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Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Edward-Wakool river system, 2013-14

Final Report

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	Executive summary	Robyn Watts
1	Introduction	Robyn Watts
2	Commonwealth environmental water use options and objectives 2013-14	Robyn Watts.
3	Commonwealth environmental watering 2013-14	Robyn Watts
4	Location of monitoring	Robyn Watts
5	Indicators	Robyn Watts
	Responses of indicators to Commonwealth environmental watering	
6.1	Fish community	Jason Thiem, Ian Wooden, Lee Baumgartner
6.2	Fish movement	Jason Thiem, Ian Wooden, Lee Baumgartner
6.3	Fish spawning and reproduction	Nicole McCasker
6.4	Fish recruitment	Keller Kopf
6.5	Riverbank and instream vegetation	Sascha Healy, Robyn Watts, Nicole McCasker
6.6	Water quality and chemistry	Julia Howitt, Nicole McCasker, Mike Grace
6.7	Organic matter characterisation	Julia Howitt
6.8	Whole stream metabolism	Mike Grace
6.9	Shrimp	James Dyer, Anthony Conallin
6.10	Frogs	Sascha Healy, Nicole McCasker
7	Synthesis	Robyn Watts
8	Recommendations	Robyn Watts

EXECUTIVE SUMMARY

This report documents the monitoring and evaluation of Commonwealth environmental watering in the Edward-Wakool system in 2013-14. It provides details of the environmental objectives of the watering actions, study design, indicators, methodology, and an assessment of ecosystem responses to environmental watering with respect to the objectives set by the Commonwealth Environmental Water Office. Results and conclusions from the monitoring and evaluation underpin recommendations for future environmental watering in this system.

Commonwealth environmental watering in the Edward-Wakool system in 2013-14

Prior to the 2013-14 water year commencing eight water use options for the mid-Murray region for 2013-14 were developed by the CEWO (2013a), taking into account likely resource availability, catchment conditions (Table 1) and other key factors including constraints on delivery of environmental water in the Edward-Wakool system. Only options 1 (Edward-Wakool River instream fish flows) and option 3 (Mid-Murray and region water quality and habitat) were monitored by this project. These options are managed within the channel and delivered with regard to demands on the delivery system and risk of downstream impacts. Environmental water may be constrained by other demands on the system, especially during the irrigation season.

The use of Commonwealth environmental water was intended to contribute to baseflows and freshes, and potentially the recession of natural bankfull/overbank flows in the Edward-Wakool River System, to achieve the following expected outcomes (CEWO, 2013b):

1. Increase movement, condition, reproduction and recruitment of native fish
2. Provide end of system flows and increase hydrological connectivity in ephemeral streams (this objective was not assessed in this project)
3. Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants
4. Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH
5. Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs.

Four environmental watering actions undertaken in the Edward-Wakool System in 2013-14 that are the focus of this report were:

1. Cod maintenance flow – Yallakool Creek

From 17 October 2013 to 16 December 2013, environmental water was delivered to Yallakool Creek (targeting flows of 500 ML/day) to support Murray cod spawning and juvenile drift, and to maintain inundation of nesting habitat. Environmental water return flows from the Murray multi-site watering event met the requirements for this watering action (approx 12,000-18,000 ML).

2. Perch pulse flow – Yallakool Creek

A perch flow was delivered to Yallakool Creek in November 2013 on top of the cod maintenance flow to attempt to stimulate fish spawning in flow-dependent species. Flows were maintained at 500 ML/day for 7 days, from 9 November 2013 flows were increased over two days to ~600 ML/day, held at this increase stage height and returned over two days back to 500 ML/day for cod maintenance. This pulse equated to a temporary river rise of approximately 15 cm in water level at Yallakool Creek Regulator and was also part of the Murray multi-site watering event. This event resulted in a rise of approximately 7-10 cm further down theWakool River system at the Wakool-Barham Road Bridge.

3. Cod maintenance flow recession – Yallakool Creek

From 17 December 2013 to 4 February 2014, 8,494 ML of Commonwealth environmental water contributed to a gradual recession from the cod maintenance flow (500 ML/day) to regulated baseflow levels (~250 ML/day) to provide benefits to aquatic vegetation, frogs and fish. The recession consisted of a 10 cm drawdown (~ 40 ML/day) every 10 days commencing around 26 December.

4. Colligen-Niemur River continuation flow

From 7 February 2014 to 12 March 2014, 5,759 ML of Commonwealth environmental water was delivered to the Niemur River via Colligen Creek to continue the existing flow in an endeavour to reduce the risk of extremely high water temperatures re-occurring, and to lessen the risk of stress and mortality of native fish and other adverse environmental impacts. From 7 February through 2 March Commonwealth environmental water contributed 200 ML/d on top of existing flows (regulated demand was ~180 ML/d). For 10 days from 3 March through to 12 March Commonwealth environmental water contributed 100 ML/d on top of existing flows. This action was overrun by a rain rejection event being passed down Colligen Creek, which further improved water quality.

Monitoring of responses to environmental watering

Monitoring and evaluation of ecosystem responses to environmental watering in the Edward-Wakool system has been undertaken since 2010. This report outlines responses to environmental watering actions in 2013-14 and some longer-term responses, as the Edward-Wakool ecosystem is still recovering from the impact of the blackwater events that occurred between 2009 and 2012.

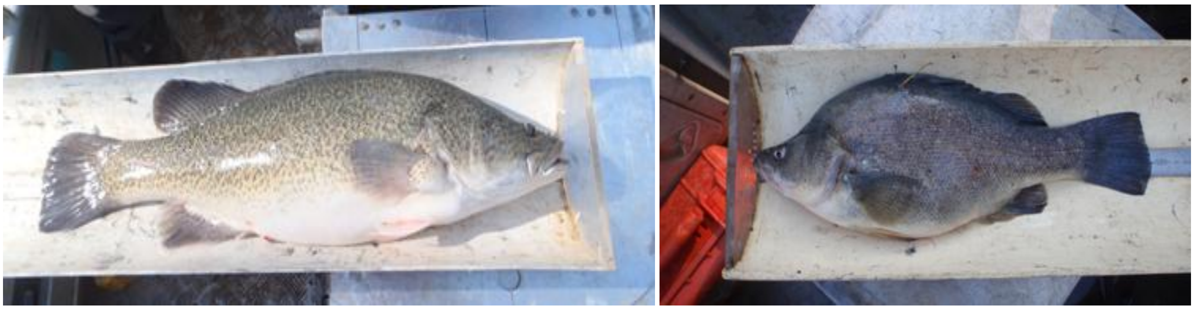
In 2013-14 monitoring was undertaken in four focus rivers. Commonwealth environmental water was delivered to Colligen Creek and Yallakool Creek (referred to as treatment rivers). In 2013-14 the Wakool River and Little Merran Creek did not receive environmental water (referred to as controls). The Edward River at Stevens Weir was also sampled as it was the source of environmental water. In addition, 41 sites throughout the system were assessed to determine longer-term responses of the fish community to major hydrological events including drought, flooding and blackwater. The frequency of sampling and locations where the indicators were monitored are listed in Table i.

Table i. Summary of location and frequency of sampling in the Edward-Wakool system in 2013-14 grouped according to the ecosystem outcome.

Expected ecosystem outcome listed in Water Use Minute number 142 (CEWO 2013b)	**Indicators**	**Study sites/reaches**			
		Focus rivers: Colligen Ck Yallakool Ck Wakool R Little Merran Ck	**Source:** Edward R (Stevens weir)	**Acoustic array sites in Wakool R, Yallakool Ck and Edward R**	**41 sites throughout system**
Increase movement, condition, reproduction and recruitment of native fish	Fish community				annual
	Fish movement			continuous	
	Fish spawning and reproduction	Fortnightly (Aug to Mar)	Fortnightly (Aug to Mar)		
	Fish recruitment	annual			
Provide end of system flows and increase hydrological connectivity in ephemeral streams	Not assessed in this project				
Maintain/improve vegetation condition, including fringing vegetation and emergent/ submerged aquatic plants	Riverbank and instream vegetation	monthly (Sept to Mar)			
Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH	Water chemistry (dissolved oxygen, light, temp)	continuous			
	Water chemistry (carbon, nutrients)	fortnightly (Aug to Mar)	Fortnightly (Aug to Mar)		
	Whole stream metabolism	continuous			
Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs	Shrimp	Fortnightly (Sept to Mar)	fortnightly (Sept to Mar)		
	Frogs	monthly (Sept to Mar)			

Ecosystem responses to environmental watering in 2013-14

Objective 1. Increase movement, condition, reproduction and recruitment of native fish



Photos: Example of fish species encountered during the 2013-14 fish community sampling: left Murray cod, right, golden perch.

- *There is a general trend towards improvement of the native fish community in the Edward-Wakool system*, although this improvement is species and location-specific. Some of the changes may be due to fish migration into the system because recruitment of some species is poor. There was an increase in the abundance of small bodied generalist species (primarily Australian smelt and carp gudgeon) in 2014 compared to 2013. There was an increase in the biomass of Murray cod, goldfish and bony herring and decrease in the biomass of common carp and golden perch in 2014 compared to 2013.
- The Sustainable Rivers Audit measure of expectedness and nativeness were calculated for fish community data collected from 2010 to 2014. *All zones were in poor condition in 2014 in terms of nativeness, an improvement over the very poor condition from 2013. In 2014 all zones were in poor to moderate condition in terms of SRA recruitment index.*
- Some individuals of acoustically tagged Murray cod, golden perch and common carp dispersed from the refuge pool into new habitats during early season unregulated flows. *Based on two years of monitoring data, Murray cod demonstrated a consistent preference for movement into the upper Wakool River over Yallakool Creek during delivery of environmental water.* The reasons for this are unknown, although it highlights the importance of maintaining habitat in both the Wakool River and Yallakool Creek. Factors such as loading of woody habitat, overhanging cover, depth of pools or physical or hydraulic barriers may have an influence on this preference.
- *The majority of tagged golden perch remained in the refuge pool throughout the environmental watering actions. Those individuals that did move, went both upstream and downstream from the refuge pool, with most movements occurring at the peak of flows or on the recession.* It is not

known whether these movements resulted in spawning, and this can be evaluated in a future assessment of recruitment by the Long term Intervention Monitoring project. However, combined with results from fish community sampling and fish spawning the results suggest that the 2013-14 environmental watering did not trigger spawning in this species.

- *All acoustically tagged golden perch and some Murray cod returned to the refuge pool at the completion of the recession flows, indicating that these flows were appropriately managed to enable native species to return to refuge habitat*.
- Nine of the 13 fish species known to occur in theEdward-Wakool River system successfully spawned in 2013-14. *Spawning patterns of the Edward-Wakool fish community were independent of the environmental watering actions*.
- *The environmental watering in Yallakool Creek during the Murray cod spawning season did not result in a significantly greater number of larvae in Yallakool Creek compared to rivers that did not receive environmental water*. These findings support the results observed in 2012-13 and the body of knowledge that shows that Murray cod spawn at peak times in November-December, regardless of flow conditions.
- Back-calculated spawning dates indicate that golden perch has spawned in all years from 2004–2010. However, the dominant cohort of golden perch and silver perch was spawned in 2009 during periods of low in-flows into the Edward-Wakool system.
- *The Yallakool Creek perch flow did not trigger a golden and silver perch spawning response in the monitored reaches, as evidenced by the absence of larvae or eggs*. It is possible that these species spawned elsewhere in the system but were undetected by the current monitoring. Future assessment of fish recruitment undertaken as part of the Long Term Intervention Monitoring project may determine if these species spawned in 2013-14.
- *Juvenile golden perch, silver perch and Murray cod recruits were not sampled in large enough numbers to detect whether environmental watering actions influenced recruitment of these species*. Recruitment of carp gudgeon occurred between August 2013 and March 2014, peaking in November-January, in all rivers regardless of receiving environmental water. In 2013-14 annual recruitment of carp gudgeon was not positively or negatively affected by environmental watering actions in Yallakool Creek and Colligen Creek. This result is different to previous years, where an increase in the abundance of larvae and juveniles was detected in response to environmental watering in Colligen Creek (Watts et al. 2013a; 2013b). Dissimilar recruitment responses to

environmental watering actions among years may be related to differences in the peak magnitude of flows or differences in the relationship between discharge and area of inundation in different rivers. This will require an evaluation of spawning responses across multiple years.

<u>Objective 2. Provide end of system flows and increase hydrological connectivity in ephemeral streams</u>

Monitoring of end of system flows and ephemeral streams was not undertaken in this project.

<u>Objective 3. Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants</u>

Photos: left, Charophyte growing in edge of water in Yallakool Creek, near Cumnock Park, right riverbank vegetation on the Wakool River in Murray Valley National Park

- *There was a significant increase in the percent cover of submerged aquatic vegetation during the Yallkool Creek cod maintenance flow*. The environmental watering enabled the submerged aquatic vegetation (in particular Characeae *sp*) to persist over an extended period of time. This is a different response to that observed in 2012-13 where the recession was rapid and submerged vegetation was rapidly exposed and desiccated.
- *There was no change in the percent cover of terrestrial riverbank vegetation in each river before, during and after the environmental watering, suggesting there was no response to environmental watering actions.* However, the monitoring concluded in March 2014, a month after the end of the maintenance flow recession, and may not have continued long enough to detect terrestrial vegetation responses to the environmental watering. Longer term responses of riverbank vegetation to environmental watering will be examined as part of the Long Term Intervention Monitoring project in the Edward-Wakool system (Watts et al 2014).

Objective 4. Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH


Photos: left, filtering water for carbon analysis; right, Colligen Creek near Niemur River offtake, 11 February 2014

- *Commonwealth environmental watering met the objective of maintaining or supporting water quality outcomes as it did not trigger any adverse water quality outcomes or a hypoxic blackwater event.* Environmental watering actions did not significantly alter dissolved carbon, total carbon or the organic matter profiles in treatment rivers relative to the control rivers. Bioavailable nutrients were extremely low in these rivers. Some statistically significant differences in nutrient concentrations were found when assessing effects of watering actions, but these differences were extremely small and were not ecologically important.
- *Very small increases in metabolic rates that were not ecologically significant resulted from environmental watering actions*, most likely because the flows were contained within the stream channel, with little inundation of backwater areas or instream benches. Rates of primary production and ecosystem respiration during 2013-2014 were at the lower end of the normal range found in rivers worldwide.

Objective 5. Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs.


Photos: left, Freshwater shrimp *Paratya australiensis*, right, Peron's Tree frog *Litoria peronii*

- The spawning of shrimp occurred independently of the environmental watering actions. *The rivers that received Commonwealth environmental water had fewer shrimp than the rivers that did not receive environmental water*. In particular, the abundance of juvenile Paratya shrimp during the Yallakool Creek perch flow was significantly lower in Yallakool Creek compared to the control rivers. The abundance of Paratya larvae may have been adversely affected by environmental watering during their spawning season, because hydraulic modelling has shown that the magnitude of the environmental watering actions in Yallakool Creek decreased the availability of slackwater habitat that is necessary for shrimp recruitment.
- Frogs were not the main focus of the environmental watering in Yallakool Creek. (Note, Commonwealth environmental water was also provided to Tuppal Creek in 2012-13 to achieve frog outcomes, but that area was not monitored by this project). Whilst a lot of frog activity was observed during the surveys, t*he environmental watering actions in Yallakool Creek and Colligen Creek did not result in frog recruitment, as no egg masses, tadpoles or metamorphs were observed during surveys*.
- In channel environmental watering actions did not inundate major in-channel geomorphological features (e.g. benches and backwaters), so may not have provided adequate or suitable habitat to support breeding and recruitment of frogs or adequate refuge from predators. There is a need to increase the understanding of interaction between instream flows and instream habitat (see flow recommendations).

Synthesis of responses to Commonwealth environmental watering

The responses to Commonwealth environmental watering observed in 2013-14 were largely consistent with those observed in previous years. In general, Commonwealth environmental water delivered to the Edward-Wakool system contributed to the maintenance of water quality, provided opportunities for longitudinal connectivity and fish movement (such as the return movement of fish to the Wakool Reserve refuge pool during recession flows), promoted instream aquatic vegetation, and created a small increase in wetted benthic area. Importantly, the long-term benefits of the Commonwealth environmental watering actions during blackwater events in 2010, 2011 and 2012 are still being realised. The environmental watering during these blackwater events mitigated extreme low dissolved oxygen concentrations (Watts et al. 2013) and thus created an area of refuge habitat and avoided critical loss of fish in the upper reaches of the Wakool River and Yallakool Creek. The benefits of those watering actions are evident, with fish populations in upper part of the Edward-Wakool system maintaining higher biomass than the populations in the lower reaches. The long-term recovery of fish populations in this system is still occurring. However, some of the changes in the fish community in the middle and lower sections of the system are possibly due to other factors, such as immigration of fish into the system.

Some of the expected outcomes of Commonwealth environmental watering actions were not observed in the focal rivers, with no detectable response (positive or negative) to Commonwealth environmental watering observed for several indicators. Although fish reproduction is occurring in this system (nine of the 12 species were collected as larvae in 2013-14), the spawning response in these species could not be attributed to Commonwealth environmental watering. So although there is evidence of some recovery in the fish community in areas impacted by the blackwater events in 2010-2012, recruitment has been limited and the recovery of the fish population has been slow, especially for large bodid long-lived species. There have also been only very small increases in river productivity resulting from environmental watering actions. Hydraulic modelling has shown that Commonwealth environmental watering actions have created small increases in wetted benthic area (Watts et al. 2013b), but this has not been sufficient to trigger an increase in gross primary productivity. The delivery of environmental water is constrained by a limited capacity to deliver higher volumes of water in this system without having impacts on third parties. The CEWO has sought to maximize the flows to a level that is acceptable to third parties in the catchment area. Constraints that limit the delivery of environmental watering actions should be examined further and managers collaborate with the community to minimise factors that may limit the benefits of Commonwealth environmental watering actions (see recommendations).

In addition to the positive and and neutral responses associated with Commonwealth environmental watering there was one negative response observed in 2013-14. There was a lower abundance of juvenile paratya shrimp in Yallakool Creek captured during the perch flow and an overall lower abundance of shrimp larvae in Yallakool Creek. This is thought to be due to a reduction in the area of slackwater during watering actions compared to area of available slackwater during base flows (see hydraulic modelling in Watts et al 2013b, Kingsford and Watts 2014). Slackwater habitat is of vital importance for many organisms including larval fish, macroinvertebrates and frogs and there is a need to increase our understanding of the interaction between instream flows and instream habitat to help managers identify critical thresholds and maximise the benefits of environmental water delivery (see flow recommendations).

A summary of the responses to Commonwealth environmental watering is presented in Table ii. The responses were classified as:

- positive, resulting in improved outcomes (dark green)
- positive, resulting in maintenance of outcomes (light green)
- negative response resulting in adverse outcomes (red)
- no detectable response (neither positive or negative) (white)
- response not assessed by this project (grey)

If we revisit the ecological objectives for the Edward-Wakool system outlined in the water use minute (CEWO, 2013b) we can conclude:

- Objective 1 (Increase movement, condition, reproduction and recruitment of native fish) has been partially achieved, but an increase in reproduction and recruitment has not occurred.
- Objective 2 (Provide end of system flows and increase hydrological connectivity in ephemeral streams (this objective was not assessed in this project) was not assessed by this project
- Objective 3 (Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants) was partly achieved, with an increase in submerged plants but not terrestrial riverbank plants.
- Objective 4 (Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH) was achieved.
- Objective 5 (Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs) was not achieved.

Table i. Summary of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2013-14. Dark green shading indicates improved outcomes, Light green indicates positive outcome resulting in maintenance, red shading indicates adverse outcome, white shading indicates no detectable response (neither positive or negative). Grey boxes are where no evaluation was undertaken. N/A = not evaluated.

Indicators	Responses to unregulated flows in Aug and Sep	Short-term responses to Commonwealth environmental water (responses to individual watering events or flows)			Annual response (Comparison among rivers across year)	Longer-term responses (across multiple years)
		Yallakool cod maintenance flow and recession	Yallakool perch flow	Colligen-Niemur continuation flow		
Fish community	N/A	N/A	N/A	N/A	N/A	Improvement of the native fish community over time
Fish movement	Movement of Murray cod and golden perch out of refuge pool	Preference by Murray cod for Wakool R compared with Yallakool Creek Return movements of golden perch to refuge pool during recession	No change in habitat occupation detected in golden perch	N/A	Preference by Murray cod for Wakool River compared with Yallakool Creek	N/A
Fish spawning and reproduction	N/A	No response detected	No response detected	N/A	9 species spawned but was not related to e-watering. More smelt, gudgeon in Edward R	N/A
Fish recruitment	N/A	N/A	N/A	N/A	No effect of e-watering on recruitment in carp gudgeon	N/A
Riverbank and instream veg	N/A	Increase in % cover of submerged aquatic veg. No response in riverbank terrestrial vegetation	N/A	N/A	Significant differences in veg between rivers but not related to e-watering	N/A
Water quality and chemistry	HIgher DOC, slower decline in Little Merran Creek	Maintain water quality, no advserse response observed	Maintain water quality, no advserse response observed	Maintain water quality, no advserse response observed	N/A	N/A
Organic matter characterisation	Inc in amount and complexity of organic matter	Maintain water quality	Maintain water quality	Maintain water quality	N/A	N/A
Stream metabolism	N/A	Maintain productivity. There were very small changes in gross primary production and ecosystem respiration that are not ecologically important (< 1 mg O2/L/Day)			N/A	N/A
Shrimp	N/A	No response detected	Significantly lower numbers of juvenile Paratya shrimp in Yallakool Creek	No response detected	Abundance of *P. australiensis* larvae lower in Yallakool Creek.	N/A
Frogs	N/A	No response detected	No response detected	No response detected	No breeding response detected	N/A

Recommendations

Recommendation 1. Use Commonwealth environmental water to manage the recession of unregulated flows and environmental watering actions

The rate of recession under regulated flows in the Edward-Wakool system is likely to be much faster than the rate of change under natural flow conditions. Slowing down the rate of recession can provide ecological benefits by creating conditions that the biota in these systems would be more adapted to. Commonwealth water contributed to a recession flow in 2013-14, and this promoted the growth and longer duration of instream aquatic vegetation in Yallakool Creek compared to 2012-13 when rates of recession were much faster. In 2013-14 all acoustically tagged golden perch and some Murray cod returned to the refuge pool at the completion of the recession flows, indicating that these flows were appropriately managed to enable native species to return to refuge habitat. Commonwealth environmental water should continue to be allocated to manage recession flows following unregulated flow events or at the end of environmental watering actions.

Recommendation 2. Continue to use Commonwealth environmental water to mitigate adverse water quality events

Commonwealth environmental water has been used on several occasions to mitigate the advserse outcomes of poor water quality events. Monitoring results have demonstrated that these actions have been successful in maintaining water quality. Rapid action and coordination of information by the Edward-Wakool e-flows Group and the Water Murray and District Dissolved Oxygen Group are a vital part of this action.

Recommendation 3. Focus timing of Commonwealth environmental watering on late winter/spring

Available hydrological modelling suggests that the flow regime of the Edward-Wakool system has been significantly altered by river regulation, with changes to the timing and volume of flows. Natural flows in the system would have been high in winter/spring and low in summer and autumn. Late winter/spring flows were a key feature in these systems and biota are likely to be adapted to this regime. Monitoring results have shown that early season unregulated flows in 2013-14 enabled all fish species to disperse from the refuge pool into new habitats. Environmental watering in winter/spring also minimises risks of adverse water quality outcomes. In the absence of natural or regulated flows in late winter or early spring, Commonwealth environmental water should be targeted at this time of the year to enhance dispersal opportunities and maximise growth and reproductive opportunities. Winter/spring flows can be delivered to complement other watering actions delivered at other times of the year targeting other ecological outcomes (e.g. fish spawning).

Recommendation 4. Introduce flow variability into environmental watering actions

The Edward-Wakool river ecosystems have evolved in the presence of flow variability, and there is good evidence to suggest that flow variability can lead to healthy and resilient populations. It is recommended that some of the natural levels of variability should be incorporated within managed environmental watering actions. In general, long periods of constant flow and rapid flow recession should be avoided. One approach to achieve this is to use a whole of system approach to manage flows in the Murray system, using upstream triggers to guide variability. Recent flow events could provide a baseline to enable this approach to be tested to determine its benefits. See flow recommendation 7 for a recommended approach to help guide these decisions.

Recommendation 5. Deliver a variety of flows over time to improve understanding of responses to environmental watering

Some results from monitoring and evaluation of environmental watering are difficult to interpret, as it is not always possible to disentangle the responses to flow from responses related to a specific river. For example, Murray cod have demonstrated a consistent preference for the upper Wakool River over Yallakool Creek based on the past two years of monitoring, however it is unclear whether this is due to a general preference for the Wakool River over Yallakool Creek, or is related to delivery of environmental water. Future targeted watering of the upper Wakool River to maintain or maximise nest site inundation should be considered, as this would improve our understanding of responses to flows by disentangling the factors of river and flow. In addition, the upper Wakool River has not been the target of environmental watering actions over the past three years.

Recommendation 6. Increasing understanding of interaction between instream flows and instream habitat

There is a need to identify and quantify the instream geomorphological features in the rivers likely to receive Commonwealth environmental water to help better target environmental watering actions, especially decisions around the magnitude of water delivery. Understanding the relationship between flow and instream features such as large woody instream habitat, geomorphological features (such as benches, backwaters) and anabranch systems will allow managers to identify critical thresholds and maximise the benefits of environmental water delivery.

Recommendation 7. 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, considering the breadth of geomorphological and ecological responses. While there has been some modelling undertaken for the Edward River, there is currently a lack of hydrological modelling on 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. The flows assessment would need to 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 low flow periods. Based on the flows assessment, it would be possible to consider which aspects of the flow regime are most or least affected by regulation, and consider how these changes are likely to affect ecological features or assets of the Edward-Wakool system (eg vegetation, bench inundation, flow requirement for fish and birds etc). This would guide decisions and operating guidelines for future environmental watering actions. The flows recommendations should not be single species or group focussed, but consider all aspects of the river ecosystem. This information would underpin environmental watering plans and actions and maximise the benefit for the whole ecosystem.

Recommendation 8. Examine constraints that limit the delivery of environmental watering actions. Collaborate with other management agencies and the community to minimise factors that may limit the benefits of Commonwealth environmental watering actions

There were no observable increases in gross primary productivity, food resources or fish spawning in response to the Commonwealth environmental watering in 2013-14. If the proposed flows assessment (see recommendation 7) recommends that higher discharges are required to provide these instream benefits, then a comprehensive examination of flow constraints and a concurrent community consulation process will required to examine constraints to the delivery of larger in-channel environmental watering events. 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 illicit ecosystem responses to flows. There are other factors (e.g. small instream barriers) that may limit how the ecosystem responds to Commonwealth environmental watering. The CEWO should actively work with other agencies and the community to reduce the impacts of these other factors to produce better ecosystem responses to environmental watering.

Table of Contents

1. INTRODUCTION

Purpose of this report

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2013-14. It provides details of the watering actions, study design, indicators, methodology, and an assessment of ecosystem responses to environmental watering with respect to the objectives set by the Commonwealth Environmental Water Office. Results and conclusions from the monitoring and evaluation underpin recommendations for future environmental watering in this system.

