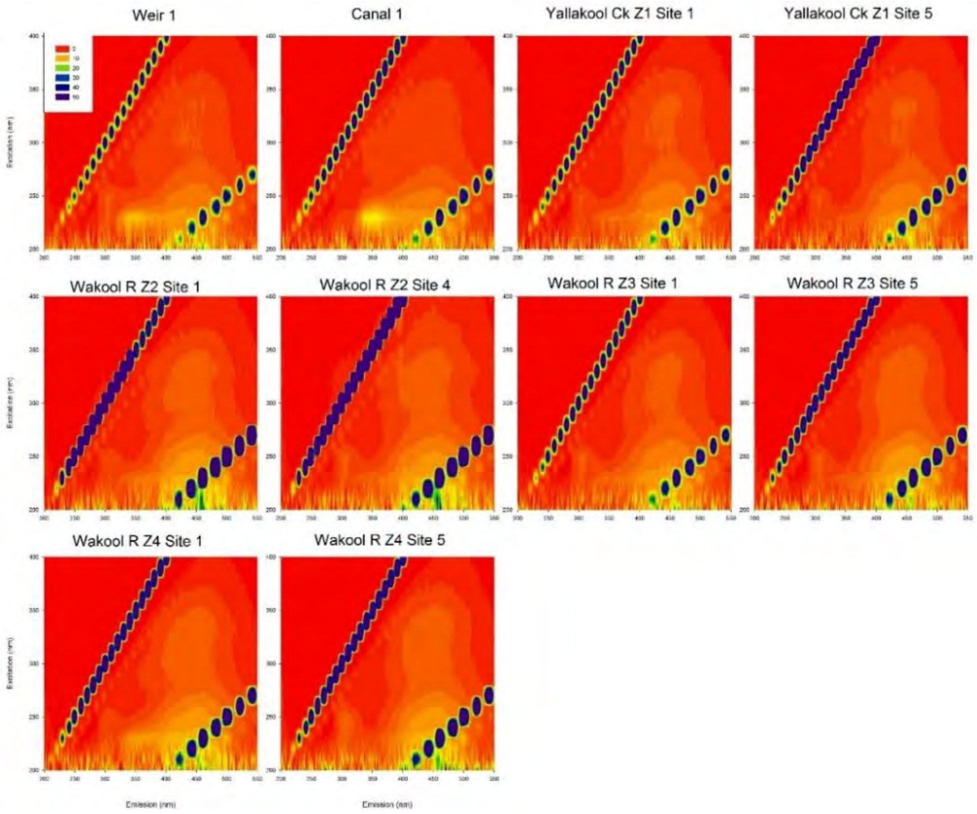

Figure 6.16 Fluorescence scans for samples collected 19/01/15

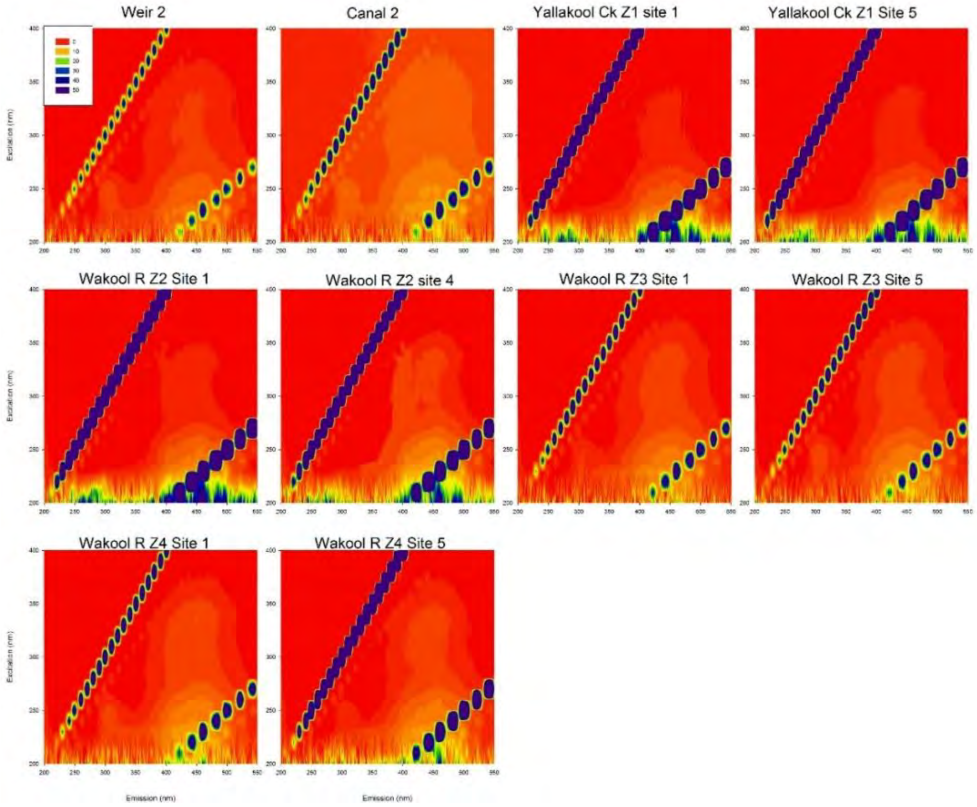

Figure 6.17 Fluorescence scans for water samples collected 16/02/15 indicating very consistent concentrations of fluorescent organic matter across sites and very low fluorescence overall.

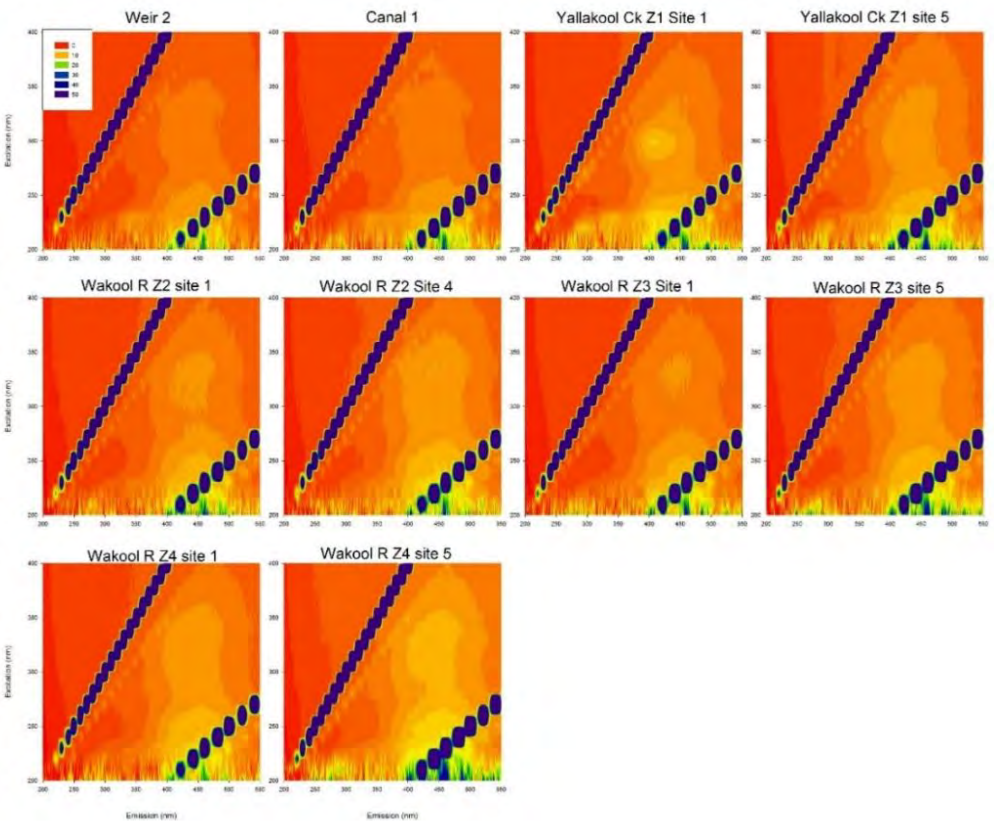

Figure 6.18 Fluorescence scans of samples collected 17/03.15.

6.5 Discussion

Returning to the questions associated with the impact of the Yallakool environmental watering action on the Edward-Wakool system, it is clear that the impact on water quality parameters was variable and in most cases very small.

Q1: *What did Commonwealth environmental water contribute to temperature regimes?*

Commonwealth environmental water was not observed to affect temperature regimes within the system, with all study zones having very similar water temperatures. Seasonal effects were the predominant influence here.

Q2: *What did Commonwealth environmental water contribute to dissolved oxygen concentrations?*

The dissolved oxygen concentrations in the Wakool River zone 2 (no Commonwealth environmental water) were lower than the concentrations at all other study sites throughout the Yallakool environmental watering action. This difference persisted beyond the end of the watering action, however it appears that Commonwealth environmental water assisted in the maintenance of dissolved oxygen concentrations over the summer in the zones receiving additional flow.

Q3: *What did Commonwealth environmental water contribute to nutrient concentrations?*

Bioavailable nutrients were similar across study sites and do not appear to have been influenced by Commonwealth environmental water. Total nitrogen and Total phosphorus were generally higher in the Wakool River zone 2 during the Yallakool environmental watering action, suggesting either dilution of these nutrients by Commonwealth environmental water at the other study sites, or that conditions in zone 2 favoured the retention of nutrients associated with organic matter or particulates (e.g. algal cells) within the water column.

Q4: *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?*

The dominant effect on dissolved organic matter appears to have been the unregulated pulse of water in early August, bringing carbon from upstream sources (the exact source cannot be determined using this sampling design as all upstream sources have not been assessed). While some very subtle differences in carbon characterisation were observed in the Wakool River zone 2 over the period of the Yallakool environmental watering action, these are not expected to result in large differences in ecosystem function.

Q5: *What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?*

The conditions required to generate blackwater were not present in Yallakool Creek and the Wakool River during this season. The impact of Commonwealth environmental water on blackwater in the system could not be assessed in this water year as there was no blackwater event.

6.6 References

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7. EFFECT OF COMMONWEALTH ENVIRONMENTAL WATER ON STREAM METABOLISM

A high level of biofilm growth impacted the performance of the dissolved oxygen probe in zone 2 (no environmental water) and required additional maintenance. Photo: J. Abell

Summary

- Battery-powered loggers were deployed at the six designated sites and recorded dissolved oxygen concentration and water temperature every 10 minutes. The metabolic parameters, gross primary production and ecosystem respiration were calculated for each day using the prescribed BASE model.
- Rates of primary production and ecosystem respiration during 2014-2015 were at the lower end of the normal range found in streams worldwide, with the exception of Zone 2, where rates were comparable with many other streams.
- Much higher ecosystem respiration rates leading to low in-stream dissolved oxygen in January 2015 were observed in Zone 2 (no Commonwealth environmental water) compared to the three zones that received Commonwealth environmental water.
- Primary production and ecosystem respiration are constrained by the very low concentrations of bioavailable nutrients and organic carbon, respectively. This lack of organic carbon input into the base of the aquatic foodweb is limiting maintenance and recovery of fish populations.
- Whilst the Commonwealth environmental watering action in Yallakool Creek in 2014-15 did not appear to stimulate gross primary production (and therefore basal food resources for invertebrates and fish), they played an important role in preventing poor water quality.

7.1 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 7.1.

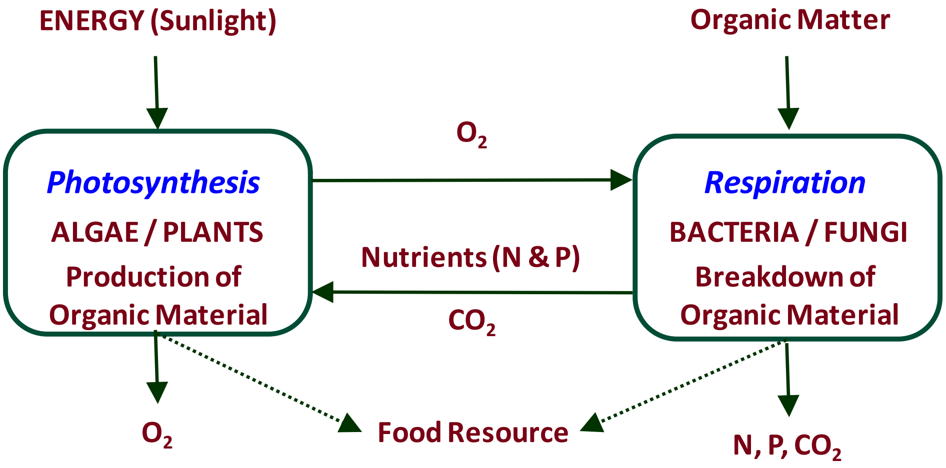

Figure 7.1. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of dissolved oxygen (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 0.5 and 10 mg O_2/L/Day.

If process rates are too low, this will 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. Warmer temperatures and a supply of organic carbon usually result in higher rates of ecosystem respiration (Roberts et al. 2007).

In general, there is 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, 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. 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.

7.2 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. 2014), 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. Questions 1 and 2 (below) relate to the basin scale evaluation. 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 Yallakool Creek-Wakool River in 2014-15. 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?*

Q4: *What did Commonwealth environmental water contribute to patterns and rates of primary productivity?*

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

- Under extended 'cease to flow' conditions of several weeks or more, the responses of gross primary production (GPP) and ecosystem respiration (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, Q4)
- Under normal 'base' flow, rates of GPP and ER will be constrained to the low-moderate range, typically 1 to 3 mg O_2/L/Day. (Q3, Q4)
- With in-stream freshes, rates of GPP and ER will increase slightly to 3 to 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, Q4)
- 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, Q4)
- Primary production in the Edward-Wakool system will be limited by low phosphorus concentrations. (Q3, Q4)

7.3 Methods

The stream metabolism measurements were performed in accordance with the LTIM Standard Operating Procedure (Hale et al. 2014).

Water temperature and dissolved oxygen were logged every ten minutes with at least one logger placed in each of the four study zones; in zones 1 and 4, loggers were placed at the top and bottom end of these zones (see Table 7.1). The positioning of DO loggers at the top and bottom end of zones 1 and 4 serves two important purposes: i) it enables assessment of whether the river reach integrated by the downstream logger (encompassing much of the zone under study) is behaving similarly to the reach above the upstream logger. This will help address whether the study zone is typical of the stream behaviour over a more extensive region, and ii) to provide two daily estimates of the metabolic rates (and re-aeration) should one logger fail.

Data were downloaded and loggers calibrated approximately once per month depending on access. Light and depth loggers were also deployed and data were downloaded on a monthly basis. The data collected by the loggers was also used to calculate daily average temperature and dissolved oxygen concentrations (see Section 6) for each of zones from early August 2014 to the end of March 2015.

Table 7.1. Summary of gross primary production (GPP) and ecosystem respiration (ER) rates and production/respiration (P/R) ratios for six sites in the four hydrological zones, August 2014 to March 2015.

Hydrological zone	Watering action	Upstream logger	Downstream logger
1 Yallakool Creek	Yallakool Creek watering action	zone 1 site 1	zone 1 site 5
2 Wakool River	no environmental water	No logger available *	zone 2 site 4
3 Wakool River upstream Thule Creek	Yallakool Creek watering action	No logger installed, but future analysis may use zone 1 site 5 as a proxy because it also received e-water and had a similar hydrograph to zone 3 site 1	zone 3 site 5
4 Wakool River downstream Thule Creek	Yallakool Creek watering action	zone 4 site 1	zone 4 site 5

* Initially, it was anticipated that zone 1, Site 5 could act as an upstream reference point for zone 2 Site 4, but the much lower flows at the latter site mean that such analysis would be highly problematic.

In accord with the LTIM Standard Protocol, water quality parameters (temperature (^{o}C), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were also measured as spot recordings fortnightly at two sites within each river reach.

Water samples were collected from two sites within each zone, and from Stevens Weir on the Edward River and the Mulwala Canal, and processed according to the methods detailed in Watts et al. (2014) to measure:

- Total Organic Carbon (TOC)
- Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC)
- Nutrients (Ammonia (NH_4^+), filtered reactive phosphorus (FRP), dissolved nitrate + nitrite (NOx), Total Nitrogen (TN) and Total Phosphorus (TP))

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 July 2015 LTIM Workshop in Sydney. 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%.

7.4 Results

Estimates of gross primary production (GPP) and ecosystem respiration (ER) for the 6 sites were produced using the BASE model (Grace et al. 2015). Data loggers were in place from early August 2014 until mid-March 2015. Regular maintenance and occasional problems with some loggers meant that there were less than the maximum 217 daily results for each site. Using the acceptance criteria for each day's diel DO curve, the acceptance rate ranged from 91% of all days with data available (185 from 205) for zone 2 Site 4, down to 26% (48 of 182) at zone 4 Site 5. The other sites were zone 1 Site 1 62% (109 of 177), zone 1 Site 5 79% (161 of 205), zone 3 Site 5 47% (85 of 180) and zone 4 Site 1 66% (121 of 182).

Figures 7.2 to 7.4 display the daily rates of GPP, ER and the P/R ratio (ratio of oxygen produced by GPP to oxygen consumed by ER) at all 6 sites (each plot is for one zone). Table 7.2 summarizes the daily metabolism results portrayed in Figures 7.2 to 7.4. Each metabolic parameter is expressed as a median with minimum and maximum values also included. The median provides a more representative estimate without the bias in the mean arising from a relatively few much higher values. The median GPP values for all six sites fall within a narrow range of 1.25 to 2.69 mg O_2/L/Day. This closeness in these median GPP rates is unsurprising given the similarity in the biogeochemical environments as noted in previous years (Watts et al. 2014). With the exception of a significantly higher value for zone 2 Site 4, all median ER values fell within the range 2.07 to 2.47 mg O_2/L/Day.

Table 7.2. Summary of primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for the six study sites, August 2014 to March 2015. 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

	Zone 1 Site 1 (n = 109)			Zone 1 Site 5 (n = 161)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.25	0.46	4.09	1.28	0.49	6.11
ER (mg O_2/L/Day)	2.07	0.49	8.36	2.71	0.34	12.76
P / R	0.56	0.29	2.61	0.48	0.19	2.43

	Zone 2 Site 4 (n = 185)			Zone 3 Site 5 (n = 85)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	2.69	0.67	9.88	1.86	0.89	4.65
ER (mg O_2/L/Day)	6.91	1.33	16.94	2.47	0.70	6.54
P / R	0.43	0.10	0.77	0.81	0.46	1.86

	Zone 4 Site 1 (n = 120)			Zone 4 Site 5 (n = 48)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.65	0.35	6.20	2.01	0.50	5.25
ER (mg O_2/L/Day)	2.04	0.65	5.74	2.27	0.59	5.74
P / R	0.72	0.22	1.54	0.85	0.21	2.03

The highest GPP was found at the site with no Commonwealth environmental watering action. There was an approximately two-fold increase in GPP at Site 4 in zone 2 compared with sites in the other three zones (Table 7.2, Figure 7.2). It is possible this doubling of rate is due to higher phosphorus concentrations at this site, although the most bioavailable form of phosphorus (FRP) is only marginally higher at this site (see Figure 6.7) and was very low (< 0.005 mg/L). The slightly higher GPP rates found in zone 2 match with observations of more filamentous algae in this zone compared to the other zones. It was also in zone 2 where problems with biofilm growth impacting performance of the DO probe was at the highest level, thereby necessitating a more frequent cleaning regime.

Despite the differences across zones, these GPP rates are still at the lower end of the 'normal' range for freshwater streams and rivers. This normal range is (approximately) 3 to 10 mg O_2/L/Day (e.g. Bernot et al. 2010; Marcarelli et al. 2011). The comparison was made assuming average water depth was 1.0 m to enable conversion from the areal units in the references given to the volumetric units presented in this report. There was very little difference in the daily GPP values measured within the two sites in both zone 1 and zone 4. This indicates that indicates that the stream reach integrated by the logger at site 5 is behaving very similarly to the stream reach above the logger at site 1.

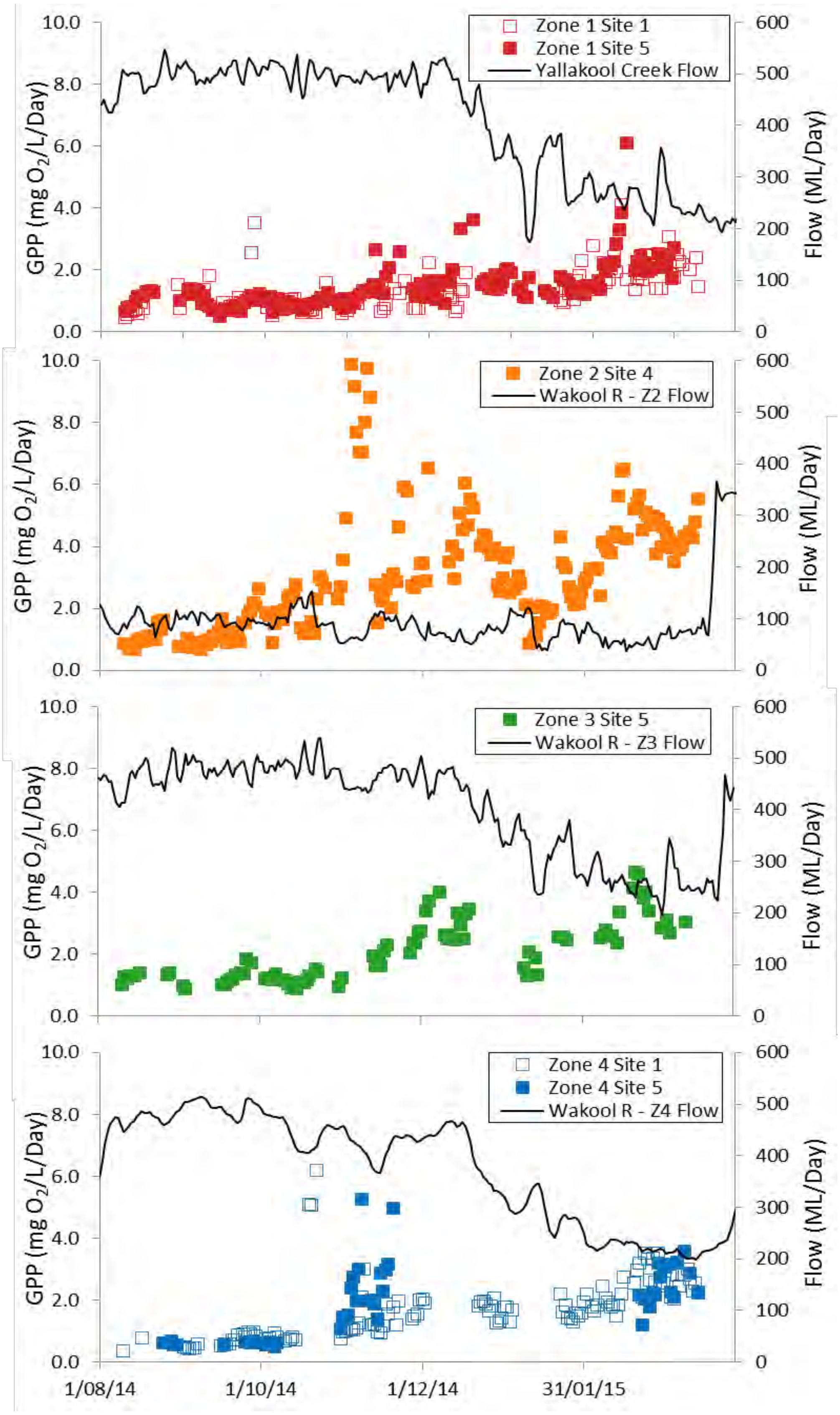

Figure 7.2 Relationships between flow and gross primary production (GPP) for Yallakool Creek (zone 1) and Wakool River (zones 2, 3 and 4) from August 2014 to March 2015

Unlike the small increase in metabolic rate (GPP) in zone 2 Site 4 shown in Figure 7.2, Figure 7.3 illustrates the substantially higher ecosystem respiration (ER) rates at this site compared with sites in the other 3 zones. Field observations indicated that there was substantially more leaf litter and other organic detritus in the shallow waters in zone 2 (R. Watts, pers. comm). This zone, unlike the others, has received only low flows over the past few years. Such accumulations of leaf litter can lead to higher respiration rates (as found here) due to an increase in the fuel (organic matter) for respiration. It is also likely that these accumulations may be the result of the lack of higher flows to re-suspend this organic matter and move it downstream.

The higher respiration rate (and lower P/R ratio, see Figure 7.4) is entirely consistent with the significantly lower dissolved oxygen concentrations found in zone 2 (at Site 4) (see Section 6.4, Figure 6.4). It is this higher respiration rate that causes the depletion of the oxygen concentration and led to the very low DO found in January 2015 and over the period December 2014 until the end of March when monitoring finished.

As noted in Section 6, it is highly likely that the Commonwealth environmental watering actions affecting the flow in zones 1, 3 and 4 played a significant role in ensuring the DO concentrations remained above 4 mg O_2/L. The mechanism of this maintenance of higher DO is most likely a combination of provision of fresh water, and lower respiration rates through lack of accumulation of significant organic carbon detritus in the marginal zones of the river.

As noted with GPP, the Ecosystem Respiration rates in the three zones receiving water from Commonwealth environmental water actions are at the low end of the ‘normal’ range for streams and rivers worldwide (typically around 2 to 20 mg O_2/L/Day, again assuming an average depth of 1 m, Bernot et al. 2010; Marcarelli et al. 2011), whereas the zone 2 median rate of 6.9 mg O_2/L/Day is around the midpoint of reported results. This finding raises an important point about such comparisons. Higher respiration rates in many other systems around the word are coupled with higher re-aeration rates from faster flowing and more turbulent water. Hence the dissolved oxygen concentration in those systems does not drop below 4 to 5 mg O_2/L. This means there is no simple target for an ‘ideal’ respiration rate. The slow, laminar (non-turbulent) flow in lowland rivers such as found in z one 2 increases the risk of low DO concentrations despite what might appear only moderate ecosystem respiration rates.

There was little difference in ecosystem respiration rates from the two sites in zone 1 and zone 4 that both had upstream and downstream data loggers. This indicates that indicates that the stream reach integrated by the logger at site 5 is behaving very similarly to the stream reach above the logger at site 1.

The most striking difference found when comparing the four panels in Figure 7.4 is that the P/R ratio in zone 2 (Site 4) was always below 0.8 whereas the other zones all had periods when this ratio exceeded 1, if not 2. A continual P/R ratio of < 1 indicates that the stream environment is always consuming more oxygen than is being produced through photosynthesis. Hence if physical re-aeration 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 January 2015 (Figure 6.4).

Although the metabolic rates in zone 2 of the Wakool River were higher than the five other sites, the total amount of oxygen (and hence organic carbon) created by photosynthesis or consumed by respiration is determined by the daily load. This load is simply the product of the metabolic rate in mg O_2/L/Day multiplied by the flow in L/Day. The result is in mass of O_2 produced or consumed on that day. The most convenient unit is kg O_2. Table 7.3 summarizes the GPP and ER loads for each of the sites. The table clearly shows that although the Wakool River zone 2 rates are highest, the amount of O_2 produced or consumed is actually *lower* than the other sites due to the much lower daily flow rates.

Table 7.3. Mean daily oxygen loads created by photosynthesis (GPP) and consumed by respiration (ER). Median values are provided in parentheses. All values are ± 1 standard deviation (sd).