The Edward-Wakool system

The Edward-Wakool system is a large anabranch system of the Murray River main channel. The system begins upstream of the Barmah choke, and travels northwest through a series of river red gum forests before discharging back into the Murray River downstream of Kyalite (Figure 1). It is a complex network of interconnected streams, ephemeral creeks, flood-runners and wetlands including the Wakool River, Yallakool Creek, Colligen-Niemur Creek and Merran Creek.

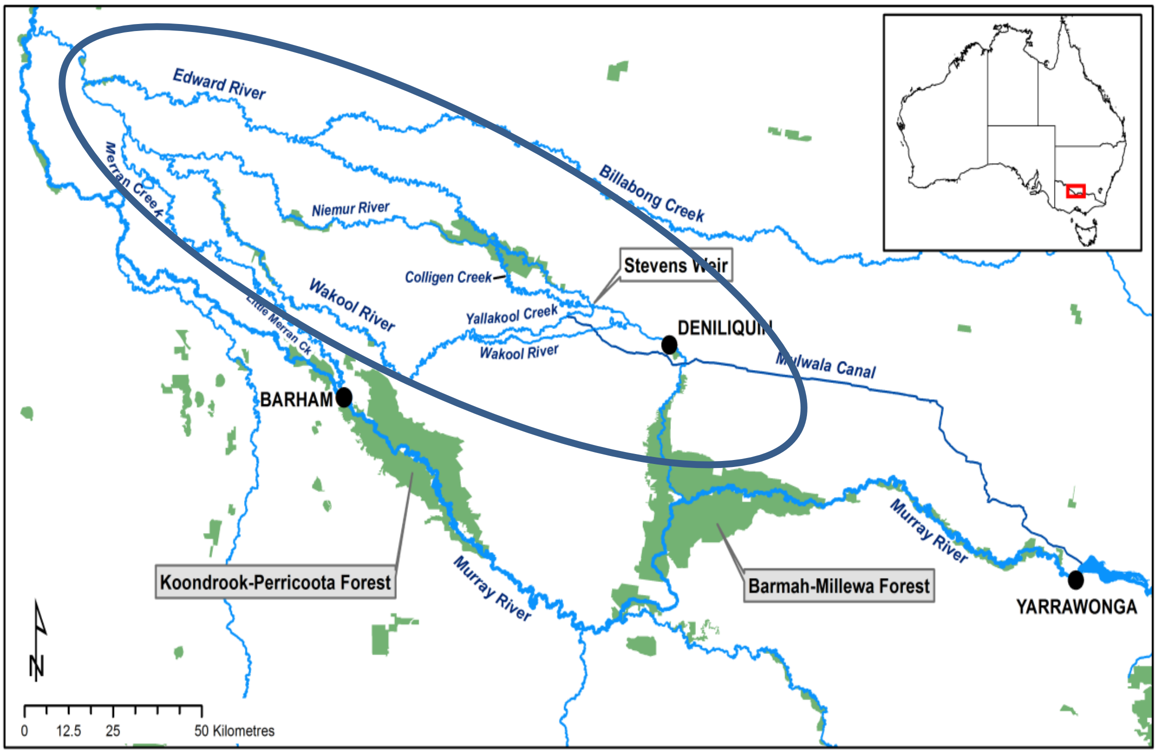


Figure 1. Map of the Edward-Wakool system.

The Edward-Wakool system has high native species richness and diversity, including threatened and endangered fish, frogs, mammals, and riparian plants. It 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.

Like many areas of the Murray-Darling Basin, the Edward-Wakool system has suffered from the effects of river regulation, migration barriers and degradation of water quality. Water regimes within the Edward-Wakool system have been significantly altered by river regulation (Green 2001; Watkins et al. 2010; Hale and SKM 2011), with changes to the timing and volume of flows. Natural flows in the system would have been high in spring and low in summer and autumn. River regulation is likely to have altered water velocities, the availability of in-channel habitat types, and ecosystem processes and functions. Although some modelling and assessment of natural flows in the Edward River is available (e.g. Green 2001; Hale and SKM 2011), there is a lack of models for the smaller rivers and creeks in the Edward-Wakool system.

History of Commonwealth environmental watering in the Edward-Wakool system

Commonwealth environmental water has been delivered to rivers in the Edward-Wakool system since 2010. Over that time there have been several occasions where instream freshes have been delivered to Yallakool Creek and Colligen Creek (Watts et al. 2013a; 2013b). In addition, there have been several watering actions where Commonwealth environmental water has been delivered from the Edward River and/or from irrigation escapes to improve water quality and create refuge during poor water quality events.

Ecosystem responses to environmental watering in 2013-14 will be influenced by the history of flows in this system. Between February 2006 and September 2010 there were periods of minimal or no flow in the Edward-Wakool system due to severe drought conditions (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 3). Since 2011 unregulated flows have occurred each year.

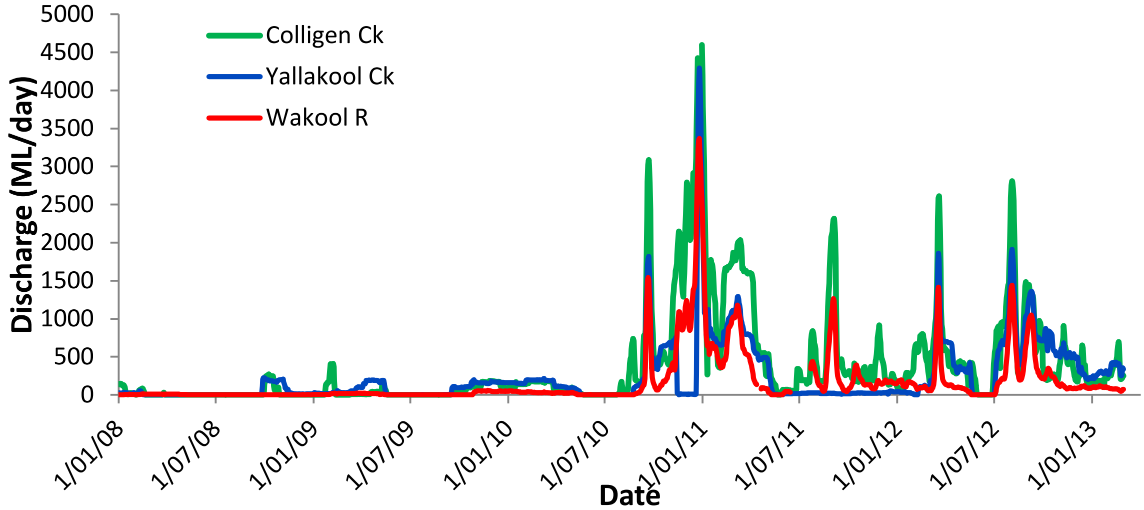


Figure 2. Daily discharge between 01/01/08 and 28/02/13 in three rivers in the Edward-Wakool system: Colligen Creek, Yallakool Creek, and the Wakool River. Daily discharge data was obtained from NSW Government water information website (NSW Office of Water, 2012) for three stations: Colligen Creek regulator (409024), Wakool River offtake regulator (409019), Yallakool Creek offtake regulator (409020).

Previous monitoring of Commonwealth environmental watering in the Edward-Wakool system

Monitoring and evaluation of ecosystem responses to environmental watering in the Edward-Wakool system has been undertaken since 2010. In 2010 a fish monitoring program was established by NSW Department of Primary Industries and the Murray Local Land Services (formerly known as the Murray Catchment Management Authority (Murray CMA)). Fish monitoring sites were established throughout the Edward-Wakool system that has now been sampled for five consecutive years. In addition, an array of acoustic receivers was established to monitor behavioural responses to environmental watering. In 2011-12, Charles Sturt University, Monash University and the Murray CMA monitored ecosystem responses to environmental watering in the Edward Wakool system (Watts et al. 2013a) focussing on four rivers: Colligen Creek, Yallakool Creek, Wakool River, and Little Merran Creek. The project involved comparing ecosystem responses in rivers that received environmental water to those in rivers that did not receive environmental water. In 2012-13 the long-term fish monitoring, fish movement and ecosystem monitoring were brought together into a single collaborative project (Watts et al 2013b).

The monitoring of Commonwealth environmental watering undertaken in 2013-14 follows on from these previous projects. The Edward-Wakool river system is still recovering from the impact of the blackwater events that occurred in 2010 and 2011. In this report we will report on longer-term responses to environmental watering as well as shorter-term responses to watering events in 2013-14. This report will also provide information to inform decisions on the timing, duration and magnitude of flows in this system to assist the adaptive management of future flows.

2. Commonwealth environmental water use options and objectives 2013-14

Prior to the 2013-14 water year commencing eight water use options for the mid-Murray region for 2013-14 were developed by the CEWO (2013a), taking into account a range of possible resource availability and the catchment conditions (Table 1). Options 1 (Edward-Wakool River instream fish flows) and 3 (Mid-Murray and region water quality and habitat), highlighted in yellow in Table 1, were monitored by this project. Options not monitored include: option 2 Ephemeral water courses; options 4 and 5 the mid-Murray River channel; option 6 Barmah-Millewa Forest; option 7 Werai Forest; and Option 8 Gunbower Forest. A summary of water use option 1 and 3 that are the focus of this monitoring report are provided below and in Appendices 1 and 2 respectively.

Table 1. Summary of water use options for the mid-Murray region for 2013-14 in relation to resource availability (from CEWO 2013a). Option 1 and 3 (highlighted in yellow) were evaluated by the current monitoring program in the Edward-Wakool system

<table>
<tr><th rowspan="2">Watering Options</th><th colspan="4">Applicable level(s) of resource availability</th></tr>
<tr><th>Low</th><th>Moderate</th><th>High</th><th>Very High</th></tr>
<tr><td>Option 1 – Edward-Wakool River System instream fish flows</td><td colspan="4">Contribute to river base flows and freshes, and the recession of bankfull and overbank flows, to support the condition and reproduction of native fish in the Edward-Wakool River System</td></tr>
<tr><td>Option 2 – Ephemeral water courses</td><td colspan="4">Contribute to river base flows and freshes to support the recovery of ephemeral streams in the Murray River catchment. Watering will support the condition and reproduction of native vegetation, fish and other vertebrates, hydrological connectivity and end of system flows, and maintenance of refuges and water quality (in particular dissolved oxygen, salinity and pH)</td></tr>
<tr><td>Option 3 – Mid-Murray region water quality and habitat</td><td colspan="4">Contribute to river base flows and freshes in the mid-Murray river channel and Edward-Wakool River System, to support management of water quality issueswithin instream environments to protect ecosystems and their functions, and to build ecosystem and population resilience by supporting landscape and habitat refuges, promoting resistance, and recovery.</td></tr>
<tr><td>Option 4 – Mid-Murray River channel</td><td colspan="3">Contribute to river freshes and the recession of bankfull and overbank flows in the mid-Murray River channel, and the inundation of low-lying wetlands/floodplains, to support the condition and reproduction of native fish and vegetation, and dispersal of native fish</td><td>Option unlikely to be pursued under this resource availability</td></tr>
<tr><td>Option 5 – Mid-Murray river channel – winter/early spring flows</td><td colspan="2">Contribute to river base flows and freshes in the Murray River channel between Hume Dam and Euston during winter and early spring, to contribute to returning a more natural pattern of flow to elements of the hydrograph affected by regulation. This option will create habitat and support survival of aquatic biota (e.g. native fish and Murray crayfish), and support hydrological connectivity</td><td colspan="2">Option unlikely to be pursued under this resource availability</td></tr>
<tr><td>Option 6 – Barmah-Millewa forest</td><td colspan="3">Contribute to base flows, freshes, bankfullflows and overbank flows in Barmah-Millewa Forest, to support inundation of floodplain vegetation, waterbird breeding, fish reproduction and habitat, hydrological connectivity between the river and floodplain, and contribute to processes such as nutrient and carbon cycling</td><td>Option unlikely to be pursued under this resource availability</td></tr>
<tr><td>Option 7 – Werai Forest</td><td colspan="3">Contribute to overbank flows (infrastructure assisted) within Werai Forest, to increase ecosystem diversity and to support the condition and reproduction of wetland and floodplain vegetation, native fish, waterbirds and other vertebrates, and processes such as primary production, as well as contribute to decomposition and nutrient and carbon cycling.</td><td>Option unlikely to be pursued under this resource availability</td></tr>
<tr><td>Option 8 – Gunbower Forest</td><td colspan="4">Contribute to river base flows and freshes in Gunbower Creek to support native fish condition. The riority for Gunbower Forest is to allow a drying phase.</td></tr>
</table>

Watering Option 1 (see Appendix 1) applies to base flows, freshes and the recession of bankful and overbank flows. The purpose of this option is to support the condition and reproduction of native fish, which may involve contributing to instream flows to maximise available breeding habitat, create conditions favourable for reproduction (e.g. freshes), or contribute to the survival of native fish (CEWO 2013a). These flows are to be managed within the channel and delivered with regard to demands on the delivery system and risk of downstream impacts. Environmental water may be constrained by other demands on the system, especially during the irrigation season.

Watering Option 3 (see Appendix 2) applies to base flows and freshes. The purpose of this option is to manage water quality issues within instream environments in the mid-Murray catchment. This option aims to contribute to the maintenance or improvement of water quality, to support the condition and reproduction of native fish, other vertebrates (e.g. frogs) and macroinvertebrates, and also contribute to the growth and survival of native fish. Where water quality issues are wide-spread, this option may include providing environmental water to create localised refuge habitat (CEWO 2013a). This option is more likely to be required during warmer months. This option may utilise releases from Murray Irrigation Limited escapes.

As both Option 1 and 3 focus on the delivery of in-channel flows, the ecological objectives for this system focus on breeding, recruitment and habitat requirements of native fish and other aquatic organisms, maintenance of water quality, provision of instream refuge habitat, as well as in-channel ecosystem functions.

To implement the water use options, the CEWO prepared more detailed water use minutes (WUM)(CEWO 2013b) for the consideration and approval of the Commonwealth Environmental Water Holder (CEWH). These WUMs reflect more detailed consideration of a range of issues and consultation with agencies and communities. The use of Commonwealth environmental water was intended to contribute to baseflows and freshes, and potentially the recession of natural bankfull/overbank flows in the Edward-Wakool River System during 2013-14, to achieve the following expected outcomes (CEWO 2013b):

1. Increase movement, condition, reproduction and recruitment of native fish
2. Provide end of system flows and increase hydrological connectivity in ephemeral streams
3. Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants
4. Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH
5. Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs.

3. COMMONWEALTH ENVIRONMENTAL WATERING IN 2013-14

The 2013–14 water year was characterised by drier than average conditions across the Murray catchment. Temperatures were above average, especially throughout summer where southern Australia experienced an extreme, multiday heatwave in January 2014. The water year started with a significant unregulated flow event in August to September 2013 coupled with considerable multi-jurisdictional environmental water deliveries through to December 2013 (including almost 200 GL Commonwealth environmental water). The unregulated flow event is evident in the Wakool River, Colligen Creek and Yallakool Creek hydrograph that received water from the Edward River (Figure 2). This event did not occur in Little Merran Creek that receives water from the Murray River.

Four environmental watering actions undertaken in the Edward-Wakool System in 2013-14 that are the focus of this report were:

1. Cod maintenance flow – Yallakool Creek

From 17 October 2013 to 16 December 2013, environmental water was delivered to Yallakool Creek (targeting flows of 500 ML/day) to support Murray cod spawning and juvenile drift, and to maintain inundation of nesting habitat. Environmental water return flows from the Murray multi-site watering event met the requirements for this watering action (approx. 12,000-18,000 ML).

2. Perch pulse flow – Yallakool Creek

A perch flow was delivered to Yallakool Creek in November 2013 on top of the cod maintenance flow to attempt to stimulate spawning in flow-dependent species. Flows were maintained at 500 ML/day for 7 days, from 9 November 2013 flows were increased over two days to ~600 ML/day, held at this increase stage height and returned over two days back to 500 ML/day for cod maintenance. This pulse equated to a temporary river rise of approximately 15 cm in water level at Yallakool Creek Regulator and was also part of the Murray multi-site watering event. This event resulted in a rise of approximately 7-10 cm further down theWakool River system at the Wakool-Barham Road Bridge.

3. Cod maintenance flow recession – Yallakool Creek

From 17 December 2013 to 4 February 2014, 8,494 ML of Commonwealth environmental water contributed to a gradual recession from the cod maintenance flow (500 ML/day) to regulated baseflow levels (~250 ML/day) to provide benefits to aquatic vegetation, frogs and fish. The recession consisted of a 10 cm drawdown (~ 40 ML/day) every 10 days commencing about 26 December. The watering advisory group, including Fisheries, LLS, OEH, SWC and CSU, supported and approved the recession hydrograph.

4. Colligen-Niemur River continuation flow

Extremely hot weather conditions from Monday 13th January 2014 resulted in several consecutive days of > 40 ^{o}C. Water quality monitoring over this period by the NSW Office of Water in the Niemur River recorded the dissolved oxygen (DO) below 4 mg/L and water temperature at 30 ^{o}C. In this instance the extremely high water temperature was the key driver of the low DO. From 7 February 2014 to 12 March 2014, 5,759 ML of Commonwealth environmental water was delivered to the Niemur River via Colligen Creek to continue the existing flow in an endeavour to reduce the risk of extremely high water temperatures re-occurring, and to lessen the risk of stress and mortality of native fish and other adverse environmental impacts. From 7 February through 2 March Commonwealth environmental water contributed 200 ML/d on top of existing flows (regulated demand was about 180 ML/d). For 10 days from 3 March through to 12 March Commonwealth environmental water contributed 100 ML/d on top of existing flows. This action was overrun by rain rejection event being passed down Colligen Creek, which further improved water quality.

Less environmental water was delivered to the Edward-Wakool River System in 2013-14 than originally anticipated (Table 2). This was largely a result of unregulated flows and multi-site environmental water contributing to environmental water actions in the Edward-Wakool system and a recommendation from the Edward-Wakool Flows Group to focus on winter-spring actions in 2014-15 over autumn deliveries in 2013-14.

Table 2. Volumes of environmental water delivered to the Edward-Wakool system in 2013-14.

Source	Approved Volume (ML)	Delivered Volume (ML)	Net usage (ML)
CEWO	45,000	16,815	14,883
1. Yallakool cod maintenance flow		met by multi-site event flows	
2. Yallakool perch pulse			
3. Yallakool cod maintenance flow recession		8,494	
4. Niemur continuation flow		5,759	

A summary of hydrological statistics for the 2013-14 water year is presented in Table 3 and a hydrograph in Figure 3. Notable differences in hydrology among the four focus rivers include:

- Minimum discharge (Q_{min}) was zero for Colligen Creek, Wakool River and Yallakool Creek as there was a period of no flow in these systems in June and early July 2013 when the regulators controlling flows into these tributaries were closed. Flow was continuous in Little Merran Creek and the Q_{90} (flow exceeded 90% of the time) was considerably higher in Little Merran Creek than in the other three rivers.
- Colligen Creek, Wakool River and Yallakool Creek received an unregulated flow pulse in August and September 2013 (Figure 2). Maximum discharge (Q_{max}) was considerably lower in Little Merran Creek than all other systems (Table 3) as it did not experience this unregulated flow. Q_{10} (flow exceeded 10% of the time) was lower in Wakool River and Little Merran Creek than Yallakool Creek and Colligen Creek.
- The median and mean flow in the Wakool River was lower than in the the other rivers.
- The range of flow was higher in Yallakool Creek than in other rivers. Little Merran Creek had the lowest coefficient of variation, because it did not receive the unregulated pulse or cease to flow.

Table 3. Summary hydrological statistics for four rivers in the Edward-Wakool system for the 2013-14 water year (1/7/13 to 30/6/2014).

Flow variable	Colligen Ck	Wakool R	Yallakool Ck	Little Merran Ck
Q_{min}	0	0	0	21
Q_{max}	874	938	1224	406
mean (Q_{mean})	326	116	335	227
median (Q_{50})	304	71	300	218
Q_{range}	874	938	1224	384
Coefficient of variation (CV)	0.633	1.428	0.725	0.388
Q_{90}	1.67	0.001	0	93.78
Q_{10}	585.3	302.5	593.9	330.2

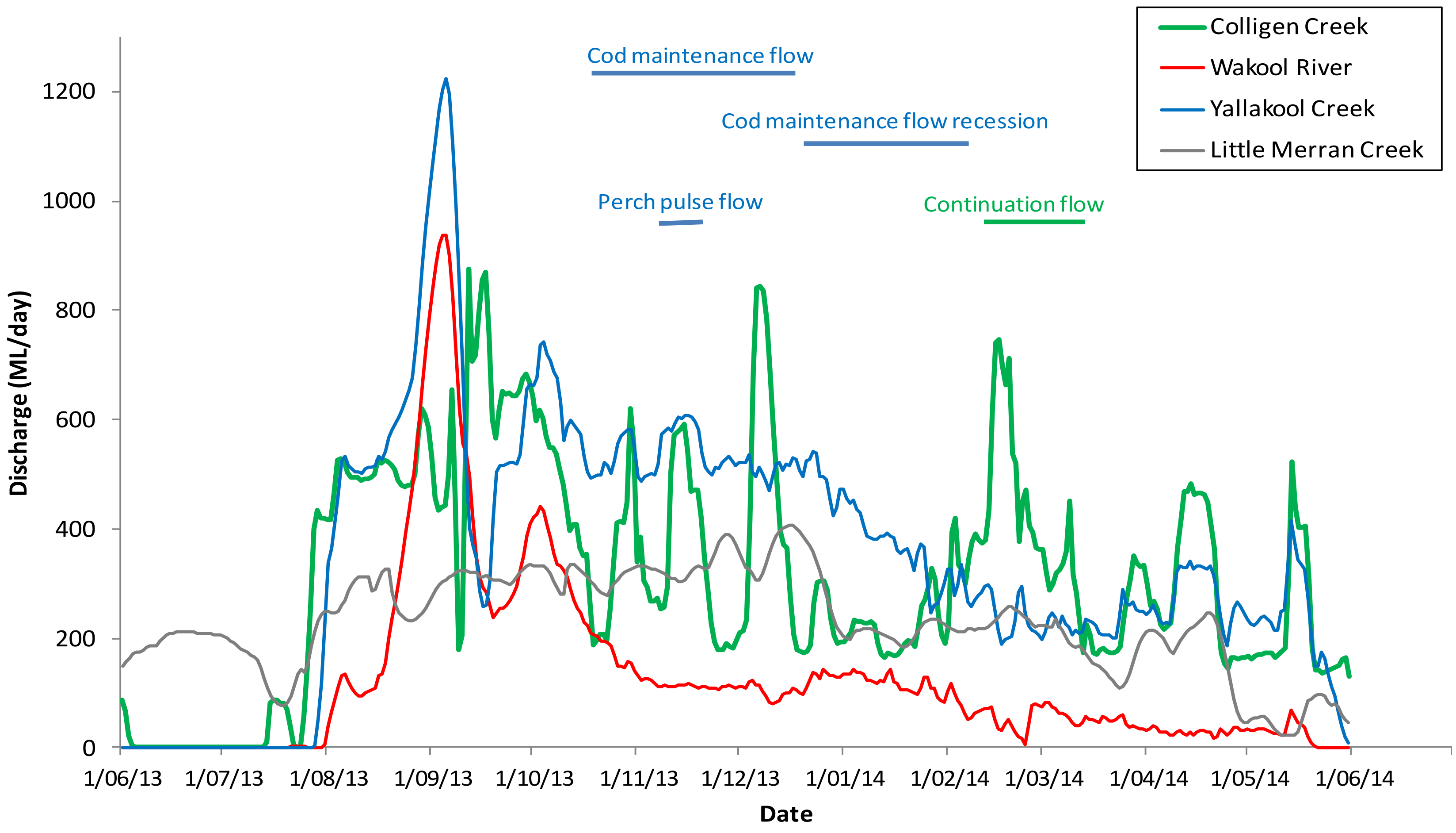


Figure 3. Daily discharge (ML/day) between 1/6/13 and 1/6/14 in Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek. Timing and duration of environmental watering in Yallakool Creek and Colligen Creek in 2013-14 is shown with coloured bars representing Commonwealth environmental watering actions 1 to 4. The high flow events in August and September are due to unregulated flows (not environmental water).

4. LOCATION OF MONITORING

The monitoring of ecosystem responses to environmental watering in the Edward-Wakool system in 2013-14 was undertaken as follows:

1. Focus river reaches

Commonwealth environmental water was delivered as freshes via regulators to Colligen Creek, and Yallakool Creek from the Edward River. This enables an assessment of the responses to environmental watering through comparisons of responses in rivers receiving environmental water ('treatment' rivers) and rivers not receiving environmental water ('control' rivers). In 2013-14 Commonwealth environmental water was delivered to Colligen Creek and Yallakool Creek (treatment rivers), and the Wakool River and Little Merran Creek served as controls (no environmental water). The Edward River at Stevens Weir was also sampled to assess the potential source of propagules for the treatment rivers (Figures 4, 5). The river reaches in each focus river ranged from 3 to 5 km in length. These reaches were also sampled to assess ecosystem responses to environmental watering in 2011-13 (Watts et al. 2013a, 2013b).

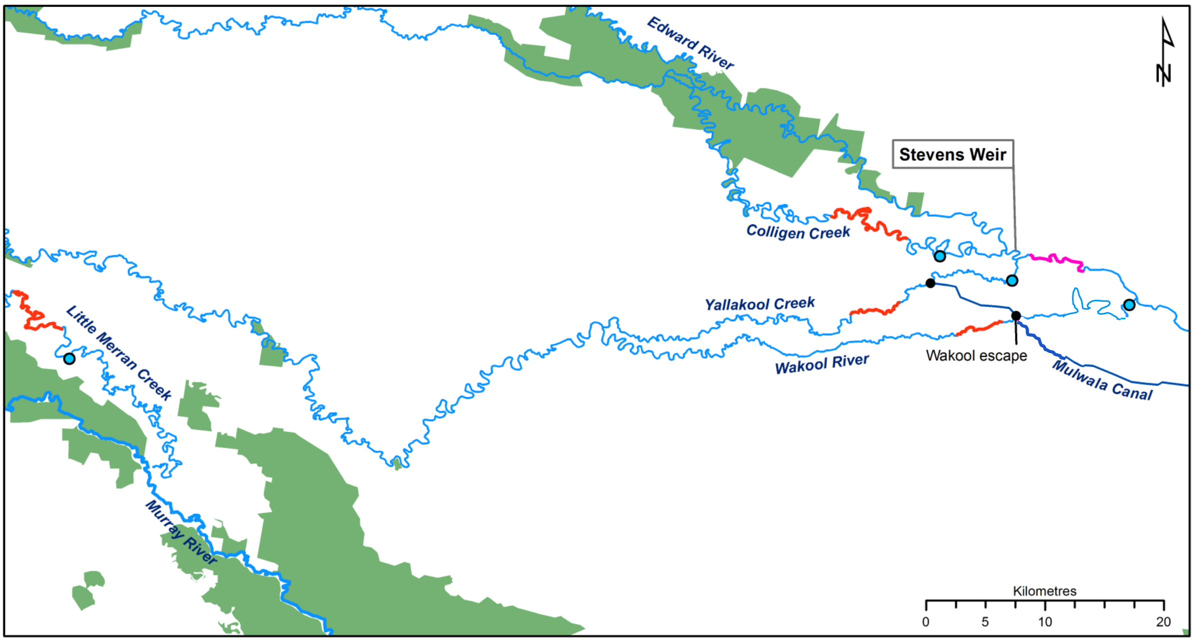


Figure 4. Location of four focus rivers for the assessment of ecosystem responses to environmental watering in the Edward-Wakool system (shown in red). The Edward River in Stevens Weir (shown in pink) was sampled as a potential source of propagules.