Zone & Site	n	GPP Load (kg O_2)	sd GPP	ER Load (kg O_2)	sd ER
Yallakool Ck, zone 1 Site 1	109	500 (460)	200	900 (760)	300
Yallakool Ck, zone 1 Site 5	161	600 (530)	200	1200 (1080)	600
Wakool R, zone 2 Site 4	185	160 (160)	80	400 (400)	200
Wakool R, zone 3 Site 5	85	800 (700)	300	1000 (960)	500
Wakool R, zone 4 Site 1	121	500 (460)	300	700 (670)	400
Wakool R, zone 4 Site 5	48	700 (480)	400	800 (630)	400

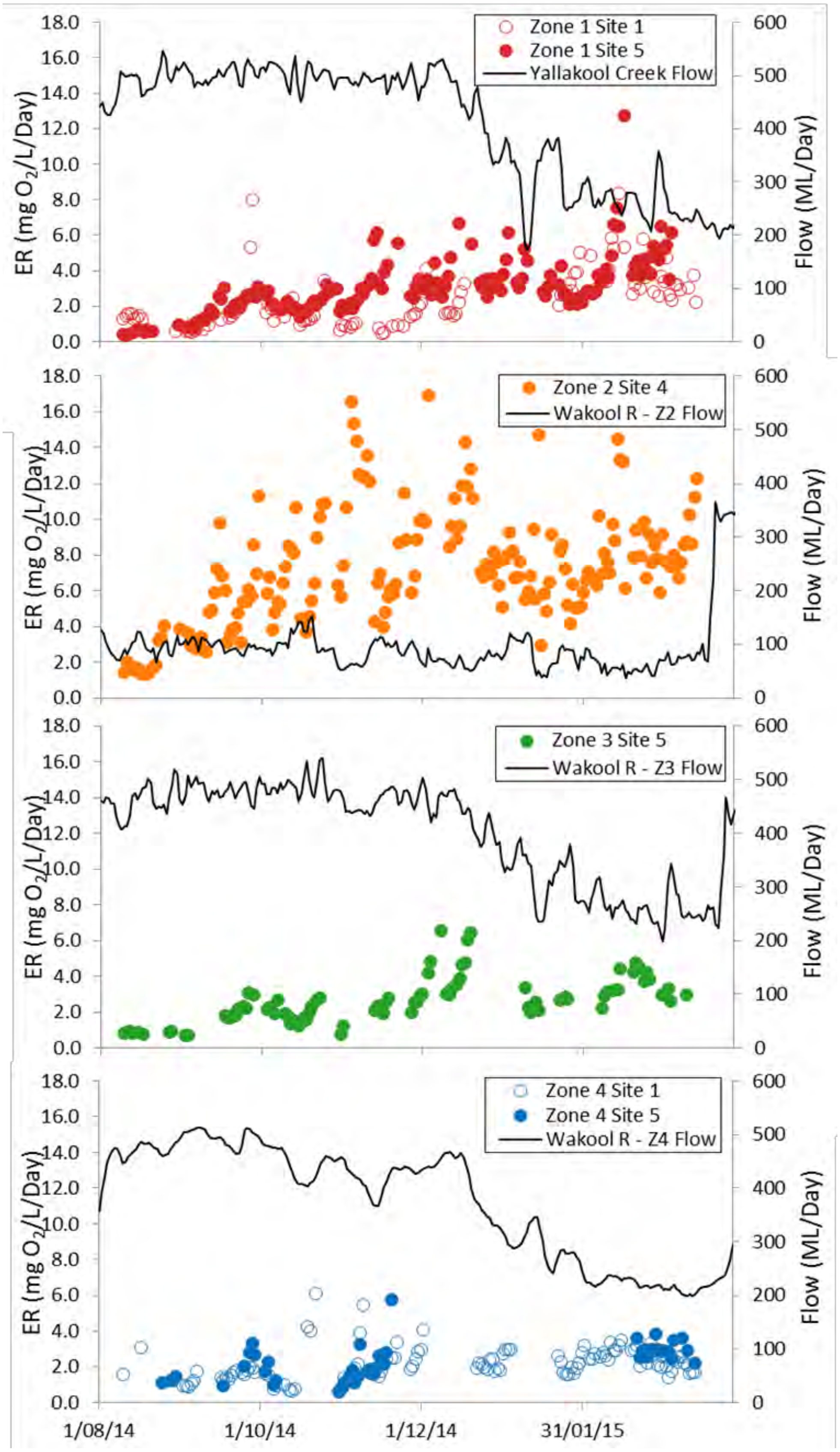

Figure 7.3. Relationships between Flow and Ecosystem Respiration (ER) for Yallakool Creek (zone 1) and Wakool River (zones 2, 3 and 4) from August 2014 to March 2015.

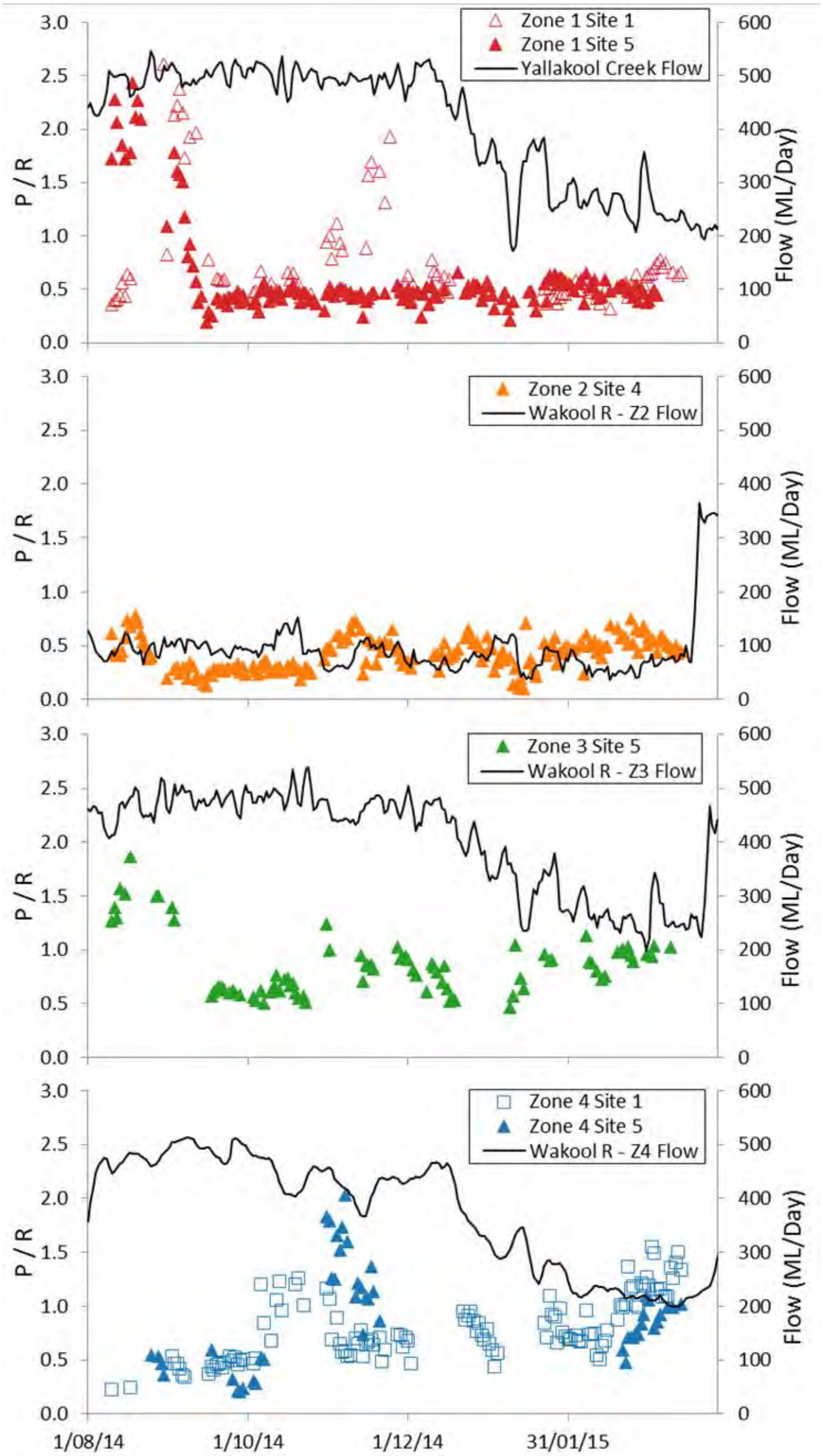

Figure 7.4. Relationships between flow and the primary production to respiration (P/R) ratio for Yallakool Creek (zone 1) and Wakool River (zones 2, 3 and 4) from August 2014 to March 2015.

Primary production is expected to depend upon temperature and light while respiration is also expected to increase with increasing temperature. Consequently, linear regressions were performed between the two metabolic parameters and these expected explanatory variables. In addition, both GPP and ER were regressed against flow. Finally both the daily GPP and ER Loads were also regressed against flow. The results of these regressions are presented in Table 7.4.

Table 7.4. Exploration of linear relationships between the metabolic parameters (GPP and ER) and flow, light and temperature for the six study sites, August 2014 to March 2014. Statistical significance was inferred at $p < 0.05$.

Zone & Site		GPP vs Flow	GPP vs Temp	GPP vs Light	GPP Load vs Flow	ER vs Flow	ER vs Temp	ER Load vs Flow
Zone 1 Site 1	r^2	0.039	0.20	0.043	< 0.01	0.41	0.27	0.024
	p	< 0.0001	< 0.0001	0.035	> 0.05	< 0.0001	< 0.0001	> 0.05
	slope	-0.0037	0.063	Positive	ca 0	-0.0085	0.167	ca 0
	slope sd	0.0004	0.013	-	-	0.0010	0.027	-
Zone 1 Site 5	r^2	0.030	0.29	0.056	0.05	0.25	0.48	0.002
	p	< 0.0001	< 0.0001	0.003	> 0.05	< 0.0001	< 0.0001	> 0.05
	slope	-0.0036	0.079	Positive	ca 0	-0.0077	0.233	ca 0
	slope sd	0.0004	0.010	-	-	0.0011	0.020	-
Zone 2 Site 4	r^2	0.180	0.32	0.21	0.041	0.15	0.37	0.15
	p	< 0.0001	< 0.0001	< 0.0001	0.0058	< 0.0001	< 0.0001	< 0.0001
	slope	-0.041	0.211	Positive	0.89	-0.064	0.394	3.5
	slope sd	0.007	0.023	-	0.32	0.011	0.039	0.6
Zone 3 Site 5	r^2	0.350	0.52	0.22	< 0.01	0.13	0.49	0.022
	p	< 0.0001	< 0.0001	< 0.0001	> 0.05	0.0006	< 0.0001	> 0.05
	slope	-0.0062	0.134	Positive	ca 0	-0.0051	0.173	ca 0
	slope sd	0.0009	0.014	-	-	0.0014	0.020	-
Zone 4 Site 1	r^2	0.340	0.24	0.023	< 0.01	0.11	0.19	0.11
	p	< 0.0001	< 0.0001	> 0.05	> 0.05	0.0003	< 0.0001	0.0002
	slope	-0.0054	0.120	*Positive*	ca 0	-0.0027	0.098	1.11
	slope sd	0.0007	0.020	-	-	0.0007	0.019	0.29
Zone 4 Site 5	r^2	0.24	0.30	0.073	< 0.01	0.27	0.25	0.099
	p	0.0004	< 0.0001	> 0.05	> 0.05	0.0002	0.0003	0.029
	slope	-0.0048	0.161	*Positive*	ca 0	-0.0044	0.130	1.06
	slope sd	0.0013	0.036	-	-	0.0011	0.033	0.47

As expected, both GPP and ER daily rates were positively correlated with mean daily water temperature (Table 7.4). As noted in the Wakool River and Yallakool Creek during the short term monitoring program (Watts et al. 2014), GPP was also weakly correlated with light although the plots showed a very large scatter. One initially surprising result was the negative correlation between flow and both GPP and ER. This appears to indicate that increasing flow suppresses GPP and ER, whereas it might be expected that, after a lag time of perhaps 1-2 weeks to enable algal growth to occur, increased flow should induce higher rates of these two basic ecosystem processes. The solution to this apparent inconsistency arises from the hydrograph. With the exception of the aforementioned anomalous zone 2 Site 4 in the Wakool River, the highest flows were in the period up to mid-

December. After this time, flows declined. This period of flow recession coincided with increasing water temperatures and daily irradiance. It is strongly suspected therefore that the apparent negative response to flow increase is actually caused by the high flows in the 'low' metabolic activity period of late winter through springtime and lower flows in peak biological activity periods of summer through to mid-autumn. Decoupling these effects will require much greater variability in daily flows within each season. One benefit of creating higher winter time flows *in all zones* would be the removal of much of the organic matter detritus such as found in zone 2 Site 4. This would then hopefully obviate the low DO observed during summer.

Daily loads of DO created through Primary Production and consumed by respiration were mostly invariant with flow although the lack of variation within seasons precludes any further analysis of trends and discernment of mechanisms.

7.5 Discussion

The flow patterns over the period Aug 10 to March 15 when metabolism was measured in the four zones had very little variability in flow over a days to weeks time-frame. Zones 1, 3 and 4 that received the environmental water had an extended period of relatively constant flow until mid-December followed by a decline to 40-60 % of the high flow values over the subsequent months of monitoring. Zone 2 had a relatively constant monthly average over the study period. Metabolism is expected to respond on a perhaps 10-20 day time frame following flow events (this time frame is conjectural based on typical algal doubling rates), as this corresponds to sufficient time post nutrient addition to generate a significantly higher biomass of primary producers. The lack of variation in flow in all zones from August to December 2014 made it very difficult to unambiguously determine the cause of the observed increases in metabolic parameters after December on a generally falling hydrograph. The increases were probably due to a combination of seasonal effects (warmer water, more sunlight) coupled with a smaller 'dilution' effect if most of the metabolism is driven by the benthos (benthic algae and the much higher microbial communities in surficial sediments compared to the water column), because having a smaller volume of water overlying the sediment will result in smaller dilution of the oxygen change. This phenomenon (less dilution of a benthically-derived oxygen change) is the most likely cause of the higher metabolic rates observed in zone 2 (Upper Wakool River). Shallower water also means greater irradiance of the sediment surface, facilitating biofilm growth. This last point is perhaps not as important given the very weak, albeit positive, relationships found between daily irradiance and GPP (Table 7.3).

Hydraulic modelling (Section 5) showed that Commonwealth environmental water resulted in a further 10% wetted area (on average) in the zones receiving environmental water. This small increase was insufficient to detect any effect on metabolic parameters. It was hypothesized that increased wetted area should result in higher metabolic rates, but this hypothesis is untestable based on this year's data.

As found in earlier work (Watts et al. 2014), the rates of GPP and ER were generally low in comparison to many other systems worldwide (Bernot et al. 2010; Marcarelli et al. 2011). This is almost certainly due to the extremely low bioavailable N and P concentrations (see Section 6).

The major outcome of relevance to management of this system from the metabolism results is the effect of *not* having any Commonwealth environmental watering action in zone 2. This zone had very low dissolved oxygen concentrations (below 4 mg O_2/L) during January 2015. This low DO is 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 re-aeration. As noted earlier, re-aeration is determined by water velocity and in particular, turbulence (which enhances mixing of air, and hence oxygen, into the water column). Median re-aeration rates across all 4 zones fell within the range of 0.8 to 1.9 /Day, typical of slow flowing, low gradient streams with generally only a limited amount of physical structures generating turbulence. It is unlikely the re-aeration 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.

Whilst the Commonwealth environmental watering action in Yallakool Creek in 2014-15 did not appear to stimulate gross primary production (and therefore basal food resources for invertebrates and fish), they played an important role in preventing poor water quality.

7.6 References

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8. RESPONSE OF RIVERBANK AND AQUATIC VEGETATION TO COMMONWEALTH ENVIRONMENTAL WATERING

Aquatic plants in the Wakool River zone 3 (Photo: Robyn Watts)

Summary

- The diversity and percent cover of aquatic and riverbank vegetation was monitored monthly from October 2014 to June 2015 at four sites in four hydrological zones in the Edward-Wakool system. Yallakool Creek and the Wakool River zones 3 and 4 received Commonwealth environmental water. The Wakool River zone 2 did not receive environmental water.
- The most abundant taxa observed include rush (*Juncus* spp.) floating pondweed (*Potamogeton tricarinatus*), old man weed (*Centipeda cunninghamii*), *Chara* spp., water couch (*Pseudoraphis spinescens)*, milfoil (*Myriophyllum* spp.), sedge (*Cyperus* spp.) and common spike rush (*Eleocharis acuta*). There were more taxa recorded in the three zones that received Commonwealth environmental water (zones 1, 3 and 4).
- There was a higher percent cover of riverbank and aquatic vegetation growing on the inundated edge of the river zones 3 and 4 that received Commonwealth environmental water than in the Wakool River zone 2 that did not receive environmental water. The cover of vegetation in Yallakool Creek zone 1 was not significantly different to that in zone 2. There was a significant positive correlation between percent cover of vegetation and average wetted benthic area of each river reach.
- There was a significantly different assemblage of vegetation among zones. The species contributing to the dissimilarity between zone 2 (no environmental water) and zones 1, 3 and 4 (environmental water) include taxa such as *C. cunninghamii* that responds to wetting of the riverbank. Several aquatic taxa such as *Potamogeton* spp., *Myriophyllum* spp. and *Azolla* spp. were absent from zone 2. Other aquatic taxa such as *Chara* spp., *E. acuta* and *Limosella* spp. were in very low abundance in zone 2.
- The response of aquatic and riverbank vegetation to environmental watering has been an ongoing process. There has been a gradual improvement in vegetation observed at sites that have received Commonwealth environmental water over the past three years.
- Between April and June 2015 there was a reduction in cover of aquatic vegetation as some taxa became desiccated or affected by frost and entered a period of dormancy during winter

8.1 Background

Riverbank vegetation and aquatic vegetation play an important role in the trophic interactions and food webs of aquatic ecosystems. Aquatic plants support riverine productivity and food webs and provide habitat for fish, invertebrates, frogs and birds (Roberts and Marston 2011). The cover and composition of aquatic vegetation can determine the availability of sites for macro-invertebrates and frogs to lay eggs and calling and spawning locations for frogs (Wassens et al. 2010). Furthermore, the response of aquatic and riverbank vegetation following a flow event can assist understanding the response of other biological indicators.

Flow management and the water regime in a river system can affect the growth and maintenance of adult plants. In addition it can strongly influence reproductive cycle, 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). Differences in seasonal patterns of inundation within a single year can result in different survival, growth and reproduction responses of riverbank and aquatic plant species (Lowe 2002). 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 herbaceous riverbank species (Lowe et al. 2010).

8.2 Questions

One of the objectives of the Yallakool Creek Environmental Watering Action in the Edward-Wakool system was to contribute to maintain or improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants (section 2.3). To evaluate this objective the following questions relating to aquatic vegetation were addressed:

Q1: *What did Commonwealth environmental water contribute to the total percent cover of riverbank and aquatic vegetation?*

Q2: *What did Commonwealth environmental water contribute to the percent cover of abundant riverbank and aquatic vegetation taxa?*

Q3: *What did Commonwealth environmental water contribute to the diversity of riverbank and aquatic vegetation?*

We hypothesised that the total percent cover and cover of abundant taxa across the 2014-15 monitoring period would be significantly higher in the zones that received environmental water compared to the Wakool River (zone 2) that did not receive environmental water.

8.3 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 October 2014 and June 2015. At each site five permanent 20 m long transects were established parallel with the river channel (Figure 8.1). Star pickets were installed at each end of the permanent transect. The lowest transect on the riverbank was labelled as transect 1 and the other four 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 m of vertical height of the bank. Transect one was 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.

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 a known height of riverbank. The taxa at each 50 cm point quadrat along the 20 m transect (40 points on each transect) was 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 from the peg at transect 3.

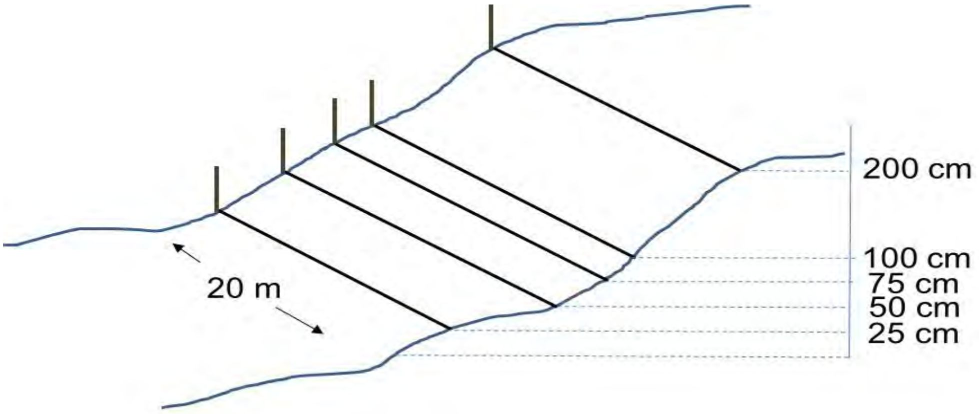

Figure 8.1. Line diagram showing spatial arrangement of transects on the river bank at each site.

Data analysis

Each species was classified into one of three categories (submerged, amphibious and terrestrial) 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.

The point quadrat data were used to estimate the percent cover of riverbank and aquatic vegetation for each transect at 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 minus the number of points recorded as log/tree trunk. This is because no vegetation would have been able to grow at that point if a log or tree trunk is present.

To test if the percent cover of vegetation was significantly different among the four zones across the entire monitoring period, the total percent cover of all taxa was analysed using a one way ANOVA with zone as the treatment factor. Analyses were undertaken incorporating the data across the entire monitoring period (October 2014 to June 2015). This enabled a comparison of zones that received environmental water to zones that did not receive environmental water. Analysis of the percent cover for the eight most common taxa were analysed individually using Kruskal-Waklis 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.

The diversity of taxa observed in transects that received environmental water was compared to transects that did not receive environmental water. The vegetation assemblage was compared among hydrological zones using one-factor analysis of similarities (ANOSIM) (PRIMER v6). Similarity percentages (SIMPER) was used to identify the taxa contributing most to the dissimilarities across zones. The ANOSIM and SIMPER analyses were undertaken using PRIMER V6 software. The data were plotted using non-metric multidimensional scaling ordination.

8.4 Results

Description of riverbank and aquatic vegetation in the Edward-Wakool system in 2014-15

A total of 34 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between October 2014 and June 2015. Three taxa were classified as submerged, 14 were amphibious and 17 were terrestrial (Table 8.1). The ten taxa having the highest percent cover were *Juncus* spp. *Potamogeton tricarinatus*, *Centipeda cunninghamii*, the charophyte *Chara* spp., *Pseudoraphis spinescens, Eleocharis acuta*, *Myriophyllum* spp, grasses, Azolla spp. and the mudwort, *Limosella* spp. It is not surprising that nine of the ten most abundant taxa were classified as submerged or amphibious taxa, as the surveys were undertaken in the active littoral zone of the riverbank. The Wakool River zone 3 had a lower proportion of terrestrial taxa (33.3%) compared to Yallakool Creek (50%) Wakool R zone 2 (39%) and Wakool R zone 4 (37.5%) (Table 8.1).

Changes in the cover of several taxa were observed over the year. *Chara* spp. grew strongly in the shallow edges of zones 1, 3 and 4 during the environmental watering (Figure 8.2, 8.3a), first appearing in transect 3 and then retreating to transects 2 and 1 on the recession of the environmental watering action. *Chara* spp. was desiccated following the recession in January 2015 and was essentially absent by March 2015. *Eleocharis* seedlings were observed to germinate on the damp riverbank after the recession of environmental water (Figure 8.3b). Changes in the cover of vegetation were also noted during the period of lower flows. For example, *Azolla* increased in abundance (especially in zone 3) in late summer/early autumn, which is to be expected during periods of lower discharge (Figure 8.2, 8.3c). In late autumn and early winter (April and May 2015) there was a slight reduction in cover of aquatic vegetation as some species became desiccated, or affected by frost and entered a period of dormancy during winter. For example, *Potamogeton* leaves were observed to go brown as it entered a period of dormancy (Figure 8.3d) and beds of *Myriophyllum* were exposed (Figure 8.3e). In June there was very low or no flow in Yallakool Creek and the Wakool River and flows in this system ceased in June 2015. During this period aquatic plants were observed to be drying on the river bed (Figure 8.3f).

Table 8.1: List of riverbank and aquatic vegetation taxa recorded at Long term Intervention Monitoring sites in the Edward-Wakool system in 2014-15. Taxa are listed in order of relative abundance as measured by number of point quadrats in which they were recorded. Group categories: S = submerged, A = amphibious, T = terrestrial. zone 1 = Yallakool Creek, zone 2 = Upper Wakool River, zone 3 = Wakool River upstream of Thule Creek, zone 4 = Wakool River downstream Thule Creek. * = present in hydrological zone

Common Name	**Taxonomic name**	**Group**	**Total number of occurrences**	**Presence in hydrological zones**			
				1	**2**	**3**	**4**
Rush	*Juncus* spp.	A	1335	*	*	*	*
Pondweed	*Potamogeton tricarinatus*	A	588			*	*
Old man weed	*Centipeda cunninghamii*	A	545	*	*	*	*
Charophyte	*Chara* spp.	S	408	*	*	*	*
Water couch	*Pseudoraphis spinescens*	A	403	*	*	*	*
Common spikerush	*Eleocharis acuta*	A	356	*	*	*	*
Milfoil	*Myriophyllum* spp.	A	355	*		*	*
Grass		T	331	*	*	*	*
Duckweed	*Azolla* spp.	A	191	*		*	*
Mudwort	*Limosella* spp.	A	164	*	*	*	*
Knotweed	*Polygonum* spp.	T	135	*	*		*
Sedge	*Cyperus* spp.	A	126	*	*	*	*
Gum seedling	*Eucalyptus* spp.	A	114	*	*	*	*
Ragwort daisy	*Senecio* spp.	T	101	*	*	*	*
Water primrose	*Ludwigia* spp.	A	92				*
Hedgehyssop	*Gratiola* spp.	T	78	*	*		*
Algae		S	75		*	*	*
Clubrush	*Scirpus* spp.	A	58		*		*
Lippia	*Phyla canescens*	T	48	*			
Daisy	*Epaltes* spp.	T	44				*
Joyweed	*Alternanthera* spp.	T	39	*	*	*	*
Lignum	*Muehlenbeckia florulenta*	A	29			*	
Australian bluebell	*Wahlenbergia* spp.	T	29			*	*
Redstem	*Ammannia* spp.	A	23				*
Cudweed	*Gnaphalium* spp.	T	19	*			*
Herb		T	8	*	*	*	*
Loosetrife	*Lythrum* spp.	A	6	*	*		
White daisy	*Calotis* spp.	T	4			*	
Hypericum	*Hypericum* spp.	T	3		*		
Germander	Teucrium spp	T	3	*			
Salt bush	*Atriplex* spp.	T	2	*			
Goodenia	*Goodenia* sp	T	2			*	
Clover	*Medicago* spp.	T	2	*			
Ribbon Weed	*Vallisneria australis*	S	1			*	
Total Taxa				**22**	**18**	**21**	**24**

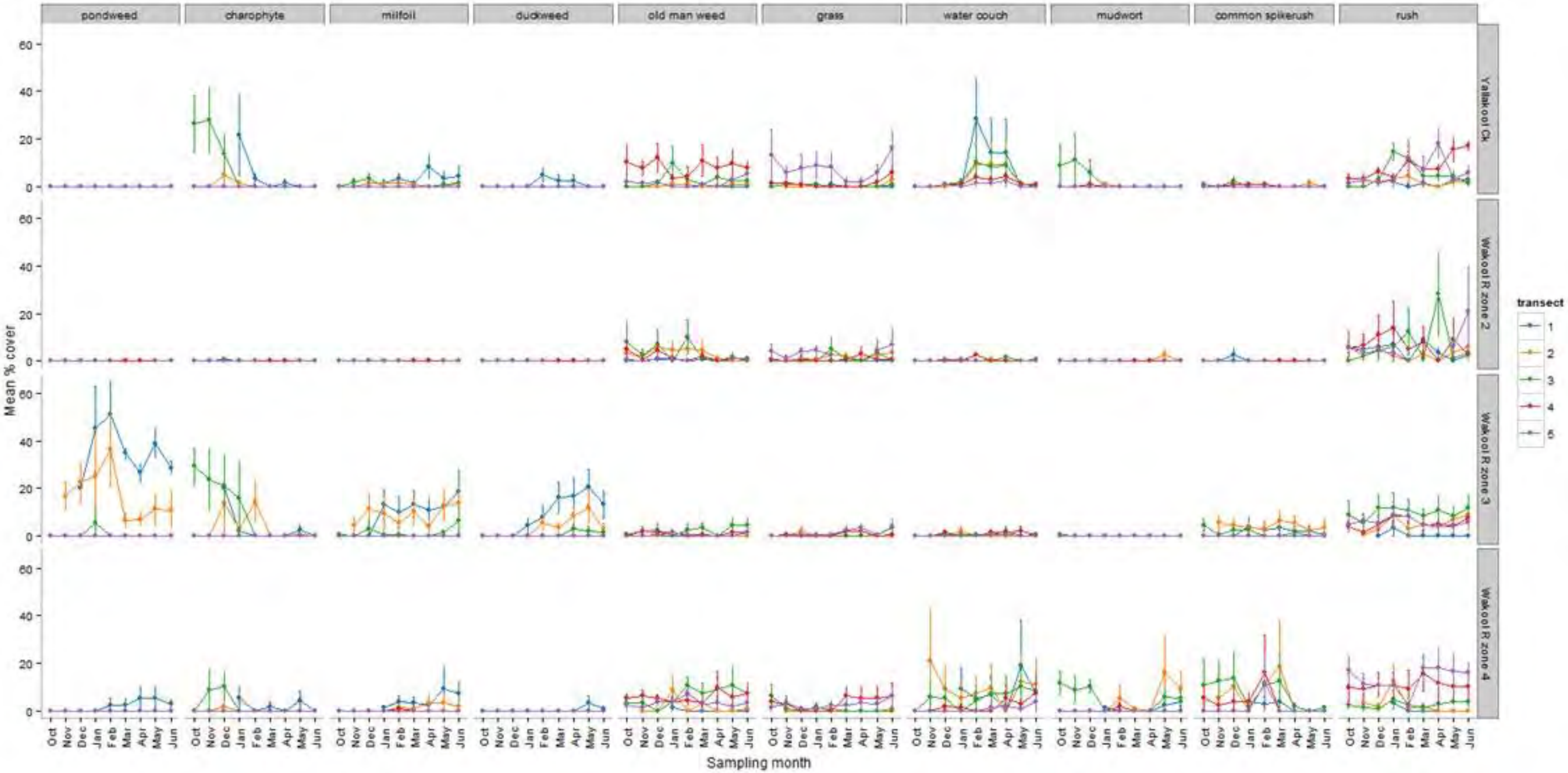

Figure 8.2. Mean percent cover (±SE) of ten most abundant riverbank and aquatic vegetation taxa monitored monthly at 16 sites across 4 hydrological zones in the Edward-Wakool system between October 2014 and June 2015. Transect 1 was lowest on the river bank.

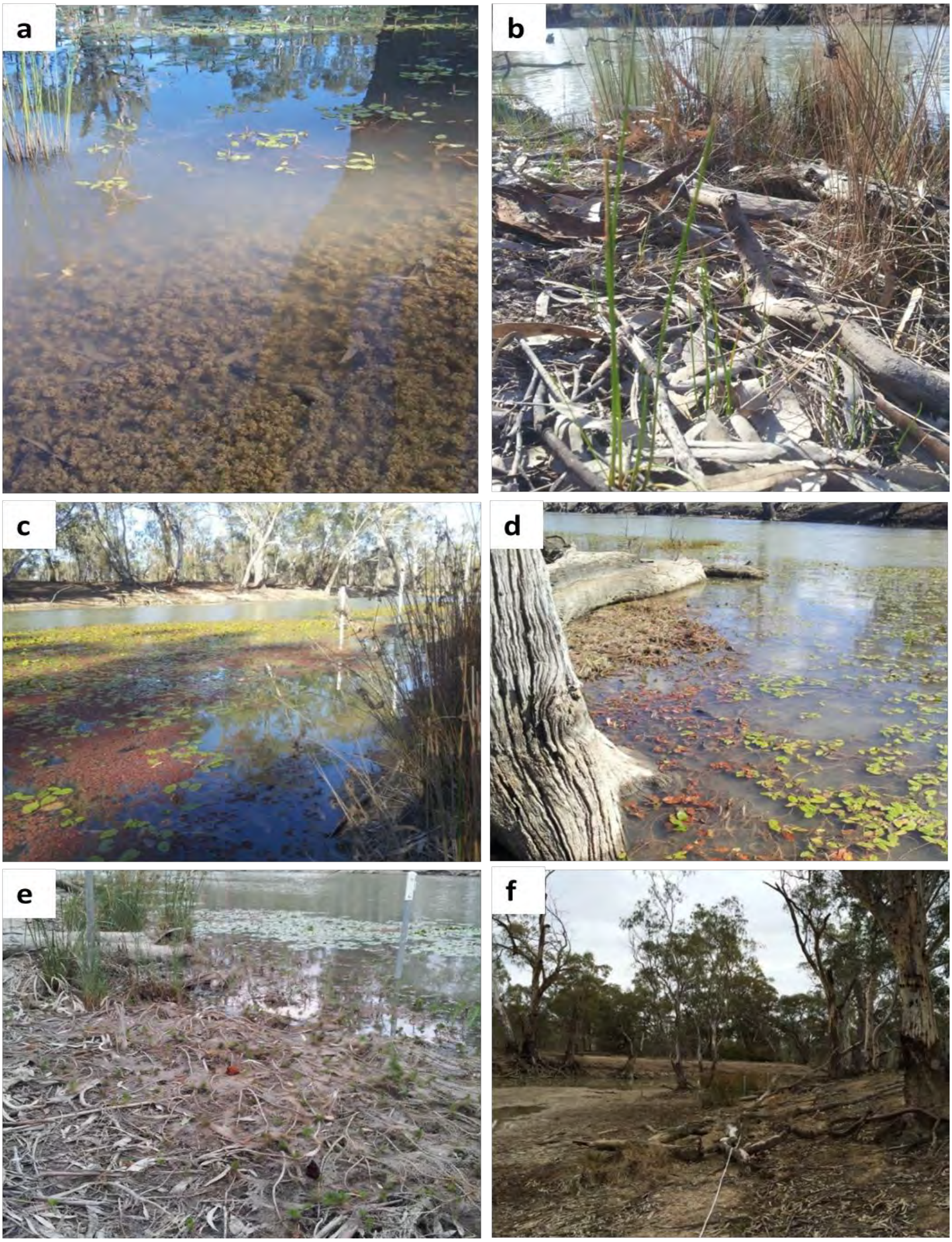

Figure 8.3. Photos of aquatic and riverbank vegetation in the Edward-Wakool system in 2014-15. a) The charophyte *Chara* spp. growing at the edge of the water at site 1 zone 3 in November 2014. b) Small *Eleocharis acuta* plants sprouting on the edge of zone 3 site 3 following the recession of environmental water. c) *Azolla* spp. increased during lower flows, d) *Potamogeton tricarinatus* leaves turning brown at onset of winter e) exposed *Myriophyllum* spp., and f) dry river bed at zone 3 site 3 in June 2015 during period of no flow.

Change in total 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 the hydrological zones that received environmental water compared to the Wakool River (zone 2) that did not receive environmental water. Results of the ANOVA partially support this hypothesis (Table 8.2, Figure 8.4). There was a significantly higher percent cover of instream aquatic vegetation growing in the Wakool River zones 3 and 4 that received Commonwealth environmental water compared to zone 2 that did not receive environmental water (F=21.548, P< 0.001). The total percent cover of vegetation in Yallakool Creek that received environmental water was not significantly higher than that in the Wakool River zone 2.

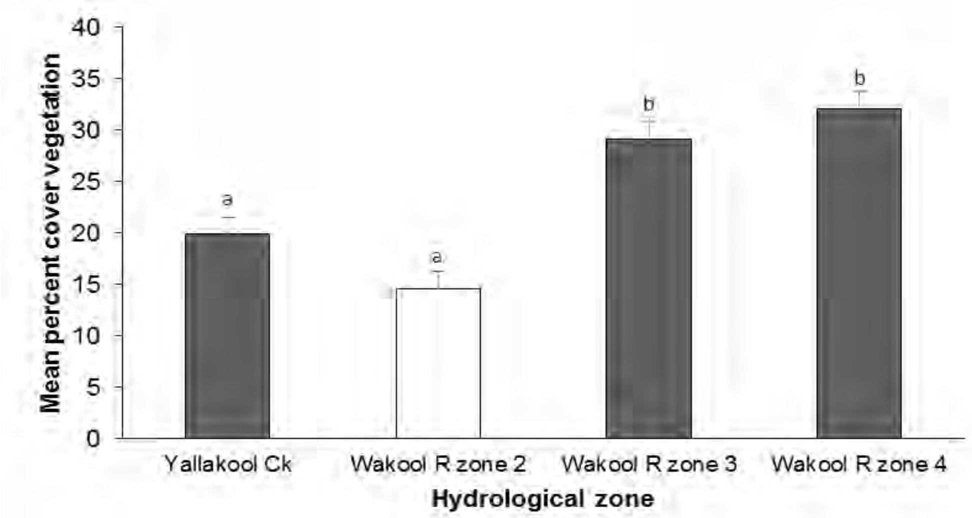

Figure 8.4: Mean percent cover (±SE) of riverbank and aquatic vegetation sampled in 2014-2-15 in the Edward-Wakool Selected Area. Yallakool Creek and the Wakool River zones 3 and 4 received Commonwealth environmental water in 2014-15 (black bars) and Wakool River zone 2 did not receive environmental water (white bar). A and B denotes unique subsets based on posthoc tests.

The response of vegetation to environmental watering was strongly influenced by geomorphology, with a significant positive correlation between percent cover of vegetation and average wetted benthic area estimated for the discharge experienced between August 2014 and January 2015 during the environmental watering action (Figure 8.5). Zone 2 that did not receive environmental water had the smallest wetted benthic area. This relationship helps explain the different responses of aquatic and riverbank vegetation to environmental watering in different hydrological zones.

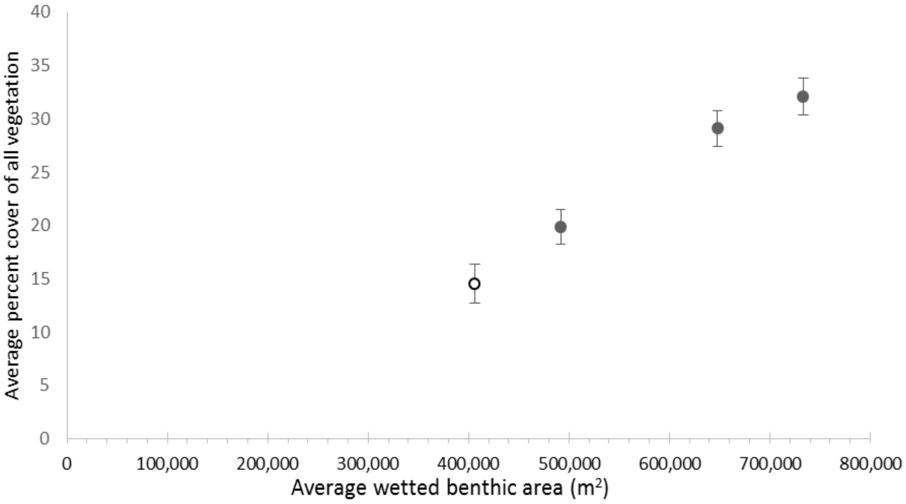

Figure 8.5: Relationship between mean wetted benthic area (m^2) for each hydrological zone and average percent cover (±SE) of riverbank and aquatic vegetation sampled in 2014-2-15 in the Edward-Wakool Selected Area.

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

There were three types of responses of individual taxa to Commonwealth environmental watering:

- Responses for some taxa partially supported the hypothesis. For example, *P. tricarinatus* and *Myriophyllum* spp. had significantly higher cover in Wakool River zone 3 compared to all other zones and were absent from zone 2. *Chara* spp., *E. acuta, C, cunninghamii, P. spinescens* and grass had increased cover of aquatic and riverbank taxa in one or more of the hydrological zones that received environmental water, compared to zone 2 that did not receive environmental water.
- For terrestrial grasses there were significant differences in percent cover among zones, but the zones receiving environmental water was not different to zone 2 (Table 8.2, Figure 8.6).
- For *Juncus* spp there was no difference in mean percent cover among all zones (Table 8.2).

Table 8.2. Results of one-way ANOVAs comparing mean percent cover of aquatic and riverbank vegetation cover of all taxa and assessed individually for the eight most common taxa across river zones for the sampling period October 2014 to June 2015. *P* values <0.05 indicates a significant difference in cover of vegetation among zones.

Analysis	df	F-value	p	significance
All taxa	3	21.548	0.000	***
Juncus spp.	3	1.788	0.158	n.s
Potamogeton tricarinatus	3	23.368	0.000	***
Centipeda cunninghamii	3	16.563	0.000	***
Chara spp.	3	3.540	0.028	*
Pseudoraphis spinescens	3	5.441	0.050	**
Eleocharis acuta	3	7.621	0.000	**
Myriophyllum spp.	3	15.456	0.000	***
Grass	3	3.914	0.016	*

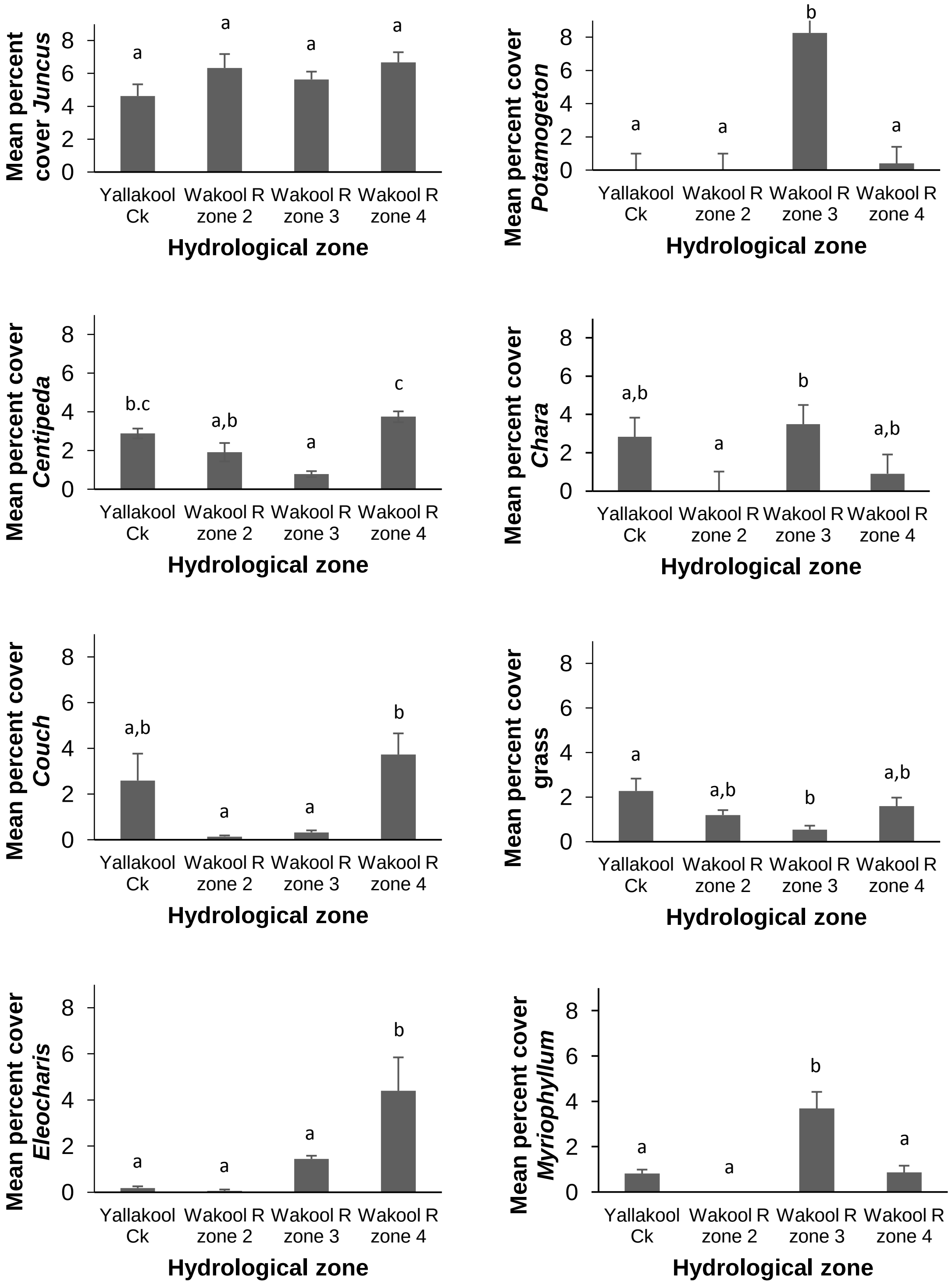

Figure 8.6. Mean cover (±SE) of eight most abundant riverbank and aquatic vegetation sampled in 2014-2-15 in the Edward-Wakool Selected Area. i) *Juncus* spp., ii) *Potamogeton tricarinatus,* iii) *Centipeda cunninghamii, iv) Chara* spp., v) *Pseudoraphis spinescens, vi) Eleocharis acuta, vii) Myriophyllum* spp., and viii) grass. Significant differences in mean cover across the four study zones are shown using small letters.

Effects of Commonwealth environmental watering on assemblage and taxonomic diversity of riverbank and aquatic vegetation

More taxa were recorded in zones 1 (n=22), zone 3 (n=21) and zone 4 (n=24) that received Commonwealth environmental water than in zone 2 (n=18) tat did not receive the environmental flow (Table 8.1).

It was expected that the vegetation assemblage in the Wakool River zone 2 that did not receive Commonwealth environmental water would be significantly different to the assemblage to zones 1, 3, and 4 that received Commonwealth environmental water in 2014-15. The four hydrological zones had significantly different assemblage of vegetation (Global R = 0.402, p = 0.001). The vegetation assemblage in zone 3 (environmental water) was most different to zone 2 (no environmental water), and this can be seen in the ordination (Figure 8.7) as there is no overlap of sites from these zones. However, there was overlap of the vegetation assemblages between zone 1 and 4 (receiving environmental water) and the Wakool River zone 2 (no environmental water).

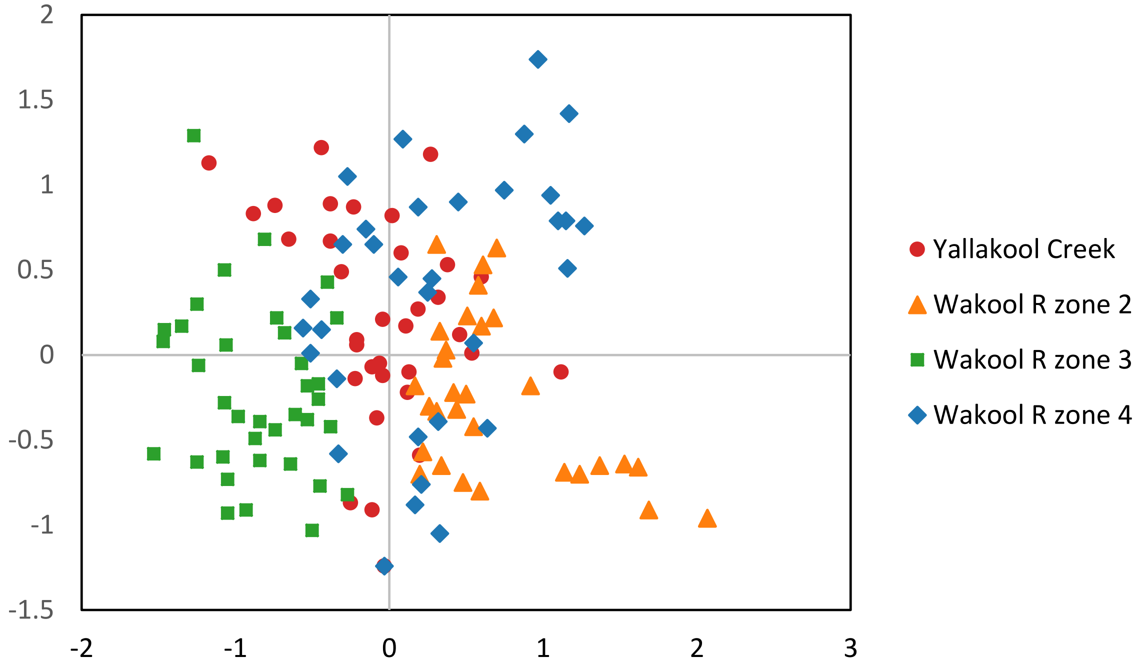

Figure 8.7. Multi-dimensional scaling ordination plot based on riverbank and aquatic vegetation assemblages from four hydrological zones in the Edward-Wakool system. Symbols represent sites within each hydrological zone. Stress = 0.24. Points that are closer together in the ordination have the most similar vegetation assemblage. Yallakool Creek and the Wakool River zones 3 and 4 received the environmental flow and Wakool River zone 2 did not receive the environmental flow.

The taxa contributing most to the dissimilarity between zone 2 (no environmental water) and zones 1, 3 and 4 (environmental water) include *C. cunninghamii* that responds to wetting of the riverbank (Table 8.3). Several aquatic taxa such as *P tricarinatus*, *Myriophyllum* spp. and *Azolla* spp. were absent from zone 2 (no environmental water) and other aquatic taxa such as *Chara* spp., *E. acuta* and mudwort were in very low abundance in zone 2 (Table 8.3). The zones receiving environmental water always had higher abundance of aquatic taxa such as *Chara* spp., *P. tricarinatus*, *Myriophyllum* spp., and taxa that respond after inundation of riverbank, such as *Limosella* spp. (Table 8.3).

Table 8.3: Results of SIMPER analysis showing the abundance of taxa that contributed most to the difference between zone 2 (no environmental water) and zones 1, 3 and 4 (received Commonwealth environmental water)

Comparison	**species**	**% contribution to difference between zones**	**Average abundance Zone 2 (no CEW)**	**Average abundance (zones with CEW)**
Wakool R Zone 2 and Yallakool Creek			**Zone 2**	**Zone 1**
	Centipeda cunninghamii	11.91	0.94	1.39
	Juncus spp.	10.83	2.16	2.06
	grass	10.24	0.67	1.08
	Chara spp.	9.53	0.02	1.01
	Eucalypt seedling	9.10	0.87	0.06
	Pseudoraphis spinescens	8.18	0.17	0.87
	Myriophyllum spp.	6.00	0.00	0.62
Wakool R Zone 2 and Wakool R zone 3			**Zone 2**	**Zone 3**
	Potamogeton spp.	18.22	0	2.54
	Myriophyllum spp.	9.77	0	1.44
	Chara spp.	9.64	0.02	1.15
	Juncus spp.	8.51	2.16	2.25
	Centipeda cunninghammii	6.68	0.94	0.58
	Azolla spp.	6.60	0	1.02
	Eucalypt seedling	6.05	0.87	0.35
Wakool R zone 2 and Wakool R zone 4			**Zone 2**	**Zone 4**
	Juncus spp.	10.51	2.16	2.34
	Centipeda cunninghammii	10.23	0.94	1.71
	Pseudoraphis spinescens	8.42	0.17	0.97
	Eleocharis acuta	8.05	0.05	1.11
	Polygonum spp.	7.94	0.37	0.96
	Mudwort	7.64	0.04	1.02
	grass	7.27	0.67	0.82
	Eucalypt seedling	6.22	0.87	0.31

8.5 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. Changes in the cover of vegetation at the monitoring sites were observed over time. Aquatic vegetation increased in cover in the shallow edges of zones 1, 3 and 4 during the environmental watering (August 2014 to January 2015) and contracted to transect 2 and then to transect 1 on the recession of the environmental watering action. Several aquatic taxa such as *P. tricarinatus*., *Myriophyllum* spp. and *Azolla* spp. were absent from the Wakool River zone 2 that did not receive Commonwealth environmental water, and other taxa such as *Chara* spp., *E. acuta* and *Limosella* spp. 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. Several components of the flow regime (duration, magnitude, rate of recession) and the river channel geomorphology can influence the response of aquatic vegetation. 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. The higher percent cover of vegetation at zones 3 and 4 reflects an increase in aquatic vegetation that have sprouted and grown in the shallow water during the period of inundation (e.g. *Chara* spp.), and also taxa that increased in cover following the environmental watering action after the water has receded. Some taxa such as *E. acuta* grow more vigorously in damp or saturated soils than in shallow water (Blanch and Brock 1994) and *Cyperus* spp. does not germinate under water but regeneration occurs with water level recession (Roberts and Marston 2011). Thus the larger the area of shallow inundation created during the watering action in combination with the recession of the event creates the greatest opportunity for plants to grow and germinate.

The watering action in 2014-15 was managed with a slower rate of recession than in 2013-14. The recession of about 40cm occurred over 30 days until it reached operational flows in the range of 200 to 240 ML/day. 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. 2014). The longer recession in 2014-15 resulted in longer duration of persistence of some taxa, such as *Chara* spp and *Limosella* spp. (Figure 8.8). The dried algae that persists on the riverbank sediment after desiccation would provide nutrients to help 'kick-start' a river productivity response during subsequent inundation events.

The response of aquatic and riverbank vegetation to environmental watering has been an ongoing process and the observations in 2014-15 document a continuation of a gradual improvement in vegetation in this system over the past few years. In addition to the watering action in 2014-15, Commonwealth environmental water was delivered to Yallakool Creek in 2011-12, 2012-13 and 2013-14, thus zones 1, 3 and 4 have been influenced by environmental water over the past 4 years. While vegetation was not formally monitored in all of the hydrological zones during that period, landholders and other community members have commented that the vegetation response to flows in 2014-15 was stronger than in 2012-13 and 13-14. It is likely that the response of riverbank and aquatic vegetation to environmental watering has been cumulative over time, as the previous watering in these zones would have enabled rhizomes of plants such as *E. acuta* or stolons of other aquatic taxa (such as *Vallisineria australis*) to spread or plants to set seed. This would contribute to the continuous improvement in response of riverbank and aquatic vegetation to environmental watering that has been observed in this system over time.

One of the longer lived taxa, *Juncus spp.*, did not significantly increase in percent cover in response to the environmental watering action. The cover of this species in Wakool River zone 2 was similar to that in the other three zones. However, there appeared to be some recruitment response of this species to Commonwealth environmental water. *Juncus* plants were also observed to be across a wide size range of zines including new recruits in zones 1, 3 and 4 there were plants suggesting recruitment has occurred during e-watering over 2012-13, 2013-14 and 2014-15, whereas in zone 2 where there has been no environmental flow the *Juncus sp.* plants were all of similar height. In the Wakool River zone 2 *Juncus* spp. tended to occur in one or two narrow bands at a height of the riverbank that corresponded with the maximum height of a previous unregulated event or at the water level of the dominant operational flow (Figure 8.9).

Figure 8.8: Mudwort *Limosella* spp. in zone 4 Wakool River, January 2015 during the e-watering recession. (Photo: S. Healy)

Figure 8.9. *Juncus* spp. occurring in a narrow band in the Wakool River zone 2 that did not receive Commonwealth environmental water. (Photo: R. Watts)

Acknowledgments

The field monitoring was undertaken by Sascha Healy and Robyn Watts, with assistance on some trips from Lachlan Webster, James Dyer, and David Bishop. Many thanks to Ian Lunt for initial discussion and assistance with the monitoring design.

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9. RESPONSE OF FISH COMMUNITY TO COMMONWEALTH ENVIRONMENTAL WATERING

Summary

- Fish community sampling was undertaken in May through June 2015 at 19 in-channel sites throughout the Edward-Wakool system. Data from these sites were compared with annual survey data from 2010–2014 from the same sites to provide context for the 2015 LTIM baseline data.
- There is a general trend of improvement in the native fish community in the Edward-Wakool system following the Millennium drought, widespread flooding and hypoxic blackwater fish kills in recent times. Improvement was species and location-specific, and the overall fish community assemblage is still considered to be in poor condition. Nativeness (the proportion of native abundance, biomass and species) was the highest on record based on six years of sampling and is classified as good.
- There was no significant difference in the abundance of the fish community assemblage between 2014 and 2015. There was, however, a significant difference in biomass, and this was driven by increases in golden perch and common carp biomass, and decreases in Murray cod, goldfish and bony herring biomass in 2015.
- Recent recruits were detected of four native short-lived species (Australian smelt, carp gudgeon, Murray-Darling rainbowfish and un-specked hardyhead) and three native longer-lived species (bony herring, Murray cod and silver perch) by the fish community survey.
- The data indicate that the fish communities of the system and region have been dynamic over the past ten years. Sustainable Rivers Audit indicators were calculated from each annual survey from 2010–2015. There was a decline in all indicators from 2010 to 2011 and there is a general trend towards improvement of the native fish community in the Edward-Wakool system back toward 2010 levels.