Colligen Creek

Yallakool Creek

Wakool River

Little Merran Creek

Figure 5. Photos of study sites in the four focus rivers; Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek.

2. Whole of system fish community assessment

A total of 41 sites were sampled throughout the Edward-Wakool system (Figure 6) to assess the response of the fish community to environmental watering. An acoustic array established in 2010 to assess fish movement in the Wakool River, Yallakool Creek and Edward River continued to be monitored in 2012-13 (Figure 7).

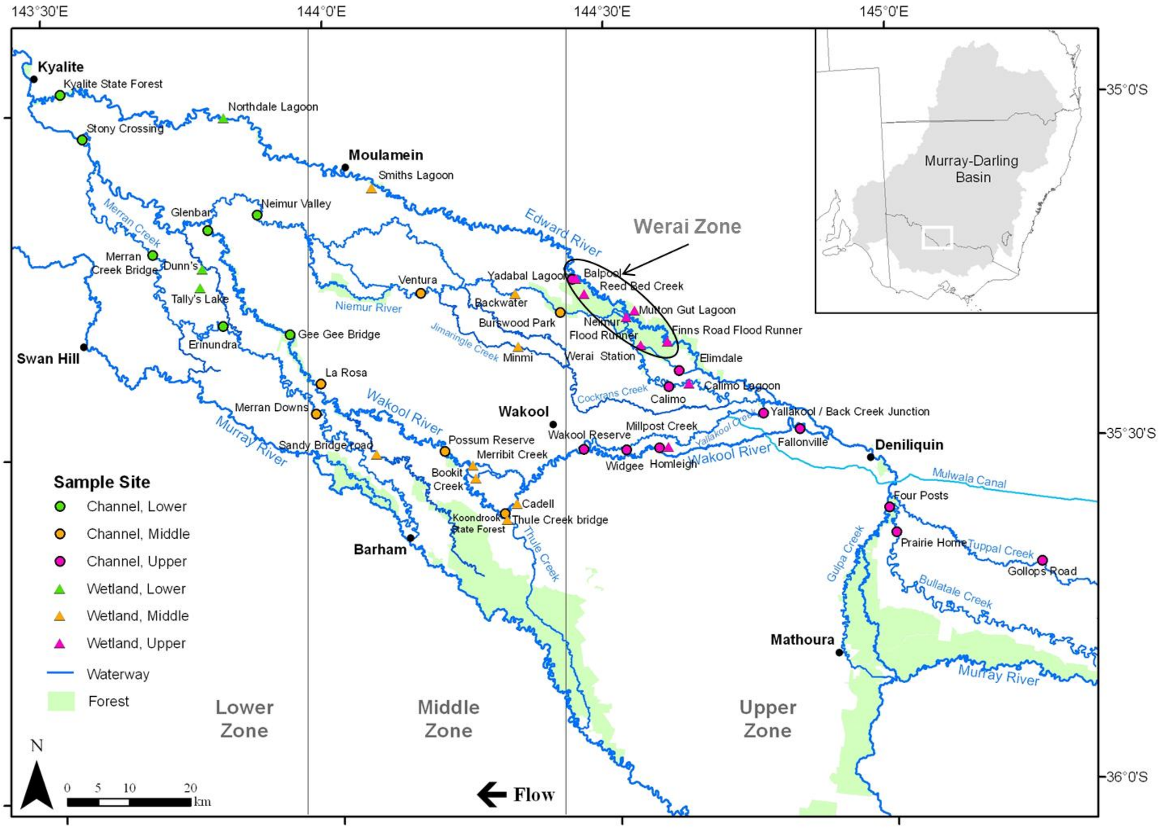


Figure 6. The location of 2014 fish sampling sites in the Edward-Wakool system nested within broad geographic zones. Note the Cadell site was not sampled in 2014.

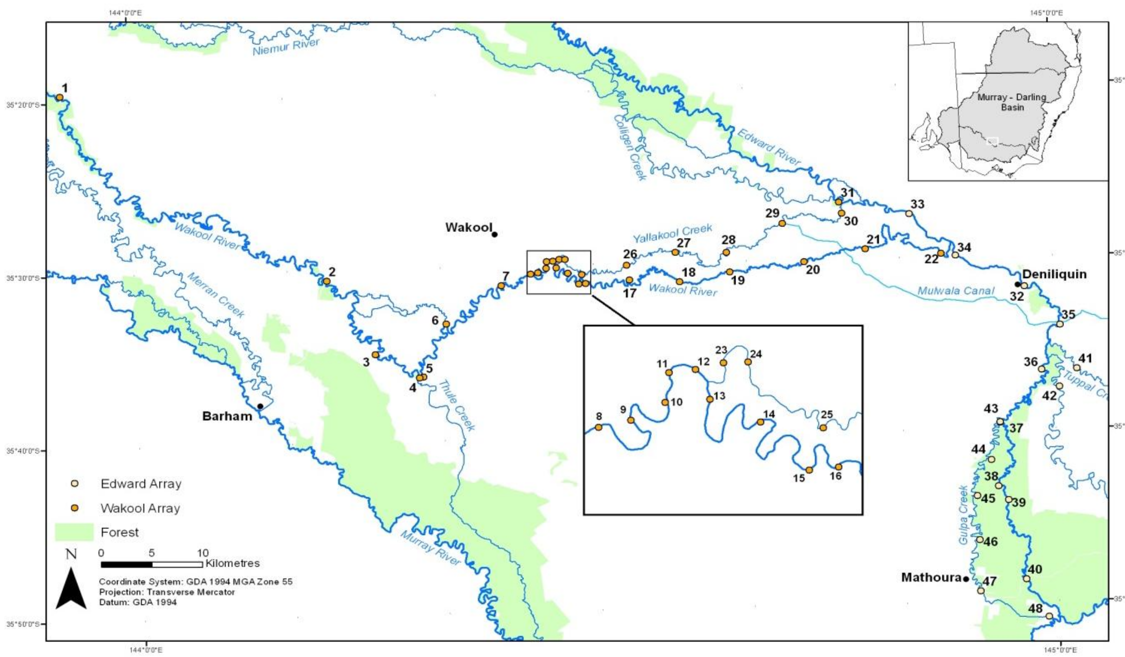


Figure 7. Overview of acoustic receiver array In the Edward-Wakool system used to detect fish movements in response to environmental water delivery in 2013-14. The array was established to detect movements in the Wakool-Yallakool River (orange) and also the upper Edward system (yellow). Detailed coverage of the original tagging location at the Wakool-Yallakool junction is enlarged for clarity.

5. INDICATORS

An ecosystem approach was used to select indicators to evaluate the responses to Commonwealth environmental watering in 2013-2014. We selected a suite of indicators that have clear linkages to each other and reflect the in-channel focus of the water use options for the Edward-Wakool system. The indicators have a strong focus on fish, including fish movement, spawning, recruitment and adult populations. The Edward-Wakool system is recognised as a priority area for fish diversity in the Murray-Darling Basin. Outcomes for fish have continued to be the focus of watering actions in the Edward-Wakool system as they are the key environmental asset and are also highly valued by the Edward-Wakool community. Many of the other indicators (e.g. water quality, vegetation, stream metabolism, shrimp) directly or indirectly influence fish population dynamics, and thus are essential to aid the interpretation and interdependencies.

A conceptual diagram (Figure 8) illustrates the linkages among indicators under different types of environmental watering. Indicators included in this monitoring program are shaded in blue. Results of hydraulic modelling were reported in Watts et al. (2013b) and Kingsford and Watts (2014).

The frequency of sampling and locations where the indicators were monitored are listed in Table 4. Some indicators were monitored continuously via logging equipment and others were sampled fortnightly or monthly. Some indicators (e.g. water quality, riverbank and instream vegetation, fish larvae abundance) were processed quickly and provide real time information to water managers allowing them to adaptively manage the watering regime to achieve the watering objective.

The responses of these indicators to Commonwealth environmental water are documented in section 6, with indicators grouped according to the expected ecosystem outcomes listed in Water Use Minute number 142 (CEWO 2013b):

1. Increase movement, condition, reproduction and recruitment of native fish
2. Provide end of system flows and increase hydrological connectivity in ephemeral streams
3. Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants
4. Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH
5. Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs

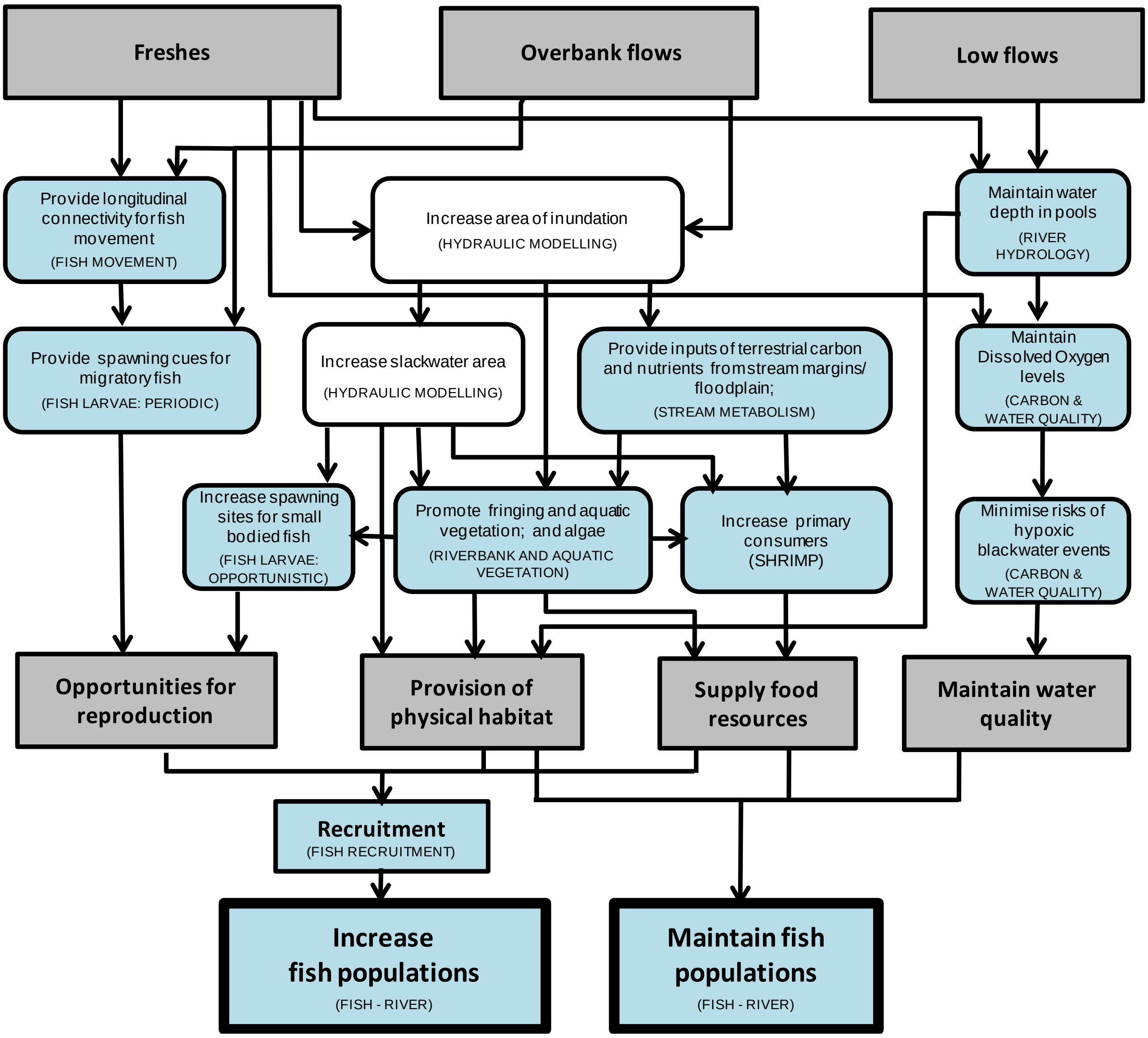


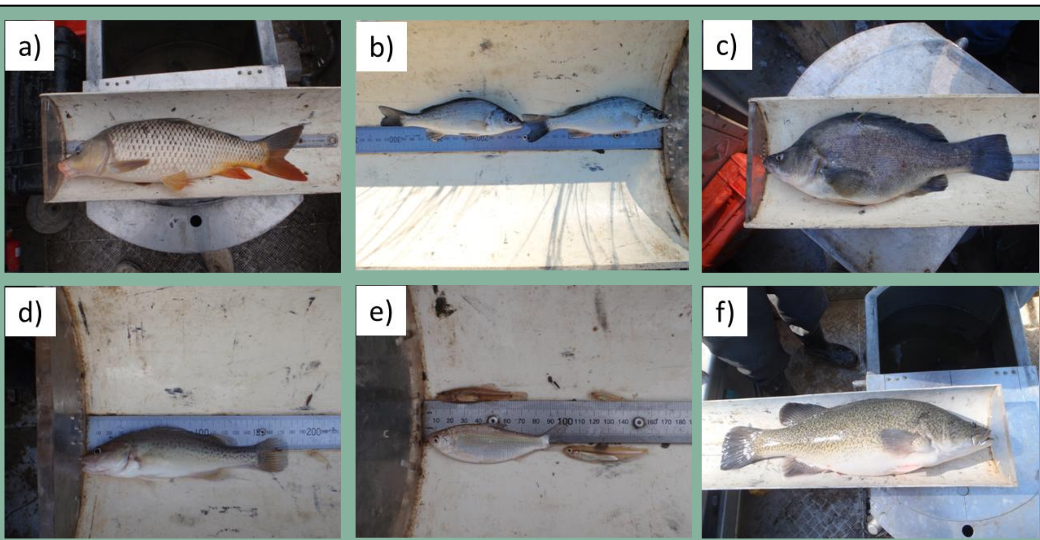
Figure 8. Conceptual diagram illustrating the linkages among indicators and links different types of environmental watering (freshes, overbank flows, low flows) to fish populations. Indicators included in this monitoring report are highlighted in blue.

Table 4. Summary of location and frequency of monitoring of indicators in the Edward-Wakool system in 2013-14, grouped according to the ecosystem outcome. Note, in-channel hydraulic modelling in the focus rivers was undertaken in 2012-13 and was reported in Watts et al. (2013b) and Kingsford and Watts (2014).

Expected ecosystem outcome listed in Water Use Minute number 142 (CEWO 2013b)	**Indicators**	**Study sites/reaches**			
		Focus rivers: Colligen Ck Yallakool Ck Wakool R Little Merran Ck	**Source:** Edward R (Stevens weir)	**Acoustic array sites in Wakool R, Yallakool Ck and Edward R**	**41 sites throughout Edward-Wakool system**
Increase movement, condition, reproduction and recruitment of native fish	Fish community				annual
	Fish movement			continuous	
	Fish spawning and reproduction	Fortnightly (Aug to Mar)	Fortnightly (Aug to Mar)		
	Fish recruitment	annual			
Provide end of system flows and increase hydrological connectivity in ephemeral streams	Hydraulic modelling	Undertaken in 2012-13 and reported in Watts et al. (2013b) and Kingsford and Watts (2014).			
Maintain/improve vegetation condition, including fringing vegetation and emergent/ submerged aquatic plants	Riverbank and instream vegetation	monthly (Sept to Mar)			
Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH	Water quality and chemistry (dissolved oxygen, light, temp)	continuous			
	Water chemistry (carbon, nutrients)	fortnightly (Aug to Mar)	Fortnightly (Aug to Mar)		
	Whole stream metabolism	continuous			
Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs.	Shrimp	Fortnightly (Sept to Mar)	fortnightly (Sept to Mar)		
	Frogs	monthly (Sept to Mar)			

6. RESPONSES OF INDICATORS TO COMMONWEALTH ENVIRONMENTAL WATERING

6.1. Fish community



Photos: Example of fish species encountered during the 2014 fish community sampling:
a) common carp, b) silver perch, c) golden perch, d) trout cod, e) (clockwise from bottom left) bony herring, flat-headed gudgeon, carp gudgeon and Australian smelt, and f) Murray cod.

Key findings

- Fish community sampling was undertaken in May and June 2014 at 41 sites (26 channel and 15 wetland sites) throughout the Edward-Wakool system.
- Ten native species and three alien species were captured. There was an increase in the abundance of small bodied generalist species (primarily Australian smelt and carp gudgeon) in 2014 in comparison to 2013. There was an increase in the biomass of Murray cod, goldfish and bony herring and decrease in the biomass of common carp and golden perch in 2014 compared to 2013.
- Juvenile Murray cod that were spawned in 2013 were captured in 2014 from both the upper Wakool River and Yallakool Creek. Back-calculated spawning dates indicate that golden perch spawned in all years from 2004 to 2010 and the dominant cohort was spawned in 2009 during periods of low in-flows in the Edward-Wakool system. Strong year classes of silver perch were present from spawning in 2009-10.
- The Sustainable Rivers Audit measure of expectedness and nativeness were calculated for fish community data collected from 2010 to 2014. All zones were in poor condition in 2014 in terms of nativeness, an improvement over the very poor condition from 2013. In 2014 all zones were in poor to moderate condition in terms of recruitment.
- There is a general trend towards recovery of the native fish community in the Edward-Wakool system, although this is species and location specific. Some of the changes may be due to fish migration into the system because recruitment of some species is poor. Combined with information on fish movement, spawning and recruitment there is a need to adapt the delivery of environmental water to maximise the recovery of native fish popoulations (see flow recommendations).

Background

Dryland rivers in Australia contain ecological communities that have adapted to extreme hydrological regimes, such as extensive flooding interrupted by long periods of low flow and drought (Humphries et al. 1999, Thoms and Sheldon 2000). The majority of fish communities within these systems have undergone severe declines, and the alteration of natural flow regimes has contributed significantly 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 invasion of generalist alien species (Bunn and Arthington 2002). Commonwealth 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 improving food availability which can translate to improved condition and larval survival (Humphries et al. 1999, Humphries et al. 2002, King et al. 2003). Further, many native fish species have been known to opportunistically use wetlands and floodplains for nursery habitat and to benefit from increased food availability (Lyon et al. 2010), and the delivery of environmental water can promote connectivity with these off-channel habitats.

Environmental water delivery has previously provided 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 a 30 GL environmental flow. The objective of the flow was to sustain existing populations by improving water quality in deteriorating conditions during an extreme drought. Spawning in 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 abundances of Murray cod or silver perch (*Bidyanus bidyanus*) (Gilligan et al. 2009). Following the environmental water release, the abundance of golden perch and carp gudgeons (*Hypseleotris* spp) was found to decline (Gilligan et al. 2009). These outcomes were all based on a short-term before and after comparison. Whether these benefits contributed to overall long term changes were not determined during such a short term study.

It is likely that short term changes in fish community redistribution during 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 increasing biomass across the system, overall improvements to fish condition, the presence of recruitment, positive changes in native fish abundance and increased species richness. For example, landscape fish diversity over longer time scales (>10 years) is influenced by available habitat, connectivity and disturbance, which are mainly influenced by the interactions between flow and geomorphology. Providing greater access to habitat through connectivity is achievable using environmental water and will lead to a detectable change, at the valley scale, over the medium-long term. These are expected and measurable changes. The ability to detect change is often influenced by the overall objective of water delivery. Changes in landscape-scale fish condition are generally only applicable if environmental water delivery occurs to drive these impacts, and that only occurs when water holdings are high.

During periods when water holdings are low, environmental water delivery can be used to prevent deterioration of fish condition, encourage dispersal 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 water delivery took place, whilst thousands of fish perished in affected reaches. The delivery of environmental water can also influence native fish reproduction directly by providing cues that stimulate spawning behaviour or provide access to suitable available habitat. Likewise, the delivery of environmental water to drive fish recruitment outcomes can therefore be influenced indirectly by: 1) increasing food resources, 2) increasing available habitat, 3) promoting suitable water quality, and 4) facilitating connectivity and dispersal as described in the conceptual diagram (Figure 8).

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. The program involved establishing long-term fish monitoring sites that have been sampled consecutively for five years. The overall objectives of this monitoring program were to identify ecological assets within the system, 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 to determine long term change 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 a system-wide multiple lines of evidence approach to water management and delivery to benefit native fish communities in the Edward-Wakool system. Two additional objectives were undertaken in 2013-14 and these included: 1) opportunistic evaluation of targeted cod flows within Yallakool Creek through the collection and daily or annual ageing of juvenile Murray cod captured during annual surveys, and 2) evaluation of cohort strength of flow dependent species golden perch and silver perch with respect to historical system-wide water availability through the use of annual ageing.

Methods

Fish community sampling was undertaken in May and June 2014 at 41 sites throughout the Edward-Wakool system (Figure 6, 9). These sites comprised 26 channel and 15 wetland sites distributed among four broad geographic zones (Upper, Middle, Lower and Werai) (Figure 6). Sampling sites were retained from Watts et al. (2013b) with the exception that Cadell was not sampled due to inaccessibility. Sampling methods were identical to those described in Watts et al. (2013b) for the Sustainable Rivers Audit (SRA) protocol, comprising a standardised effort of electrofishing and unbaited bait traps at each site.

Juvenile Murray cod were retained from Yallakool Creek and upper Wakool River sites in 2013 and 2014, with otoliths removed to determine daily age (if < 1 year old) or annual age (if > 1 year old) given targeted watering for this species over the past two years. Additionally, golden perch and silver perch were retained from all sites sampled, and additional opportunistic samples were retained and analysed (i.e. from previous sampling in the catchment). Otoliths were removed to determine annual age (Figure 10) and cohort strength relating to previous broad scale hydrological conditions in the system (i.e. drought and flooding) given both golden perch and silver perch are considered flow dependent spawners. All ageing was conducted by Fish Ageing Services (www.fishageingservices.com), and otoliths were checked where relevant for the presence of calcein marks to differentiate among stocked and wild individual golden perch and Murray cod (see Crook *et al.* 2009). It is important to note that any golden perch or Murray cod stocked prior to 2011, or immigrating into the Edward-Wakool from elsewhere, are unlikely to have received a calcein mark.

To determine changes in both the abundance and biomass of the fish community assemblage, two separate analyses were conducted to using year of sampling (2010, 2011, 2012, 2013 and 2014), broad geographic zone (Lower, Middle, Upper and Werai) and habitat type (Channel and Wetland) as factors. Only data collected using the standardised SRA sampling protocol from previous surveys was included in the analysis. Data were analysed using a three-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 groups differed within factors (Year, Zone or Habitat). Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between factors. For comparison with the findings of Watts et al. (2013), individual species were grouped into flow guilds comprising four native fish groups and one general alien species group based on life-history similarities (*after* Baumgartner et al. 2013); foraging (flow) generalists, apex predators, flow dependant specialists, floodplain (off-channel) specialists and alien species.

Changes over time to the overall condition of the fish community assemblage were quantified using three main SRA Indicators (see Robinson 2012). The SRA derived Indicators calculated were; Expectedness (provides a comparison of existing catch composition with historical fish distributions), Nativeness (a combination of abundance and biomass describing the proportion of the community comprised of native fish), and Recruitment (provides a proportion of the entire native fish population that is recruiting). Recruitment was further divided; recruiting taxa (proportion of native species present recruiting), and recruiting sites (proportion of sites where recruitment occurs). These Indicators produce a score that is related to Reference conditions, and receive a condition rating (Extremely Poor (0-20), Very Poor (21-40), poor (41-60), Moderate (61-80), Good (81-100).

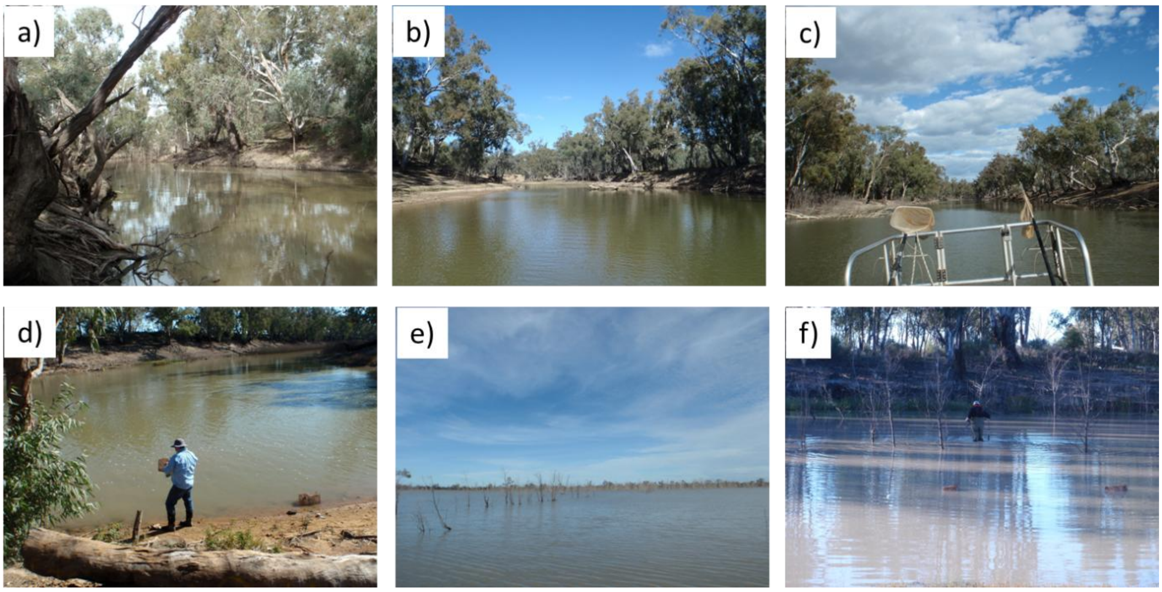


Figure 9. An example of fish community sites sampled in 2014 in the Edward-Wakool system including: a) Gollops Road on Tuppal Creek, b) Four Posts on the Edward River, c) Werai Station on Colligen Creek, d) Stoney Crossing on the Wakool River, e) Tally's Lake, and f) Northdale Lagoon.