9.1 Background

Dryland rivers in Australia contain ecological communities that have adapted to extreme hydrological regimes, where long periods of low flow and drought can be interrupted by extensive flooding (Humphries et al. 1999, Thoms and Sheldon 2000). The majority of fish communities within these systems have undergone severe declines, largely as an artefact of altered flow regimes since European settlement. Flow regulation has reduced habitat complexity, altered the timing and magnitude of flows necessary for critical life stages for fish, reduced in- and off-channel connectivity and has promoted the invasion of generalist alien species (Bunn and Arthington 2002). Environmental water can be used to restore more natural flow characteristics to benefit native fish by increasing reproduction opportunities, by creating the cues necessary to facilitate migration to trigger a spawning response or by improving food availability which can translate to improved condition and larval survival (Humphries et al. 1999, Humphries et al. 2002, King et al. 2003). The delivery of environmental water can also promote connectivity with off-channel habitats such as wetlands and floodplains, which many native fish species have been shown to opportunistically use for nursery habitat and to benefit from increased food availability (Lyon et al. 2010).

Environmental water delivery has previously resulted in detectable short-term changes in fish communities in the Edward-Wakool system. For example, Gilligan et al. (2009) examined changes to the fish community before, during and after 30 GL of stock and domestic and environmental flows. The objective of the flow was to sustain existing populations by improving water quality in deteriorating conditions during an extreme drought. Spawning of Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) and un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*) was detected during the event, although there was no change detected in the abundance of Murray cod (*Maccullochella peelii*) or silver perch (*Bidyanus bidyanus*) (Gilligan et al. 2009). Following the environmental water release, the abundance of golden perch (*Macquaria ambigua*) and carp gudgeon (*Hypseleotris* spp) declined (Gilligan et al. 2009). These results were all based on short-term before and after comparisons. It is likely that short-term changes in fish community structure following environmental water delivery are driven by movement, localised changes in hydraulic and structural habitat availability, and food resources. However, changes in fish community composition at the reach and valley scale are also likely to occur as a result of improvements to fish body condition, increased spawning opportunities, and subsequent young-of year recruitment, all of which result in positive changes in native fish abundance and biomass.

Our ability to detect change is often influenced by the objectives and scale of environmental water delivery. For example, measuring changes to fish assemblages at the landscape-scale in association with environmental water delivery are generally possible only when environmental water availability is high. During periods when water availability is low, environmental water delivery is most often used to prevent deterioration of fish body condition, encourage movements to refuge sites and to sustain populations present within refuge areas. For instance, a previous environmental watering action in the Edward-Wakool river system successfully prevented a hypoxic blackwater event and protected many fish when water was released from irrigation escapes into the upper Wakool River and Yallakool Creek. Many fish survived in the area where environmental water was delivered, whilst thousands of fish perished in reaches affected by blackwater. The delivery of environmental water can also influence native fish reproduction directly by providing cues to stimulate spawning behaviour or provide access to suitable available habitat. Likewise, the delivery of environmental water to drive fish recruitment can be influenced indirectly by: 1) increasing food resources, 2) increasing available habitat, 3) promoting suitable water quality, and 4) facilitating connectivity and dispersal.

A system-wide fish monitoring program was established in 2010 to provide baseline information on native fish population status in the Edward-Wakool system and inform management targets and actions (*see* Watts et al. 2014a, b). The program involved establishing long-term fish monitoring sites which have been sampled consecutively for six years. Based on these surveys and short-term intervention monitoring of larval fish in the Edward-Wakool system (Watts et al. 2012, 2013, 2014) eleven native fish species and five alien species have been recorded as adults or larvae/early juveniles in this system between 2010 and 2015 (Table 9.1).

The overall objectives of the monitoring program were to: 1) identify ecological assets within the system, 2) quantify the health of the fish community with respect to large-scale hydrological events including the millennium drought, large-scale flooding and hypoxic blackwater, and 3) determine long-term trajectories in the fish community assemblage associated with these major events. It is expected that this information, combined with information collected on the movement of fish, fish reproduction and fish recruitment, will provide system-wide ‘multiple lines of evidence’ to inform water management and delivery, that will maximise the benefit to native fish communities in the Edward-Wakool system.

Table 9.1 List of i) pre-European expected native fish species present in the central Murray region of the Murray-Darling Basin, and ii) known alien species, recorded as adults or larvae/early juveniles in the Edward-Wakool system between 2010 and 2015.

Common name[1]	Species name	Found as adults[2]	Found as larvae/early juveniles[3]
i) Expected Native species[4]			
Agassiz's glassfish (olive perchlet)	*Ambassis agassizii*		
Australian smelt	*Retropinna semoni*	**Y**	**Y**
bony herring	*Nematolosa erebi*	**Y**	-
carp gudgeon	*Hypseleotris* spp.	**Y**	**Y**
dwarf flathead gudgeon	*Philypnodon macrostomus*		
flathead galaxias	*Galaxias rostratus*		
flathead gudgeon	*Philypnodon grandiceps*	**Y**	**Y**
freshwater catfish	*Tandanus tandanus*		
golden perch	*Macquaria ambigua*	**Y**	-
Macquarie perch	*Macquaria australasica*		
mountain galaxias	*Galaxias olidus*		
Murray cod	*Maccullochella peelii*	**Y**	**Y**
Murray hardyhead	*Craterocephalus fluviatilis*		
Murray River rainbowfish	*Melanotaenia fluviatilis*	**Y**	**Y**
river blackfish	*Gadopsis marmoratus*	-	**Y**
shorthead lamprey	*Mordacia mordax*		
silver perch	*Bidyanus bidyanus*	**Y**	**Y**
southern purple spotted gudgeon	*Mogurnda adspersa*		
southern pygmy perch	*Nannoperca australis*		
trout cod[5]	*Maccullochella macquariensis*	**Y**	-
unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	**Y**	**Y**
ii) Known Alien species			
common carp	*Cyrpinus carpio*	**Y**	**Y**
goldfish	*Carrassius auratus*	**Y**	
eastern gambusia	*Gambusia holbrooki*	**Y**	**Y**
oriental weatherloach	*Misgurnus anguillicaudatus*	**Y**	**Y**
redfin perch	*Perca fluviatilis*	**Y**	**Y**

[1] common names as per Humphries and Walker (2013)
[2] Based on annual adult fish surveys in the Edward-Wakool system (2010-2015)
[3] Based on short-term intervention monitoring surveys in the Edward-Wakool system (2012-2014) (Watts et al. 2014a, 2014b)
[4] Pre-European (PERCH) list of the expected native species present in the central Murray region of the Murray-Darling Basin.
[5] Found in the wider Edward-Wakool River system, but outside the project study zones.

9.2 Questions

Evaluation of the 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. Data from the Edward-Wakool system will be evaluated at the Selected Area scale (Watts et al. 2014c) 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 first 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 following long-term Selected Area evaluation questions, as outlined in the Monitoring and Evaluation Plan for the Edward-Wakool system (Watts et al. 2014c), will be assessed in 2019:

Q1: *Does Commonwealth environmental water contribute to maintain or enhance existing levels of fish recruitment in the Edward-Wakool river system?*

Q2: *Does Commonwealth environmental water contribute to maintain or increase native fish diversity and abundance in the Edward-Wakool river system?*

Q3: *Does Commonwealth environmental water contribute to maintain or increase native fish biomass in the Edward-Wakool river system?*

Q4: *Does Commonwealth environmental water contribute to maintain or enhance fish condition in the Edward-Wakool river system?*

Q5: *Does Commonwealth environmental water contribute to the recovery of fish communities following negative conditions within the Edward-Wakool river system?*

Selected Area hypotheses:

H_1 Commonwealth environmental water contributes to the maintenance of native fish community structure (abundance and diversity) during drought through water replenishment and enhancement of water quality.

H_2 Commonwealth environmental water contributes to maintenance of or increases in native fish biomass.

H_3 Commonwealth environmental water contributes to the maintenance of or increases in native fish condition.

H_4 Commonwealth environmental water contributes to maintain of or increases in fish recruitment in the Edward-Wakool river system?

9.3 Methods

Fish community sampling was undertaken in May and June 2015 at 19 sites throughout the Edward-Wakool system (Figure 9.1) using standardised Sustainable Rivers Audit (SRA) protocol (i.e. a standardised effort of electrofishing and unbaited bait traps at each site) as described in Watts et al. (2014c). All fish captured were identified to species and enumerated, and a subset weighed (g) and total or fork length (mm) recorded. Length was used to distinguish new recruits for each species (Table 9.2), and when a subset of fish was measured proportions of juveniles and non-juveniles were scaled to total catch by method for each species. Similarly, species- and method-specific biomass was scaled to total catch when subsampling had occurred during measurement.

To place the 2015 fish community assemblage data in the context of previous monitoring programs, analysis was undertaken using annual data collected from the same 19 in-channel sites in the preceding five years (2010 to 2014). To determine differences in fish communities among years, abundance and biomass data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities.

Sustainable Rivers Audit (SRA) fish community indices were calculated to quantify overall condition of the fish community assemblage, and to place 2015 in the context of previous years. Data were first portioned into recruits and non-recruits. Large-bodied and generally longer lived species (max. age >3 years) were considered recruits when length was less than that of a one-year-old. Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 9.2).

Eight fish metrics were calculated using the methods described by Robinson (2012). These metrics were subsequently aggregated to produce three indices (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition score. Metric and indicator aggregation used Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) (Davies et al. 2010, Carter 2012). Note that the SRA method calculates an overall recruitment index for the entire system for each year of sampling, whereas in section 11 we present a more detailed assessment of recruitment and develop growth and recruitment indices to compare recruitment among hydrological zones.

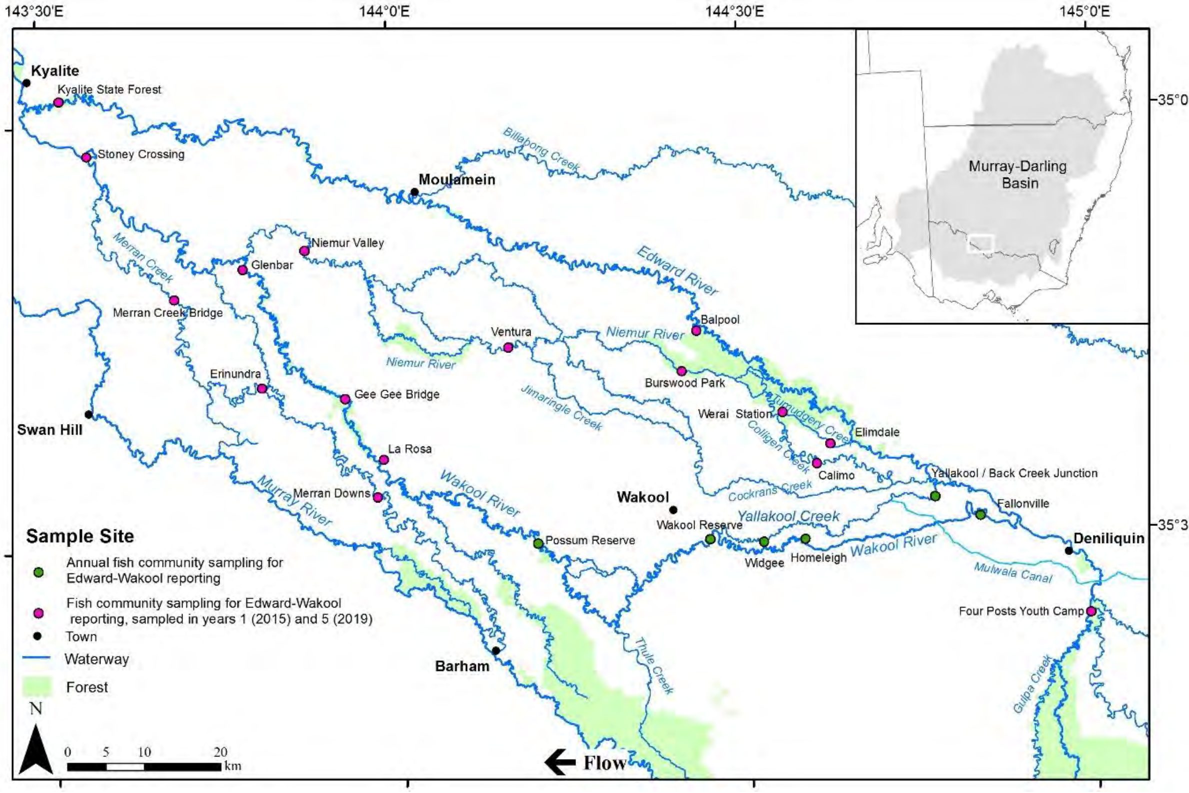

Figure 9.1. Locations of fish community sampling sites in the Edward-Wakool river system 2010 to 2014. Note that data collected from Balpool, Fallonville and Werai Station sites were not used in this report as they were not sampled annually over the entire six year period (2010–2015).

Expectedness represents the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition (Table 9.3). This value is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). Nativeness represents the proportion of native compared to alien fishes, and is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robinson 2012). Recruitment represents the recent reproductive activity of the native fish community within each hydrological zone, and is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled; Table 9.3), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three indices were subsequently aggregated to generate a weighted overall Fish Condition Index (Carter 2012). The index was divided into five equal categorical bands to rate the condition of the fish community as; "Excellent" (81–100), "Good" (61–80), "Moderate" (41–60), "Poor" (21–40), or "Very Poor" (0–20).

Table 9.2. Size limits used to distinguish new recruits for each species recorded in the Edward-Wakool system using standardised Sustainable Rivers Audit (SRA) protocol. Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)
Native species	
Australian smelt	40 mm (Pusey et al. 2004)
carp gudgeon	35 mm (Pusey et al. 2004)
flat-headed gudgeon	58 mm (Pusey et al. 2004; Llewellyn 2007)
un-specked hardyhead	38 mm (Pusey et al. 2004)
Murray-Darling rainbowfish	45 mm (Pusey et al. 2004: for *M. duboulayi*)
bony herring	67 mm (Cadwallader 1977)
silver perch	75 mm (Mallen-Cooper 1996)
golden perch	75 mm (Mallen-Cooper 1996)
trout cod	150 mm
Murray cod	222 mm (Gavin Butler, *Unpublished data*)
Alien species	
eastern gambusia	20 mm (McDowall 1996)
oriental weatherloach	76 mm (Wang et al. 2009)
redfin perch	60 mm (maximum reported by Heibo & Magnhagen 2005)
common carp	155 mm (Vilizzi and Walker 1999)
goldfish	127 mm (Lorenzoni et al. 2007)

11.4 Results

2015 sampling

A total of 1,109 fish comprising ten native and three alien species were captured using the standardised Sustainable Rivers Audit (SRA) protocol across 19 in-channel sampling sites in 2015. This included three species listed as threatened (trout cod (*Maccullochella macquariensis*) (endangered; Fisheries Management Act, EPBC Act), silver perch (vulnerable; Fisheries Management Act, critically endangered; EPBC Act), and Murray cod (vulnerable; EPBC Act)).

In order, Australian smelt (*Retropinna semoni*), common carp (*Cyprinus carpio*), bony herring (*Nematolosa erebi)*, Murray-Darling rainbowfish and carp gudgeon were the most abundant species, respectively (Figure 9.2). One trout cod was captured at Four Posts on the Edward River, four silver perch were captured across three sites (Erinundra, Homeleigh and Merran Downs) and five flat-headed gudgeon (*Philypnodon grandiceps*) were captured across three sites (Elimdale, Wakool Reserve, Yallakool/Back Creek Junction). Recruits were detected in three native longer-lived species (bony herring (*n*=7 of 13 sites captured), Murray cod (*n*= 9 of 16 sites captured) and silver perch (*n*=1 of 3 sites captured); Figure 9.2), and four native short-lived species (Australian smelt (*n*=8 of 19 sites captured), carp gudgeon (*n*= 11 of 13 sites captured), Murray-Darling rainbowfish (*n*=9 of 9 sites captured) and un-specked hardyhead (*n*=4 of 5 sites captured); Figure 9.2). Few alien species recruits were captured (common carp (*n*=3 of 19 sites captured), goldfish (*Carassius auratus*) (*n*= 4 of 9 sites captured) and eastern gambusia (*Gambusia holbrooki*) (*n*=1 of 1 site captured); Figure 9.2).

In order, common carp, Murray cod, golden perch and goldfish contributed the greatest overall biomass in 2015, with an average (± SE) biomass per site of 11,019 ± 1,622 g, 3,963 ± 1,176 g, 3,020 ± 427 g and 259 ± 125 g, respectively (Figure 9.3).

Table 9.3. List of Pre-European (PERCH) expected native species present in the central Murray region of the Murray-Darling Basin. Table shows rarity scores and presence/absence of these species based on Fish community sampling undertaken at 19 sites throughout the Edward-Wakool system using standardised Sustainable Rivers Audit (SRA) protocol. Rarity scores of 0.10, 0.45 and 0.85 correspond to rare or cryptic, locally abundant and common and abundant species, respectively, and are based on expert opinion of the probability of detection at a single site.

Common name	Rarity score	Presence/absence native fish species during annual fish community survey at 19 sites					
		2010	2011	2012	2013	2014	2015
Australian smelt	0.85	Y	Y	Y	Y	Y	Y
bony herring	0.45	Y	Y	Y	Y	Y	Y
carp gudgeon	0.85	Y	Y	Y	Y	Y	Y
dwarf flat-headed gudgeon	0.10	N	N	N	N	N	N
flat-headed galaxias	0.45	N	N	N	N	N	N
flat-headed gudgeon	0.45	Y	Y	N	N	Y	Y
freshwater catfish	0.45	N	N	N	N	N	N
golden perch	0.85	Y	Y	Y	Y	Y	Y
Macquarie perch	0.10	N	N	N	N	N	N
mountain galaxias	0.10	N	N	N	N	N	N
Murray cod	0.85	Y	Y	Y	Y	Y	Y
Murray hardyhead	0.45	N	N	N	N	N	N
Murray-Darling rainbowfish	0.45	Y	Y	Y	Y	Y	Y
olive perchlet	0.45	N	N	N	N	N	N
river blackfish	0.45	N	N	N	N	N	N
shortheaded lamprey	0.10	N	N	N	N	N	N
silver perch	0.85	Y	Y	Y	Y	Y	Y
southern purple spotted gudgeon	0.45	N	N	N	N	N	N
southern pygmy perch	0.45	N	N	N	N	N	N
trout cod	0.10	N	N	N	N	Y	Y
un-specked hardyhead	0.45	Y	Y	Y	Y	Y	Y

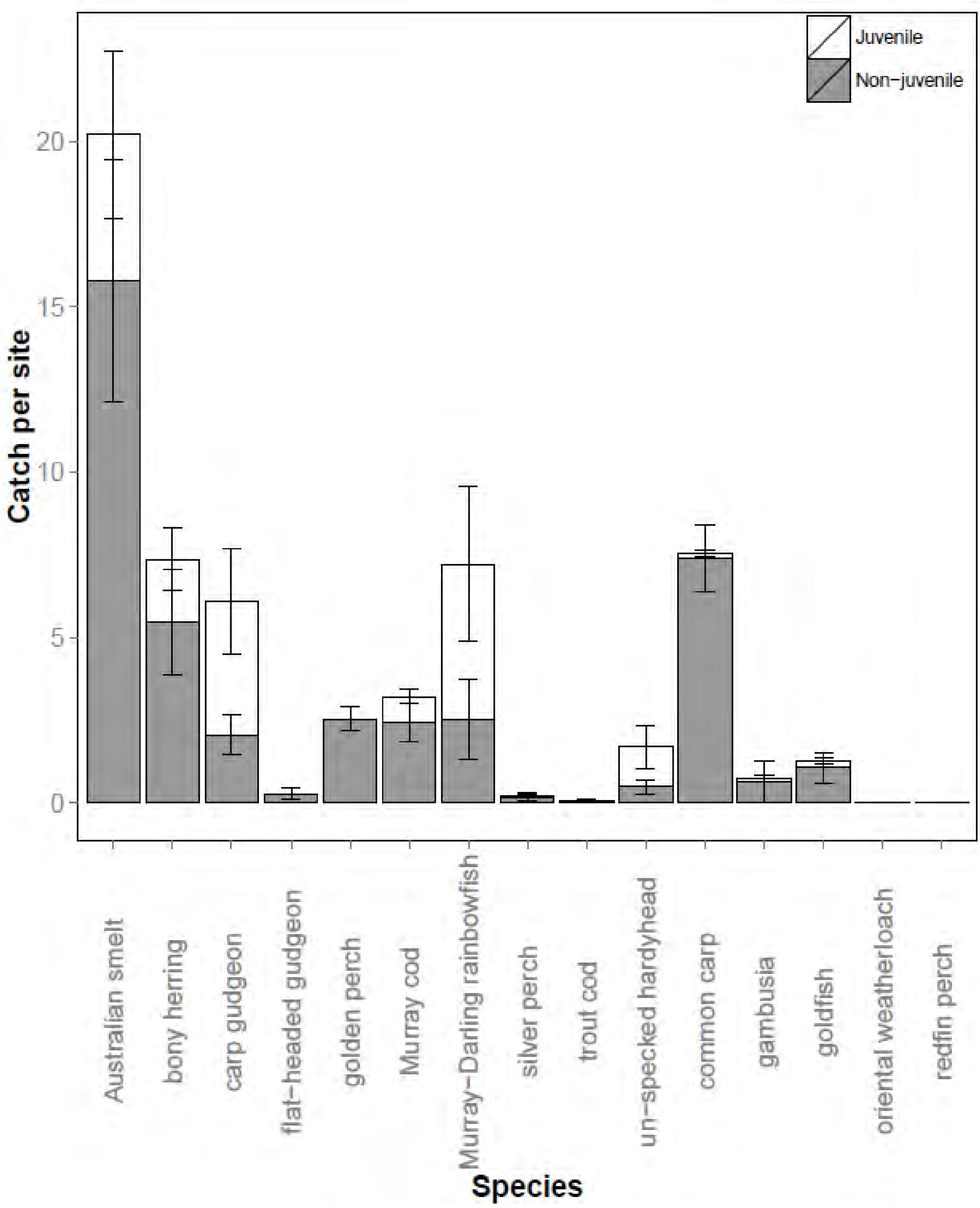

Figure 9.2. Catch per site (mean ± SE) of fish sampled in the Edward-Wakool river system from 19 in-channel sites that were sampled in 2015. Juveniles and non-juveniles were defined based on the length cut-offs in Table 9.2.

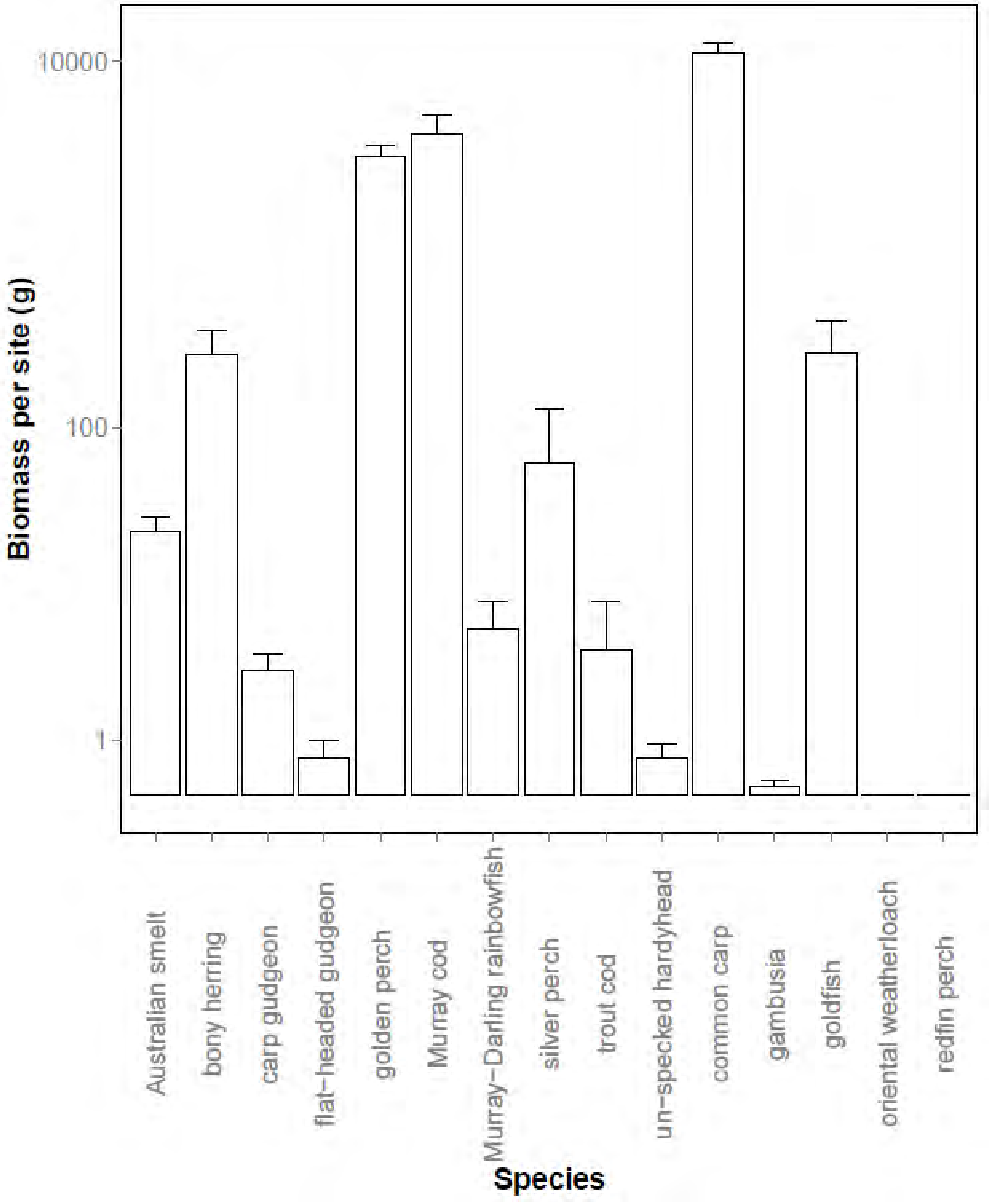

Figure 9.3. Biomass per site (g; mean ± SE) of fish sampled in the Edward-Wakool river system from 19 in-channel sites that were sampled in 2015.

2010–2015 comparison

The fish community assemblage differed significantly in abundance among years (2010–2015 inclusive; *Pseudo*-$F_{5,108}$ = 8.058, P <0.001; Figure 9.4), although pair-wise tests indicated that the community assemblage was not significantly different between 2014 and 2015 (t=1.404, P=0.085). Biomass of the community assemblage was significantly different among years (2010–2015 inclusive; *Pseudo*-$F_{5,108}$ = 5.928, P < 0.001; Figure 9.5). Pair-wise tests indicated that these differences in biomass were significant between 2014 and 2015 (t=1.808, P=0.015). SIMPER analysis indicated that the differences between 2014 and 2015 were primarily driven by variability in the biomass of golden perch, Murray cod, goldfish, bony herring and common carp (Table 9.4).

Sustainable Rivers Audit indices including Expectedness, Recruitment and Overall Condition were highest in 2010 at the commencement of the long-term sampling program. All metrics including Nativeness rated as 'good' with the exception of Expectedness which was 'moderate' (Table 9.5). There was a general trend downwards to 'poor' condition in all of these indices in 2011 across the Edward-Wakool system, except for Expectedness which remained 'moderate' (Table 9.5; Figure 9.6). All metrics increased in 2015 compared to 2011, and Nativeness in 2015 was the highest recorded across the six years of sampling (Table 9.5). In 2015 Nativeness rated as 'good', Expectedness was 'moderate', and Recruitment and Overall Condition were 'poor' (Table 9.5; Figure 9.6).

Table 9.4. The contribution of fish species biomass to variability between 2014 and 2015 in the Edward-Wakool river system, determined through SIMPER analysis. Note only species contributing ≥10% to changes in community composition are included.

Indicator	Species	Contribution to difference (%)	2015 change
Biomass	golden perch	22	increase
	Murray cod	20	decrease
	goldfish	13	decrease
	bony herring	12	decrease
	common carp	11	increase

Table 9.5. Sustainable Rivers Audit indices, reported by sampling year, in the Edward-Wakool river system. Note that only data collected from the same 19 in-channel sites each were used in the calculation of these metrics.

	Sustainable Rivers Audit (SRA) Indicator			
Sampling year	Nativeness	Expectedness	Recruitment	Overall condition
2010	73.6 ± 3.9	55.3 ± 1.9	70.9	62.7 ± 2.7 (good)
2011	38.7 ± 4.0	42.5 ± 3.1	27.2	22.8 ± 1.9 (poor)
2012	46.1 ± 3.9	37.7 ± 2.3	38.0	28.5 ± 1.9 (poor)
2013	53.1 ± 5.4	32.3 ± 2.8	28.3	21.5 ± 2.1 (poor)
2014	66.5 ± 3.3	49.6 ± 2.3	42.4	40.4 ± 1.8 (moderate)
2015	73.7 ± 2.4	51.5 ± 2.0	37.1	39.9 ± 1.2 (poor)

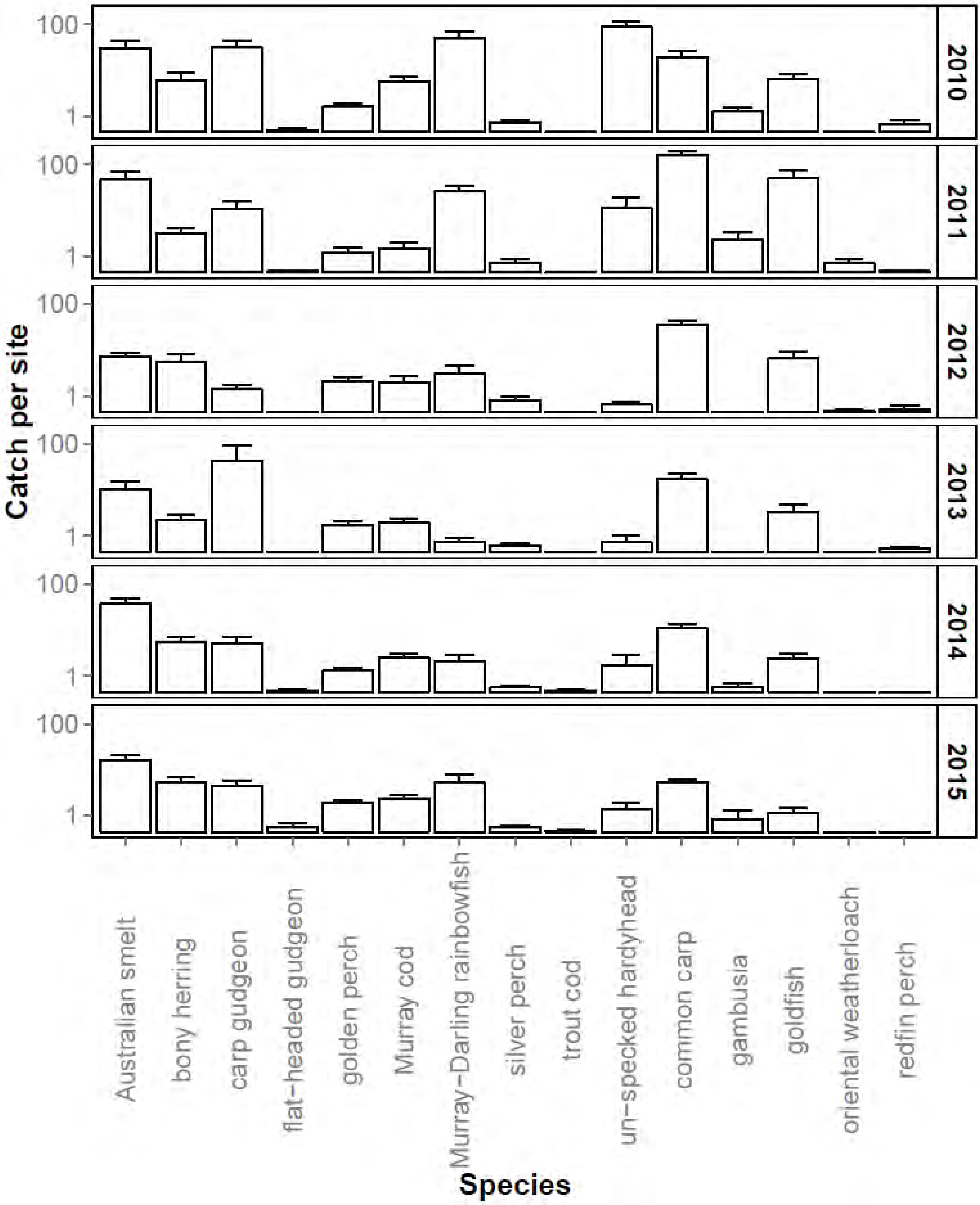

Figure 9.4. Average (±SE) catch per unit effort (CPUE) per site of fish sampled in the Edward-Wakool river system from 19 in-channel sites that were sampled once each year from 2010–2015.

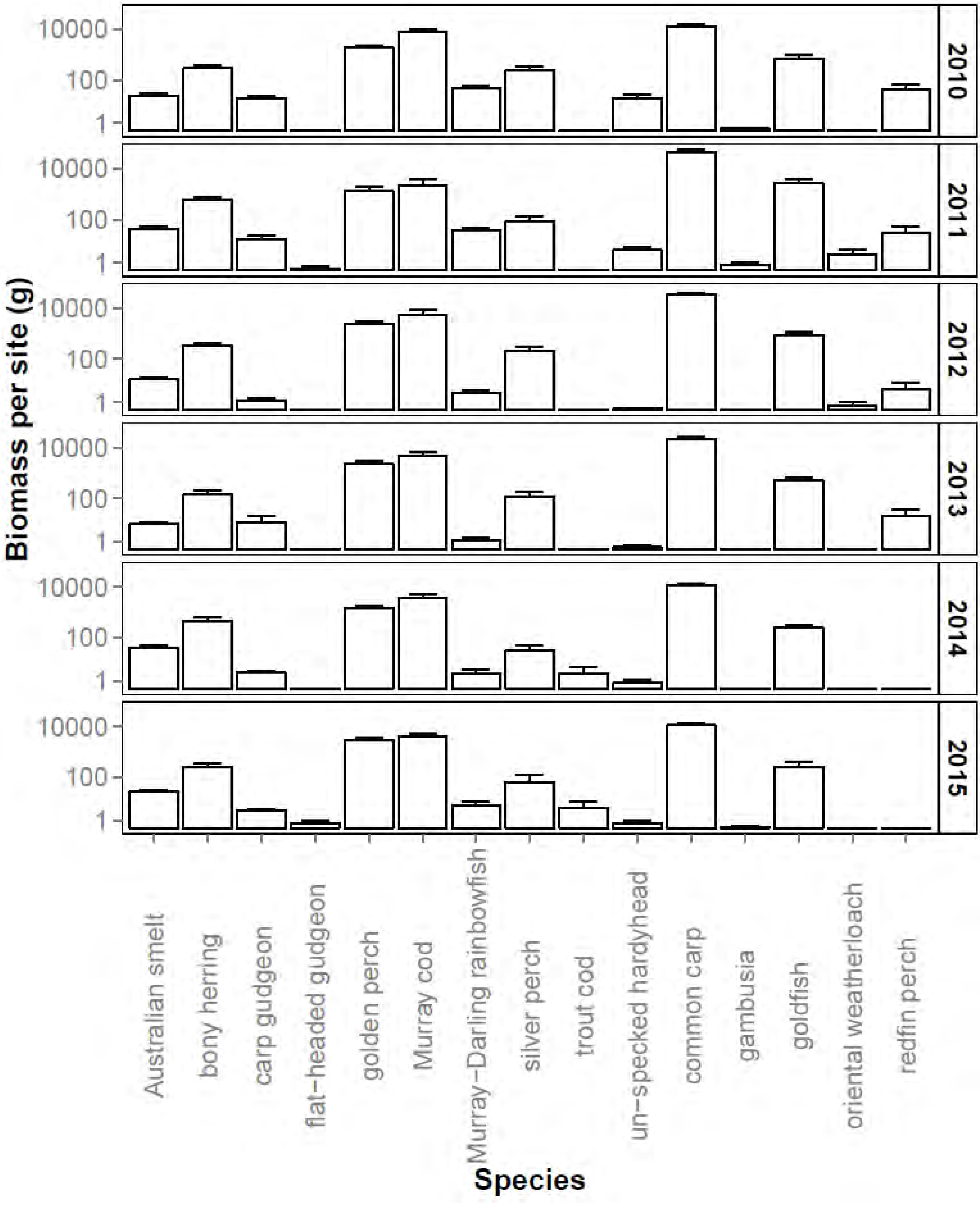

Figure 9.5. Average (±SE) biomass (g) per site of fish sampled in the Edward-Wakool river system from 19 in-channel sites that were sampled once each year from 2010–2015.

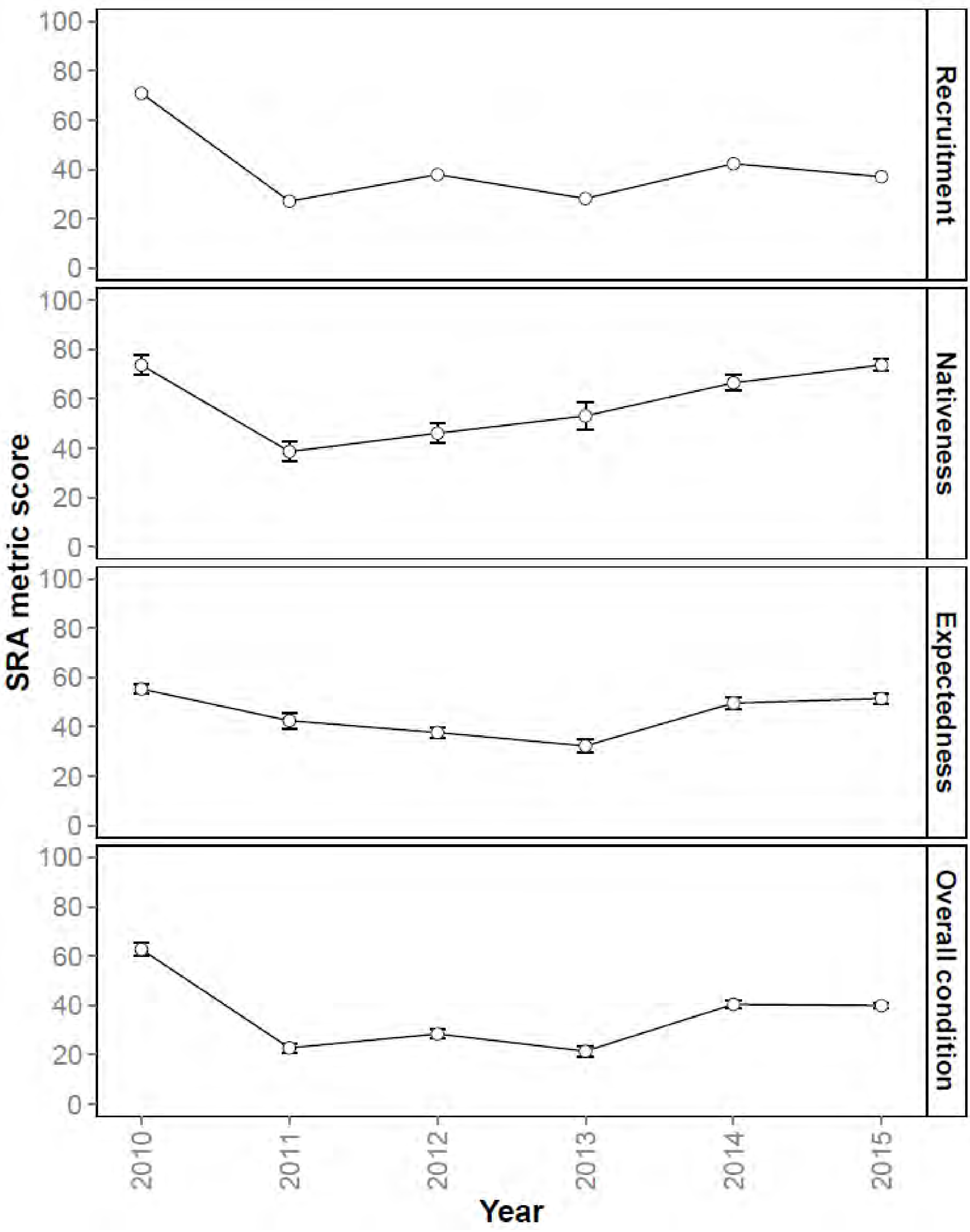

Figure 9.6. Sustainable Rivers Audit (SRA) indices from 2010 to 2015 in the Edward-Wakool river system based on surveys undertaken at 19 in-channel sites.

9.5 Discussion

The current study provides a benchmark with which to compare changes in the fish community assemblage composition across the Edward-Wakool system over the next five years under the LTIM program. Previous monitoring consisting of annual surveys dating back to 2010 provided context for the current study. Sustainable Rivers Audit indicators were calculated from each annual survey from 2010–2015, demonstrating a transition in Overall Fish Condition from 'good' to 'poor' between 2010 and 2015. Across a broader geographic scale, the SRA Report 1 conducted from 2004–2007, scored the Overall Fish Condition of the upper zone of the Central Murray Valley (of which the Edward-Wakool system is a part) as 'moderate' (Davies et al. 2008). Sampled again from 2008–2010 the SRA Report 2 scored the same zone as 'very poor' (Davies et al. 2012). While these results are not directly transferable to the findings of the current study given the narrower spatial scale of interest here, the data indicate that the fish communities of the system and region have been dynamic over the past ten years.

There is a general trend towards improvement of the native fish community in the Edward-Wakool system back toward 2010 levels. The composition of the fish community has undergone significant changes over recent years as a result of major hydrological events, including severe drought and widespread flooding, as well as hypoxic blackwater events. The responses of fish to these events have been species and location-specific. In 2010, following long-term drought, small-bodied generalist native species such as carp gudgeon, Murray-Darling rainbowfish and un-specked hardyhead were numerically dominant within the Edward-Wakool system. Widespread flooding throughout the southern Murray-Darling Basin (MDB) in 2010-11 resulted in substantial inundation of off-channel habitats and an increase in the abundance of alien species, particularly common carp and goldfish. Concurrently, populations of native fish within some locations of the Edward-Wakool system, as well as other locations within the southern MDB, suffered as a result of hypoxic blackwater events (King et al. 2012; Whitworth et al. 2012; McCarthy et al. 2014).

Some locations in the Edward-Wakool system appear to be recovering from the effects of blackwater and associated fish kills. Presumably this is a result of active re-colonisation as has been demonstrated following fish kills in other systems (e.g. Lyon and O'Connor 2008). It is not possible to determine to what extent Commonwealth environmental watering has contributed to this re-colonisation because it is a system-wide response and not isolated to the areas receiving environmental water. Native fish in the Edward-Wakool system have previously demonstrated movement responses to increased discharge (*see* Watts et al. 2014a, b) and Commonwealth environmental water can be actively used to facilitate this re-colonisation by increasing lateral and longitudinal connectivity among habitats. Additional remediation of the native fish community has been undertaken at some locations throughout the Edward-Wakool system via stocking of Murray cod and golden perch. A recent evaluation of these efforts indicates that recovery of these species is occurring (Thiem et al. 2015). However, stocking does not appear to be facilitating the recovery in these locations and is outweighed by natural spawning and recruitment in the case of Murray cod, and potentially immigration of both species from elsewhere within or outside of the Edward-Wakool system (Thiem et al. 2015).

The general trends apparent in this current study are largely in agreement with the findings of Bice et al. (2014), and align with existing knowledge of the life-history requirements of the fish found within the system (Baumgartner et al. 2014). Bice et al. (2014) identified a decrease in the abundance of small-bodied generalist species during a shift from drought to post-flood conditions in the River Murray River, and an increase in the abundance of alien species (particularly common carp) post-flooding. However, it is worthwhile noting that a complete absence of floodplain specialist species within the Edward-Wakool system is apparent following six years of intensive sampling, and this is likely due to localised extinction following long-term disconnection of off-channel habitats. Subsequently, it is important to recognise that any future watering of these off-channel habitats is undertaken with realistic expectations that floodplain species may not return immediately, if at all. Future off-channel watering strategies should support long-term watering plans that will enable conservation stocking or translocation, and the subsequent re-establishment of resident populations of off-channel specialists.

A number of large-bodied native species were captured in the current study, although only Murray cod and golden perch were commonly encountered. The presence of Murray cod juveniles at > 50% of sampling sites is consistent with data collected in 2015 larval sampling (this report , section 10) and recruitment (this report, section 11), as well as previous monitoring reports (Watts et al. 2014a, 2014b; Thiem et al. 2015). It appears that spawning is occurring annually for this species, at least in the focal zones monitored for larvae, and that survival and growth of larvae is occurring throughout the Edward-Wakool system (Thiem et al. 2015). While both golden and silver perch represent excellent candidate species for monitoring the delivery of environmental water given they are both considered flow-cued spawners (*see* Baumgartner et al. 2014), no evidence collected to date has indicated that spawning has occurred within the Edward-Wakool system (Watts et al. 2014a, 2014b; this report, section 10). Regardless, the Edward-Wakool system at the very least provides necessary habitat that supports juveniles and adults of both species as they have been captured in this system in recent years (Watts et al. 2014a, 2014b). Recent evidence suggests that golden perch (and likely silver perch) life-history operates over substantial spatial scales across the southern connected MDB (Zampatti et al. 2014), and the inter-connectedness of Edward-Wakool golden and silver perch will be addressed under this project (fish movement) and other concurrent collaborations.

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10. FISH SPAWNING AND REPRODUCTION RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

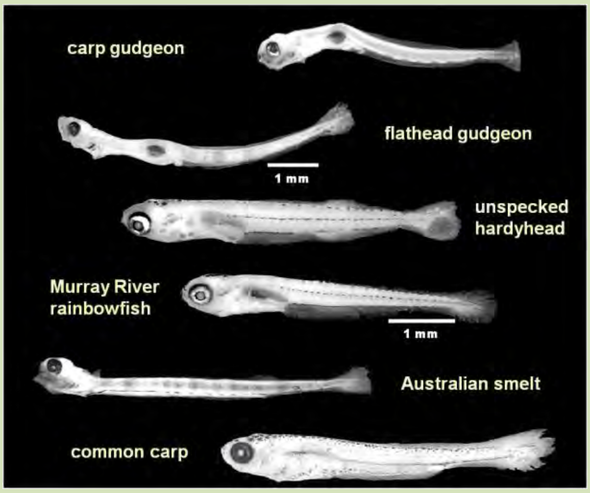


Photo: Larval fish species found in the Edward-Wakool River system (Source: Serafini and Humphries 2004).

Summary

- Fish spawning and reproduction responses to Commonwealth environmental watering were assessed by monitoring the presence and abundance of fish larvae throughout the spring and summer of 2014-15. Larval fish were sampled fortnightly from September 2014 to March 2015 using a combination of light traps and drift nets across four study zones: Yallakool Creek, Wakool River zone 2, Wakool River zone 3, and Wakool River zone 4.
- Seven of the 11 native fish species known to occur in the selected area were collected as larvae or early juvenile stages, indicating the successfully spawning of these species. In addition, a recently described species, *Galaxias oliros* (obscure galaxias, Raadik 2014), was collected as a juvenile in Yallakool Creek. This is the first collection of a Galaxiid species in the region since larval fish monitoring of the system commenced in 2011.
- The spawning patterns of the Edward-Wakool fish community appeared to be independent of Commonwealth environmental watering actions in 2014-15. The Yallakool Creek environmental watering action during the Murray cod spawning season did not result in a significantly greater number of Murray cod larvae in Yallakool Creek or the Wakool River zones 3 and 4 when compared to Wakool River zone 2 (no environmental water). These findings concur with results observed during monitoring of similar watering actions in 2012-13 and 2013-14 and support the body of knowledge that shows that Murray cod spawn at peak times in November and December, regardless of flow conditions.
- The environmental watering action did not trigger a golden and silver perch spawning response in the monitored reaches, as evidenced by the absence of larvae or eggs, but this is not surprising as the action was not planned to target a spawning response in these species.
- Environmental watering actions that target the inundation of in-channel geomorphological features, increase the area of slackwater, and help establish instream aquatic vegetation are likely to be advantageous to small bodied fish species for spawning and nursery grounds.

10 .1 Background

The delivery of environmental water is seen as a key way of enhancing the spawning and recruitment of native fish species (Murray-Darling Basin Commission 2004). The environmental and hydraulic conditions under which the spawning and recruitment of Murray-Darling fish varies across species. Humphries et al. (1999) proposed three broad groups for native fish based on their life history, and likely flow requirements for spawning and recruitment. ‘Mode 1’ fish, are characterised as long-lived, large-bodied fish species whose spawning, or magnitude of spawning is thought to be associated with flow pulses (e.g. golden perch and silver Perch); ‘Mode 2’ fish, are characterised as long-lived, large-bodied fish species whose spawning is independent of flow conditions, but whose recruitment may benefit from flow events (e.g. Murray cod, trout cod, river blackfish); and ‘Mode 3’ fish are short-lived, small-bodied fish that also spawn independently of flow pulses, and may well flourish under low flow conditions due to the warm temperatures and higher food resources that such environments can provide (e.g. carp gudgeon, Australian smelt, unspecked hardyhead, flathead gudgeon, Murray river rainbowfish) (Humphries et al. 1999).

Flow-response studies of native fish spawning and recruitment that have been conducted since Humphries et al. (1999) proposed the three modes, and in particular those that have focussed on assessing both overbank and large within channel environmental flows, give support to the three life history modes, in particular confirming 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), and the independence of species such as Murray cod spawning from flow conditions (Rowland 1983; Humphries 2005; Koehn and Harrington 2006; King et al. 2009, King et al. 2015). Less has been documented on the role of flow in the spawning and recruitment for smaller bodied species, however two of the key instream habitat features considered important for the spawning and successful recruitment of these species are the prevalence of slackwater areas (Humphries et al. 1999) and the presence of in stream aquatic vegetation (Bice et al. 2014).

Monitoring of the abundance and diversity of larval fish was undertaken from September 2014 to March 2015 to evaluate the short-term spawning response of the Edward-Wakool fish assemblage to specific Commonwealth environmental watering actions, and in the long term, to provide important information on the flow-spawning ecology relationships of the Edward-Wakool fish assemblage.

10.2 Questions

Evaluation of fish spawning and reproduction to Commonwealth environmental watering in the Edward-Wakool River system for the Long term Intervention Monitoring Project is being undertaken at the i) Selected Area scale (Watts et al. 2014a), and ii) Basin scale (Hale et al. 2014), 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. This is the first year of a multi-year monitoring project, and as such this report will evaluate only short-term response questions specific to the Edward-Wakool selected area.

Here, we address three key questions relating to fish spawning and reproduction. The first two questions relate to the assessing the effect of 2014-15 Yallakool Creek environmental watering action in meeting objectives relevant to fish spawning and reproduction: Two of the objectives of the Yallakool Creek Environmental Watering Action (Aug 2014- Jan 2015) were to support inundation of Murray cod nesting sites and contribute to maximising Murray cod recruitment, and to contribute to improved opportunities for the reproduction of native fish.

Q1: *Did the delivery of the sustained flow in Yallakool Creek during the Murray cod spawning period result in significantly more fish larvae compared to zones that did not receive environmental water?* This question addresses the 2014-15 watering objective to support inundation of Murray cod nesting sites. Based on the knowledge that Murray cod spawn independently of flow conditions, we hypothesise that Yallakool Creek environmental watering action will not result in a significantly greater number of Murray cod larvae compared with other zones.

Q2: *What is the effect of Commonwealth environmental water on the spawning of small-bodied opportunistic species?*
This question addresses the 2014-2015 watering objective to contribute to improved opportunities for the reproduction of native fish. We hypothesize that environmental watering actions that increase in-stream aquatic vegetation and the area of slackwaters associated with the main channel will increase the spawning and successive recruitment of opportunistic species.

Q3: *What is the effect of Commonwealth environmental water on the spawning of flow-dependent spawners?*
While there were no in-channel environmental watering actions in 2014-15 that targeted the spawning of flow-dependent spawners, such as golden perch and silver perch, we report on this

question relating to flow-dependent spawners, as proposed in the Edward-Wakool M&E plan (Watts et al. 2014), in order to contribute to the understand the flow-spawning relationships for these species. We hypothesise that there will be no golden perch or silver perch spawning in response to the 2014-15 Yallakool Creek environmental watering action.

10.3 Methods

Modified quatrefoil light traps were used to sample larval fish, and were deployed every fortnight commencing the week of 17 September 2014 to 2 March 2015 (n=13 sampling trips) in Yallakool Creek (zone 1), Upper Wakool River (zone 2), Mid Wakool River (zone 3), and Mid Wakool River (zone 4). Three light traps were deployed overnight at five sites in each of the four zones. Light traps were made from clear perspex (the details of which can be found in Humphries et al. 2002), had an entrance width of 5 mm between each of the four capture cylinders, and were wrapped in nylon mesh (3mm knot-to-knot) to prohibit larger fish from entering the traps (Vilizzi et al. 2008). Light traps were set at dusk and retrieved the following morning. Each light trap was 'baited' with a yellow Cyalume® 12 h light stick. Upon retrieval, light traps were rinsed down and samples preserved individually in 90% ethanol, where they were then returned to the laboratory for processing.

Drift nets were also used to 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 weekly over five weeks, with sampling occurring from 10 November to 10 December 2014. Here, three drift nets were deployed overnight at one site at each of the four study zones. Drift nets were constructed from 500 μm mesh, and had opening diameter of 50 cm which tapered over 1.5 m to an end of 9 cm, to which a reducing bottle was fitted. The volume of water filtered by the nets was calculated using Oceanic® flow meters positioned at the mouth of each drift net. This allowed larval abundance to be expressed as a unit of density: number of individuals per m^3. 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.

All eggs/larvae collected in light trap and drift net samples were identified to species according to Serafini and Humphries (2004), and enumerated. 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. However, as no trout cod adults have been found in the study zones were larval sampling takes places, all cod larvae collected were recorded as Murray cod larvae. The developmental stage of each individual was recorded as either larvae, or juvenile/adult, according to classifications of Serafini and Humphries (2004).

Data analysis

The spatial distribution of larval fish can be patchy. To take this into account larvae from the three light traps at each site were pooled, to provide abundance data at the site level. The Monitoring and Evaluation Plan for the Edward-Wakool LTIM project (Watts et al. 2014a) states that for individual watering events, data would be analysed with a Before-After, Control-Impact design to compare changes in abundances of larvae in zones that receive environmental water to zones that did not receive environmental water; before, during and after environmental water releases. This type of analysis works best for short term events or ‘pulse’ disturbances. In 2014-15, the protracted nature of the environmental water action in Yallakool Creek over 4 months, meant that this style of analysis was unsuitable for testing responses in fish spawning across control/impacts, because the duration of the event itself was longer than many of the seasonal windows in which spawning of some species takes place. In 2014-15 we took the approach of testing if the total production of larvae (an indication of the magnitude of spawning across a season) varied significantly between the four zones. Difference in mean total abundance of larvae for species (where there was sufficient data) across the zones was conducted using a one way ANOVA. We hypothesised that the total production of fish larvae across the 2014-15 spawning season would be significantly higher in the zones that received Commonwealth environmental water (zones 1, 3 and 4) compared to those that did not (zone 2). For light trap data, this analysis was restricted to the Murray cod (Q1), and the small-bodied opportunistic species, Australian smelt and carp gudgeon (Q2) as not enough larvae were sampled of other species. Larval abundances were log-transformed prior to statistical analyses when necessary to normalise data and stabilize variances. Data from one sampling trip (5 to 8 January 2015), was removed prior to analysis, because heavy rain prohibited access to Zone 1 and 2. For drift net data, any eggs or larvae of golden and silver perch found were to be counted, identified and data pooled across the three drift nets at each site per trip (Q3). Catch-per-unit-effort was calculated from the total number of eggs/larvae collected at the site level, divided by the total amount of water filtered by the three nets.