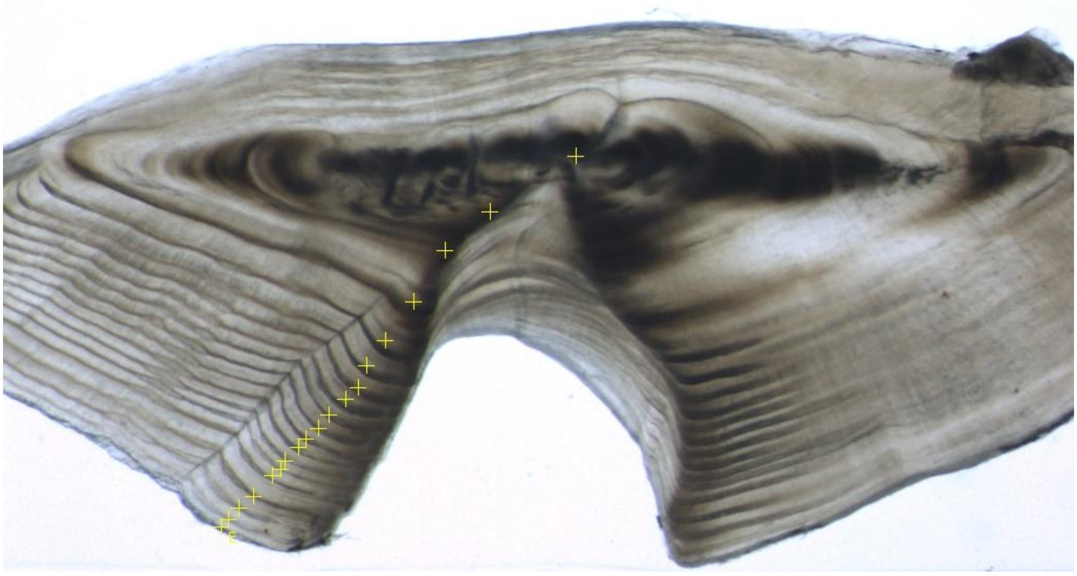


Figure 10. Example of an ear bone (otolith) from a 17 year-old golden perch captured from the Edward-Wakool system. Yellow crosses indicate annual growth increments beginning at age 0 (centre).

Results

Abundance

A total of 4849 fish were collected including 10 native species and three alien species. As in previous years no floodplain specialist species were captured, although the three remaining flow guilds (apex predators, flow specialists and foraging generalists) were well represented (Table 5). Murray cod dominated apex predator capture in the upper and lower channel zones, and one trout cod was captured for the first time in five years of sampling from the upper channel zone (Table 6). Golden perch were the most abundant flow specialist, and silver perch were infrequently captured (Table 6). Australian smelt and carp gudgeon were the most abundant native species, with other foraging generalists including un-specked hardyhead, bony herring and Murray-Darling rainbowfish frequently captured (Table 6). The fish community assemblage in the Edward-Wakool system differed significantly in abundance among years, zones and habitats (Table 7). Pair-wise tests indicated that significant differences occurred between 2014 and 2013 (t=2.727, $P<0.001$), and SIMPER analysis indicated that these observed differences were primarily driven by differences in foraging generalists Australian smelt and carp gudgeon (Table 8). Goldfish also contributed to differences between years (Table 8).

Biomass

Common carp, Murray cod and golden perch occupied the greatest overall biomass in 2014. Apex predator biomass was greatest in the mid and upper zones, with most contributed from Wakool Reserve and Four Posts (Figure 11). Foraging generalist biomass was highest in the mid and lower zones from Gee Gee Bridge, Possum Reserve, Wakool Reserve and Merran Creek Bridge (Figure 12). Flow specialist biomass was highest at Balpool and Wakool Reserve sites (Figure 13), and the total biomass of alien species (primarily common carp) was highest at sites in the mid and upper zones, with Smith's Lagoon contributing the greatest overall biomass of alien species (Figure 14). Fish community biomass differed significantly among years, zones and habitats (Table 7). Pair-wise tests indicated that significant differences in biomass at sites occurred between 2014 and 2013 ($t=2.440$, $P<0.001$), and SIMPER analysis indicated that these observed differences arose from changes in the biomass of the apex predator Murray cod, the biomass of alien species common carp and goldfish (Table 9). Biomass differences between 2013 and 2014 were also attributable to the flow specialist golden perch and the foraging generalist bony herring (Table 10).

Sustainable Rivers Audit (SRA) Indicators

Both expectedness and nativeness SRA indices were highest from all zones sampled in 2010, with expectedness moderate and nativeness poor (Table 11). There was a general trend downwards in these indices in 2011 across most zones, particularly in nativeness values, primarily due to an increase in the abundance and biomass of common carp following natural flooding events in 2010-11. These indices recovered to pre-flood levels, but by 2014 the upper, middle and lower zones were in poor condition in terms of expectedness, while the Werai zone was in very poor condition (Table 11). All zones sampled in 2014 were in poor condition in terms of nativeness, an improvement over the very poor condition from 2013 (Table 11). Although many expected species were present, the poor rating for 2014 is largely because floodplain specialist species expected to occur within the Edward-Wakool system remain undetected. All zones sampled remained in poor to moderate condition in terms of recruitment (proportion of taxa and proportion of sites) in all years, except for the Werai zone in 2013 which was in very poor condition 2013 (proportion of sites only). Both recruitment indices were higher in 2014 compared with 2013, with the exception of the upper zone which had a lower proportion of taxa recruiting in 2014 (Table 11).

Table 5. Summary of total catch (mean ± SE catch per site in parentheses) over five years of sampling in channel and wetland habitats in the Edward-Wakool system.

Species	Channel					Wetland				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Apex predators										
Murray cod	159 (8±2)	34 (2±1)	51 (3±1)	57 (3±1)	76 (3±1)	22 (3±2)	0	0	8 (1±1)	8 (1±1)
trout cod	0	0	0	0	1 (1±1)	0	0	0	0	0
Flow dependent specialists										
silver perch	10 (1±1)	10 (1±1)	13 (1±1)	7 (1±1)	6 (1±1)	6 (1±1)	0	0	2 (1±1)	0
golden perch	38 (2±1)	25 (2±1)	58 (3±1)	48 (2±1)	37 (2±1)	19 (2±2)	4 (1±1)	4 (1±1)	6 (1±1)	4 (1±1)
Foraging generalists										
Australian smelt	678 (34±13)	1035 (44±18)	620 (25±11)	341 (14±4)	1539 (60±15)	81 (9±3)	740 (62±37)	265 (23±9)	101 (7±4)	429 (29±10)
bony herring	157 (8±4)	84 (4±2)	162 (7±3)	61 (3±1)	152 (6±2)	49 (5±3)	31 (3±2)	102 (8±5)	10 (1±1)	25 (2±1)
carp gudgeon	809 (41±13)	281 (12±5)	135 (2±1)	932 (36±34)	183 (8±3)	1952 (196±115)	292 (25±12)	616 (55±25)	585 (37±19)	993 (67±26)
flat-headed gudgeon	3 (1±1)	1 (1±1)	0	0	1 (1±1)	10 (1±1)	0	0	16 (1±1)	25 (2±2)
Murray rainbowfish	1110 (56±19)	631 (27±8)	84 (4±2)	11 (1±1)	79 (4±2)	533 (54±33)	235 (20±11)	140 (11±5)	8 (1±1)	43 (3±2)
un-specked hardyhead	1749 (88±26)	301 (13±8)	7 (1±1)	13 (1±1)	57 (3±2)	823 (83±30)	158 (14±10)	109 (9±5)	6 (1±1)	228 (16±11)
Alien species										
common carp	487 (25±7)	3632 (152±27)	1022 (43±6)	526 (21±5)	489 (19±5)	720 (72±38)	1712 (143±66)	955 (74±36)	284 (18±5)	222 (15±6)
gambusia	28 (2±1)	78 (4±2)	0	1 (1±1)	11 (1±1)	72 (8±6)	51 (5±3)	8 (1±1)	7 (1±1)	56 (4±2)
goldfish	193 (10±3)	1131 (48±19)	231 (9±3)	105 (5±2)	84 (4±1)	387 (39±22)	546 (46±25)	493 (41±27)	59 (4±2)	101 (7±3)
oriental weatherloach	0	9 (1±1)	1 (1±1)	0	0	0	0	1 (1±1)	0	0
redfin perch	8 (1±1)	1 (1±1)	3 (1±1)	3 (1±1)	0	0	0	0	2 (1±1)	0

Table 6. Summary of total catch (mean ± SE catch per site in parentheses) during 2014 sampling in the Edward-Wakool system.

Species	Channel				Wetland				Total
	Upper	Middle	Lower	Werai	Upper	Middle	Lower	Werai	
Apex predators									
Murray cod	27 (3±1)	18 (3±2)	25 (4±2)	6 (2±1)	0	8 (2±1)	0	0	84
trout cod	1 (1±1)	0	0	0	0	0	0	0	1
Flow dependent specialists									
silver perch	1 (1±1)	1 (1±1)	3 (1±1)	1 (1±1)	0	0	0	0	6
golden perch	14 (2±1)	4 (1±1)	12 (2±1)	7 (3±2)	2 (1±1)	2 (1±1)	0	0	41
Foraging generalists									
Australian smelt	944 (95±34)	167 (28±15)	132 (19±7)	296 (99±26)	129 (33±16)	234 (39±22)	48 (16±8)	18 (9±9)	1968
bony herring	11 (2±1)	45 (8±3)	90 (13±5)	6 (2±2)	11 (3±3)	14 (3±2)	0	0	177
carp gudgeon	111 (12±6)	32 (6±2)	34 (5±3)	6 (2±1)	228 (57±38)	614 (103±58)	102 (34±19)	49 (25±20)	1176
flat-headed gudgeon	1 (1±1)	0 (0±0)	0	0	1 (1±1)	9 (2±1)	15 (5±5)	0	26
Murray rainbowfish	46 (5±2)	20 (4±4)	11 (2±2)	2 (1±1)	10 (3±2)	32 (6±3)	1 (1±1)	0	122
un-specked hardyhead	36 (4±4)	13 (3±2)	8 (2±1)	0	2 (1±1)	66 (11±9)	160 (54±52)	0	285
Alien species									
common carp	317 (32±11)	76 (13±5)	65 (10±2)	31 (11±5)	64 (16±9)	143 (24±14)	12 (4±1)	3 (2±2)	711
gambusia	11 (2±1)	0 (0±0)	0	0	26 (7±6)	5 (1±1)	21 (7±5)	4 (2±2)	67
goldfish	34 (4±2)	9 (2±2)	41 (6±2)	0	43 (11±6)	46 (8±6)	8 (3±1)	4 (2±1)	185

Table 7. Results from PERMANOVA comparisons of site abundance and biomass of fish sampled annually in the Edward-Wakool system from 2010–2014.

Source of variation	df	MS	Pseudo-*F*	*P*
Site abundance				
Year	4	8913.3	11.546	0.001
Zone	3	5983.1	7.750	0.001
Habitat	1	17571.0	22.761	0.001
Year*Zone	11	1062.2	1.376	0.038
Year*Habitat	4	1167.5	1.512	0.064
Zone*Habitat	3	1754.5	2.273	0.004
Year*Zone*Habitat	11	668.0	0.865	0.752
Residual	147	772.0		
Site biomass				
Year	4	5019.7	7.840	0.001
Zone	3	5075.7	7.927	0.001
Habitat	1	17335.0	27.073	0.001
Year*Zone	11	846.4	1.322	0.079
Year*Habitat	4	998.9	1.560	0.065
Zone*Habitat	3	1208.2	1.887	0.027
Year*Zone*Habitat	11	799.6	1.249	0.125
Residual	147	640.3		

Table 8. Changes in fish species site abundance between 2013 and 2014 as determined through SIMPER analysis. Note only species contributing ≥10% to change are included.

Species	Contribution to change (%)	2014 response
Australian smelt	15	Increase
carp gudgeon	14	Increase
goldfish	10	Increase

Table 9. Changes in fish species site biomass between 2013 and 2014 as determined through SIMPER analysis. Note only species contributing ≥10% to change are included.

Species	Contribution to change (%)	2014 response
Murray cod	18	Increase
common carp	18	Decrease
golden perch	16	Decrease
goldfish	13	Increase
bony herring	10	Increase
goldfish	10	Increase

Table 10. Pre-European (PERCH) list of the expected native species present in the central Murray region of the Murray Darling Basin.

Common name	Scientific name	Found in present study				
		2010	2011	2012	2013	2014
Long lived apex predators						
Murray cod	*Maccullochella peelii*	Y	Y	Y	Y	Y
trout cod	*Maccullochella macquariensis*	N	N	N	N	Y
Flow dependent specialists						
silver perch	*Bidyanus bidyanus*	Y	Y	Y	Y	Y
golden perch	*Macquaria ambigua*	Y	Y	Y	Y	Y
Foraging generalists						
Australian smelt	*Retropinna semoni*	Y	Y	Y	Y	Y
bony herring	*Nematalosa erebi*	Y	Y	Y	Y	Y
carp gudgeon	*Hypseleotris* spp	Y	Y	Y	Y	Y
dwarf flat-headed gudgeon	*Philypnodon macrostomus*	N	N	N	N	N
flat-headed gudgeon	*Philypnodon grandiceps*	Y	N	N	Y	Y
freshwater catfish	*Tandanus tandanus*	N	N	N	N	N
Macquarie perch	*Macquaria australiasica*	N	N	N	N	N
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	Y	Y	Y	Y	Y
Murray hardyhead	*Craterocephalus fluviatilis*	N	N	N	N	N
shortheaded lamprey	*Mordacia mordax*	N	N	N	N	N
river blackfish	*Gadopsis marmoratus*	N	N	N	N	N
un-specked hardyhead	*Craterocephalus stercusmuscarum*	Y	Y	Y	Y	Y
Floodplain (or off-channel) specialists						
flat-headed galaxias	*Galaxias rostratus*	N	N	N	N	N
mountain galaxias	*Galaxias olidus*	N	N	N	N	N
olive perchlet	*Ambassis agissizi*	N	N	N	N	N
southern purple spotted gudgeon	*Mogurnda adspersa*	N	N	N	N	N
southern pygmy perch	*Nannoperca australis*	N	N	N	N	N

Table 11. SRA indicators separated by geographic zones within the Edward-Wakool system, with values generated from 2014 sampling indicated in bold.

Location	Year	Expectedness (OE_metric)	Nativeness	Recruitment (proportion of taxa)	Recruitment (proportion of sites)
Upper	2010	74	59	67	64
Upper	2011	56	33	63	56
Upper	2012	49	31	63	52
Upper	2013	36	34	75	51
Upper	**2014**	**55**	**48**	**67**	**52**
Middle	2010	64	46	78	65
Middle	2011	43	15	63	51
Middle	2012	49	21	75	63
Middle	2013	38	32	56	37
Middle	**2014**	**56**	**46**	**78**	**67**
Lower	2010	75	52	78	66
Lower	2011	56	16	57	57
Lower	2012	49	33	75	58
Lower	2013	36	35	71	48
Lower	**2014**	**55**	**54**	**78**	**64**
Werai	2010	Not sampled			
Werai	2011	19	24	67	57
Werai	2012	37	41	67	49
Werai	2013	30	34	43	38
Werai	**2014**	**37**	**51**	**57**	**47**

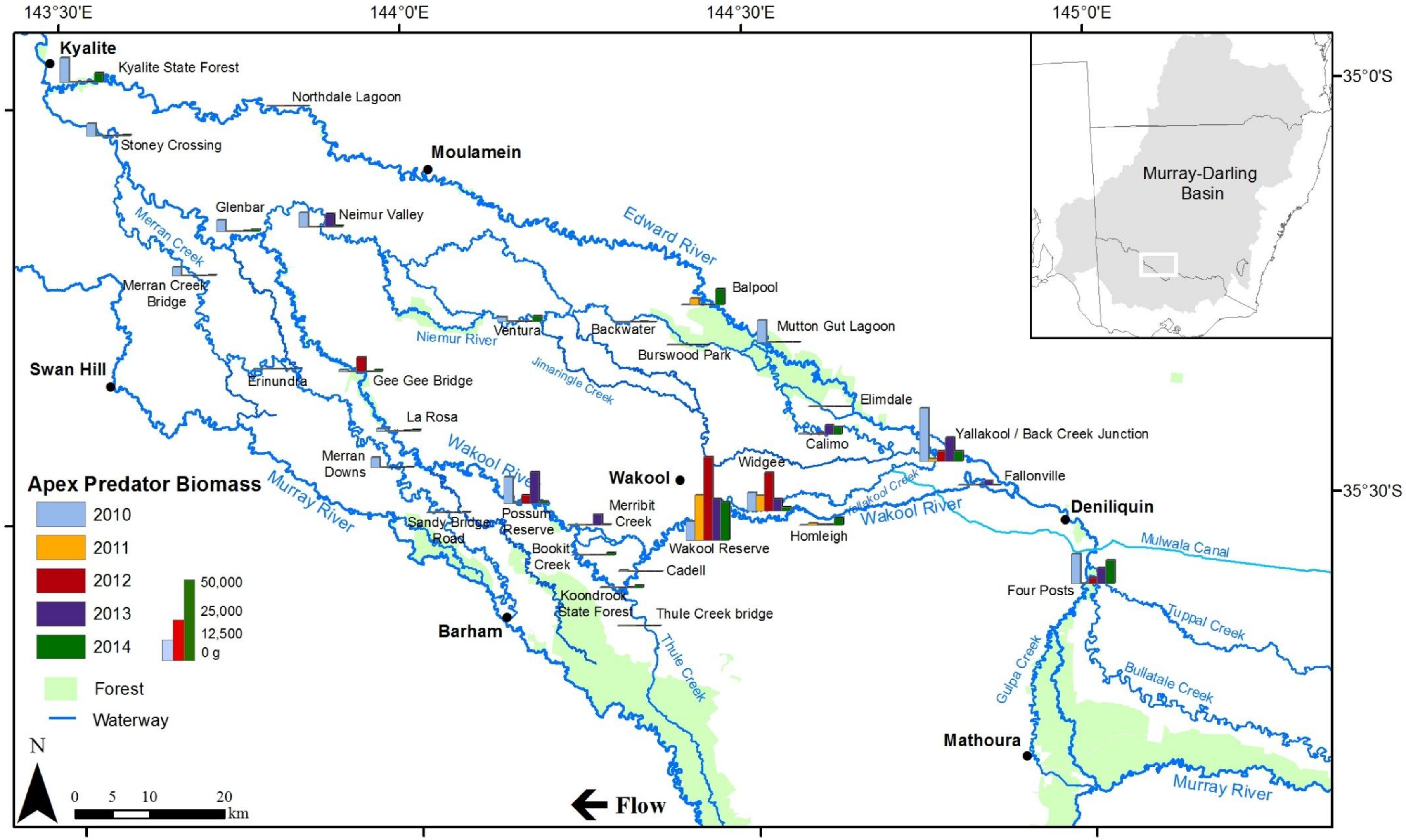


Figure 11. Total apex predator biomass at each sampling site (grams per site) over five years of sampling in the Edward-Wakool system.

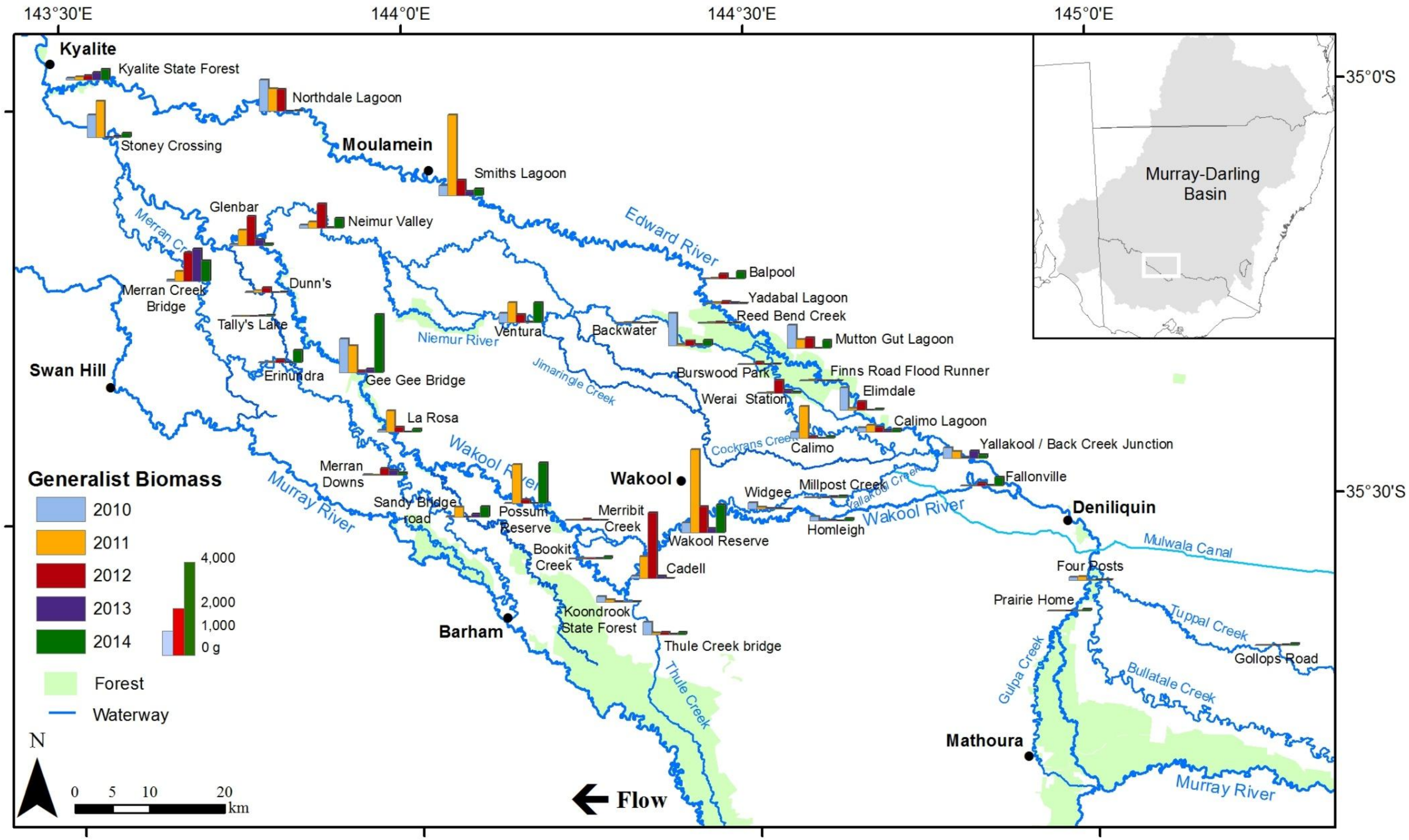


Figure 12. Total foraging generalist biomass at each sampling site (grams per site) over five years of sampling in the Edward-Wakool system.

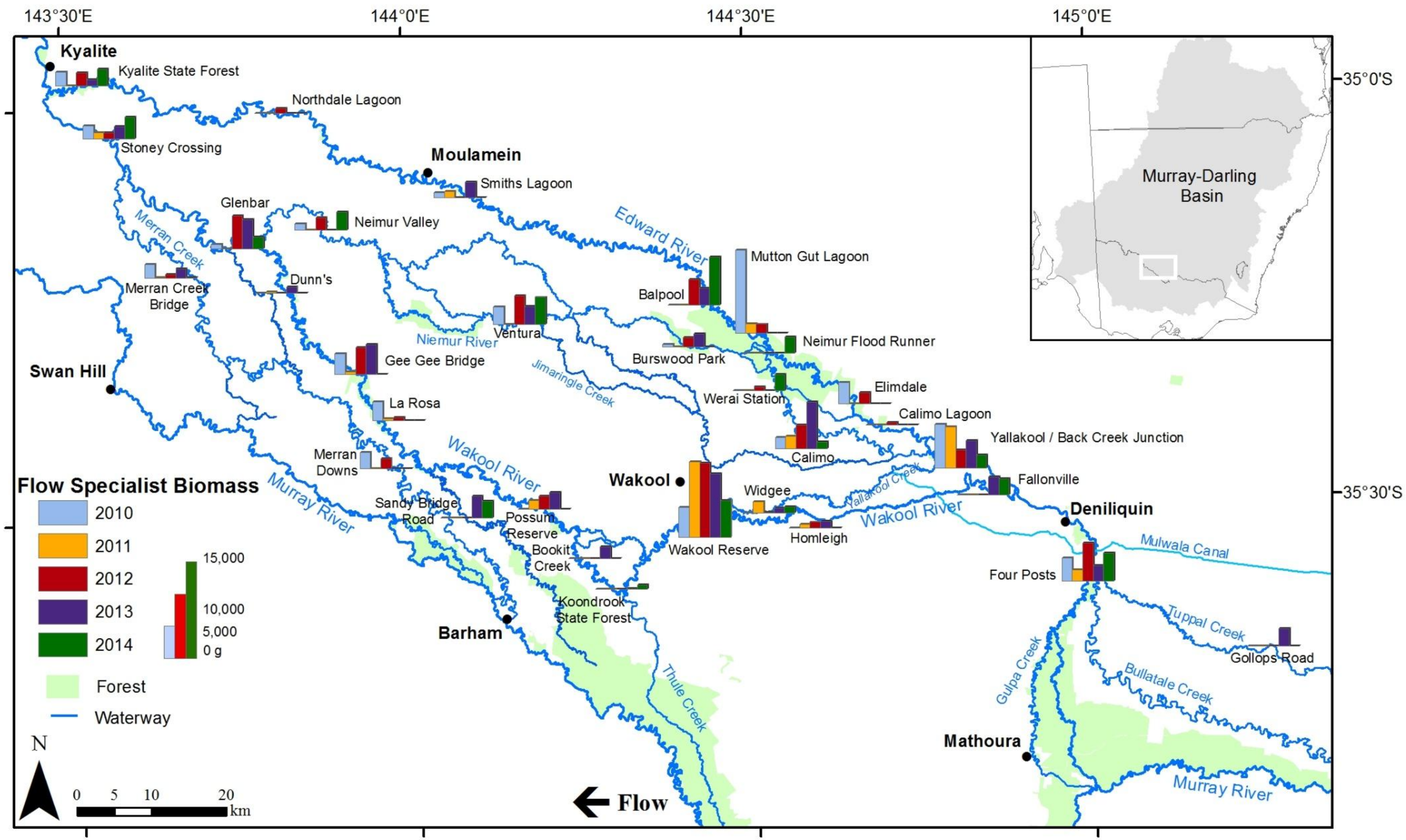


Figure 13. Total flow specialist biomass at each sampling site (grams per site) over five years of sampling in the Edward-Wakool system.