Statistical analyses were carried out using the freeware R and the R package MASS (R Development Core Team 2013). 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. Corresponding figures were plotted using log-transformed abundances.

10.4 Results

A total of 4,249 fish larvae, representing eight fish species, were collected in the 2014-15 monitoring study from light traps (*n*=2945) and drift nets (*n*=1304) combined. Across the four zones, Yallakool Creek (zone 1) comprised 11.6% of the total light trap catch, with Wakool River zone 2, zone 3 and zone 4 comprising of 28%, 29%, and 32% of light trap catch, respectively.

Seven of the 8 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 10.1). Carp gudgeon (*Hypseleotris* spp., n= 2040), were the most numerically abundant larvae caught, with Australian smelt (*Retropinna semoni*, n= 289) and flathead gudgeon (*Philypnodon grandiceps*, n= 69) larvae also detected widely across all study zones (Table 10.1). Unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*, n= 5) and Murray River rainbowfish (*Melanotaenia fluviatilis*, n=3), were rare, but showed evidence that spawning had taken place in 2 of the four zones. Gambusia (*Gambusia holbrooki*, n=1) was the only introduced species captured as larvae. One notable finding was the collection of a young juvenile Galaxiid (*Galaxias oliros*, n=1) from Yallakool Creek during the week starting 30 September 2014 (Figure 10.1). This is the first observation of Galaxiids being found in this area since short term intervention monitoring commenced in 2011-12, and its presence as a juvenile may indicate that spawning occurred locally.

Of the large-bodied, native fish species known to the Edward-Wakool River system, two species, Murray cod (*Maccullochella peelii*, n=511), and river blackfish (*Gadopsis marmoratus,* n=3) were collected as larvae. While Murray cod were collected as larvae in all four zones, river blackfish were collected only in the Upper Wakool River (zone 2). This is the third year that river blackfish larvae have been sampled in the upper Wakool River, suggesting spawning populations of this species are localised. There were no silver perch (*Bidyanus bidyanus*) or golden perch (*Macquaria ambigua*) eggs or larvae collected from light traps or drift nets (Tables 10.1 and 10.2).

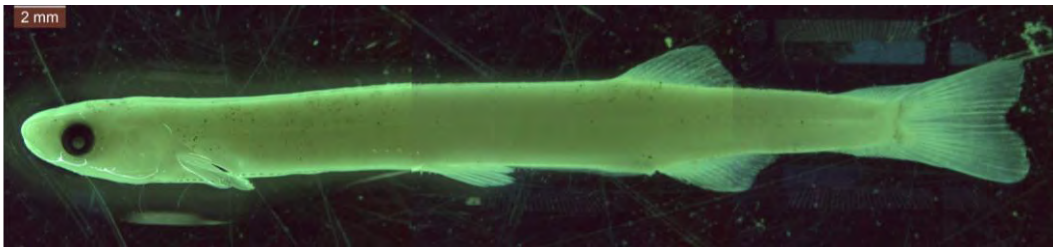


Figure 10.1: Juvenile obscure galaxias (*Galaxias oliros*) collected from Yallakool Creek (Photo: N. McCasker)

Table 10.1: Light trap total abundance of fish larvae (L) and juveniles/small adults (JA) sampled in the four study zones of the Edward-Wakool River system in Spring/Summer 2014. Grand totals and percent contribution provided in the far right column.

Common name	**Yallakool Ck**		**Wakool R Z2**		**Wakool R Z3**		**Wakool R Z4**		**Total**	
	L	**JA**	**L**	**JA**	**L**	**JA**	**L**	**JA**	**L**	**JA**
Native										
Australian smelt	92	4	42	1	119	18	36	4	289 (9.8%)	27 (0.5%)
carp gudgeon	118	413	581	232	645	2293	696	1948	2040 (69.3%)	4886 (98.1%)
flathead gudgeon	12	40	26	15	4	2	27	6	69 (2.3%)	63 (1.3%)
unspecked hardyead	3	-	-	-	2	-	-	1	5 (0.2%)	1 (<0.1%)
Murray River rainbowfish	2	-	-	-	1	-	-	-	3 (0.1%)	-
obscure galaxias	-	1	-	-	-	-	-	-	-	1 (<0.1%)
bony herring	-	-	-	-	-	-	-	-	-	-
silver perch	-	-	-	-	-	-	-	-	-	-
golden perch	-	-	-	-	-	-	-	-	-	-
river blackfish	-	-	3	-	-	-	-	-	3 (0.1%)	-
trout cod	-	-	-	-	-	-	-	-	-	-
Murray cod	99	1	168	-	72	-	172	2	511 (17.4%)	3 (0.1%)
Introduced										
gambusia	-	-	-	-	-	-	1	-	1 (<0.1%)	-
oriental weatherloach	-	-	-	-	-	-	-	-	-	-
redfin perch	-	-	-	-	-	-	-	-	-	-
carp	-	-	-	-	-	-	-	-	-	-
goldfish	-	-	-	-	-	-	-	-	-	-
Unidentified	15	-	-	-	5	-	4	-	24 (0.8%)	-

Table 10.2: Drift net abundance and CPUE of fish and crustacea larvae sampled from the four study zones in the Edward-Wakool River system in Spring/Summer 2014. *n*= total no of larvae collected, filt.vol (ML) = total volume of water sampled, CPUE= total no of larvae collected/ total volume of water sampled (ML), for each zone. Fish species listed are those known to occur in the Edward-Wakool river system. Trout cod, however, are the only species not found in the study zones.

Common name	**Yallakool Ck**			**Wakool R-Z2**			**Wakool R-Z3**			**Wakool R-Z4**		
	n	filt. vol (ML)	CPUE	*n*	filt. vol (ML)	CPUE	*n*	filt.vol (ML)	CPUE	*n*	filt.vol (ML)	CPUE
Native												
Australian smelt	-	-	-	-	-	-	-	-	-	-	-	-
carp gudgeon	2	27.127	0.0046	80	37.524	0.1332	-	-	-	2	1.396	0.0895
flathead gudgeon	-	-	-	-	-	-	-	-	-	-	-	-
unspecked hardyead	-	-	-	-	-	-	-	-	-	-	-	-
Murray River rainbowfish	-	-	-	-	-	-	-	-	-	-	-	-
obscure galaxias	-	-	-	-	-	-	-	-	-	-	-	-
bony herring	-	-	-	-	-	-	-	-	-	-	-	-
silver perch	-	-	-	-	-	-	-	-	-	-	-	-
golden perch	-	-	-	-	-	-	-	-	-	-	-	-
river blackfish	-	-	-	-	-	-	-	-	-	-	-	-
trout cod	-	-	-	-	-	-	-	-	-	-	-	-
Murray cod	579	27.127	1.3340	612	37.524	1.0193	10	0.264	2.3638	19	1.396	0.8506
Introduced												
gambusia	-	-	-	-	-	-	-	-	-	-	-	-
oriental weatherloach	-	-	-	-	-	-	-	-	-	-	-	-
redfin perch	-	-	-	-	-	-	-	-	-	-	-	-
carp	-	-	-	-	-	-	-	-	-	-	-	-
gold fish	-	-	-	-	-	-	-	-	-	-	-	-
crustaceans	2	27.127	0.0046	20	37.524	0.0333	3	0.264	0.7092	4	1.396	0.1791

Seasonal timing of spawning

The seasonal timing of the appearance of larvae in the Edward-Wakool system reflected similar patterns to previous monitoring in this system (Watts et al. 2013, Watts et al. 2014b). Australian smelt larvae were the first species detected as larvae in the 2014-2015 monitoring period (Figure 10.2). Larval sampling commenced on 17 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 27 October 2014 and 8 Dec 2015, with abundance peaking in mid November, showing consistent trends to the 2012-13 and 2013-14 monitoring periods (Figure 10.2). Carp gudgeon had the longest spawning period of all fish, with larvae detected for more than four months. Carp gudgeon larvae appearing first in Wakool River (zone 3) and Wakool River (zone 4) in mid October, and by mid November were present in Yallakool Creek and Wakool River (zone 2) (Figure 10.2). Peak abundance of larval carp gudgeon larvae occurred during December and January. Flathead gudgeon had a narrower spawning window than carp gudgeon, detected as larvae in all study zones for 3 months between October 2014 and January 2015, with the exception of a small number of larvae collected as early as 30 September in Yallakool Creek (zone 1) (Figure 10.2).

The smaller numbers of larvae caught for Murray River rainbowfish, unspecked hardyhead, river blackfish and gambusia means it is not possible to generalise on their spawning patterns. Of note is that river blackfish were collected as larvae only from 2 sites in Wakool River (zone 2) on two sampling occasions between mid October and mid November, also consistent with previous years observations (2013-14 and 2011-12).

Difference in total larval production across rivers

It was hypothesised that the total production of fish larvae across the 2014-15 spawning season would be significantly higher in the zones that received environmental water (zones 1, 3 and 4) compared to the upper Wakool River (zone 2). Results of the multiple one-way ANOVAS were not able to support this hypothesis, as we found no significant difference in the mean total number of larval fish for the three most abundant species; Australian smelt, carp gudgeon and Murray cod across the four zones (Table 10.3, Figure 10.3). The absence of golden perch or silver perch eggs or larvae in drift nets and light traps, suggest these species did not spawn in the selected area in 2014-15, noting that it was not an objective of Commonwealth environmental watering action in 2014-15 to target a perch spawning response.

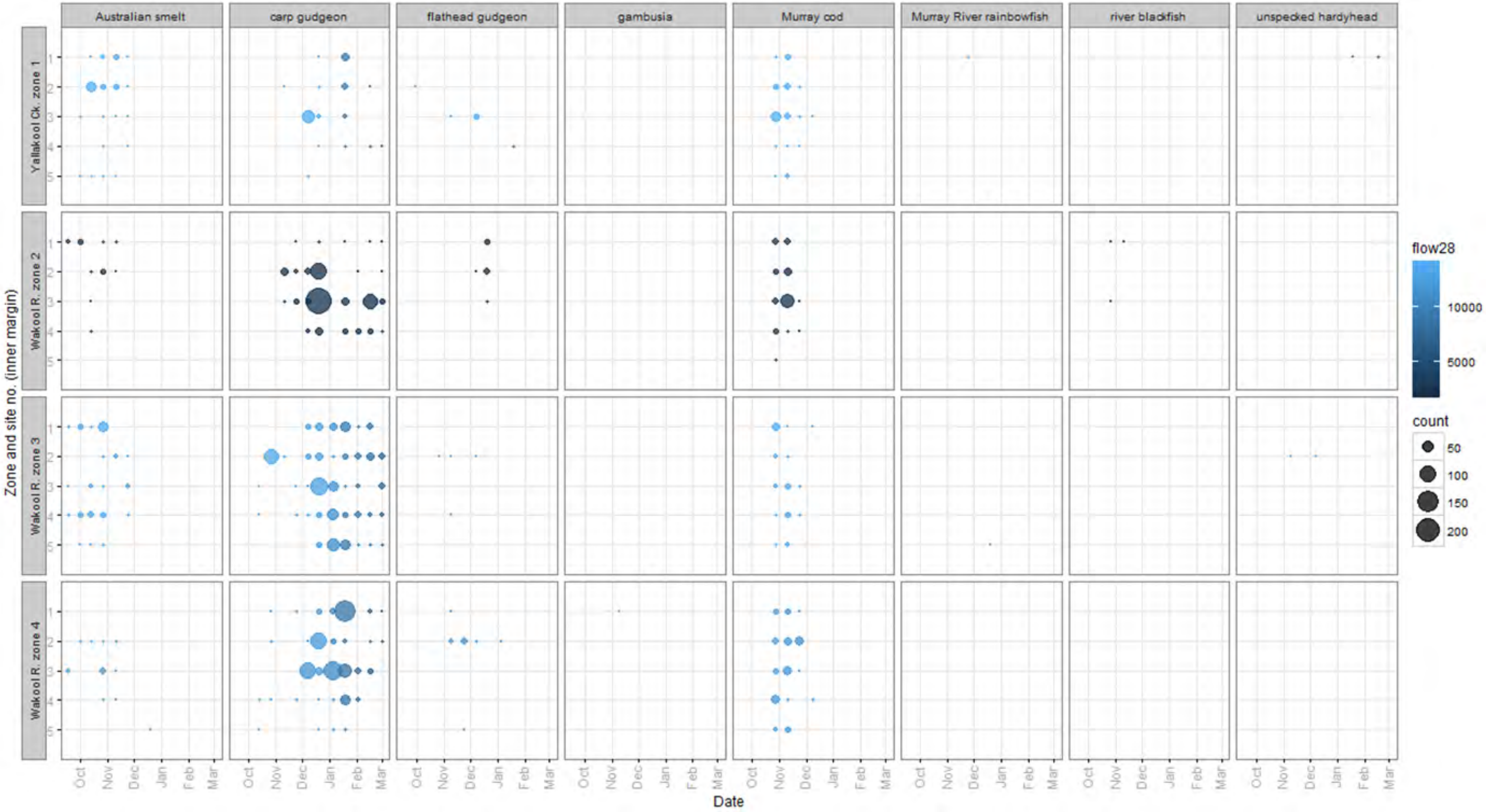
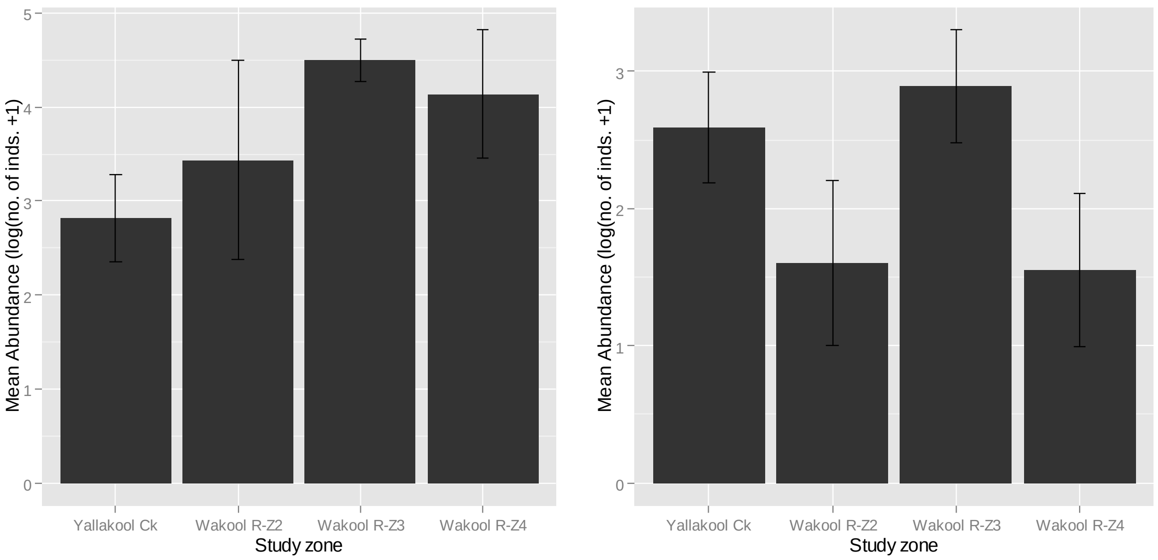


Figure 10.2: Bubble plots representing relative abundance of larval fish collected in light traps from each site across the 2014-15 sampling period. Bubble size (count) represents relative abundance based on maximum number of individuals collected. Bubble colour (flow28) represents cumulative discharge (ML) over the 28 days prior to sampling.

Table 10.3: Results of multiple one-way ANOVAS comparing total mean larvae abundance for i) Australian smelt, ii) carp gudgeon and iii) Murray cod, across river zones for the entire sampling period. *P* values <0-05 indicates there was a significant differences in mean larval fish abundance across zones.

Fish species	df	F-value	p
Australian smelt	3, 16	1.866	0.176
Carp gudgeon	3, 16	1.216	0.336
Murray cod	3, 16	1.022	0.409


i) carp gudgeon *ii) Australian smelt*

ii) Murray cod

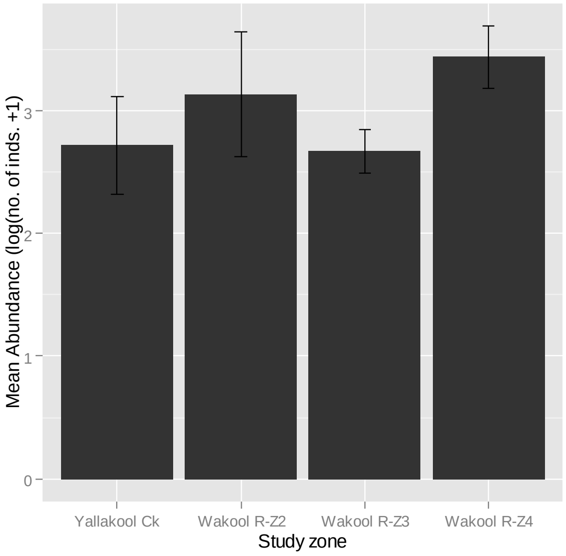


Figure 10.3: Mean total abundance (±SE) of larval sampled in the 2014-2-15 spawning season in the Edward-Wakool Selected Area, for *i)* carp gudgeon, *ii)* Australian smelt and *iii)* Murray cod. Note Y-axes vary. There was no significant difference in mean larval abundance across the four study zones for any of the three fish species tested.

10.5 Discussion

The Commonwealth environmental watering action in Yallakool Creek in 2014-15 did not have a significant effect (either positive or negative) on the spawning response of native fish.

One of the objectives of the sustained environmental flows in the Yallakool Creek in November 2014 to February 2015 was to support inundation of Murray cod nesting sites and contribute to maximising Murray cod recruitment. A similar watering action was delivered in 2012-13 and 2013-14, with no significant differences in Murray cod abundance detected between Yallakool Creek and the nearby upper Wakool River, which did not receive environmental flows at that time (Watts et al. 2013, Watts et al. 2014b). The results in 2014-15 support the previous results, where the number of Murray cod larvae collected in Yallakool Creek was not significantly greater than that in the Wakool River (zone 2) that did not receive environmental water. These findings support the strong body of knowledge that shows Murray Cod spawn at peak times in November-December, regardless of flow conditions (Rowland 1983; Humphries et al. 2005; Koehn and Harrington 2006; King et al. 2009).

Conditions that promote the number of adult breeding pairs to nest in rivers for equilibrium species, such as Murray cod and river blackfish, will likely play a large role in explaining the numbers of larvae observed across the rivers studied. Results from the fish movement work conducted in previous years (Watts et al. 2013, Watts et al. 2014b) have shown that, despite the delivery of environmental water to Yallakool Creek in early spring, Murray cod appeared to have exhibited a preference for moving into the upper Wakool River, suggesting that discharge per se may not be a key determinant in nest site location for this species. Instead, for Murray cod, other habitat variables such as the abundance of habitat structure (e.g. woody debris) may be important for nest building (Koehn 2009). An environmental watering action targeting the upper Wakool River would provide an opportunity to better understand the effects of river flow on fish spawning responses.

One of the objectives of the 2014-15 Commonwealth environmental watering was to contribute to improved opportunities for movement, condition, reproduction and recruitment of other native fish. Larval abundance of opportunistic species did not appear to be significantly different in study zones receiving environmental water. Those species that spawned, such as carp gudgeon, Australian smelt and flathead gudgeon, are common and widespread throughout the Murray-Darling Basin. Other species such as unspecked hardyhead and Murray rainbowfish, spawned, but in low numbers (n<10). Slackwater and slow water environments, and the presence of aquatic vegetation are considered important for the spawning and recruitment of many small bodied species (Humphries et al. 2010).

For low-flow specialists, such as many of the smaller bodied native fish species, environmental watering actions that provide a significant increase in low flow habitats (such as inundated slackwaters, backwaters and off channel wetlands) and aquatic vegetation during the spawning months, is likely to see an increase in habitat for both larvae and adult life stages. With the positive response in aquatic vegetation to Commonwealth environmental water in the Yallakool Creek (zone 1) and Wakool River (zones 3 and 4) this year (this report, section 8), it is anticipated that this will have positive effects for such species in upcoming spawning seasons.

The collection of a juvenile Galaxiid from the newly described species *Galaxias oliros* (commonly known as obscure Galaxias, Raadik 2014)) is of notable mention. Raadik (2014) recently revised the taxonomy of the Mountain Galaxias *Galaxisas olidus*, describing 12 new species within the *G. olidus* complex. The name '*oliros*' comes from a combination of the names of *G. olidus* and *G. rostratus*, as it shares morphological characteristics with both taxa. It's common name 'obscure galaxias', further reflects that despite being a widespread and common species, it has remained previously obscure due to its morphological similarity with *G. olidus*. Obscure galaxias is small bodied fish recorded to 13 cm, but commonly found at 7.5 to 9 cm long. It is olive to grey-brown in colour, and described as having a distinct body pattern, particularly on its sides, and with a gill cover that may have a large turquoise or gold patch, and a distinctly silver or white belly (Raadik 2014).

The obscure galaxias occurs widely through the Murray River system and its tributaries, occupying areas of low to moderate elevation from 0-600 m in lowland to foothill reaches. It can be found in a range of stream types from slow to moderately fast flowing creeks and rivers, as well as in lentic habitats such as billabongs, wetlands, and disconnected pools, and as such, is considered a hardy species, with a high tolerance to physico-chemical parameters such as turbidity and salinity (Raadik 2014). Individuals are commonly found amongst aquatic vegetation and submerged woody debris (Raadik 2014), thought are also considered more pelagic (found in the open water) and more mobile than other species in the *G. olidus* complex . Spawning of *G. oliros* occurs much earlier in the season compared with the majority of Murray-Darling fishes, from late May to early July (Raadik 2014), and unlike other species in the Galaxias genus, are not considered to undertake diadromous migrations. More detailed information regarding the spawning ecology and habitat and flow requirements specific for this species has not been reported, and warrants further study. Ongoing monitoring of larval fish assemblage in the Edward Wakool Selected Area across the different hydrological zones will be advantageous in understanding more of this species ecological requirements, and elucidating the influence environmental watering actions may be having on the local population of this species.

10.6 References

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11. MURRAY COD, GOLDEN PERCH AND SILVER PERCH RECRUITMENT AND GROWTH RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

Young-of-Year Murray cod recruit estimated to be 133 days old sampled in the Wakool River zone 4 (photo: R. Kopf)

Summary

- The 2014-15 watering year is the first time that LTIM Selected Area fish recruitment monitoring has been undertaken to evaluate long-term annual changes in recruitment and growth of Murray cod, silver perch and golden perch within the Edward-Wakool system. The selected area fish recruitment monitoring enables a comparison of recruitment among different hydrological zones in this system. This approach is different to the basin-scale fish recruitment index (see Section 9) that calculates one overall recruitment index for the entire system. The selected area fish recruitment monitoring utilised backpack electro-fishing, standardised angling and set-lines. Given that this was the first year of monitoring, it was not possible to evaluate the trajectory of change (positive, neutral, negative) in annual recruitment indices or growth but this will be possible in future monitoring years.
- Four sites were sampled in each of four hydrological zones in the Edward-Wakool system: Yallakool Creek zone 1, Wakool River Zone 2, Wakool River Zone3 and Wakool River Zone 4. The sites were sampled between February and March 2015.
- Recruitment of Murray cod, including young-of-year (YOY) and age-class 1 (1+) fish, was consistent among all zones.
- Extremely low numbers of silver perch and golden perch recruits sampled was interpreted as low recruitment of these species in these zones, and possibly in the Edward River upstream, during 2014-15.
- A high degree of zone-specific variation in length-at-age of 1+ Murray cod recruits suggests that growth of this species is likely to be a useful indicator to evaluate long-term annual changes in response to environmental flows. Differences in the growth rates of Murray cod recruits among zones were not related to Commonwealth environmental water delivery in 2014-15.
- Analyses suggest that additional recruitment sampling effort, increasing from 4 to 12 sites per zone or visiting the 4 sites on 3 sampling occasions, would be required in order to confidently assess the effect of environmental water delivery among zones.

11.1 Background

One objective of environmental water delivery is to provide recruitment outcomes for native fish. Once reproduction has occurred, the ultimate measure of spawning success is the number of individuals that survive to different stages of life. Recruitment can be defined in various ways but for purposes of this report, it is defined as an index of relative abundance (catch per unit effort) of young-of-year (YOY) and age class 1 (1+) fish. These age-classes were selected for indices because they represent individuals surviving through the high mortality larval stages of development (Hurst and Conover 1998; Byström et al. 2006; King et al. 2013).

Recruitment in fish that live in flowing water environments is tightly coupled with historical patterns of the natural flow regime associated with flooding, drought and more regular seasonal cycles (Lytle and Poff 2004). The flow regime is a driver of energy production, slack-water habitat and inundation of floodplains and back-water areas (Bunn and Arthington 2002), which all may influence recruitment of riverine fish in Australia and world-wide (King et al. 2013). Given the relatively high reproductive output of fishes, small changes in recruitment success can result in cascading effects on populations, communities the ecosystems they inhabit. Therefore, improving management of regulated river flow regimes and environmental watering actions in the Murray-Darling Basin has potential to benefit native fish communities via changes in recruitment (King et al. 2009; Rayner et al. 2009; Rolls et al. 2013).

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.

11.2 Questions

The aims of this monitoring component were to develop growth and recruitment indices for young-of-year (YOY) and age-class 1 (1+) Murray cod, golden perch and silver perch and to provide the first year of data for the following long-term monitoring questions:

Q1: *Did Commonwealth Environmental Water affect the growth rate of Murray cod, golden perch and silver perch during the first year of life?*

Q2: *Did Commonwealth Environmental Water contribute to the recruitment of Murray cod, golden perch and silver perch?*

It was predicted that the 2014-15 Yallakool Creek watering action would achieve better growth rates and recruitment of juvenile Murray cod, provided that the flow increased primary productivity or the availability of habitat (such as large woody debris and other instream structure) for recruits, as these habitats can create slack-water habitat and concentrate food and provide cover for young fish.

11.3 Methods

Field sampling

Four sites were sampled in each of four hydrological zones within the Edward-Wakool system: Yallakool Creek zone 1, Wakool River zone 2, Wakool River zone 3 and Wakool River zone 4. Each of the 16 sites were sampled in a randomly selected order between February and March 2015. Autumn sampling was undertaken to allow fish larvae hatched during spring and summer to reach the juvenile, Young-of-Year (YOY) stage, while at the same time sampling age-class 1 (1+) recruits which survived a previous winter. 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. These species were selected for recruitment analyses based on stakeholder input as they represent the three primary species of interest to recreational anglers in the Edward-Wakool system. These species also have a longer life span than the smaller bodied fish species, and responses of these species to environmental watering is expected over a longer time-span (2-5 years).

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. Since this was the first year of fish recruitment monitoring, the required level of effort to detect differences among zones was unknown. Therefore effort was estimated based on the recommended sampling distances of 40-100 times the average wetted width for standardised surveys (Hughes and Peck 2008).

Higher than normal power settings were used in backpack electrofishing to maximise the sampling efficiency of small-bodied recruits, which are less susceptible to electrical currents than larger individuals (Dolan and Miranda 2003). A power of 1.5-3.0 A was achieved at all sites using 250-450V of pulsed direct current at a frequency of 45Hz. Sampling was undertaken during low to moderate flows in February or March at all wadeable depths between 0 to 1.2 m, alternating banks when possible to follow the wadable shoreline adjacent to the thalweg (lowest point of the main discharge carrying portion of the river). 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. Recreational anglers have previously reported catching large numbers of silver perch in the Edward-Wakool system, particularly following floods in 2010-11. 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 and consisted of 8 to 14 lb monofilament attached to a baited hook, 0.04 g to 0.08 g split shot weight, rod and spinning reel. A size 6 to 10 J-hook modified to form a circle hook was used to target the small mouth-size of recruits. Each angler used a different bait consisting of 10 to 20 mm of worm, or 5 to 10 mm^3 of cheddar cheese. Baits were cast into a range of habitats, left still, slowly retrieved and repeated every 5 to 15 minutes occasionally moving locations. Species and length were recorded for all individuals caught.

Ten set-lines, each with a 3 to 10 m (100 lb) monofilament main-line and two 0.5 to 1.5 m (4 lb) leaders were set at each site. Lines were set, baited and hauled hourly during day-light hours for 5 to 7 hours at each site. Hook type and bait matched those in the standardised angling section. Set-lines were deployed from the river bank into the thalweg, spaced 10 to20 m apart along a 100 to 200 meter reach. Species and length were recorded for all individuals caught.

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. Length limits estimated to be the maximum potential size of YOY and 1+ recruits for target species were 310 mm total length (TL) for Murray cod (Anderson et al. 1992) and 285 mm TL for golden perch (Mallen-Cooper and Stuart 2003). Lethal sampling of silver perch was not permitted under the conditions of our sampling permit because it is a state listed threatened species, and therefore all individuals of this species were released alive. Fewer than 50 Murray cod $\leq$ 310 mm TL per zone and fewer than 50 golden perch $\leq$ 285 mm from each of the four zones were euthanized by immersion in a 1% concentration over-dose of benzocaine and stored on ice until being transported to a freezer at the end of each day.

Laboratory methods

To determine the annual age and growth rate of recruits, sagittal otoliths from sub-sampled 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. Each section was read blind by an independent consultant and twice by the sub-project leader from digital images taken at 16X magnification with transmitted light using standard methods previously validated for all species (Anderson et al. 1992; Mallen-Cooper and Stuart 2003).

Otolith section radius measurements (0.001 mm) were made from the primordium to each annulus and to the edge of the otolith. Final age estimates were based only on samples with matching age readings from all 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. Otoliths from fish assumed to be YOY, or younger and a sub-sample of larvae (from CAT 1 larval fish monitoring) were extracted for daily age estimation. Otoliths for daily age estimation were extracted and mounted on a microscope slide using Crystal Bond glue and ground/polished with lapidary film to identify micro-increments. Microincrements were viewed and enumerated under transmitted light at 250-400 X magnification. All otolith sections were checked under a fluorescence stereomicroscope fitted with an excitation filter to identify the presence of calcein marks that discriminate hatchery released and wild recruits (Crook et al. 2011).

Data analysis

Statistical analyses were performed only on Murray cod recruits because inadequate sample sizes of golden perch (n=0) and silver perch (n=3) recruits prohibited comparisons. Growth curves derived from annual and daily age estimates were fitted to the sample from each zone separately and to the sample from 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. The logistic model was described by the equation:

$$\mathrm{TL} = TL0 + \frac{Asymp. - TL0}{1 + \left(\frac{Age}{A_{50}}\right)^{-Growthindex}}$$

where *TL* = total length (mm) and *Age*= fish age in years, *TL0 =* TL at age 0, *Asymp.*= the asymptote, A_{50} represents the median age and the *growth index* is the slope of the curve at its midpoint. The weighting procedure was undertaken so that the model would most accurately fit age-length data of recruits, while the low sample sizes fish in age-classes older than 1+ was assumed not representative of the true variation in length-at-age.

Otolith age-length estimates were used to distinguish all YOY and 1+ Murray cod recruits from other age-classes. Since silver perch could not be sampled for aging purposes, due to threatened species permit restrictions, length ranges of 50-110 mm and 120-220 mm approximated from Mallen-Cooper and Stuart (2003) were assumed to represent YOY and 1+ recruits respectively. The mean length of recruits was compared statistically among zones using one-way ANOVA since this data was normally distributed with equal variance.

Recruitment indices of YOY and 1+ Murray cod, were calculated from catch per unit effort of backpack electrofishing, set-lines and angling. Catch per unit effort (CPUE) values were expressed as the number of recruits per 1000 seconds of sampling effort aggregated at the site-level and fitted to a Generalized Linear Mixed Effects Model (GLMM). The GLMM tested whether CPUE of YOY and 1+ recruits varied significantly in relation to the fixed effects of gear type and zone. Site was incorporated as a random effect. The best model was determined by the lowest Akaike Information Criterion (AIC) with an alpha of 0.05 used to distinguish the significance of fixed effects.

Given that this was the first year of sampling, it was not possible to evaluate the trajectory of change (positive, neutral, negative) in annual recruitment indices or growth but this will be possible in future monitoring years. Additionally, no recruitment indices were available from previous years in order to make comparisons.

A power analysis using an alpha of 0.05, desired power of 0.80, the current sample size of 4 sites per zone, and the residual standard deviation in Murray cod recruit CPUE was undertaken to estimate the number of sites required in order to confidently test for mean differences in recruitment among zones.

11.4 Results

A total of 8 native fish species and 5 invasive species were sampled in fish recruitment monitoring. Of notable importance was the presence of adult silver perch in all zones, and the presence of three river blackfish in Wakool River zone 2, site 2.

Recruit growth

Sections of otoliths from Murray cod resulted in clearly discernible alternating patterns of opaque and translucent zones that were used to distinguish recruits and other age-classes (Figure 11.1). Only 2 out of 45 annual otolith ages were not consistent among all three reads and these were not used in analyses. Murray cod YOY ranged from 52 to 99 mm TL and 113 to 149 days old, while 1+ recruits ranged widely from 141 to 257 mm TL (Figure 11.2).

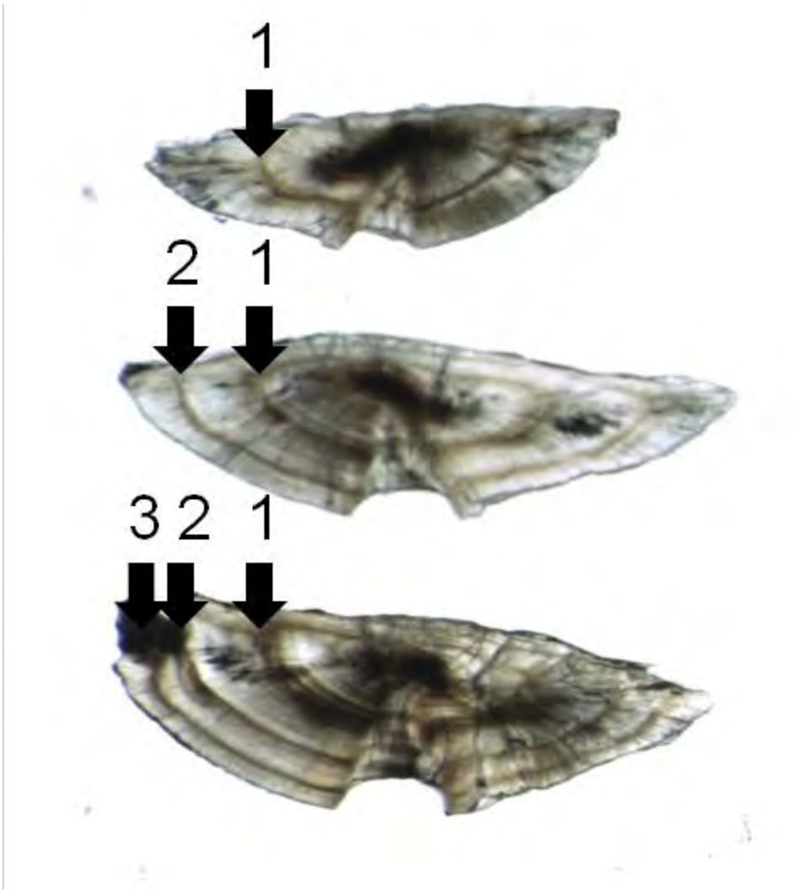

Figure 11.1: Assumed annual opaque and translucent growth zones in sections of Murray cod otoliths aged for fish recruitment sampling.

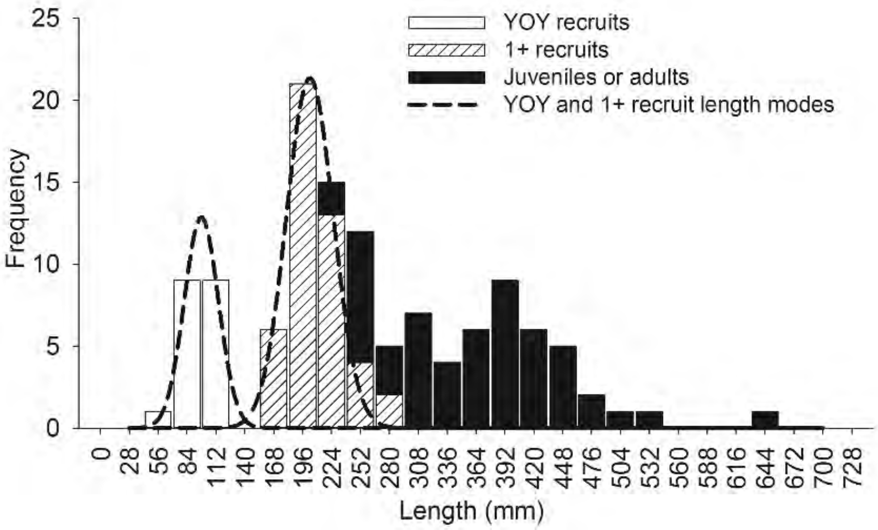

Figure 11.2: Length modes of Murray cod recruits sampled in the Edward-Wakool system 2014-15.

The logistic growth model provided a significant (df=93; F = 1252; P<0.001) fit to describe Murray cod age-length data (Figure 11.3). Apparent differences in growth curves among zones were not significant, so a single growth curve for the whole Edward-Wakool system was used to describe the age-length relationship. The fitted growth index parameter (Table 11.1) provides a useful index of Murray cod recruit growth that can be compared with future years in order to evaluate the long-term effects of Commonwealth environmental water delivery.

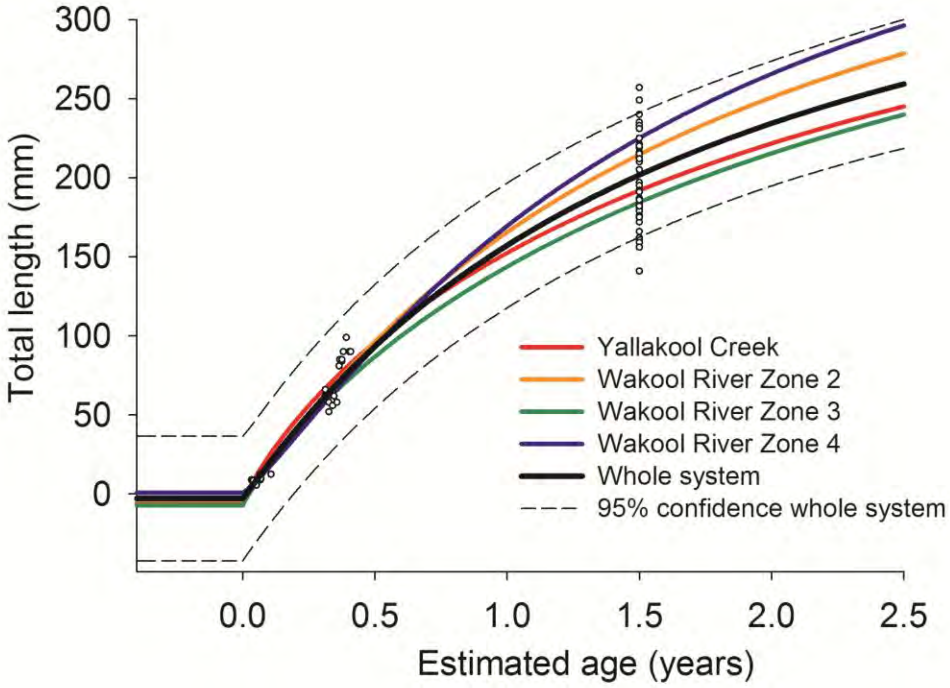

Figure 11.3: Growth curves of Murray cod recruits sampled in the Edward-Wakool system 2014-15.

Table 11.1: Logistic model growth index for Murray cod recruits sampled in the Edward-Wakool system in 2014-15.

Growth parameters	Estimate	Std. Error	t value	P value
Growth index	1.02	0.14	7.29	<0.0001

Although there were no differences in age-length models among zones, the length-at-age of 1+ Murray cod recruits was highly variable (Figure 11.4). The variability in 1+ Murray cod recruits length was partly explained by significant (ANOVA; df= 44; F = 15.2; P < 0.001) differences among the four zones sampled (Figure 11.5). Recruits in Yallakool Creek zone 1 and Wakool River zone 3 that received Commonwealth environmental water, were significantly smaller than recruits in Wakool River zone 2 and Wakool River zone 4. However, since Commonwealth environmental water was also delivered to Wakool River zone 4, where the largest 1+ recruits were sampled, the pattern of decreasing size of recruits with environmental water delivery was not consistent among all zones.

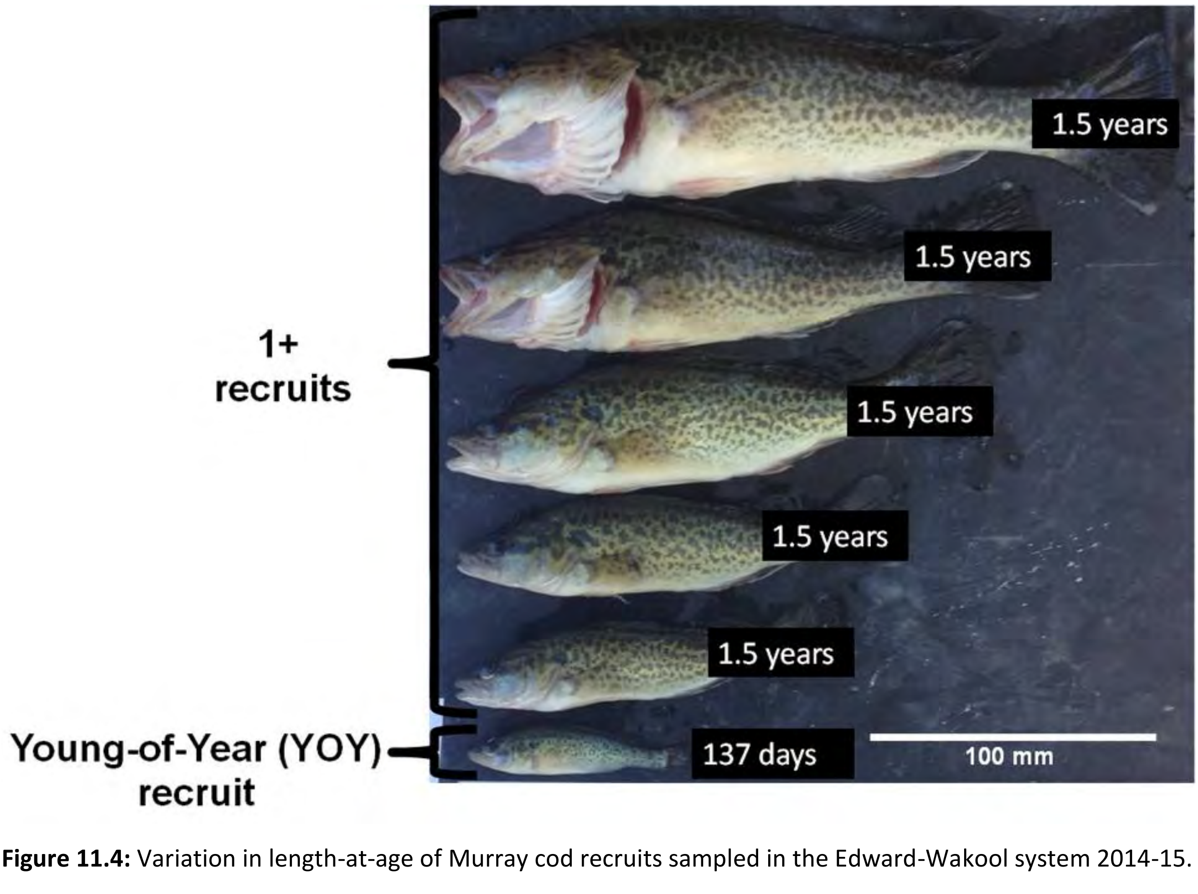

Figure 11.4: Variation in length-at-age of Murray cod recruits sampled in the Edward-Wakool system 2014-15.

The difference in mean length of 1+ Murray cod recruits among zones was as high as 46 mm which equates to a 20% mean difference in TL among zones. However, there were no significant differences in the mean length of YOY recruits among zones (Figure 11.5), which indicates that differences in the size of 1+ recruits occurs after the YOY stage, over their first winter and/or the following spring-summer period.

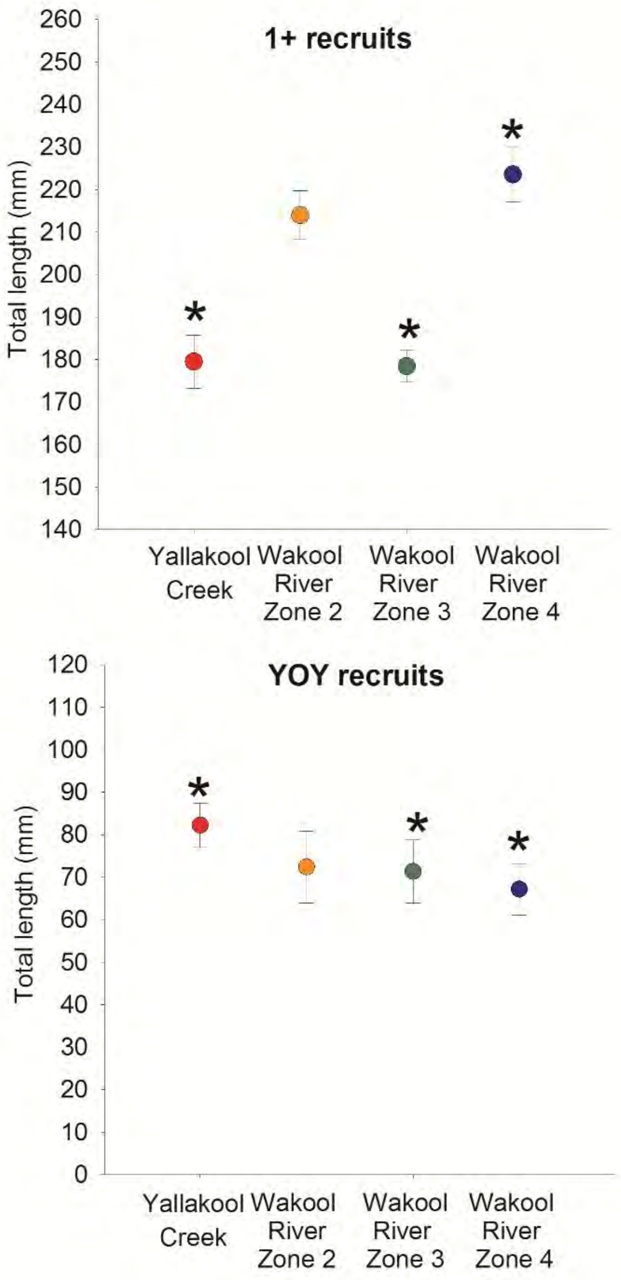

Figure 11.5: Mean (+/- SE) length of Murray cod recruits including age-class 1 (1+) and Young-of-Year (YOY) fish sampled in the Edward-Wakool system in 2014-15. The asterisk denotes river zones which received Commonwealth environmental water in 2013-14 and 2014-15. Wakool River zone 2 was the only zone that *did not* receive Commonwealth environmental water.

Relative abundance of recruits

Murray cod were the most abundant of the three species being targeted for the evaluation of fish recruitment (Table 11.2). Murray cod recruits were sampled consistently among all zones which included 19 YOY, 46 1+ recruits and 55 fish in older age-classes. Three silver perch between 120 mm and 220 mm TL were assumed to be 1+ recruits, and no golden perch recruits were sampled.

Table 11.2: 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.

		Stage of development		
Species	Zone	YOY recruit	1+ recruit	Other Juvenile or Adult
Murray cod	Yallakool Creek	5	15	17
	Wakool River zone 2	5	11	11
	Wakool River zone 3	3	14	13
	Wakool River zone 4	7	6	14
Silver perch	Yallakool Creek	0	1	6
	Wakool River zone 2	0	0	2
	Wakool River zone 3	0	1	5
	Wakool River zone 4	0	1	1
Golden perch	Yallakool Creek	0	0	0
	Wakool River zone 2	0	0	0
	Wakool River zone 3	0	0	1
	Wakool River zone 4	0	0	2

Indices of YOY and 1+ recruitment of Murray cod (Figure 11.6) were developed for the Edward-Wakool system for the 2014-15 year. The recruitment index values (Table 11.3) will be useful in the future to evaluate long-term annual changes in recruitment of Murray cod in relation to Commonwealth environmental water delivery.

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 11.3), 1+ recruits were sampled more efficiently than YOY. Both YOY and 1+ recruitment indices were modelled separately for each gear type with all zones combined (Figure 11.6). The GLMM incorporating river zone resulted in AIC's of 30.2 and 61.9 for YOY and 1+ recruits respectively, while the gear-only models resulted in the best fit with AIC's of 15.9 and 52.7 respectively. A range of different GLMM's testing for the effect of interactions among fixed effects all resulted higher AIC values.

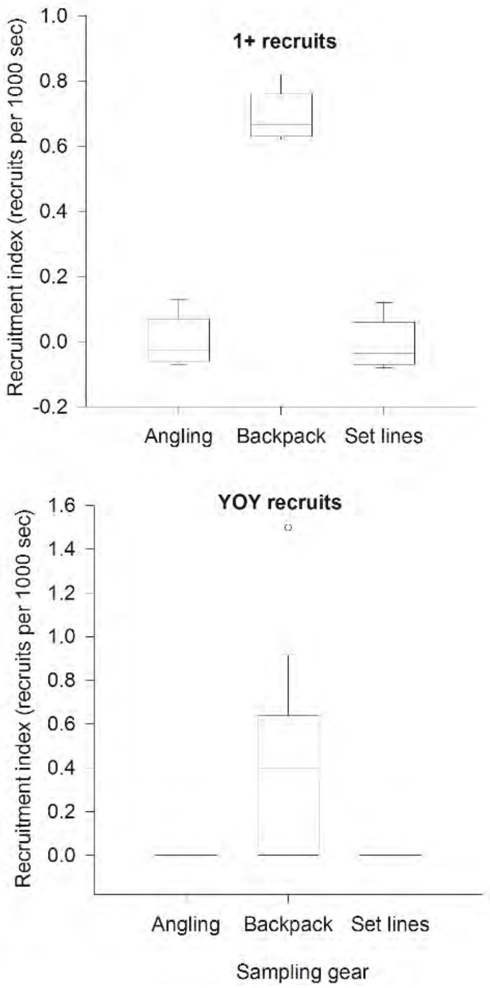

Figure 11.6: Catch per unit effort (1000 seconds) for age-class 1 (1+) and Young-of-Year (YOY) Murray cod recruits sampled in the Edward-Wakool system in 2014-15 using different sampling methods. Box plots represent median, upper and lower quartiles +/- 95% CI.

Table 11.3: Recruitment indices for Young-of-Year (YOY) and age-class 1 (1+) Murray cod for the Edward-Wakool system in 2014-15.

	YOY recruitment index			1+ recruitment index		
Fixed effects	value	Std. Error	p-value	value	Std. Error	p-value
Angling	0.00	0.08	NS	-0.13	0.13	NS
Backpack e-fishing	0.40	0.08	<0.0001	0.69	0.12	<0.0001
Set lines	0.00	0.08	NS	-0.01	0.12	NS

The statistical power (0.12) of the 1+ Murray cod recruitment index used to compare zones was less than the desired power of 0.80. It is therefore important to emphasize that the result of no significant differences in Murray cod recruitment among zones should be cautiously interpreted.

In order to confidently test for significant differences in Murray cod recruitment among zones the power analysis suggested that 12 monitoring sites, instead of 4, would need to be sampled within each zone. Therefore, the recruitment indices of Murray cod (Table 11.3) in the present year is reported for the entire Edward-Wakool system, by gear type, which will be useful in comparisons of long-term annual changes in fish recruitment in relation to environmental water delivery.

11.5 Discussion

The 2014-15 year represents the first year of new monitoring methods undertaken to evaluate long-term annual changes in selected area recruitment and growth of Murray cod, silver perch and golden perch in the Edward-Wakool system. The new methods undertaken were effective in sampling a wide range of fish species and in developing the first year indices of recruitment and growth for Murray cod. Thirteen species of fish were sampled, including silver perch at all zones and recruit-stage river blackfish that were also sampled at the same location (Wakool River zone 2) as the 2014-15 larval fish monitoring (section 10).

The recruitment index for 1+ Murray cod across zones of the Edward-Wakool system represents a robust indicator that will be useful in future years to evaluate long-term annual changes in relation to flow variability and Commonwealth environmental water delivery. The extremely low numbers of silver perch and golden perch recruits may be interpreted as: 1) low detection of the sampling gear, or 2) low recruitment. High annual variability in silver perch and golden perch recruitment is expected based on knowledge of the species’ reproductive biology and early life history (Mallen-Cooper and Stewart 2003). Therefore, years of low or no recruitment may be expected for these species. Given that recreational anglers have previously reported catching large numbers of young silver perch and golden perch using similar gear to the monitoring methods used here, the low number of recruits of these species sampled was interpreted as low, or zero, recruitment rather than a detection failure. Although Commonwealth environmental water delivery in 2014-15 was not designed to promote spawning or recruitment of golden perch or silver perch, the consistent presence of adult silver perch among all zones and golden perch sampled here and in the boat electrofishing fish community sampling (section 9) suggested that recruitment of these species may have been possible but that it was low, or did not occur in the 2013-14 or 2014-15.

Recruitment of Murray cod, including YOY and 1+ fish, occurred consistently among all zones. This result is comparable to the presence of Murray cod larvae sampled among all zones (section 10) and knowledge of the species reproductive biology and early life-history (Humphries et al. 1999; King et al. 2013). However, a power analysis suggested that additional sampling effort, increasing from 4 to 12 sites per zone, or visiting 4 sites on 3 occasions are required in order to confidently test for zone-specific changes in fish recruitment. Therefore, if comparing zone-specific responses in fish recruitment to environmental water delivery is a priority, it is recommended that 8 additional sites in each zone will be need to be monitored in future years.

A high degree of zone-specific variation in length-at-age of 1+ Murray cod recruits suggested that growth of this species may be a useful indicator to evaluate ecological responses to environmental flows within the Edward-Wakool system. Other small-bodied species exhibit flow-growth responses (Tonkin et al. 2011), although these relationships have not been evaluated in large-bodied native species of the Murray-Darling Basin. Monitoring in 2014-15 suggested low, or no, recruitment of silver perch and golden perch and therefore growth indices were not developed for these two species in this sampling year.

The large zone-specific differences in length of 1+ Murray cod recruits did not correspond to the hydrological zones of Commonwealth environmental water delivery. The results suggest that growth of 1+ Murray cod recruits may have been affected by other ecological factors, such as food, competition or habitat availability that were not assessed as part of the LTIM Project. It is possible that small-scale variability in environmental conditions (e.g. differences among reaches within a zone) are influencing growth. It is not known to what extent these factors were influenced by the timing or magnitude of Commonwealth environmental water delivered to the Yallakool Creek-Wakool River system in 2014-15, and these factors could be examined by studies that are complementary to the LTIM project.

Conclusion

The results from 2014-15 fish recruitment monitoring suggested that:

1) the new monitoring methods undertaken to assess recruitment are likely to be useful indicators in evaluating long-term annual changes in fish recruitment and growth in response to Commonwealth environmental water delivery because the zone-specific differences in growth suggest that rates of immigration and emigration of Murray cod recruits were low among the zones sampled in 2014-15.