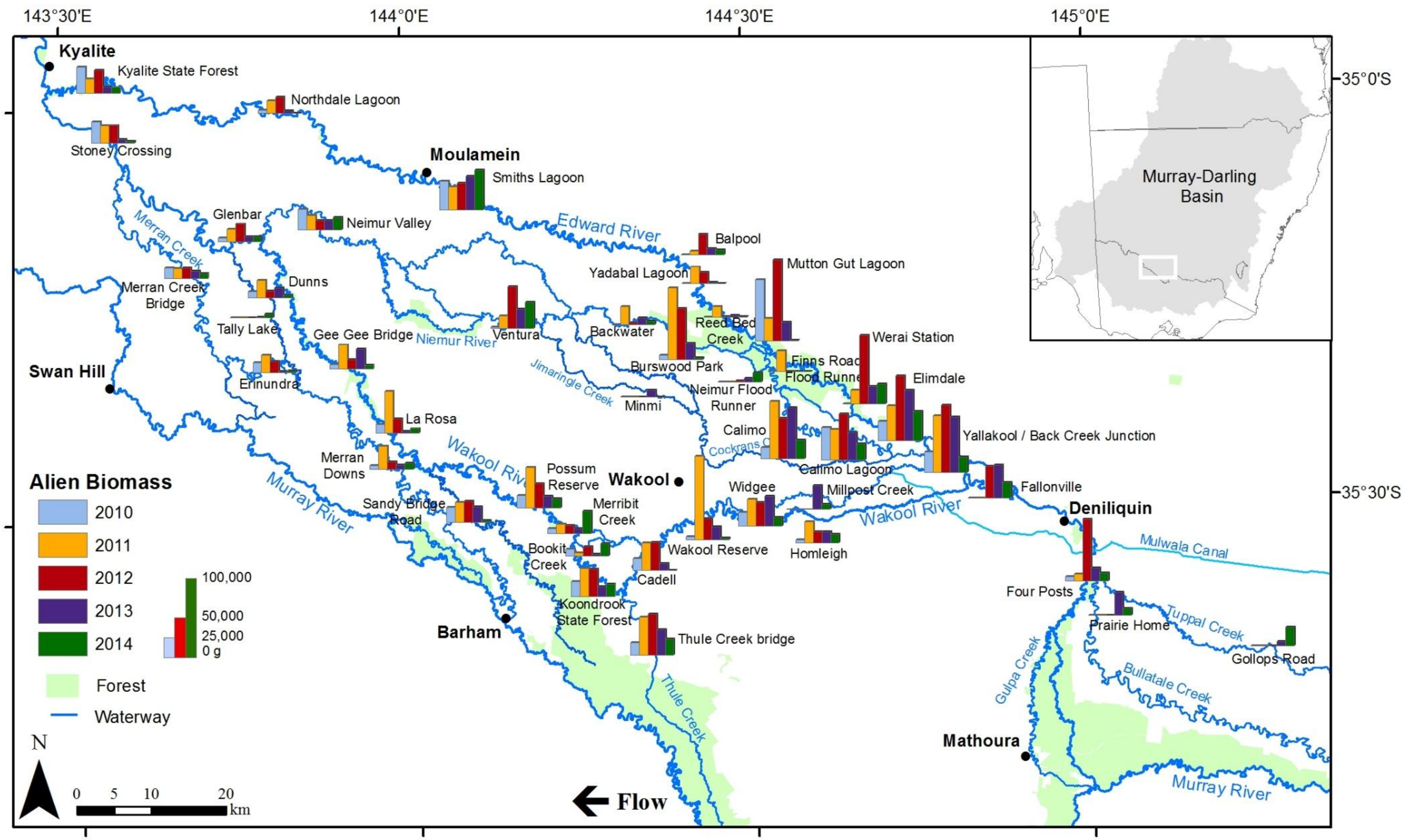


Figure 14. Total alien species biomass at each sampling site (grams per site) over five years of sampling in the Edward-Wakool system.

Daily and annual age

Eight possible young-of-year (YOY) Murray cod were captured from the mid and upper Wakool River and Yallakool Creek in 2013 (length range 83–146 mm) and all were aged as 0+. Two sites on Yallakool Creek each contributed two individuals spawned in the 2012-13 watering year (Back Creek Junction and Widgee), with back calculated dates estimating that hatching occurred from 29 November 2012 to 6 January 2013. Three YOY Murray cod were captured from the upper Wakool River (Fallonville), with back calculated dates estimating that hatching occurred from 14 December 2012 to 12 January 2013. One YOY Murray cod was captured from the mid-Wakool River (Possum Reserve) and had an estimated hatch date of 6 November 2012.

Four possible YOY Murray cod were captured in 2014 from the upper Wakool River and Yallakool Creek. Ageing identified that these four fish comprised a 1+ fish (220 mm; spawned in the 2012-13 watering year) from Back Creek Junction on Yallakool Creek, and three YOY (0+) fish (length range 90–135 mm) from Back Creek Junction on Yallakool Creek (estimated hatch date 12 November 2013), Homeleigh on the Wakool River (estimated hatch date 16 January 2014) and Wakool Reserve on the Wakool River (estimated hatch date 13 December 2014). None of these Murray cod were confirmed to be marked with calcein, indicating they were not hatchery-reared.

Golden perch collected in 2014 (n=44) exhibited a narrow size structure, comprising both sub-adult and adult fish, and ranged in size from 312–526 mm with a dominant size class of 351–400 mm (Figure 15a). These fish comprised a dominant age-class of 4+ individuals with age ranging from 3–17 years (Figure 15b). Approximate back-calculated spawning dates indicate that the dominant cohort was spawned in 2009 during periods of low in-flows into the Edward-Wakool system, and that spawning occurred in all years from 2004–2010 (Figure 16). Three individual fish were excluded from this plot as they represented stocked hatchery-reared fish with identifiable calcein marks and comprised a 1+ individual captured at Four Posts on the Edward River, a 2+ individual captured at Stoney Crossing on the Wakool River and a 4+ individual captured at Fallonville on the Wakool River.

Silver perch collected in 2013 (n=23) and 2014 (n=34) exhibited a narrow size structure, comprising both mature and immature fish, and ranged in length from 126–338 mm in 2013 and 130–370 mm in 2014, with a dominant size class of 251–300 mm in both years of sampling (Figure 17a). These fish comprised a dominant age-class of 3+ individuals in 2013 and subsequent 4+ individuals in 2014, and age ranged from 3–5 years in 2013 and 1–8 years in 2014 (Figure 17b). Approximate back-calculated spawning dates indicate that the dominant cohort in both years of sampling resulted from spawning in 2009, coinciding with periods of low in-flows in the Edward-Wakool system. Results also indicate that some spawning occurred in all years from 2005–2012, with the exception of 2006 (Figure 18).

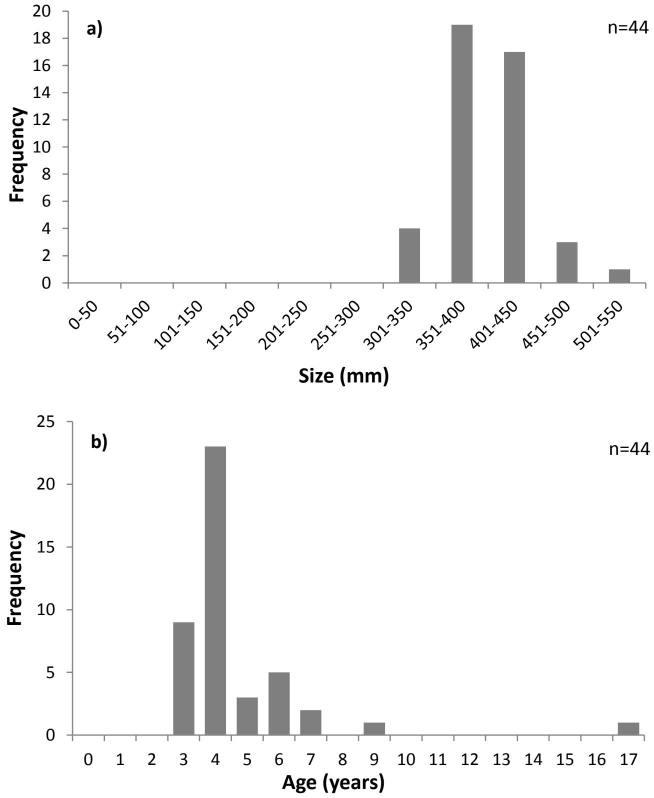


Figure 15. a) Length-frequency of golden perch collected from the Edward-Wakool system in 2014 and, b) associated annual age.

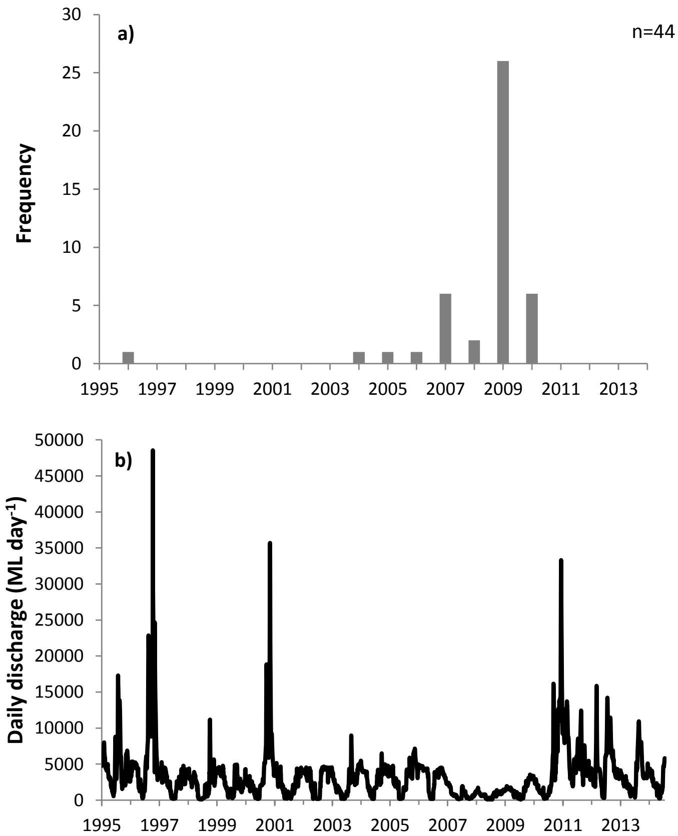


Figure 16. a) Approximate spawning year of golden perch collected from the Edward-Wakool system in 2014 and, b) associated mean daily discharge entering the Edward-Wakool system.

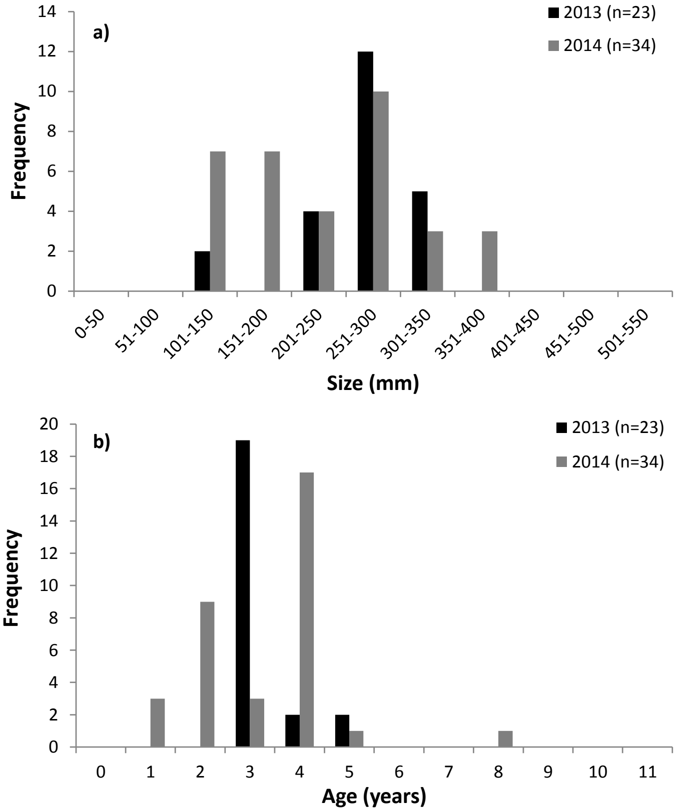


Figure 17. a) Length-frequency of silver perch collected from the Edward-Wakool system in 2013 and 2014 and, b) associated annual age.

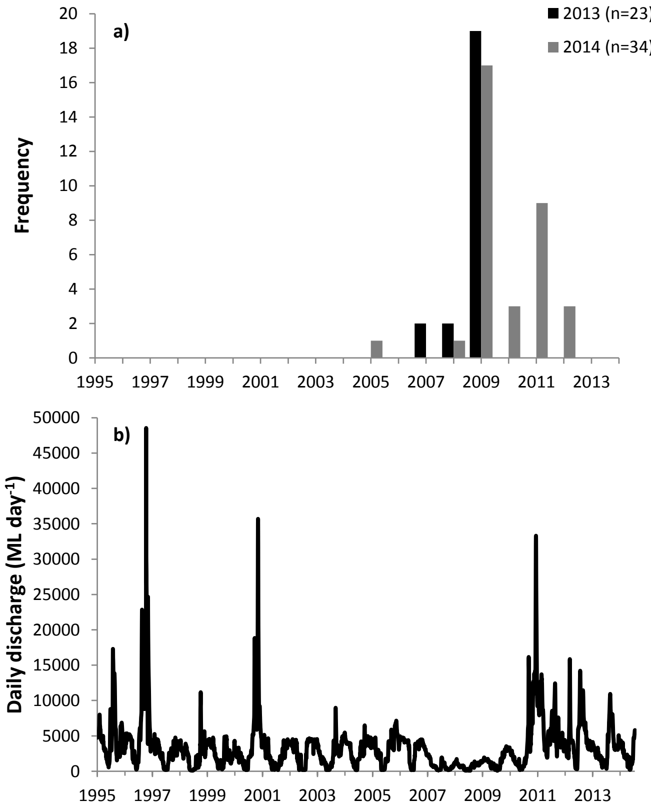


Figure 18. a) Approximate spawning year of silver perch collected from the Edward-Wakool system in 2013 and 2014 and, b) associated mean daily discharge entering the Edward-Wakool system.

Discussion

Edward-Wakool system health: SRA metrics

There is a general trend towards improvement of the native fish community in the Edward-Wakool system. 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, and the responses of fish to these events have been species and location-specific. 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 Murray River, and an increase in the abundance of alien species (particularly common carp) post-flooding. The results from this study are largely in agreement with the findings of Bice et al. (2014), and align with existing knowledge of the life-history requirements of these flow guilds (Baumgartner et al. 2013). Some locations in the Edward-Wakool system appear to be recovering from the effects of blackwater and associated fish kills, presumably as a result of active recolonisation as has been demonstrated following fish kills in other systems (e.g. Lyon and O'Connor 2008). Commonwealth environmental water can be actively used to facilitate this recolonisation by increasing lateral and longitudinal connectivity among habitats, and native fish in the system have previously demonstrated movement responses to increased discharge (*see* Fish movement chapter). Additional remediation of the native fish community has been undertaken at some locations throughout the Edward-Wakool system through the stocking of key recreational species Murray cod and golden perch. This stocking may confound our ability to distinguish natural recovery of the system from the effects of stocking based on the abundance or biomass of these species. However, differentiating among these wild and hatchery-reared fish is possible up to four years of age when chemical marking has been undertaken, as has been the case in the Edward-Wakool system for all individuals of these species stocked since 2011-12. This marking procedure should be continued into the future to enable quantification of long-term ecosystem recovery to inform management actions within the system.

A complete absence of floodplain specialist species within the Edward-Wakool system is apparent following five 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. Future off-channel watering strategies should support long-term watering plans that will enable conservation stocking, and the subsequent re-establishment, of resident populations of off-channel specialists. As a consequence of the lack of off-channel specialist species, continuing to measure ecosystem recovery using indices such as Expectedness may require revision of targets, although Nativeness and Recruitment indices will continue to be applicable.

Apex predators

The results from this study suggest that long-lived apex predators (primarily Murray cod) are still recovering from a blackwater event that occurred in late 2010. Biomass remains substantially lower than pre-blackwater levels at many sites, indicating that long lived species take substantial time to recover despite localised stocking efforts in the region. There is some evidence of larval recruitment during in-channel flow conditions in both the Wakool River and Yallakool Creek over the past two years. Murray cod, a nesting species, is threatened by highly variable flow regimes which can expose nests and limit larval survival (Lake 1967; Cadwallader 1977). Although high flow years have been demonstrated to result in stronger year classes for Murray cod (Rowland 1998), the species predominantly spawns in-channel and where abundant benthic prey is available to larvae during low flow conditions (King 2004; Kaminskas & Humphries 2009). King et al. (2009) demonstrated that delivery of environmental water can enhance the spawning and recruitment of Murray cod. Further, Baumgartner et al. (2013) presented a stylised hydrograph targeting large-bodied long lived species and hypothesised that higher stable flows maximise nest-site inundation and produce a microinvertebrate bloom to increase food resources available to larvae as a result of in-channel bench inundation. Yallakool Creek has been the target of nest inundation flows for this species over the past two watering years, and spawning of Murray cod has occurred during Commonwealth environmental water delivery in both years, although higher stable flows delivered to Yallakool Creek in 2012-13 did not result in a microinvertebrate bloom (Watts et al. 2013b).

Flow dependent specialists

Golden and silver perch represent excellent candidate species for monitoring the delivery of environmental water given they are both considered flow-cued spawners (*see* Baumgarnter et al. (2013) and references therein). Further, previous evidence has indicated a positive relationship between cohort strength and seasonal inflows (Roberts et al. 2008). In the current study we identified that golden perch biomass in the Edward-Wakool system declined in 2014 compared with 2013. It is worthwhile noting that significant declines in the abundance of golden perch were not apparent, and subsequently the capture of larger (but not more) golden perch in 2013 likely contributed to the observed differences in biomass between years.

Annual ages of golden perch and silver perch were examined to determine cohort strength in relation to large scale hydrological events. This revealed that: 1) the dominant cohorts for both species were spawned in 2009-10 near the end of the Millennium drought, 2) spawning occurred throughout the Millennium drought, and 3) silver perch spawned and recruited following flooding. Spawning and recruitment can occur for golden and silver perch in low flows years, supporting the suggestion that these species may have a more flexible life-history strategy than previously considered and do not rely solely on overbank flooding (Humphries et al. 1999, Balcombe et al. 2006). Spawning in both species occurred in the Murray River during the Millennium drought at various locations (e.g. King et al. 2005, Tonkin et al. 2007, Zampatti and Leigh 2013a, b). Indeed, Zampatti and Leigh (2013a) identified a strong cohort of golden perch resulting from spawning in 2009-10 in the lower Murray River. Three possible, but not mutually exclusive, explanations exist that may explain the presence of a strong cohort spawned during drought conditions: 1) stocking of unmarked fish, 2) immigration from elsewhere within the southern connected Murray-Darling Basin, or 3) localised spawning and recruitment solely within the Edward-Wakool system. Stocking of these species occurs and represents a possible explanation, although is unlikely to be the source for silver perch as this species is not regularly stocked into rivers in NSW. The contribution of stocking to wild populations remains relatively unknown throughout the entire Murray-Darling Basin, although a current project funded by Murray Local Land Services in the Edward-Wakool system to evaluate stocking effectiveness at blackwater affected sites may clarify this issue locally. Some level of immigration of these species into the Edward-Wakool system is likely to occur given both species are highly mobile. For example, White et al. (2011) reported large catches of juvenile silver perch at Torrumbarry fishway, indicating synchronised and presumably large-scale movements. Further, numerous studies have documented large-scale movements of golden perch in the Murray-Darling Basin (e.g. Reynolds 1983, O'Connor et al. 2005). Emigration from the Darling into the Murray River has recently been identified for golden perch by Zampatti et al. (2014) through the examination of strontium stable isotope ratios in otolith structures and this technique may elucidate the natal origin of both species residing within the Edward-Wakool in the future. However, until evidence is presented to the contrary, targeted Commonwealth environmental water delivery within the Edward-Wakool system towards key life-history stages of these two flow dependent species remains best practice.

Foraging generalists

Foraging generalists are the most abundant guild within the Edward-Wakool system. Biomass and abundance were highest during drought conditions, although distribution was extended throughout the system irrespective of flow. Many native fish species use wetlands and floodplains for nursery habitat and feeding, and thus allowing movement into and out of connected off-channel habitats can increase recruitment and population persistence of some species (Lyon et al. 2010). Foraging generalists are short-lived (<5 years) and can also be schooling species with generally flexible life-history strategies that enable them to opportunistically exploit a range of habitats (Baumgartner et al. 2013). For example, carp gudgeon thrive under extreme low flow conditions as they are able to spawn multiple times within a season and deposit their eggs on the abundant submerged and emergent macrophytes that grow as a result of stable water levels (Bice et al. 2014). This species will also rapidly colonise off channel habitats, frequently dominating the abundance of native fish in wetlands (Lyon et al. 2010). Subsequently, watering strategies that contribute to both low stable water levels and the inundation of off channel habitats can be equally beneficial to generalist species.

Alien species

There is a general trend towards system wide reductions in the abundance and biomass of alien species, although common carp still dominate overall site biomass at most locations. There was a substantial increase in alien species biomass following flooding in 2010-2011, primarily resulting from large-scale spawning and recruitment of common carp in the Edward-Wakool system. This result is consistent with evidence from other locations indicating the importance of floodplain inundation providing key spawning and nursery habitat for this species in the Murray-Darling Basin (Stuart and Jones 2006, Macdonald and Crook 2014). However, substantial declines in subsequent years suggest either emigration from the Edward-Wakool system or mortality associated with a limited capacity for the system to sustain high numbers. Future monitoring of in-channel environmental watering is unlikely to detect large spawning or a recruitment event given that most of this occurs in off-channel habitats. Additional management interventions for common carp including the use of carp cages and impending deployment of the Koiherpes virus, along with increasing knowledge of carp spawning and recruitment hotspots should result in continued declines within the Edward-Wakool system.

6.2. Fish movement

Photos: left, Surgery to insert tags into fish. right; A VR2W acoustic receiver rigged for deployment next to a V13-1x A69 acoustic tag.

Key findings

- Acoustic telemetry was used to monitor the movements of four species of fish in 2013-14 (Murray cod (n=23), golden perch (n=17), silver perch (n=3), common carp (n=12)). There was an inadequate sample size of silver perch to base any conclusions on.
- Early season unregulated flows in 2013-14 enabled all species to disperse from the refuge pool into new habitats.
- Based on two years of monitoring data, Murray cod demonstrated a consistent preference for movement into the upper Wakool River over Yallakool Creek during delivery of environmental water. The reasons for this are unknown, although it highlights the importance of maintaining habitat in both the Wakool River and Yallakool Creek. Factors such as loading of woody habitat, overhanging cover, depth of pools or physical or hydraulic barriers may have an influence on this preference.
- The majority of tagged golden perch remained in the refuge pool throughout the environmental watering actions. Those individuals that did move, went both upstream and downstream from the refuge pool, with most movements occurring at the peak of flows or on the recession. It is not known whether these movements resulted in spawning, and this can be evaluated in a future assessment of recruitment by the Long term Intervention Monitoring project. However, combined with results from fish community sampling (section 6.1) and fish spawning (section 6.3) the results suggest that the 2013-14 environmental watering did not trigger spawning in this species. There is a need to adapt the delivery of environmental water to encourage the breeding of golden perch and silver perch (see flow recommendations).
- The majority of common carp remained in the refuge pool. Those individuals that did move, went mainly upstream from the refuge pool into Yallakool Creek.
- All acoustically tagged golden perch and some Murray cod returned to the refuge pool at the completion of the recession flows, indicating that these flows were appropriately managed to enable native species to return to refuge habitat and should be incorporated into annual watering priorities.

Background

Freshwater fish are highly mobile and move in response to biotic (e.g. food availability, competition, predation and maturation) and abiotic (e.g. discharge, water temperature, water quality and habitat availability) stimuli in order to spawn, disperse and feed (Lucas et al. 2001). Flow is a major stimulus for both the migratory and non-migratory movements of freshwater fish (Agostinho et al. 2007, Taylor and Cooke 2012). Elevated flows increase both longitudinal and lateral connectivity in river systems. Within river channels, elevated flows enable movement among previously disconnected pools, and subsequently increase opportunities for fish to colonise new habitats, promoting population mixing (David and Closs 2002). In lowland river systems, newly inundated off-channel habitats are often colonised rapidly as they contain abundant food resources, as well as suitable spawning and rearing habitats for a variety of species (Lyon et al. 2010).

Given the climatic variability in Australia and the associated unpredictable hydrology, numerous species rely on in-channel flows, rather than off-channel connections, to complete their life cycle (Humphries et al. 1999). For example, golden perch and silver perch are broadcast spawners with no parental care, and spawning can occur anytime from early November to March (Roberts et al. 2008; King et al. 2009). This suggests that both species are in a state of 'reproductive readiness' over a specified season and are awaiting suitable environmental conditions to spawn. If these conditions are not achieved minimal spawning may occur or the species will simply resorb gonads. While cohort strength for these species is typically linked with high flow years, in-channel spawning has frequently been documented in non-flood years, and the rapid responses of spawning to rising water levels has led to the classification of these species as being flow dependent specialists (Baumgartner et al. 2013). Spawning events are often preceded by long-distance migrations (Reynolds 1983, Mallen-Cooper and Stuart 2003, O'Connor et al. 2005), thus monitoring the timing of these movements in relation to flows can elucidate the timing and location of spawning events in response to water delivery.

Murray cod exhibit a different life-history strategy, and are typically considered an in-channel specialist that spawns over a predictable period each year (October to December) (Humphries and Lake 2000, King et al 2009). Elevated flows are considered important to promote pre-spawn movements associated with mate search and nest selection, as well as maximising available spawning habitat (Baumgartner et al. 2013). Both Lake (1967) and Cadwallader (1977) warned that large variations in water level over a season can risk nest exposure and egg desiccation. Subsequently, environmental watering strategies have been proposed that maintain stable water levels during the expected spawning period (Baumgartner et al. 2013). Further, given the nest guarding behaviour of males, Murray cod also exhibit predictable, and detectable movements (or lack thereof) immediately post-spawning. The signature associated with this behaviour is frequent movements to identify a nest site, followed by a stationary period of up to 14 days which gives the eggs enough time to hatch (7 days) and for the larvae to become free swimming (another 7 days). Upon hatching, larvae require a food source (typically zooplankton) to survive. Productivity blooms following elevated in-channel flows provide abundant food resources. It is therefore expected that, regardless of whether flows stimulate spawning, year class strength is also a function of discharge (Mallen-Cooper and Stuart 2003) because it serves to both protect nesting habitat and provide a food source for larvae.

Telemetry is a useful method for obtaining detailed movement information on freshwater fish, as it enables quantification of the magnitude, timing and frequency of individual responses to abiotic stimuli such as flows (Taylor and Cooke 2012). In Australia, telemetry has been used to identify the spawning related movements of golden perch in response to flow events (O'Connor et al. 2005). Leigh and Zampatti (2013) used telemetry to quantify the lateral movements of Murray cod during high discharge events. Using telemetry, Simpson and Mapleston (2002) identified a positive correlation between the distance moved by Mary River cod and discharge. Telemetry can also be used to quantify large scale dispersal, including movements to and from refuge habitats, and serves as an additional line of evidence to infer successful spawning (e.g. Thiem et al. 2013, Walsh et al. 2013).

Acoustic telemetry was used to monitor the movements of four species of fish in the Edward-Wakool system in 2013-14 (Murray cod, golden perch, silver perch and common carp) in relation to delivery of Commonwealth environmental water. Fish movement responses were monitored in relation to the delivery of Commonwealth environmental water into Yallakool Creek aiming to: 1) support Murray cod spawning by maintaining inundation of nest sites and to promote larval drift, 2) stimulate spawning in flow dependent species (golden perch and silver perch), and 3) contribute to a gradual water level recession following the cessation of Murray cod nest site inundation flows.

Methods

To monitor fish movement responses to the delivery of Commonwealth environmental water, a series of 48 passive acoustic receivers were deployed along the Wakool and Edward rivers, and Yallakool Creek (Figure 7). The study focussed on fish movements into and out of the largest refuge pool in the system located at Wakool Reserve, which is at the junction of Yallakool Creek and the Wakool River. This pool is approximately 5 km long, and under low flow conditions provides a valuable refuge pool for a diverse native fish community. Under higher flow conditions fish disperse from this pool throughout the remainder of the system, and if travelling upstream of the refuge pool fish can either occupy or travel through the highly regulated Yallakool Creek which has previously received Commonwealth environmental water, or the Wakool River which typically receives minimal inflows throughout the watering year.

Acoustic telemetry methods were identical to those described in Watts et al. (2013b). Briefly, the acoustic receivers used in this study are a submerged, omni-directional receiver that records the unique identity of a fish swimming within the detection range of the receiver (~500 m) that has previously been fitted with an acoustic tag, along with the time and date of the detection. Multiple acoustic receivers are referred to as an array, and the spatial extent of the acoustic array deployed in this study spanned the Wakool River from Gee Gee Bridge upstream to the Edward River offtake, including the entirety of Yallakool Creek. From here the acoustic array encompassed the Edward River from Stevens Weir upstream to the Murray River Offtake, the length of Gulpa Creek and the lower reaches of Bullatale and Tuppal creeks (Figure 7). The combined distance of waterway covered by the acoustic array in this study was approximately 430 km (Figure 7). The locations of acoustic receivers were strategically selected to monitor key locations within the Edward-Wakool system, including remnant pools, potential barriers, stream confluences and entry and exit of tagged fish from the study area. Acoustic receivers provided continuous data on the locations of tagged fish throughout the monitoring period, and data was retrieved quarterly.

The surgical insertion of additional acoustic tags was not undertaken in 2013-14 as there was an adequate sample size of acoustic tags with active batteries for three of the four focal species (Murray cod, golden perch and common carp) from previous tagging events throughout key movement periods (see Watts et al. 2013b). Acoustic receiver data were downloaded and stored in a purpose built SQL database, and prior to analyses data were screened to remove single detections and ambiguous records (Clements et al. 2005). The movements of each species were reconstructed over time to examine daily habitat use among seasons and in relation Commonwealth environmental water delivery. Specifically, we examined the timing and direction of movements away from the main refuge pool at Wakool Reserve for each species based on the proportion of acoustically tagged fish detected in a location on any given day. When fish moved upstream of the refuge pool, data were further examined to determine waterbody selection between the Wakool River and Yallakool Creek.

Results and discussion

There were 23 Murray cod, 17 golden perch, 12 common carp and three silver perch detected within the Edward-Wakool acoustic telemetry array from 1 June 2013 until 30 April 2014 (Table 12). These individuals were tagged in previous years (see Watts et al. 2013b) and subsequently remain within the acoustic receiver array. Adequate sample sizes of Murray cod, golden perch and common carp were detected at the beginning of the study period. A substantial decline in the number of tagged individuals of all of these species by January 2014 resulted primarily from battery life expiration (Figure 19). There was an inadequate sample size of silver perch detected throughout this study to base any conclusions upon, and subsequent results focus only on the remaining three species.

Table 12. Summary of the number of fish implanted with acoustic tags that were subsequently detected within the Edward-Wakool acoustic receiver array during 2013/14 and their associated length and weight. Values are reported as mean ± SE, with range in parentheses.

Species	Number detected	Length (mm)	Weight (g)
Murray cod	23	630 ± 25	4085 ± 415
		(341–795)	(450–8110)
golden perch	17	426 ± 14	1506 ± 172
		(330–536)	(643–2933)
common carp	12	482 ± 30	2616 ± 538
		(313–632)	(629–6656)
silver perch	3	326 ± 35	505 ± 136
		(258–376)	(260–728)

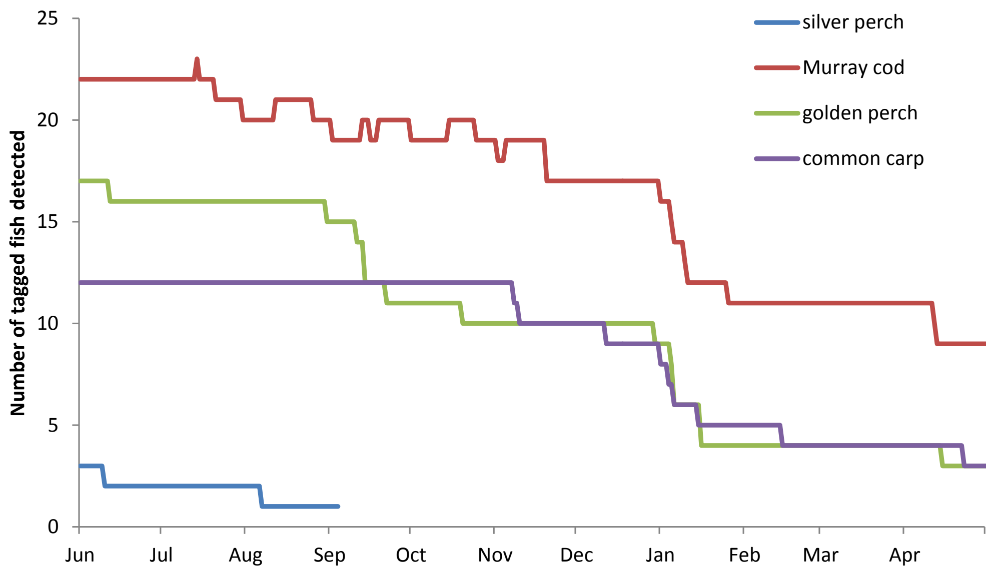


Figure 19. The number of fish tagged with acoustic transmitters that were detected within the acoustic array during the study period in 2013-14.

Murray cod

Murray cod occupied a discrete area at the beginning of the study, and movements out of the Wakool Reserve refuge pool were rare; an unsurprising result given no inflows into the system occurred during this time and the system is largely disconnected, resulting in a series of isolated pools (Figure 20a). Movements out of the refuge pool began in early August 2013, were concurrent with elevated inflows from both Yallakool Creek and the Wakool River, and were generally in an upstream direction. A peak in inflows from both waterbodies prompted the greatest proportion of movements out of the refuge pool, with >30% of the tagged sample moving into upstream habitats associated with this inflow rise in early September 2013, resulting in >60% of the tagged sample occupying upstream habitats during this time. From mid-September onwards for the remainder of the study there was generally from 20–40% of the tagged sample in upstream habitats, with the remaining individuals present in the Wakool Reserve refuge pool. Upon initiation of selection of upstream habitats following high inflows, there was a strong preference exhibited by Murray cod for the upstream reaches of the Wakool River compared with Yallakool Creek, despite comparatively lower flows in the Wakool River as a result of Commonwealth environmental water delivery to Yallakool Creek (Figure 20b). During the nesting period for this species, typically mid-October to mid-December and indicated by the period of maintenance flow delivered to Yallakool Creek, Murray cod were predominantly present within the Wakool Reserve refuge pool or in the upper Wakool River (Figure 20a, b). Recession flows delivered from December 2013 until February 2014 resulted in the return of a small proportion of Murray cod to the refuge pool, although it appears that the majority of these individuals came from the upper Wakool River rather than Yallakool Creek (Figure 20b).

The timing and duration of the movements exhibited by Murray cod in the Edward-Wakool system, as evidenced through a shift in their habitat use, are consistent with the pre-spawning movements of Murray cod in other locations (e.g. Koehn et al. 2009). This may indicate that fish used the early season freshes to take advantage of newly inundated or connected habitat and are actively seeking out suitable breeding partners or nesting sites. It is difficult to decouple the timing of the movements of Murray cod out of the refuge pool from the elevated inflows given that these inflow peaks have occurred at a similar time over the last two years of monitoring. It is possible that Murray cod are simply taking advantage of the reconnection of pools to opportunistically explore new habitats, as has been demonstrated for other species (e.g. David and Closs 2002). Although it is worthwhile noting that the movements of Murray cod from the Ovens River are consistent with the results observed in this study, with Koehn et al. (2009) identifying long periods of high site fidelity and subsequent rapid movements in late August and early September. Further, the results presented here, including a preference for the refuge pool and the majority of upstream movements resulting in preference of the upper Wakool over Yallakool Creek, are consistent with those identified in 2012-13 under similar flow conditions. The reasons for the preference of the upper Wakool River over Yallakool Creek remain unknown, although highlight the importance of maintaining available habitat in this section of river. It may be that the loading of woody habitat or proportion of overhanging cover or depth is greater in the Wakool River, or there are barriers preventing fish movement into Yallakool Creek, as these are all factors that have been demonstrated to affect microhabitat selection of Murray cod in other rivers and can be more important than hydrologic conditions (Koehn 2009). Although Commonwealth environmental water was delivered to Yallakool Creek to maintain nest site inundation and Murray cod did not exhibit a preference for this location, it is important to note that the majority of the tagged sample resided within the refuge pool during the spawning season.

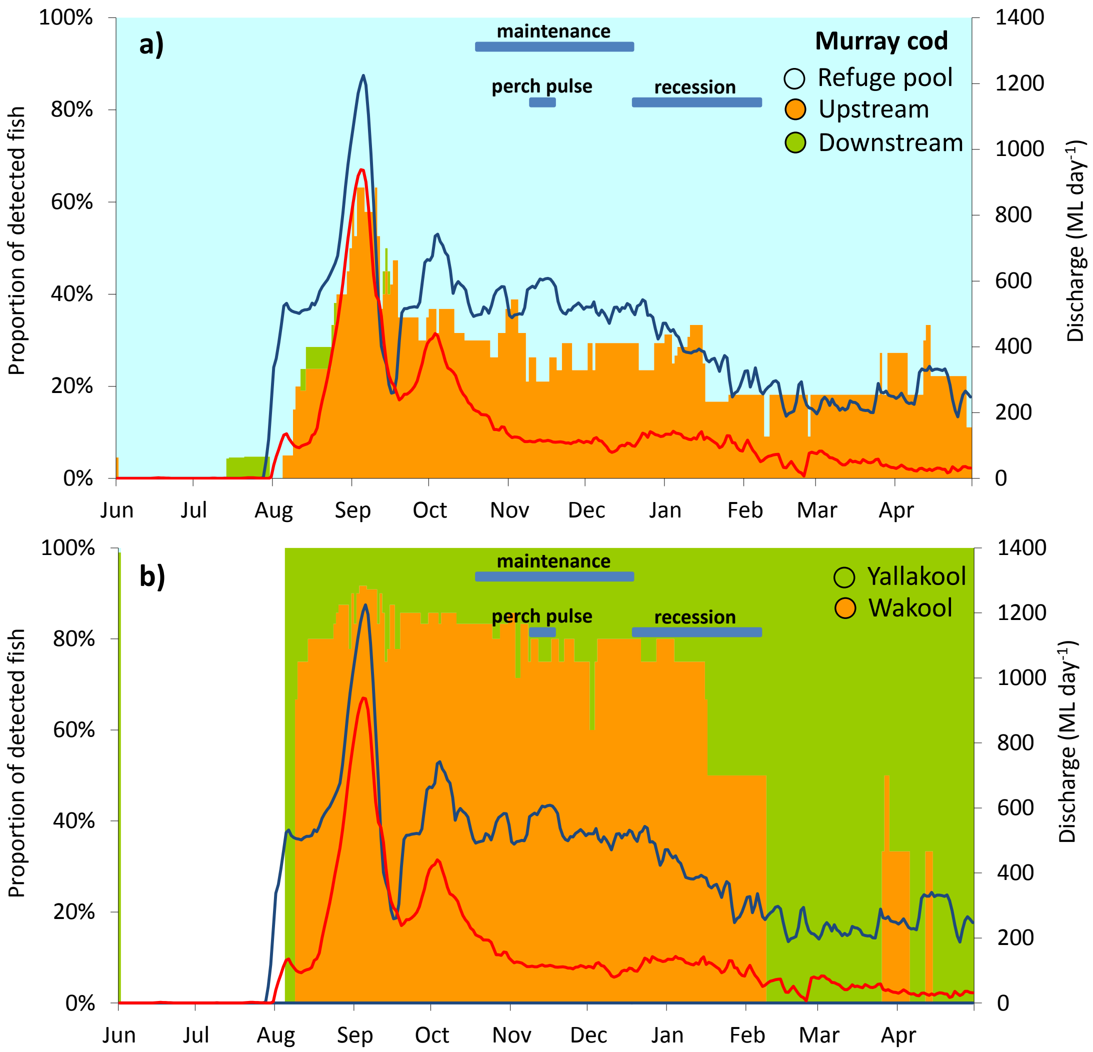


Figure 20. Daily habitat selection of Murray cod shown as the proportion of detected fish in a) either the refuge pool, or upstream or downstream of this location, and b) the upstream located individuals that subsequently selected either Yallakool Creek or the upstream Wakool River. Habitat selected is plotted in relation to time of year and Yallakool Creek (blue line) and Wakool River (red line) inflows (second y-axis).

Golden perch

Golden perch occupied the Wakool Reserve refuge pool at the beginning of the study when there was a lack of inflows until August (Figure 21a). Similar to Murray cod, golden perch movements out of the refuge pool corresponded with elevated inflows. Selection of upstream habitats was observed as a series of peaks in residency corresponding to an initial rise in inflows in early August, then with a maximum discharge in early September 2013 and after a peak in early October 2013 (Figure 21a). Approximately 25% of the tagged sample occupied locations upstream of the refuge pool in early September 2013. Golden perch also exhibited selection of downstream habitats, with approximately 25% of the tagged sample detected downstream in September 2013, and the timing of these shifts to downstream habitats likewise coinciding with elevated inflows.

No detectable shifts in the proportion of individuals occupying different habitats occurred in response to the perch pulse flow in Yallakool Creek in November 2013. Upon initiation of shifts to upstream habitats following high inflows, there was initially an equal preference for both the upper Wakool River and Yallakool Creek, although after late September 2013 the majority of golden perch located upstream of the Wakool Reserve refuge pool were in Yallakool Creek, including during delivery of Commonwealth environmental water (Figure 21b). On the 7th September 2013 one golden perch (334 mm, 714 g) moved on the falling limb of the hydrograph from the upper Wakool River into the Edward River and was subsequently detected in Gulpa Creek (receiver station number 47; Figure 7). A second golden perch (396 mm, 1120 g) moved on the falling limb of the hydrograph on the 12th October 2013 from Yallakool Creek into the Edward River and was detected in the upper Edward River at Taylor's Bridge (receiver station number 38; Figure 7). Three individuals moved into downstream habitats almost concurrently and to similar locations. For example, one golden perch (404 mm, 1085 g) moved from the refuge pool to the vicinity of Thule Creek (receiver station number 4) in late August, and a second individual (420 mm, 1224 g) moved to this location in early September 2013. This second individual moved further downstream the following week and was detected at the Barham-Moulamein Road Bridge (receiver station number 2) along with another tagged golden perch (396 mm, 1120 g). A fourth individual (536 mm, 2933 g) was detected at this location following a rapid downstream movement in mid-October 2013. Return movements of golden perch to the refuge pool from both upstream and downstream habitats coincided with recession flows delivered from December 2013 to February 2014, and by the end of recession flow 100% of the tagged sample of golden perch were located in the refuge pool (Figure 21a, b).

The timing of movements are consistent with the results from 2012-13, whereby the majority of movements occurred at the peak of flows, or on the falling limb of the hydrograph. These results are also consistent with the findings of Koster et al. (2014) in the Murray and Goulburn rivers. In 2012-13 there was an equal preference of golden perch for both Yallakool Creek and the upper Wakool River, with a late season preference for Yallakool Creek that was consistent with the observations from this study. It is not known whether these movements resulted in spawning, and this can be evaluated in a future assessment of recruitment by the the Long term Intervention Monitoring project (Watts et al. 2014). However, combined with results from fish community sampling (section 6.1) and fish spawning (section 6.3) the results suggest that the 2013-14 environmental watering did not trigger spawning in this species. Consistent with results from 2012-13, the majority of tagged golden perch occupied the refuge pool throughout the study, particularly outside of peaks in discharge. The Yallakool Creek recession flow resulted in return movements from Yallakool Creek to the refuge pool for all tagged individuals. The movement into downstream habitats is consistent with previous studies that demonstrate site fidelity throughout much of the year and a strong homing ability in this species (Crook 2004; O'Connor et al. 2005). O'Connor et al. (2005) observed synchronised downstream movements of a number of tagged golden perch to the junction of the Murray and Wakool rivers which coincided with a rise in both water temperature and discharge.

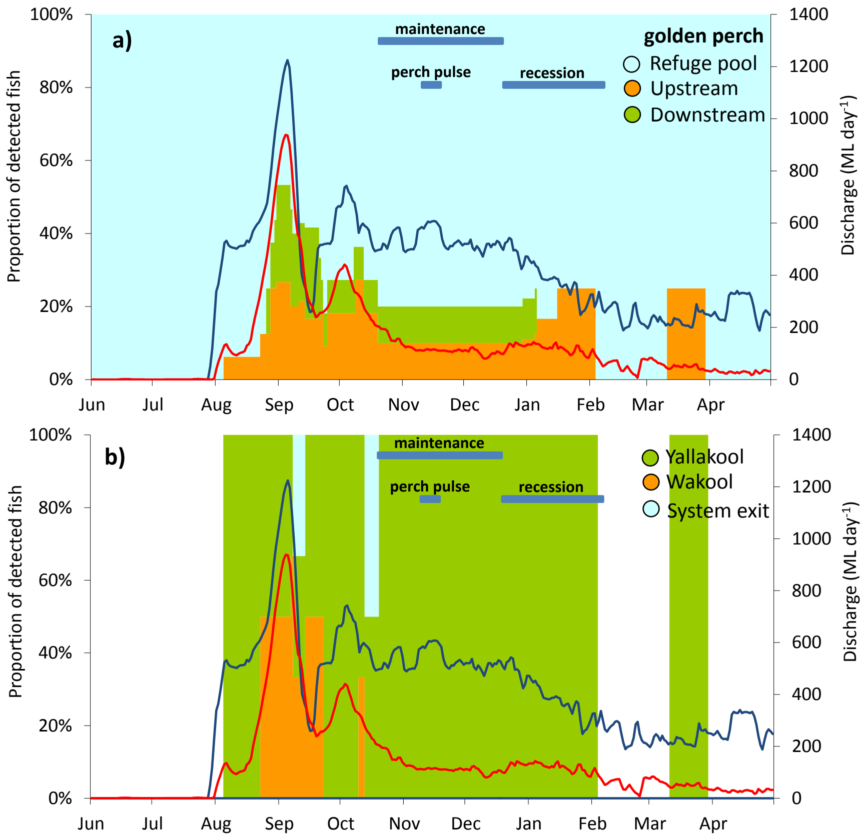


Figure 21. Daily habitat selection of golden perch shown as the proportion of detected fish in a) either the refuge pool, or upstream or downstream of this location, and b) the upstream located individuals that subsequently selected either Yallakool Creek or the upstream Wakool River. Habitat selected is plotted in relation to time of year and Yallakool Creek (blue line) and Wakool River (red line) inflows (second y-axis).

Common carp

Common carp primarily occupied the Wakool Reserve refuge pool (~60% of the tagged sample) at the beginning of the study when there were no inflows, although ~15% were present downstream of the refuge pool and ~25% were present upstream (Figure 22a). Residency outside of the refuge pool was highest during peak discharge in early September 2013 (~80% of the tagged sample), with the proportion of the tagged sample highest in both upstream (~40%) and downstream (~35%) locations during this time. Returns from downstream habitats to the refuge pool occurred by early October 2013, and returns from upstream habitats to the refuge pool ceased by early-January 2014. Common carp exhibited a preference for Yallakool Creek over the upper Wakool River during the study period (Figure 22b). A small proportion of the tagged sample occupied the upper Wakool River during peak discharge in September 2013 and again during the perch flow in mid-November 2013, although outside of these short-term events the majority of the tagged samples were confined to Yallakool Creek, including during delivery of Commonwealth environmental water. By early January 2014, during the recession flows, there were no common carp present upstream of the refuge pool. On the 25th September 2013 one common carp (313 mm, 629 g) moved from Yallakool Creek into the Edward River and remained there. In addition, two common carp moved downstream to Thule Creek (receiver station number 4; Figure 7) and one common carp was detected at Lambrook which is ~8 km upstream of Thule Creek. These movements began as early as August 31st 2013 and all individuals reached respective downstream locations by the 3rd September 2013, with return movements to upstream habitats ending by the 6th September 2013.

Although peaks in the occupation of upstream and downstream habitats coincided with peaks in discharge in 2012-13, the resulted observed in 2013-14 contrast with previous observations. For example, in 2012-13 there was consistent occupation of upstream habitats by common carp until the cessation of flows in late May 2013 when the entire tagged sample retreated to the refuge pool. There were, however, similarities between years in terms of a preference of common carp for Yallakool Creek. Previous studies of common carp movement have identified complex and often variable movements by this invasive species, ranging from localised movements where individuals exhibit strong site fidelity to wide-ranging movements, with individuals occupying >200 km of river (Jones and Stuart 2009). Subsequently Jones and Stuart (2009) recommended targeting of overwintering habitats as one strategy likely to be effective in reducing adult populations.

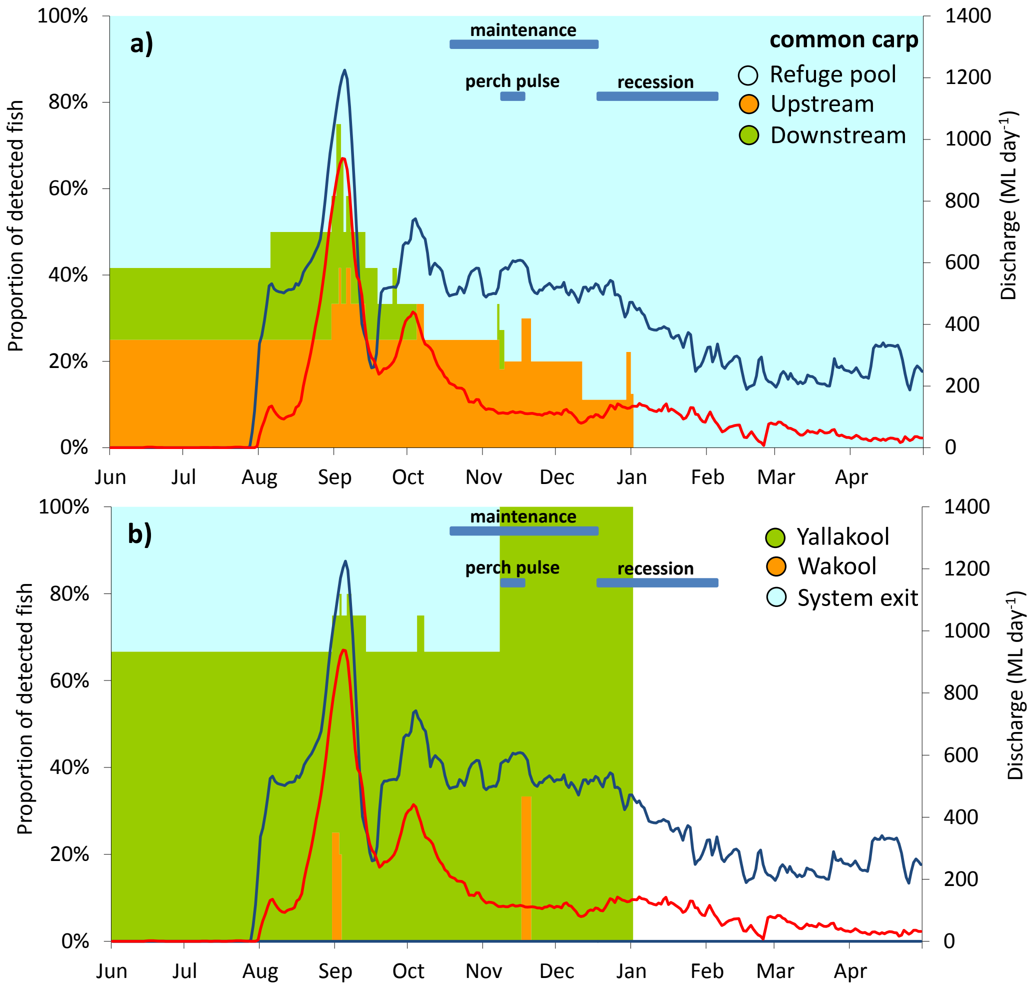


Figure 22. Daily habitat selection of common carp shown as the proportion of detected fish in a) either the refuge pool, or upstream or downstream of this location, and b) the upstream located individuals that subsequently selected either Yallakool Creek or the upstream Wakool River. Habitat selected is plotted in relation to time of year and Yallakool Creek (blue line) and Wakool River (red line) inflows (second y-axis).

6.3. Fish spawning and reproduction

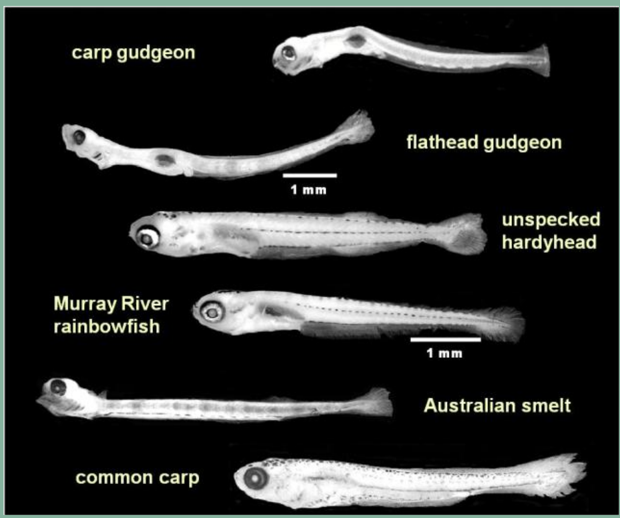


Photo: Larval fish species found in the Edward-Wakool River system (Source:Serafini and Humphries 2004).

Key findings

- Larval fish sampling was conducted fortnightly across the four focal rivers plus from Stevens Weir on the Edward River from August 2013 to March 2014. Of the 13 fish species known to Edward-Wakool River system, nine species were recorded to have successfully spawned.
- The spawning patterns of the Edward-Wakool fish community were independent of the environmental watering actions. The environmental watering actions had no significant effect (either positive or negative) on the spawning response.
- The cod maintenance flow in Yallakool Creek during the Murray cod spawning season did not result in a significantly greater number of larvae in Yallakool Creek compared to rivers that did not receive environmental water. These findings support the results observed in 2012-13 and the body of knowledge that shows that Murray cod spawn at peak times in November-December, regardless of flow conditions.
- The Yallakool Creek perch flow did not trigger a golden and silver perch spawning response in the monitored reaches, as evidenced by the absence of larvae or eggs. It is possible that these species spawned elsewhere in the system but were undetected by the current monitoring. Future assessment of fish recruitment undertaken as part of the Long Term Intervention Monitoring project may determine if these species spawned in 2013-14.
- For flow-dependent species, such as golden and silver perch, it is likely that the magnitude and duration of the water actions was not great enough to promote spawning. There is a need to adapt the delivery of environmental water to encourage the breeding of golden perch and silver perch (see flow recommendations).
- Environmental watering actions that target the inundation of in-channel geomorphological features and increase the area of slackwater available to small bodied fish as spawning and nursery grounds are likely to be advantageous to these species.