2) there was no identified relationship (either positive or negative) between environmental watering over the 2014-15 year and the growth rate of Murray cod recruits. The selected area fish recruitment monitoring was particularly useful in making comparisons of growth and recruitment among zones of the Edward-Wakool. Better growth rates and recruitment of juvenile Murray cod may be achieved by

managing for summer low-flow conditions which can increase temperature and prey density (Humphries et al. 1999) as compared with the delivery of higher flows during summer. Management of flows should also be considered alongside of other important environmental factors such as the availability of habitat for recruits (e.g. large woody debris and other instream structure) which can create slack-water habitat and can concentrate food and provide cover for young fish. Recruitment and growth of golden perch and silver perch may be expected to be highest following over-bank spring floods, or environmental flows which inundate backwater areas and wetlands for suitable periods of time to generate food and provide suitable habitat for larvae and young juveniles to develop.

11.6 References

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12. SUMMARY AND SYNTHESIS

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2014-15. It is the first annual report of the Long Term Intervention Monitoring (LTIM) Project funded by the Commonwealth Environmental Watering Office (CEWO) that commenced in 2014 and continues until 2019. Being the first year of the program, this report provides an assessment of short-term responses to environmental watering in 2014-15 with respect to the objectives set by the Commonwealth Environmental Water office. Evaluation of responses across multiple years will be undertaken in subsequent reports. This report builds on previous short-term monitoring and evaluation projects undertaken in the Edward-Wakool system since 2010 (Watts et al. 2013a, Watts et al 2013b, Watts et al. 2014), however some of the monitoring sites, indicators and methods employed for this project are different to those undertaken for the short-term monitoring projects.

Commonwealth environmental water delivered to Yallakool Creek in 2014-15 had the following positive outcomes in reaches receiving environmental water (Table 12.1):

- Increased variation in discharge (section 4)
- Increased in-channel longitudinal connectivity (section 4)
- Increased lateral connectivity. There was an increase in wetted benthic area and area of slackwater and slow water in Wakool River zones 3 and 4, but not in Yallakool Creek (section 5)
- Maintained dissolved oxygen levels and ecosystem respiration (section 6)
- Increased cover and diversity of instream aquatic vegetation, particularly in Wakool River zones 3 and 4, but not consistently in Yallakool Creek zone 1 (section 8)
- Potentially contributed to an increase in the diversity of native fish, with one new species, *Galaxias oliros* (obscure galaxias) recorded in Yallakool Creek (section 10).

There was one negative response to Commonwealth environmental watering in 2014-15 (Table 12.1), being a reduction in the area of slackwater in Yallakool Creek during the environmental watering action compared to area of available slackwater during base flows (section 5). This finding was consistent with observations in 2013-14 (Watts et al 2014) of a lower abundance of shrimp larvae in Yallakool Creek during the environmental watering. Shrimp are not monitored as part of the LTIM Project, but it is expected that the increased area of fast flows in Yallakool Creek during the environmental watering action will have had a negative effect on larval shrimp, and the increase in slack water and slow water in zones 3 and 4 will have had a positive outcome for shrimp and other taxa in those zones that require slow flowing water for recruitment and survival.

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 (section 5), this increase was not sufficient to trigger an increase in gross primary productivity (section 7). 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.

Fish spawning (section 10), and fish recruitment (section 11) indicators did not respond to environmental watering action. Although there is good evidence that fish reproduction occurs in this system (nine species collected as larvae in 2014-15, see section 10; nine species collected as larvae in 2013-14, Watts et al. 2014), the spawning response could not be attributed to the watering action because a similar level of reproduction occurred in the Wakool River (zone 2) that did not receive environmental water. Although there is evidence of some recovery in the fish community in areas impacted by the blackwater events in 2010-2012 (section 9), some of the improvement in the fish community is likely to be due to other factors, such as immigration of fish into the system.

The responses to Commonwealth environmental watering observed in 2014-15 were consistent with those observed previously in this system. The good outcomes for dissolved oxygen and aquatic vegetation will help improve the system for longer term benefits to be realised, providing habitat for invertebrates and small bodied fish and potentially improving riverine productivity. Good dissolved oxygen levels and increased instream habitat are essential for the long-term health of this system and could lead to improved outcomes for fish in the longer term.

The environmental watering that was implemented during the blackwater events of 2010 to 2012 mitigated extreme low dissolved oxygen concentrations (Watts et al. 2013) and created an area of refuge habitat and water quality conditions to avoid critical loss of fish in the upper reaches of the Wakool River and Yallakool Creek. The benefits of those watering actions area still evident, with fish populations in the upper reaches having higher biomass than those in the lower reaches (section 10). The long-term recovery of fish populations in this system is ongoing. Some of the benefits of the Commonwealth environmental watering actions are expected to be realised over a much longer time frame 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 2014-15.

🟩 Positive response to environmental watering (green)
🟥 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	Short-term response to Yallakool Creek e-watering event (Aug 2014-Jan 2015) (< 1 year)	Response to e-watering assessed across 2014-15 watering year (1 year)	Longer-term response to e-watering (assessed across 1-5 years)
Hydrology	Hydrological connectivity	🟩	🟩	N/A TO BE ASSESSED IN YEARS 2 TO 5 OF THE LONG-TERM INTERVENTION MONITORING PROJECT
	Coefficient of variation of discharge	N/A	🟩 zone 3 and 4 only	
Hydraulic modelling	In-channel wetted benthic area	🟩	N/A	
	Area of slackwater	🟩 zone 3 and 4 only	N/A	
	Area of slow flowing water	🟩 zone 3 and 4 only	N/A	
	Area of fast flowing water	🟥 zone 1		
Stream metabolism, water quality, and organic matter characterisation	Rates of gross primary productivity	▨	▨	
	Rates of ecosystem respiration	🟩	🟩	
	Rates of primary productivity	▨	▨	
	Dissolved organic matter	▨	▨	
	Dissolved oxygen	🟩	🟩	
	Temperature	▨	▨	
	Nutrient concentration	▨	▨	
	Modification of type and amount of DOM	▨	▨	
Riverbank and aquatic vegetation	Percent cover of riverbank and aquatic vegetation	N/A	🟩	
	Diversity of riverbank and aquatic vegetation	N/A	🟩	
Fish movement	Native fish survival, dispersal and synchronised movement	N/A	N/A	
Fish spawning and reproduction	Abundance of 'Opportunistic' (e.g. small bodied fish) species	N/A	▨	
	Abundance of ‘flow-dependent’ spawning species (e.g. golden and silver perch)	N/A	▨	
Fish recruitment	Growth rate of young-of-year (YOY) and age-class 1 (1+) Murray cod	N/A	▨	
	Recruitment of young-of-year (YOY) and age-class 1 (1+) Murray cod	N/A	▨	
Fish community	Fish condition	N/A	N/A	
	Fish recovery	N/A	N/A	

Assessment of outcomes against the Commonwealth environmental watering objectives

An assessment of the outcomes against the ecological objectives for 2014-15 in the Edward-Wakool system outlined in the Water Use Minute 10008 (CEWO, 2014) is presented in Table 12.2 and an assessment of outcomes against the specific objectives for the Yallakool Creek environmental watering action in 2014-15 is provided in Table 12.3. Some of the watering objectives were achieved, some were not achieved and some were not assessed in the Edward-Wakool system in 2014-15. In both of these assessments 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 environmental watering action in 2014-15.

Table 12.2. Assessment of outcomes of Commonwealth environmental watering in the Edward-Wakool system in 2014-15 against the broad environmental watering objectives outlined in water use Minute 10008. Green shading indicates positive response, red shading indicates negative 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 10008	**Objective achieved or not achieved**
Improve the diversity and condition of native fish and other native species including frogs, turtles and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit	Improved diversity of native fish, with one new species detected Diversity and condition of frogs, turtles and invertebrates not assessed
	Improvement in reproduction and recruitment of native fish not achieved
Improve 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. Increased lateral connectivity at some sites
Support inundation of low-lying wetlands/floodplains habitats within the system	Inundation of low lying in-channel features at some sites
Maintain health of riparian, floodplain and wetland native vegetation communities	Floodplain and wetland vegetation not assessed.
	Cover and diversity of riverbank and aquatic vegetation was improved at most sites
Contribute to a more natural wetting-drying cycle for ephemeral wetlands and watercourses	Not assessed
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 most sites receiving environmental water
	Reduced area of slackwater in Yallakool Creek

Table 12.3. Assessment of outcomes of Commonwealth environmental watering against the environmental watering objectives defined for the Yallakool Creek environmental watering action in 2014-15. Green shading indicates positive response, red shading indicates negative response, grey shading indicates no detectable response (either positive or negative) to environmental watering. White boxes indicate no evaluation was undertaken.

Commonwealth environmental watering objective for the Yallakool Creek environmental watering action	Objective achieved or not achieved
Support inundation of Murray cod nesting sites and contribute to maximising Murray cod recruitment	Extent of inundation of Murray cod nesting sites not assessed, but it is expected that the environmental flow inundated nests
	No detectible improvement in Murray cod recruitment
Contribute to improved opportunities for movement, condition, reproduction and recruitment of native fish	Fish movement not assessed in 2014-15
	No detectible improvement in reproduction or recruitment of native fish
Increase hydrological connectivity, including inundation of slackwater habitats areas downstream of the Yallakool-Wakool confluence, providing opportunities for recruitment of small bodied native fish, frogs and shrimp	There was increased longitudinal connectivity. There was increased lateral hydrological connectivity at some sites
	Reduced area of slackwater in Yallakool Creek
Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants	Cover and diversity of riverbank and aquatic vegetation was improved at most sites
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
Contribute to maximising outcomes in the Wakool from outflows from Koondrook-Perricoota and provide greater volume of receiving water	Not assessed, because a planned outflow from Koondrook-Perricoota by NSW Forestry did not occur

13. RECOMMENDATIONS AND APPLICATION THROUGH ADAPTIVE MANAGEMENT INTO 2015-16 USE OF COMMONWEALTH ENVIRONMENTAL WATER

During 2014-15 LTIM progress reports on Commonwealth environmental watering actions were provided to the Commonwealth Environmental Water Office in September 2014 (Watts 2014), December 2014 (Watts 2014b) and March 2015 (Watts 2015). The LTIM progress reports, combined with regular meetings of the Edward Wakool Operations Advisory Group and feedback from local community representatives throughout 2014-15, informed the planning of Commonwealth environmental water use in the Edward-Wakool system during 2015-16.

The ten recommendations below include, where applicable, a note to indicate if the recommendation has been applied (as at 31 October 2015) in the 2015-16 use of Commonwealth environmental water in the Edward-Wakool system (commenced on 4 September 2015). In summary, the ten recommendations are to:

1. Increase the duration of the recession of environmental watering actions,
2. Avoid long periods of constant flows,
3. Consider a trial of shifting the focus of the delivery of environmental water from Yallakool Creek to the Wakool River,
4. Consider the delivery of base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat,
5. Continue to include a water use option in planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events,
6. Set watering action objectives that identify the temporal and spatial scale at which the response is expected,
7. Consider the implementation of a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/day,
8. Consider the implementation of an environmental watering action in the Edward River to target golden perch and silver perch spawning,
9. Undertake comprehensive flows assessment for the smaller creeks and rivers of the Edward-Wakool system, and
10. Collaborate with other management agencies and the community to maximise the benefits of Commonwealth environmental watering actions.

Recommendation 1. Increase the duration of the recession of Commonwealth environmental watering actions relative to the Yallakool Creek environmental watering actions in 2012-13 and 2013-14.

Natural in-channel river freshes are often characterised as having a steep rise and extended recession. An extended recession at the end of a flow event will:

- Increase the time for some aquatic vegetation taxa to maximise tuber development before becoming exposed and so enhance future resilience.
- Increase the period of time in which there is an area of shallow inundated riverbank or damp riverbank sediment in which new vegetation seedlings can emerge and grow. There was evidence of seedlings emerging following the recession at some sites in zone 3 in 2014-15 (see section 8)
- Maximise the opportunity for seed set in some plants. Conditions for seed set can vary among taxa but some species set seed only occurs if flood recession is slow.

Recommendation #1 from the 2013-14 Edward-Wakool monitoring report (Watts et al. 2014) states “Use Commonwealth environmental water to manage the recession of unregulated flows and environmental watering actions”. In response to this, environmental water was delivered to Yallakool Creek in 2014-15 with a managed recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day. Whilst this rate of recession is suitable to avoid stranding of taxa, it is unlikely to maximise outcomes in aquatic vegetation. We recommend that the rate of recession be further decreased and the duration of the recession increased compared to the environmental watering event in 2014-15. The rate should be guided by analysis of rates of recession of modelled unregulated events and by ecological requirements of a wide range of taxa.

Adaptive management response in 2015-16: This recommendation has been applied in the 2015-16 use of Commonwealth environmental water in the Yallakool Creek and Colligen Creek-Niemur River watering actions, particularly to maximise outcomes for instream aquatic vegetation. For example, the recession period for 2015-16 flows in Yallakool Creek was over nine weeks compared to four weeks in 2014-15.

Recommendation 2. Avoid long periods of constant flows by commencing the recession of environmental watering actions earlier and introducing flow variability into environmental watering actions.

River 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"*.

The environmental watering action in Yallakool Creek in 2014-15 resulted in an extended period of relatively constant discharge of approximately 500 ML/day in Yallakool Creek from 12th August until mid December 2014. The recession commenced when there were no Murray cod larvae caught in larval light traps, with the aim being to minimise the risk of eggs in Murray cod nests being exposed.

One strategy to decrease the period of 'constant' flows is to commence the recession of environmental watering actions of this type earlier. There is minimal risk of adverse outcomes because if a long recession is implemented (see recommendation #1) then there will be a period of time before the water levels would be lowered to the depth at which Murray cod nests would be exposed. Using this strategy to reduce the period of constant flows would also reduce the risk of notching occurring on riverbanks due to long duration of constant discharge. Another strategy to decrease the period of 'constant' flows is to incorporate some of the natural levels of variability within managed environmental watering actions, setting bounds for the river operators to work within. 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. This recommendation is consistent with one of the key recommendations of Thoms et al. (2000).

Adaptive management response in 2015-16: This recommendation has been applied in the 2015-16 use of Commonwealth environmental water in the Yallakool Creek, Wakool River and Colligen Creek-Niemur River watering actions. For example, in 2015-16 the River Operator (Water NSW) was provided with an 'operating range' during the period when constant flows were most likely to occur. This trialled the use of the 'operating range' to improve flow variability at a small scale whilst not risking the ability to achieve other targeted outcomes, such as providing nesting habitat for Murray cod. Colligen Creek is likely to have increased levels of variability compared to other systems due to the River Operator passing rain rejection or other operational flows through the creek. Evaluation of 2015-16 watering actions will inform the 'operating range' in future watering actions.

Recommendation 3. Consider a trial of shifting the focus of the delivery of environmental water from Yallakool Creek to the Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system.

Since 2011 Commonwealth environmental watering actions in the Wakool-Yallakool Creek system have focussed delivery of the majority of environmental water to the system via Yallakool Creek, whereas over the same period the delivery of environmental water to the upper Wakool River has been very modest.

The recommendation is to shift the focus of environmental watering from Yallakool Creek to the upper Wakool River, through the delivery of operational base flows in Yallakool Creek and higher flows in the upper Wakool River. This would not exceed the current operational constraint of 550 to 600 ML/day downstream of the confluence with Yallakool Creek. This proposed action would not result in any difference to the environmental watering outcomes in the Wakool River zones 3 and 4 downstream of the Wakool-Yallakool confluence, because environmental water from the upper Wakool River would flow into that part of the system.

Shifting the environmental watering action from Yallakool Creek to the Wakool River in 2015-16 or subsequent years would achieve the following:

- Targeted environmental watering of the upper Wakool River would facilitate understanding of responses to flows in this system by disentangling the confounding factors of river and flow. Some of the monitoring results to date have been difficult to interpret, as it is not possible to disentangle the responses to environmental watering from responses related to a specific river. For example, Murray cod have demonstrated a consistent preference to move into the upper Wakool River during environmental watering actions in Yallakool Creek (Watts et al. 2013, 2014), however it is unclear whether this is due to a general preference for the Wakool River, or is an avoidance of Yallakool Creek when it is receiving environmental water. If flow is a major contributor to this response then one would expect the positive vegetation and water quality responses observed in Yallakool Creek in 2013-14 (Watts et al. 2014) and 2014-15 (this report) to be observed in the upper Wakool River if it were to receive more environmental water.
- Environmental watering in the upper Wakool River would enable an evaluation of whether a substantial environmental flow in this system is capable of scouring the leaf litter that has built up in the channel in lower reaches of zone 2. This build-up of leaf litter in the shallow

water may be one of the factors resulting in low dissolved oxygen (section 6) and high ecosystem respiration (section 7) in zone 2.

- Environmental watering in the Wakool River zone 2 would Improve connectivity between the upper Wakool River and Yallakool Creek because the upper Wakool River zone 2 connects to Yallakool Creek via Black Dog Creek when discharge is greater than approximately 80 MLd^{-1} discharge in the Wakool River (see section 5)

Adaptive management response in 2015-16: During 2015-16 environmental water planning this recommendation was considered, and a small volume of Commonwealth environmental water was delivered to the upper Wakool River to maximise outcomes for instream aquatic vegetation and the potential movement of native fish. However, the full recommendation of shifting the focus of environmental watering from Yallakool Creek to the upper Wakool River has not yet been trialled.

Recommendation 4. Consider the delivery of base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat

Under current operational practices the flows to the Wakool River and Yallakool River cease during late autumn and early winter. During this period large sections of the riverbed dry up completely, with the exception of the larger deeper permanent pools. Telemetry has shown that Murray cod, golden perch and silver perch spend this period in permanent pools (Watts et al. 2013, 2014). Although this period of no flow may be accommodated by the large bodied fish species, it may be detrimental for some other taxa. For example, river blackfish is a territorial species that has been shown to maintain a home range of only 100’s of metres (Khan et al. 2004, Koster and Crook 2008). Both adults and larvae of this species have been recorded in the upper Wakool River (see sections 9, 10 and 11). The period of no flow in this system would force individuals to move out of their home range to the permanent pools, where they would be more vulnerable to predation.

The proposed delivery of a small environmental flow (e.g. 40 ML/day) to the Wakool River and/or Yallakool Creek during winter would create more favourable conditions for taxa, such as river blackfish, that have different flow requirements to the large bodied fish species. The proposed environmental watering action may increase the resilience of these populations and could potentially increase the rate at which these populations increase over time. The proposed watering action would not jeopardise the drying of the riverbank that occurs during winter, as the majority of riverbank would be exposed and experience a period of drying during the delivery of the small winter environmental flow.

There are operational issues around the delivery of base flows during autumn and winter that would need to be resolved, especially for the period of time when Stevens Weir is traditionally open and the weirpool level is low. This would mean the water level in the weir may not be high enough to deliver environmental water through the Wakool regulator by gravity feed. Other options, such as those listed below, for the delivery of environmental water to create adequate baseflows in the upper Wakool River should be explored as there are potentially benefits for a wide range of taxa from this action :

- Direct pumping is a feasible option, as the proposed flow is at a low rate
- Guided by catchment conditions and water availability, the winter operation of Stevens Weir could be alternated from year to year to provide more system wide variability to flows over years. For example, in some years Stevens Weir could be kept sufficiently full to enable low winter base flows to be provided into the upper Wakool, Yallakool and Colligen-Niemur systems, while in other years the Stevens Weir could be fully opened and the weir fully lower to enable bank drying to occur.

Recommendation 5. Continue to include a water use option in planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events

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 Flows Group and the Water Murray and District Dissolved Oxygen Group are a vital part of this action.

Adaptive management response in 2015-16: This recommendation was applied in the 2015-16 planning for the use of Commonwealth environmental water in the Edward-Wakool River system, especially to contribute to contingency responses to hypoxic blackwater events should they occur.

Recommendation 6. Set watering action objectives that identify the temporal and spatial scale at which the response is expected and are realistic given the magnitude of environmental watering actions proposed.

Some ecosystem responses to environmental watering can be rapid, occurring during an environmental watering action or a short time immediately after the watering action. For example, hydrological, water quality and productivity responses to watering actions can occur over a short timeframe. In contrast, other components of the ecosystem may respond to environmental watering only after a sequence of watering actions or after several years of environmental watering. For example, ecosystem components such as fish diversity are more complex and make take several years to show a detectable response.

In light of this, it is important that stakeholders set realistic flow targets that are relevant for the spatial and temporal scale of environmental watering. If unrealistic or unclear objectives are set for an environmental watering action and subsequently not achieved it will result in perceived failure of the watering action. This is particularly important in the Wakool-Yallakool system where there are delivery constraints (such as the constraint of 600 ML/day at the confluence of the Wakool River and Yallakool Creek) that limit the magnitude of environmental watering actions. As this constraint limits the spatial extent to which riverbanks can be inundated, flow objectives associated with environmental watering events in this system need to be appropriate for the spatial and temporal scale of the watering actions. Based on several years of monitoring in this system it is evident that environmental watering actions in Yallakool Creek of a maximum discharge of 600 ML/day does not result in increased river productivity and does not improve reproduction or recruitment of native fish, so these objectives should not be set for future watering actions of this magnitude. Other watering actions could be trialled to achieve these outcomes (see recommendations 7 and 8).

Adaptive management response in 2015-16: This recommendation has been applied in the setting of objectives for the planned use of Commonwealth environmental water in the Edward-Wakool River system during 2015-16. Objectives now reflect the maintaining/supporting role from the use of Commonwealth environmental water in the Edward-Wakool River system.

Recommendation 7. Consider the implementation of a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/day (possibly up to 1000 to 1200 ML/day). This would facilitate a test of the hypothesis that larger in-channel environmental watering action will result in increased 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 4). In the absence of river regulation natural flows in the system would be seasonal, with high flows typically occurring from July to November in winter and spring and lower flows in summer and autumn. Late winter and spring flows were a key feature in this system prior to river regulation.

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/day in Yallakool Creek), August/September 2012 (max discharge 1360 ML/day Yallakool Creek) and August/September 2013 (max discharge 1224 ML/day 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/early spring also brought carbon into the system from upstream without causing adverse effects on dissolved oxygen and water quality (Watts et al. 2013, 2014). Current knowledge from four years of monitoring of environmental watering in the Edward-Wakool system from 2011 to 2015 has shown that longer duration 600 ML/day environmental watering actions in Yallakool Creek have not increased river productivity and have not triggered spawning of golden perch or silver perch (Watts et al. 2013, 2014).

If a larger magnitude Commonwealth environmental watering action trial was undertaken in late winter/spring, based on previous monitoring results we would predict it would bring pulses of carbon into the system and enhance opportunities for dispersal, growth and reproduction. A short-duration flow trial in Wakool-Yallakool system at a higher discharge than the current operational constraint of 600 ML/day would facilitate learning and improve future delivery of environmental water to this system. Conducting a trial in winter/spring would cause least disruption to landholders farming practices. The trial need not be of long duration because productivity responses can occur in response to shorter duration events (1 to 2 weeks). This proposed flow trial would also facilitate on-ground validation of hydraulic modelling (section 5) 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.

Recommendation 8: Consider the implementation of an environmental watering action in the Edward River to target golden perch and silver perch spawning, as this is a larger system that does not have the same level of delivery constraints as the Wakool-Yallakool system.

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). No evidence to date has indicated that spawning in these species has occurred within the Edward-Wakool system (Watts et al. 2014, this report). However, the Edward-Wakool system does provide habitat that supports juveniles and adults of both species, as they have been captured in this system in recent years (Watts et al. 2014). 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 Edward-Wakool LTIM project (fish movement) and other concurrent collaborations.

Environmental watering actions in the Wakool-Yallakool system are currently constrained to a maximum of 600 ML/day and actions of this magnitude (whilst not targeting golden perch and silver perch spawning) have not triggered spawning in these species. The Edward River main stem is a larger system and is more similar to other larger river systems (e.g. Goulburn River) where golden perch have been observed to spawn in recent years. The Edward River can also receive higher flows than the Wakool-Yallakool system. We proposed 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 systems to guide the development of a hydrograph during an environmental flow planning workshop.

Recommendation 9. Undertake comprehensive flows assessment for the smaller creeks and rivers of the Edward-Wakool system.

There is a need for a scientific expert panel to use a reputable flows method to provide guidelines for delivery of environmental water in the Edward-Wakool system, considering the breadth of hydrological, geomorphological and ecological responses. While there has been some hydrological modelling undertaken for the Edward River (Green 2001; Hale and SKM 2011, section 1 this report) there is currently no hydrological modelling on the unregulated flow regimes of the smaller creeks and rivers in the Edward-Wakool system and this information is required to underpin decisions on environmental watering in this system. A flows assessment of this system should consider factors such as natural rate 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, but consider all aspects of the river ecosystem 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) but has not yet been implemented.

Recommendation 10. Collaborate with other management agencies and the community to maximise the benefits of Commonwealth environmental watering actions

There were no observable increases in gross primary productivity or fish spawning in response to the Commonwealth environmental watering in 2014-15. This was consistent with observations from monitoring undertaken in 2012-13 (Watts et al. 2013) and 2013-14 (Watts et al. 2014). These results, along with other research, suggest that a larger area of in-channel riverbank inundation may be required to trigger responses in these parameters. The preliminary 2D hydraulic modelling of in-channel flows (section 5) show examples where key geomorphic features within the channel are inundated at different discharges. A more detailed examination of in-channel geomorphology and inundation patterns will help determine the discharge at which the best outcomes can be achieved from environmental water at the same time as minimising third party impacts. In the meantime, it is strongly recommended that there is continued monitoring of discharge, metabolism, food resources, habitat and fish community metrics (e.g. recruitment, movement, long term community structure) across a diverse range of base flow, natural flows and watering actions over a wide spread of seasons to better understand the conditions that are required to produce ecosystem responses to flows.

In addition, there are other factors (e.g. fast recession on operational flows, small instream barriers, stock management in riparian zones) that may limit how the ecosystem responds to Commonwealth environmental watering. The Commonwealth Environmental Water Office should actively work with other agencies and the community to identify and reduce the impacts of these factors to produce better ecosystem responses to environmental watering.

Adaptive management response in 2015-16: This recommendation has been applied in the use of Commonwealth environmental water in the Edward-Wakool River system during 2015-16. The use of Commonwealth environmental water to provide slower, more natural rates of recessions to high flow events (e.g. rain rejections and other operational flows) is an example of this.

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14. ACKNOWLEDGEMENTS

We respectfully acknowledge the Traditional Owners, their Elders past and present, their Nations of the Murray–Darling Basin, and their cultural, social, environmental, spiritual and economic connection to their lands and waters.

We extend our thanks to the Wakool River Association, the Edward-Wakool Anglers Association and landholders in the Edward-Wakool river system for allowing access to their properties and for their keen interest in this project. Community liaison was undertaken by staff from the Murray Local Land Services, with particular thanks to Josh Campbell. We particularly thank James Abell and Chris Smith who undertook the majority of the field work. Assistance with fieldwork and/or laboratory work was undertaken by James Abell, Tom Butterfield, Josh Campbell, Jonathon Doyle, Peter Graham, Duncan McLay, Timothy McGarry, Glenn Miller, Sean Lethlean, Kate Martin, Rod Martin, Rohan Rehwinkel, Chris Smith, Lachlan Webster, John St Vincent Welch, and Ian Wooden. Maps were prepared by Simon McDonald and Deanna Duffy (Charles Sturt University Spatial Analysis Unit), Rod Martin (NSW DPI) and Ian Wooden (NSW DPI). Tina Hines at the Monash University Water Studies Centre processed carbon and nutrient samples. Fish sampling was carried out under NSW Fisheries license (P11/0003-1.0) and approved by the CSU Animal Care and Ethics Committee (10/101). This project was funded by the Commonwealth Environmental Water Office with in-kind contributions from Charles Sturt University, Murray Local Land Services, NSW Department of Primary Industries, Monash University and NSW Office of Environment and Heritage.