Background

One of the key objectives of the 2013-2014 watering actions in the Edward-Wakool system was to provide improved spawning conditions for native fish. The delivery of the Yallakool Creek perch pulse flow was aimed at illiciting a spawning response from golden and silver perch, as the spawning, or magnitude of spawning for these species has been well documented to be associated with flow. Murray cod are a long-lived species whose spawning is independent of flow conditions, but whose recruitment may benefit from flow events. The delivery of the Yallakool Creek cod maintainence flow was aimed at providing stable continuous flow conditions for Murray cod during their breeding season. Monitoring of the abundance and diversity of larval fish was undertaken from August 2013 to April 2014 to evaluate the spawning response of of the Edward-Wakool fish assemblage to specific Commonwealth environmental watering actions.

Questions

1) Does the delivery of a pulse flow to the Yallakool River in November result in a golden perch and silver perch spawning response *(Yallakool perch pulse flow)?*
2) Does the delivery of a sustained flow in the Yallakool River during the Murray cod spawning period result in a significantly greater number of larvae compared to rivers that did not receive environmental water *(Yallakool maintainence and recession flows)*?
3) Does the delivery of within channel flows benefit the spawning of small-bodied fish species?
4) Was the overall production of fish larvae across the 2013-2014 spawning season significantly greater in the rivers receiving environmenental watering actions compared to those that did not? *(All environmental watering actions)*

Methods

Larval fish sampling was conducted fortnightly across the four focus rivers and the Edward River at Stevens Weir from August 2013 to March 2014. Colligen Creek and Yallakool Creek received environmental freshes, the Wakool River and Little Merran Creek did not receive environmental freshes and the Edward River was included as it was the source of the environmental water delivered to Colligen Creek and Yallakool Creek. For detailed methods description see Watts et al. (2013b), but briefly, three light traps were set at five sites within each river fortnightly, and additional targeted drift net sampling was undertaken to sample for golden and silver perch eggs/larvae before, during and after the Yallakool perch pulse flow in the Yallakool Creek. Colligen Creek and Wakool River were also sampled using drift nets during the time of the pulse perch flow in order to act as controls.

Data analysis

An asymmetrical BACI (before-after, control-impact) (Underwood 1991) statistical design was used to test the effect of specific 2013-2014 environmental water actions on larval abundance in the Edward-Wakool river system. Differences in mean number of larvae between control/impact rivers and before/during/after environmental freshes were evaluated statistically for each watering action using two-way mixed effects analysis of variance (ANOVA). Because there were multiple sampling times used to represent before, during and after environmental flows, and multiple rivers used as 'Control' rivers, sampling trip (random effect) was nested within Period (fixed effect, three levels: before, during and after), and river (random effect) was nested in Treatment (fixed effect, two levels: control rivers, impact rivers). Impact rivers received environmental freshes, while Control rivers were those that did not receive environmental water. For this analysis particular interest is in the Period x Treatment interaction term, which indicates a significant effect of the environmental watering action. Visual assessment of mean (±1SE) biomass plots, grouped by Period and Treatment, were used to confirm if the significant interaction term was positively or negatively associated with the environmental watering action. The dates and rivers used to detect changes in fish larvae was consistent with the approach used to assess aquatic vegetation and shrimp responses. The null hypothesis for all watering actions was that mean larval abundance of native fish species in the rivers which received environmental water would not be significantly different to the control rivers.

To test if the production of larvae (total abundance) was significantly different across the 5 rivers across the entire spawning season, total larval abundance was analysed for all species (where there was enough data) using a one way ANOVA with river as the grouping variable. When significant differences were indicated, *post hoc* pairwise comparisons were undertaken to determine differences between the Rivers. Response variables were log-transformed prior to statistical analyses when necessary to normalise data and stabilize variances. Statistical analyses were carried out using the freeware R and the R package NLME (R Development Core Team 2013).

Results and discussion

A total of 9,728 larval fish, representing 9 fish species, were collected in the 2013-14 monitoring study (Table 13). Six of the 9 fish species collected as larvae were native species. Similiarly to 2012-

2013 spawning year (Watts et al. 2013b), small-bodied fish species made up the majority of larvae collected across the five rivers, and were represented by Australian smelt (*Retropinna semoni*, n=5238), carp gudgeon (*Hypseleotris* spp., n=3341) and flathead gudgeon (Philypnodon grandiceps, n=352), Murray River rainbowfish (*Melanotaenia fluviatilis*, n=1) and gambusia (n=1). No larvae of unspecked hardyhead were collected, despite being found in previous years throughout the Edward-Wakool River System, albeit in small numbers (Watts et al. 2013b).

Large-bodied, long-lived 'equilbrium' species (sensu Humphries et al. 1999) that spawned in the Edward-Wakool River system were Murray cod (*Maccullochella peelii*, n=401), river blackfish (*Gadopsis marmoratus,* n=6), common carp (*Cyrpinus carpio*, n=102), and redfin perch (*Perca fluviatilis*, n=2). There was no evidence of flow dependent 'periodic' species (sensu Humphries et al. 1999) such as silver perch (*Bidyanus bidyanus*) or golden perch *(Macquaria ambigua)* spawning (Table 13).

Table 13. Catch summary of fish larvae collected using light traps and drift nets from rivers in the Edward-Wakool system during the 2013-2014 spawning season.

	Light traps						*Drift nets*			
Species	*Col.*	*Yal.*	*Wak.*	*L.Mer.*	*Edw.*	Total	*Col.*	*Yal.*	*Wak.*	*Total*
Native										
Australian smelt	374	200	199	245	4220	5238	1	0	0	1
carp gudgeon	262	59	44	395	2581	3341	0	0	0	0
Murray cod	15	214	126	9	37	401	12	10	7	29
flathead gudgeon	123	3	15	81	130	352	0	0	0	0
river blackfish	0	0	6	0	0	6	0	0	0	0
Murray River rainbowfish	0	1	0	0	0	1	0	0	0	0
silver perch	0	0	0	0	0	0	0	0	0	0
golden perch	0	0	0	0	0	0	0	0	0	0
unspecked hardyhead	0	0	0	0	0	0	0	0	0	0
Introduced										
Common carp	13	2	31	24	32	102	42	113	6	161
Redfin	0	0	0	1	1	2	0	0	0	0
gambusia	1	0	0	0	0	1	0	0	0	0
oriental weatherloach	0	0	0	0	0	0	0	0	0	0
Unidentified	175	39	33	6	30	283	0	0	0	0
Total	**963**	**518**	**454**	**762**	**7031**	**9728**	**55**	**123**	**13**	**191**
%	9.9	5.3	4.7	7.8	72.3					

Seasonal timing in appearance of larval fish

The seasonal timing and peaks of larval production throughout the spawing period followed similar trends to the 2012-2013 spawning period (Watts et al. 2013b). The duration and timing of the spawning period for small-bodied species including Australian smelt, carp gudgeon and flathead gudgeon differed across rivers (Figure 23). Australian smelt larvae were collected early the spawning season (14-15°C), occurring from September to January. For the other abundant species, carp gudgeon, Murray cod, flathead gudgeon and carp, average larval abundance peaked during late spring and early summer (October to December 2013) (Figure 23). Carp gudgeon had the longest spawning period of up to 6-7 months in most rivers, with the exception of Yallakool Creek where larvae were only collected for for months between December and March 2014 (Figure 23). Temperatures noted at the onset of larvae first collected varied across the rivers; larvae were first found in Colligen Creek when temperatures were 16°C but not until 22°C in Yallakool Creek. Flathead gudgeon where generally the last species to commence spawning, and had a narrow spawning window than carp gudgeon, spawning between 2-3 months between October to January, when temperatures were 19-20°C (but up to 26°C in the Wakool River) (Figure 23).

Murray cod larvae were found in all the rivers between October and January, with abundance peaking in mid October to mid November; again, showing similar trends to the 2012-2013 spawning period (Figure 24). The spawning trends of carp were also consistent with the 2012-2013 spawning period, with larvae appearing through the system from September through to the start of December, but most abundant in October with temperatures between 16-20°C.

Difference in total larval production across rivers

The total production of fish larvae over the 2013-2014 spawning period was significantly different across the five rivers for Australian smelt, carp gudgeon, Murray cod, and flathead gudgeon (Table 14). Australian smelt larvae, the most abundant species, was found in significantly greater numbers in the Edward River weirpool (d.f=4,24, F-test=9.44, p=0.001) (Figure 25*i*). This trend is consistent with findings from the 2012-2013 spawning season (Watts et al. 2013b). Carp gudgeon larvae were found in significantly greater numbers in the Edward weirpool, followed by Little Merran Creek (d.f=2,24, F-test=6.55, p=0.002)(Figure 25*ii*). Murray cod larvae were signficiantly more abundant in both Yallakool Creek and the Wakool River compared to the other rivers (d.f =4, F-tst=14.89, p=<0.001), but there was no significant difference between these two rivers, despite the Yallakool Creek receiving environmental water (Figure 25*iii*). There was a signficiant difference in larval abundance flathead gudgeon across the five rivers (df=4, 24, F-test=0.007), with greatest numbers collected in Edward and Colligen, and least in the Yallakool River (Figure 25*iv*). Carp were the only species whose larvae abundances were not significantly different across rivers (df=4,24, *F*-test=2.41, p>0.05).

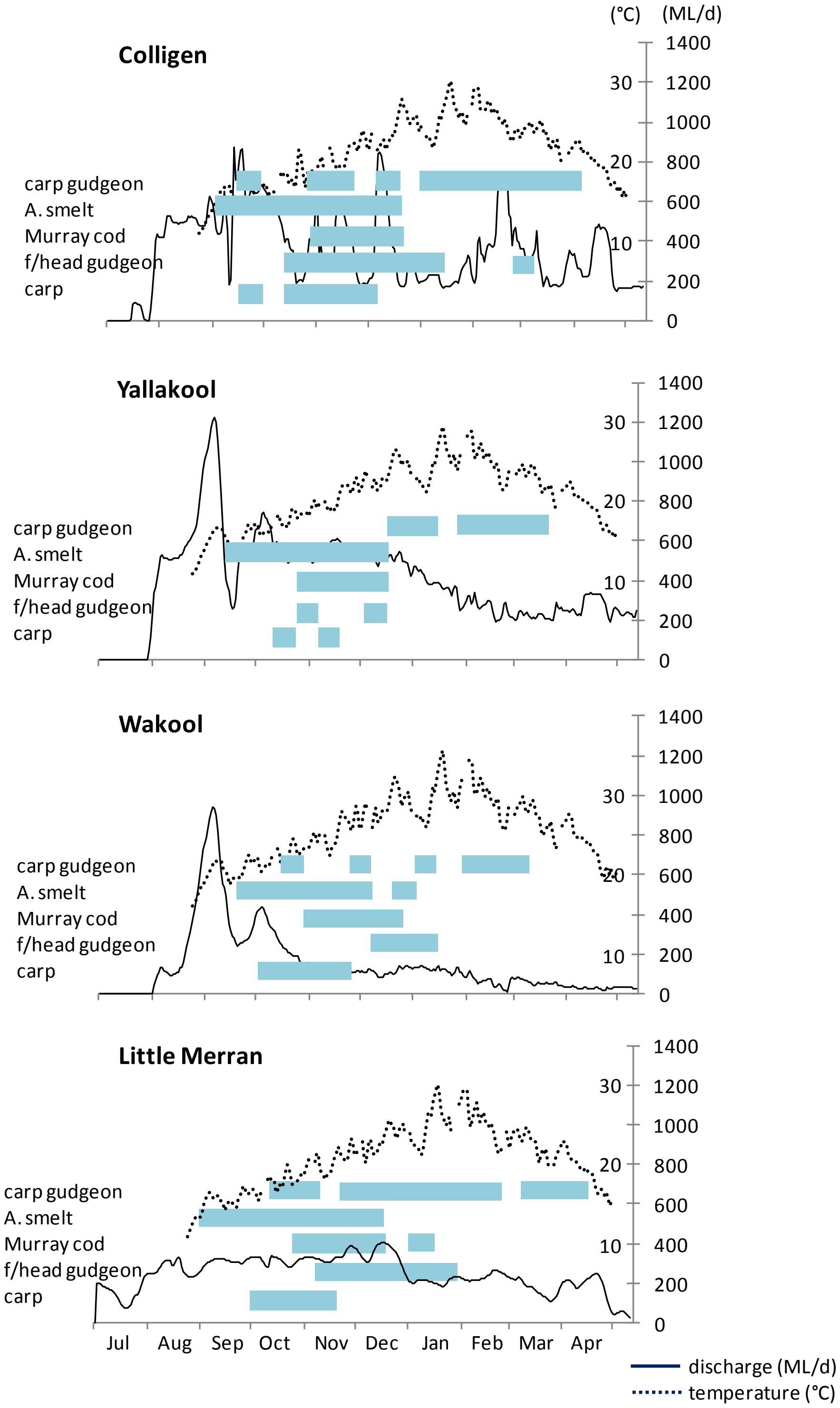


Figure 23. Occurrence (blue bars) of the fish larvae sampled in Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek from August 2013 to April 2014, along with discharge (solid line) and temperature (dashed line) profile

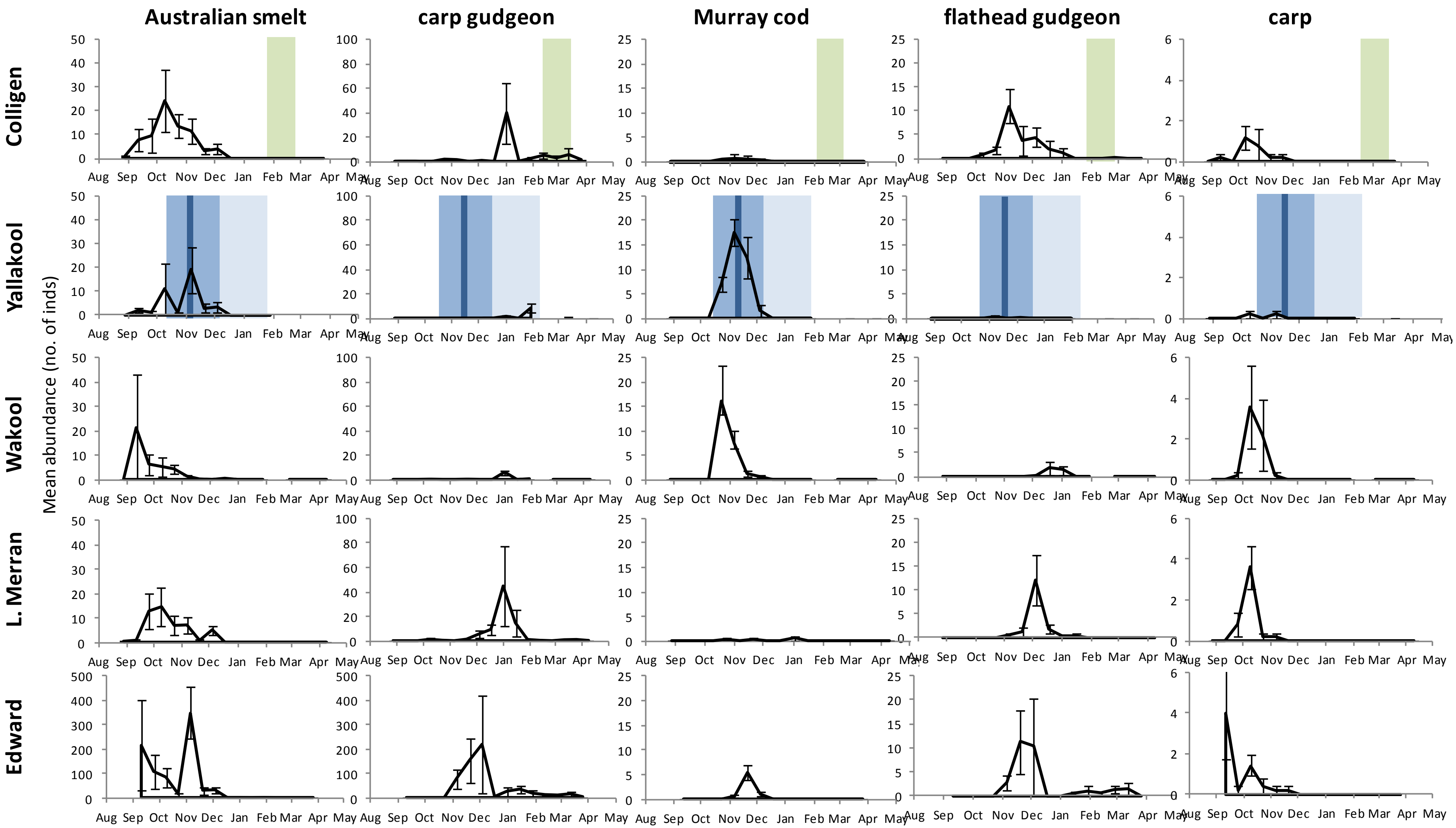


Figure 24. Mean larval fish abundance (±1SE) for the five most common fish species in the Edward-Wakool river system over the 2013-2014 spawning season. Coloured bars represent environmental water delivery; = Yallakool cod maintenance flow, Yallakool perch pulse flow, = Yallakool recession flow, and = Colligen-Niemur continuation flow. The Wakool River and Little Merran Creek did not receive environmental water and the Edward River (weirpool) was the source of the environmental water. Note Y axes vary.

Table 14. Results of one-way anova comparing total mean abundance of larval fish species with River as the main factor. Fish species with P values <0.05 indicates there was a significant difference in larval fish abundance across rivers.

Fish species	df	*F*-test	p
Australian smelt	4,24	9.44	0.001
carp gudgeon	4,24	6.55	0.002
Murray cod	4,24	14.89	<0.001
flathead gudgeon	4,24	4.83	0.007
carp	4,24	2.41	0.083

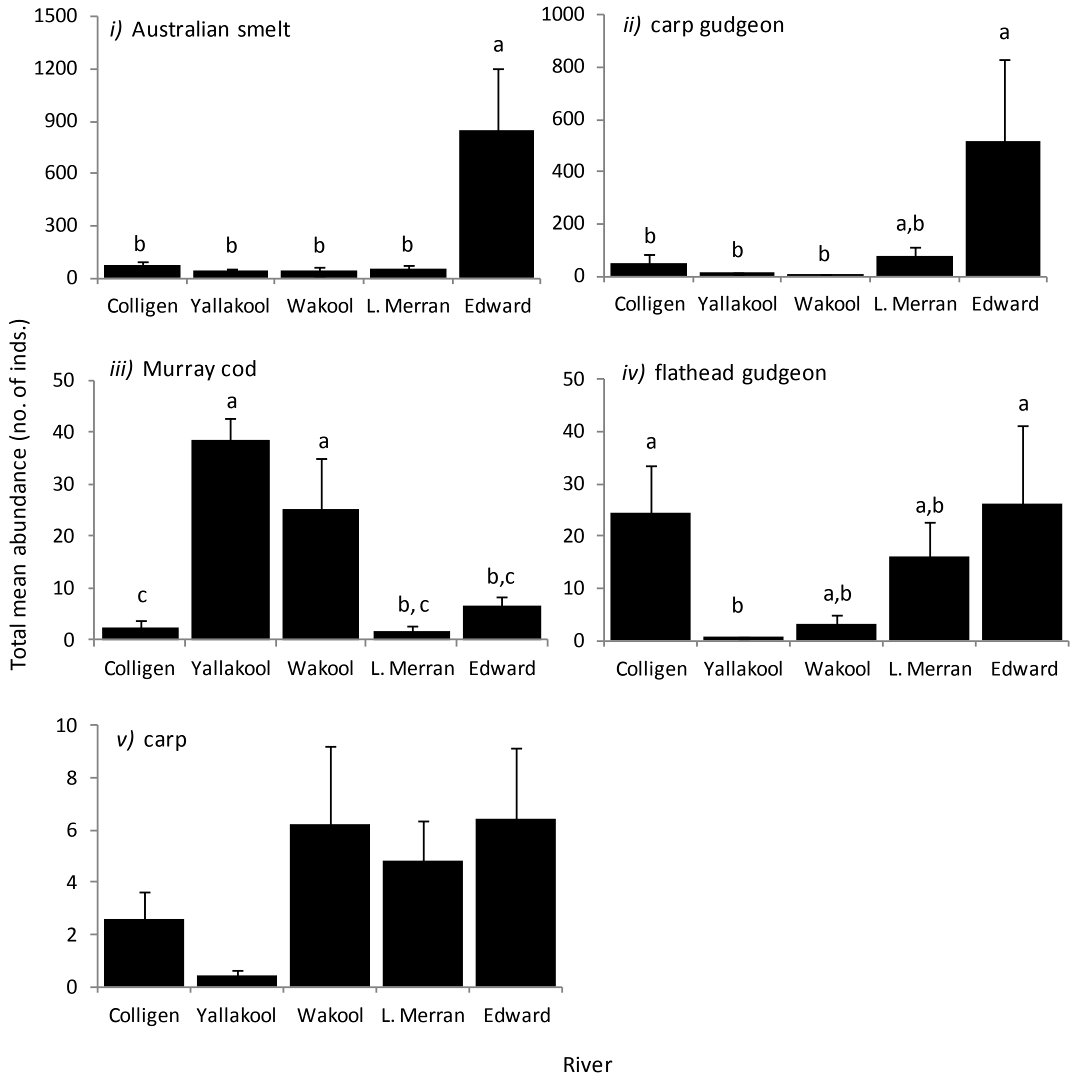


Figure 25. Mean total abundance (±1SE) of larvae sampled in the 2013-2014 spawning season in the Edward Wakool River system, for *i)* Australian smelt, *ii)* carp gudgeon, *iii)* Murray cod, *iv)* flathead gudgeon and *v)* carp. Note Y-axes vary. Letters denote homogenous sub-set groups based on Tukey's *post hoc* significance tests. There was no significant difference in carp larval abundance across the focus rivers.

Environmental watering event-based analysis

Yallakool Creek cod maintenance and recession flows

The cod maintenance flow in Yallakool Creek from October to December 2013 coincided with the spawning period for Murray cod. Murray cod larvae were found in all 5 rivers, and appeared from mid-October through to early January 2013 (Figure 23). The total abundance of Murray cod larvae collected were greatest in Yallakool Creek (n=214) and the Wakool River (n=126) and lowest in the Edward River (n=37), Colligen Creek (n=15) and Little Merran Creek (n=9). Despite the delivery of the maintenance flow in Yallkool Creek, mean numbers of Murray cod larvae were not significantly greater in Yallakool Creek compared with rivers that did not receive environmental water (Wakool River and Little Merran Creek) (CI: 1,139, *F*-test=1.698, $p>0.05$, Table 15). While a significant interaction between Control: Impact Rivers and Time Period was detected (Table 15), this was due to mean abundance of Murray cod in Little Merran Creek being very low both during and after the environmental flow compared with the higher numbers of larvae observed in both Yallakool Creek and Wakool Creek during the time of the environmental flow (Figure 26c).

There was no significant change in Australian smelt, carp gudgeon or flathead gudgeon larvae abundances in Yallakool Creek during the maintenance flow or recession flow compared to control rivers (Table 15, Figure 26). Statistical analyses were not peformed for the other fish species due to the low numbers sampled.

Yallakool Creek perch pulse flow

We found no evidence to indicate that golden perch or silver perch spawned in response to ‘perch’ flow delivered to Yallakool Creek in November 2013. No golden or silver perch eggs, larvae or juveniles were found in the targeted drift netting activities, or the fortnightly light trapping. Unlike the 2012-2013 spawning season where two silver perch larvae were collected in Little Merran Creek independently of environmental flows, spawning activity for this species was not detected across the Edward-Wakool River system this year.

Larval abundances of carp gudgeon, Australian smelt, Murray cod and flathead gudgeon were not found to be significantly different in the Yallakool River before and after then delivery of Yallakool perch pulse flow (Table 15, Figure 27). Statistical analyses were not peformed for the other fish species due to the low numbers sampled.

Table 15. Statistical results for 2 way mixed-effects Analaysis of Variance (ANOVA). A significant interaction between the two fixed factors: Period (before, during, after) and CI (control rivers, impact rivers) indicates that the mean abundance of larval fish within Impact Rivers and Control rivers responded different across time. An effect due to the watering action could be determined if the significant interaction was due to mean larval abundance changing in the impact river as compared to the control river, not vise-versa (See Figures 67-69).

Species	Main effect	d.f	F-test	p-value
Perch pulse flow: Yallakool creek				
carp gudgeon	Period (B-A)	1,55	3.028	0.087
	CI (C-I)	1,55	0.420	0.519
	Period*CI	1,55	1.530	0.221
Australian smelt	Period (B-A)	1,55	4.314	0.042
	CI (C-I)	1,55	0.328	0.568
	Period*CI	1,55	0.091	0.763
Murray cod	Period (B-D-A)	1,55	4.400	0.040
	CI (C-I)	1,55	1.539	0.219
	Period*CI	1,55	0.024	0.877
flathead gudgeon	Period (B-D-A)	1,55	1.413	0.329
	CI (C-I)	1,55	0.214	0.645
	Period*CI	1,55	1.278	0.263
carp	n/a			
Cod maintenance and recession flows: Yallakool creek				
carp gudgeon	Period (B-D-R)	2,139	5.440	0.005
	CI (C-I)	1,139	0.281	0.596
	Period*CI	1,139	0.101	0.903
Australian smelt	Period (B-D-R)	2,139	13.064	<0.001
	CI (C-I)	1,139	0.012	0.9105
	Period*CI	1,139	2.906	0.058
Murray cod	Period (B-D-R)	2,139	10.573	<0.001
	CI (C-I)	1,139	1.698	0.194
	Period*CI	1,139	4.038	0.019
flathead gudgeon	Period (B-D-R)	2,139	0.902	0.408
	CI (C-I)	1,139	0.946	0.332
	Period*CI	1,139	0.358	0.699
carp	n/a			
Colligen-Neimur continuation flow				
carp gudgeon	Period (B-D-A)	2,73	0.438	0.647
	CI (C-I)	1,73	1.194	0.278
	Period*CI	2,73	1.049	0.355
Australian smelt	n/a			
Murray cod	n/a			
flathead gudgeon	n/a			
carp	n/a			

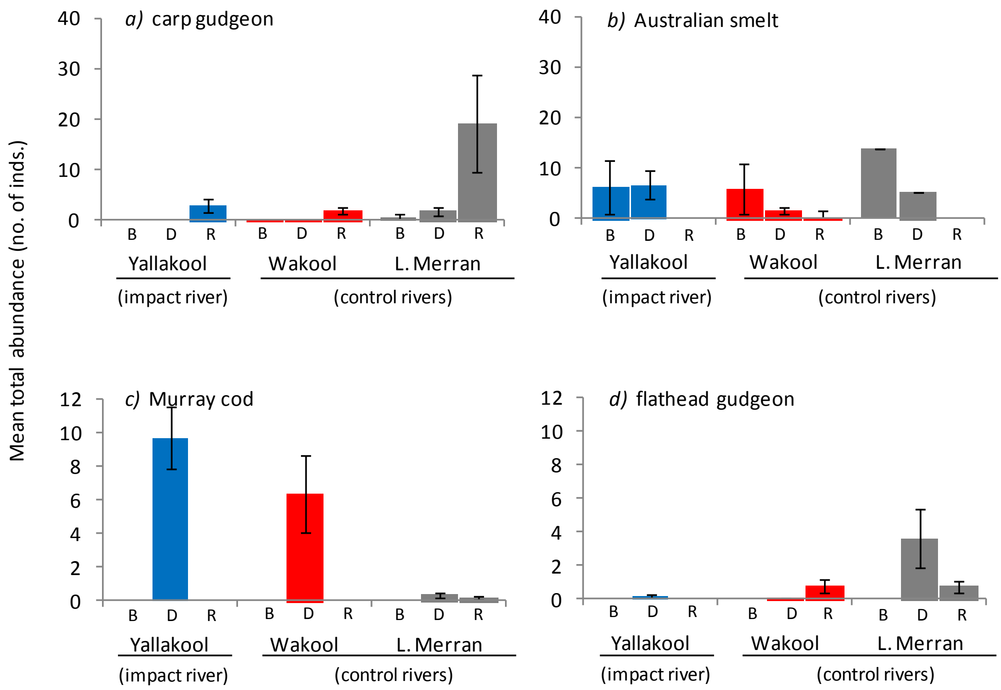


Figure 26. Mean abundance (±1SE) of fish larvae present in the Edward-Wakool river system during the Yallakool Creek cod maintenance and recession flow from October 2013 to January 2014; *a)* carp gudgeon, *b)* Australian smelt, *c)* Murray cod and *d)* flathead gudgeon. The Wakool River and Little Merran Creek did not receive environmental water and were used as controls.

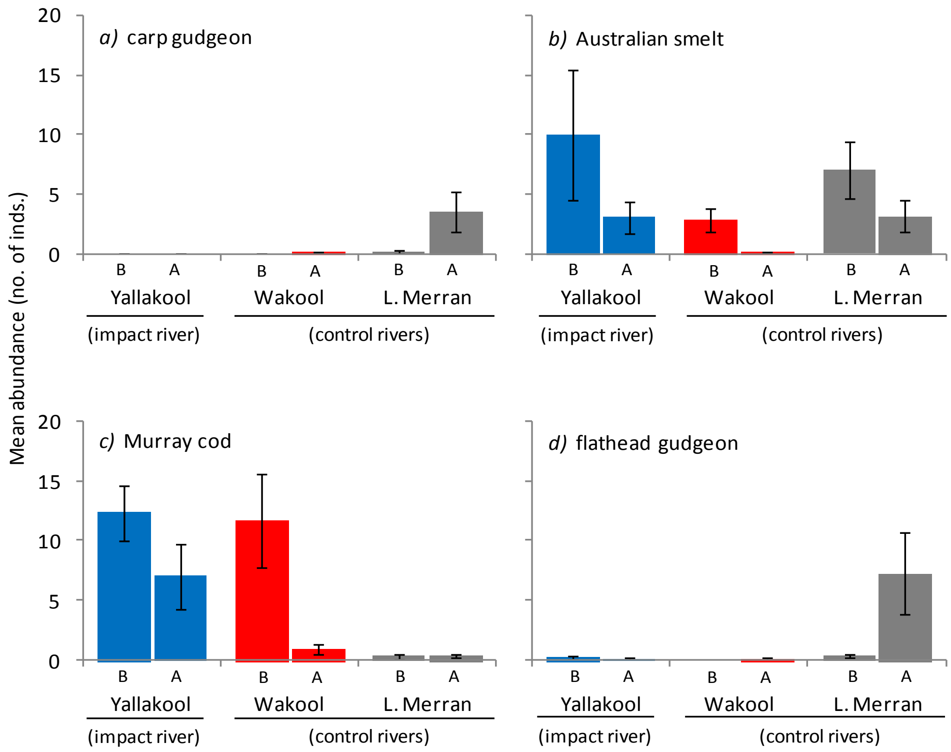


Figure 27. Mean abundance (±1SE) of fish larvae present in the Edward-Wakool River system immediatley before (B) and after (A) the delivery of the Yallakool Creek 'perch pulse flow' in November 2014 ; *a)* carp gudgeon, *b)* Australian smelt, *c)* Murray cod and *d)* flathead gudgeon. This flow was aimed at eliciting a golden and silver perch spawning response. The Wakool River and Little Merran Creek did not receive environmental water (controls).

Colligen-Nieumur continuation flows

Carp gudgeon were the only species still spawning in the Edward-Wakool River system in Feburary 2014 when the Colligen-Neiumur continuation flow was delievered (note: Flathead gudgeon larvae were sampled in the Colligen Creek at this time, but only a small number of individuals were collected). Statistical comparisons of Before-During-After, and Control-Impact Rivers revealed there was no significant change in carp gudgeon abundances either during or after the continuation flow compared to th 'control' rivers that did not receive environmental water (df=2,73, *F*-test=1.049, p>0.05, Table 15, Figure 28).

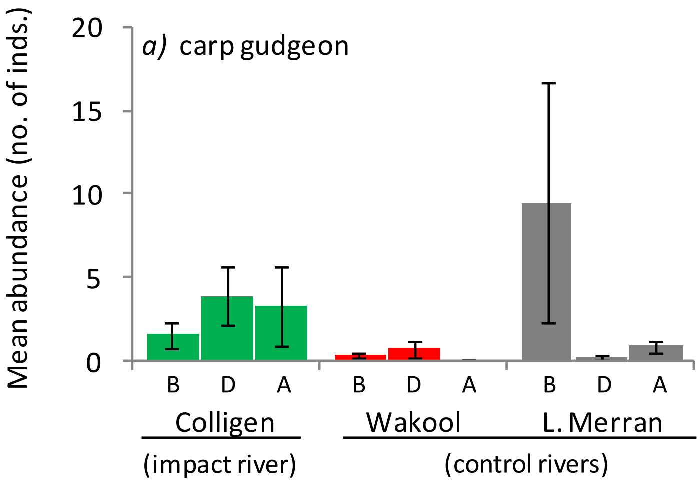


Figure 28. Mean abundance (±1SE) of carp gudgeon larvae present in the Edward-Wakool River system before, during and after the time that Colligen-Neimur Creeks received a 'continuation flow' in February 2014. The Wakool River and Little Merran Creek did not receive environmental water, and were used as controls. Significant differently responses between control and impact rivers, before, during and after the watering action are marked with an asterisk.

Summary

Environmental watering actions in the Edward-Wakool system in 2013-14 had no significant effect (either positive or negative) on the spawning response of the Edward-Wakool fish community.

In-channel freshes targetting golden and silver perch spawning in the Edward-Wakool River system did not result in eggs or larvae being detected. Further lines of evidence (for example, fish movement section 6.2 and the capture of juveniles at the end of the spawning season in April section 6.1), help to provide a more definitive conclusion as to whether or not these targeted pulses result in spawning responses of these two species. Spawning of golden perch was also not detected in 2012-2013. For flow-dependent species such as golden and silver perch, it is likely that the magnitude and duration of the water actions was not great enough to promote spawning.

Sustained and stable flows were maintained in the Yallakool Creek in November 2013-February 2013-4, with the aim of enhancing the spawnng and recruitment of Murray cod. A similar water action was delivered and monitored in November 2012, and no significant differences in Murray cod were detected between Yallkool Creek and the nearby Wakool River, which did not receive environmental flows at this time. The results in 2013-14 support the results observed in 2012-13, where the number of Murray cod larvae collected in Yallakool Creek was not significiantly greater than that in the Wakool River 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, will likely play a large role in explaining the numbers of larvae observed across the rivers studied. Results from the fish movement work conducted over 2012-2013 and 2013-14 indicate that Murray cod show a preference for the upper Wakool River over Yallakool Creek, and that discharge may not be a key determinant in nest site location for this species. Instead, other habitat variables such as the abundance of habitat structure such as woody debris may be important for Murray cod (Koehn 2009). The delivery of environmental flows to the upper Wakool River would provide an opportunity to better understand the effects of river and flow on spawning responses, as environmental flows have only been delivered to the Yallakool Creek to date.

Larval abundance of opportunistic species did not appear to benefit from the environmental flows delivered to the system. 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 hardyheads and Murray rainbowfish, which while found to have spawned in low numbers during the 2012-2013 spawning period, were not captured as larvae during the 2013-2014 survey period. Slackwater and slowwater environments 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, it may be that unless watering actions can provide a significant increase in low flow habitats (such as inundated slackwaters, backwaters and off channel wetlands) for periods of time that allow the spawning, hatching and rearing of larvae to take place, then the spawning response of such species in relation to watering actions will also be limited (Humphries et al. 1999). We hypothesise that environmental flows that target the inundation of in-channel geomorphological features and increase the area of slackwaters available to small bodied fish as spawning and nursery grounds is likely to be advantageous to these populations.

6.4. Fish recruitment

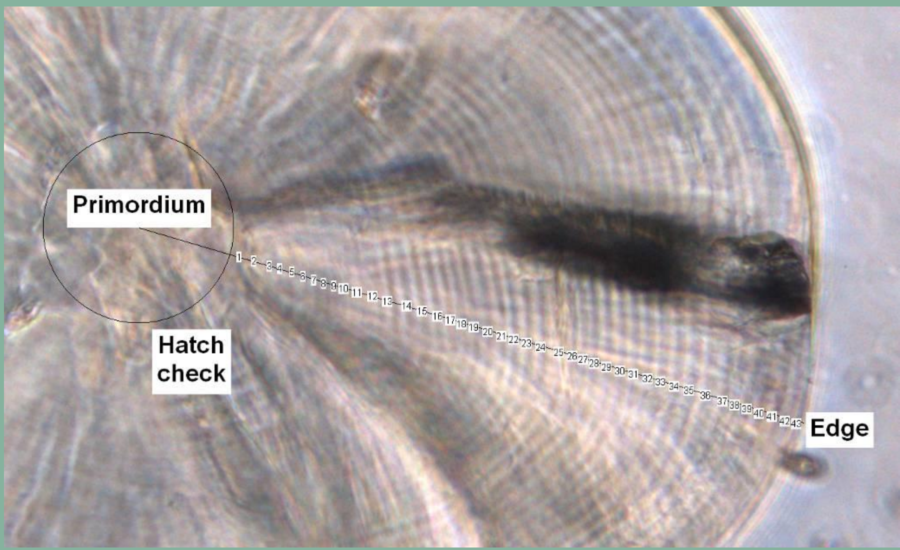


Photo: Image of a carp gudgeon otolith showing daily microincrements post-hatch

Key findings

- Recruitment was assessed for carp gudgeon, one of five small-bodied fish species found in the Edward-Wakool system. Carp gudgeon were a target species because larvae and juveniles of this species have previously shown evidence of positive changes in abundance following environmental watering actions in the Edward-Wakool system.

- Juvenile golden perch, silver perch and Murray cod were not sampled in large enough numbers to detect whether environmental watering actions influenced recruitment of these species in the Edward-Wakool system. To ensure there is adequate numbers of juveniles to evaluate the effect of environmental watering on recruitment of these species, future monitoring will include targetted sampling to ensure an adequate number of young of year recruits are sampled (Watts et al. 2014).

- Recruitment of carp gudgeon occurred between August 2013 and March 2014, peaking in November-January, in all rivers regardless of receiving environmental water. In 2013-14 annual recruitment of carp gudgeon was not positively or negatively affected by environmental watering actions in Yallakool Creek and Colligen Creek. This result is different to previous years, where an increase in the abundance of larvae and juveniles was detected in response to environmental watering in Colligen Creek in Spring (Watts et al. 2013a; 2013b).

- Dissimilar recruitment responses to environmental watering actions among years may be related to differences in the peak magnitude of flows or differences in the relationship between discharge and area of inundation in different rivers. This will require an evaluation of spawning responses across multiple years.

Background

One objective of environmental watering in the Edward-Wakool system 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 juvenile or adult stages; this referred to as recruitment. 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, and creates slack-water habitat and inundates back-water areas (Bunn and Arthington 2002; Price et al. 2013) which influence recruitment of riverine fishes (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 and the ecosystems they inhabit. Therefore, improving management of regulated river flow regimes and environmental watering actions has potential to benefit native fish communities via changes in recruitment (see Rayner et al. 2009; King et al. 2009; 2013; Rolls et al. 2013). Likewise, the mismanagement of river flow can be detrimental to native fish communities due in large part to changes in recruitment required to sustain populations (see Humphries et al. 1999; Humphries et al. 2002). It is well-established that most 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 (King et al. 2013).

The aim of this section is to evaluate whether environmental watering actions affected recruitment of fish in the Edward-Wakool system.

Juvenile golden perch, silver perch and Murray cod were not sampled in large enough numbers in the fish community surveys (see section 6.1) to detect whether environmental watering actions influenced recruitment of these species in the Edward-Wakool system. To ensure there is adequate numbers of juveniles to evaluate the effect of environmental watering on recruitment of these species, future monitoring will include targetted sampling to ensure an adequate number of young of year recruits are sampled (Watts et al. 2014).

The present section, therefore, focuses on whether recruitment of a small-bodied native fish, carp gudgeon (*Hypseleotris spp*.), was influenced by environmental watering actions in the Edward-Wakool system in 2013-14. Carp gudgeon are considered to be a foraging generalist (Baumgartner et al. 2013) whereby recruitment is expected to be highest under low-flow conditions (Humphries et al. 1999). However, previous years of monitoring in the Edward-Wakool system (Watts et al. 2013a;

2013b) have shown that carp gudgeon larvae and juveniles have benefitted from environmental watering actions that potentially increased the availability of slack-water habitat with-in the main channel. Here we test whether environmental watering actions in 2013-14 influenced annual recruitment of carp gudgeon.

Q. Was annual recruitment of carp gudgeon different among rivers that did or did not receive environmental water in 2013-14?

Methods

For purposes of this report, recruitment is defined as the relative abundance of carp gudgeon entering the juvenile stage of development between a standard length (SL) of 10 to 15 mm. This length range was selected to represent the number of individuals surviving through the critical period early life-history phases from eggs through larval development, whereby greater than 99.4% of mortality is estimated to occur in carp gudgeon (McCasker 2009). The expectation was that changes in early life-history survival affected by environmental watering actions would be detected by changes in relative abundance of recruits (10 to 15 mm SL).

Recruits were collected as part of the fortnightly light trap sampling (see section 5.3) undertaken at five sites in each of the four focus rivers (Yallakool Creek, Wakool River, Colligen Creek and Little Merran Creek) in the Edward-Wakool system. All carp gudgeon were staged, enumerated and measured to the nearest 0.01 mm (SL or TL). A sub-sample (n=50) of carp gudgeon recruits were measured for both SL and TL to develop a linear regression (SL $= y_0 + b \times$ TL) conversion equation. Otoliths (sagitta) were extracted from 20-25 juvenile carp gudgeon between 10-15 mm SL from each river sampled thoughout the year between August 2013 and April 2014.

Otoliths were fixed to a microscope slide with the sulcus facing up using CrystalBond thermoplastic glue. The sagittal plane was polished flat with a grinding wheel fitted with a 15 µm or 6 µm wet polishing pad or with 6 µm, 3 µm and 1 µm dry lapping film. Microincrements were counted from the hatch check out to the most anterior edge (Figure 29) using a compound microscope and 20X or 40X objective. In sections where a hatch check was not apparent, microincrement counts started at the mean radius of hatch checks determined from otoliths where a check was discernable. Recruitment sampling did not target or sample adults approaching the asymptotic length of species', therefore it was not appropriate to attempt fitting standard fisheries growth curves, such as Gompertz or von Bertalanffy models. Other regression models, including exponential growth, power functions, and polynomial functions, were fitted to daily age-length data but a standard linear regression (Days post-hatch $= y_0 + b \times$ SL) provided the best fit.

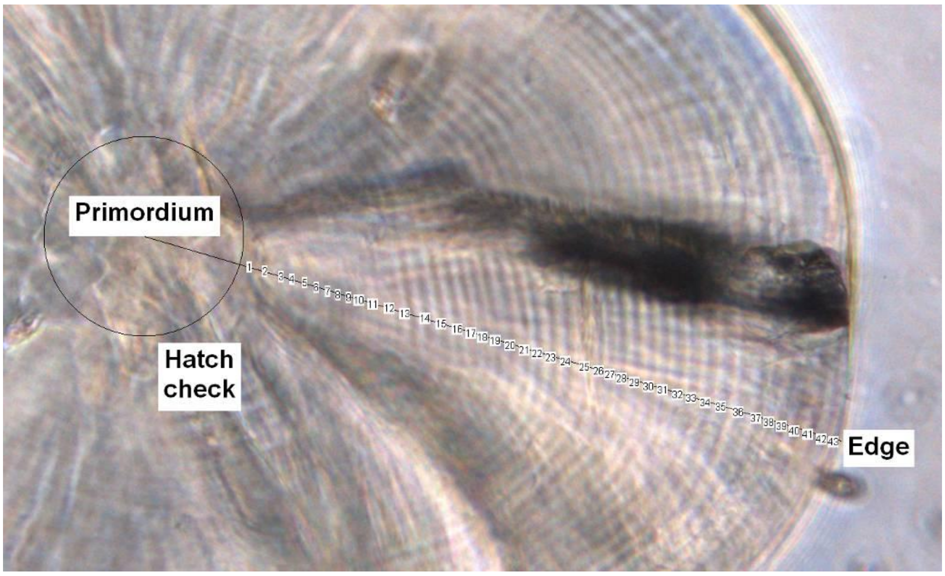


Figure 29. Image of a typical carp gudgeon otolith illustrating an estimated 43 daily microincrements post-hatch at 12.0 mm SL.

Daily ages, post-hatch, were estimated for all recruits using age-length linear regressions fitted for each river. Estimated daily ages of all recruits were rounded to the nearest whole number and subtracted from the Julian mid-week date of capture in order to assign individual recruit hatch dates. An annual index of carp gudgeon recruitment was calculated for each river using the median number of recruits sampled across the five sites and peak recruitment months (November-January). Recruits with estimated hatch dates falling before 1 August 2013 were excluded from the analysis to avoid confounding effects fish hatched in previous environmental watering years. Carp gudgeon recruits were present in samples collected over eight months (August – March) and five sites per river which represented 40 replicates per river for annual recruitment indices. A Generalized Linear Mixed Model (GLMM; Zurr et al 2009) was used test whether there were significant differences in recruitment among months and rivers for the 2013-14 year. Site was incorporated as a random effect because differences within rivers were not of interest to this study. Fixed effects included River and Month. The GLMM fitted values of abundance were used to represent the recruitment indices for each river and month for the 2013-14 year.

Environmental watering actions in 2013-14 were undertaken throughout October and November in Yallakool Creek. If environmental watering actions influenced annual recruitment, we expected the recruitment index of carp gudgeon in Yallakool Creek to be consistently higher or lower than each of the other rivers (Wakool; Colligen Creek; Little Merran Creek) which did not receive environmental water. The null hypothesis tested was that carp gudgeon recruitment in Yallakool Creek was not different to the Wakool River, Colligen Creek or Little Merran Creek.

Results and discussion

Aged carp gudgeon recruits (n=1024) ranging in length from 9.5-11.9 mm SL were a mean of 31 ± 0.1 SE days old across rivers and months for the 2013-14 year. Microincrements in otoliths were clearly apparent (Figure 29) and readable in most sections. Approximately 13% of carp gudgeon otoliths, were considered unreadable and not used in analyses due to poor preparation and individual variation in clarity. Unreadable otolith sections occur in all fish aging studies regardless of the species or researcher, and the percentage of unreadable otoliths may be reduced in the future as preparation skills and methods improve. We assumed that the potential bias introduced as a result of excluding unreadable otoliths was likely to be less than the known bias of including unreadable samples. All length measurements were converted to a SL using the equation: SL =*0.564* + *0.802* X TL which was a highly predictable linear relationship (R^2=0.99; DF=49; P<0.0001).

A standard linear regression (R^2=0.66; DF=54; P<0.0001) provided the best fit to age-length data (Figure 30). Confidence intervals (5% and 95%) on regressions fitted to age-length data (Figure 30) had precision of ± 16.1 days which encompassed age-length estimates for previous years in the Edward-Wakool system (Watts et al. 2013a; 2013b). Confidence intervals and estimates of precision allowed individual recruit hatch dates to be assigned to a particular month with a 95% level of confidence. The linear regression fitted to age-length data (Figure 30) was used for back-calculating recruit hatch dates to compare recruitment among months and rivers for the 2013-14 year.

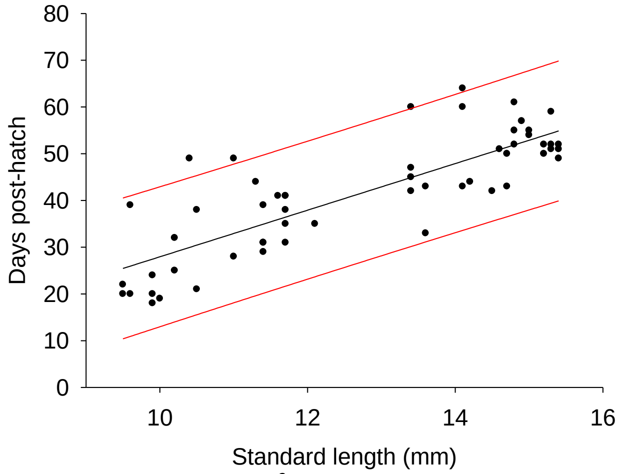


Figure 30. Estimated daily age-length regression (R^2=0.66; DF=54; P<0.0001) for carp gudgeon recruits sampled in the Yallakool Creek, Wakool River, Little Merran Creek and Colligen Creek between August 2013 and April 2013. Redlines lines represent 95% confidence bands. Days post-hatch =-*21.9129* + *4.9860* X SL

There were significant differences in carp gudgeon recruitment among rivers and months for the 2013-14 year (Table 16). A total of 1024 carp gudgeon recruits were sampled with a mean ± SE abundance per site ranging from 1.3 ± 0.7 to 12.6 ± 4.3 in Wakool River and Colligen Creek respectively. Recruitment index values among rivers followed the same general pattern with highest values in Colligen Creek and all other rivers with significantly lower recruitment (Table 16). Recruits hatched between August and March in all rivers (Figure 31) with peaks occurring between November and January. Monthly means number of recruits ranged from 0.55 ± 0.55 in March to 24.5 ± 8.3 in December. Monthly recruitment index values peaked in November and December while all other months showed equally low levels of recruitment (Table 16, Figure 32). The seasonal timing and duration of carp gudgeon recruitment in 2013-14 was similar to the past two years in the Edward-Wakool (Watts et al. 2013a; 2013b) and consistent with previous studies in mid-Murray River (Beesley et al. 2012). Most recruits hatch during late spring and early summer despite larvae and juveniles being present across a wider range of months. Elevated recruitment between November and January may be related to increases in temperature-specific spawning activity or to increases food (zooplankton) availability (see Humphries et al. 2013).

Table 16. Recruitment index values for carp gudgeon in the Edward-Wakool system for 2013-14. Higher recruitment index values estimated by the Generalized Linear Mixed Model indicate more recruits hatched by river or month.

Factor	N	Recruitment index values	SE	P-value
Colligen	507	8.0	4.6	NS
Yallakool	83	-10.6	3.5.	<0.05
Wakool	50	-11.4	3.5	<0.05
Little Merran	384	-3.0	3.0	<0.05
Sept.	22	-0.7	5.0	NS
Oct.	1	-1.8	5.0	NS
Nov.	282	12.3	5.0	<0.05
Dec.	490	22.7	5.0	<0.0001
Jan.	115	3.4	5.0	NS
Feb.	65	1.5	5.0	NS
March	11	-1.3	5.0	NS

We conclude that environmental watering actions in Yallakool Creek had no significant effect (either positive or negative) on annual recruitment of carp gudgeon in the Edward-Wakool system during 2013-14. Colligen Creek had the highest recruitment among all rivers and this occurred during bi-modal peaks in September and December irrespective of an environmental watering action that started in March 2014 (Figure 31). The annual recruitment index for carp gudgeon in Colligen Creek was significantly higher than Yallakool Creek, the Wakool River and Little Merran Creek (Table 16, Figure 32). A small peak in carp gudgeon recruitment in Yallakool Creek overlapped the timing of environmental watering (Figure 31) but this event had no significant influence on annual recruitment compared to other rivers (Table 16). This result is different to past years (Watts et al. 2013a; 2013b), whereby a majority of carp gudgeon recruits hatched during November environmental watering actions. Another peak in recruit hatch dates in Yallakool Creek during 2013-14 occurred in January, which was later in the year than peaks in rivers which did not receive environmental water and later compared to previous years (Watts et al. 2013a; 2013b).

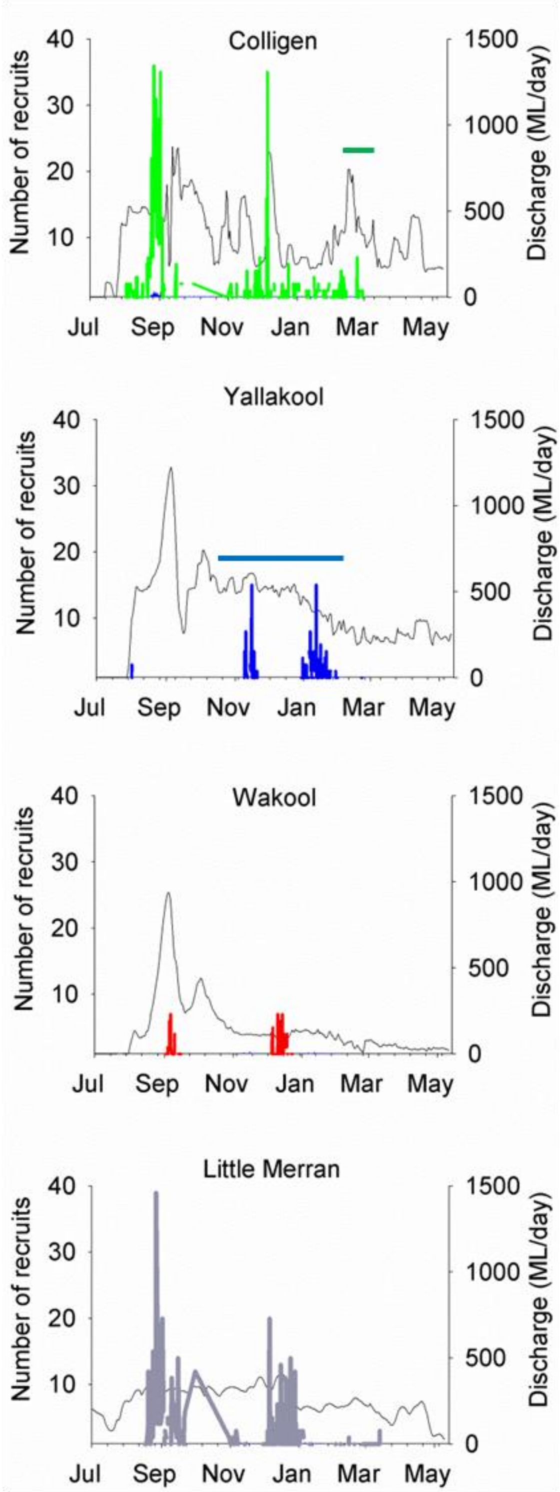


Figure 31. Back-calculated number of recruits (n=1024) hatched per day between August 2013 and April 2014. Black lines represent daily discharge and coloured peak lines represent recruitment. Horizontal bands represent the timing of environmental watering actions in Colligen and Yallakool Creeks.

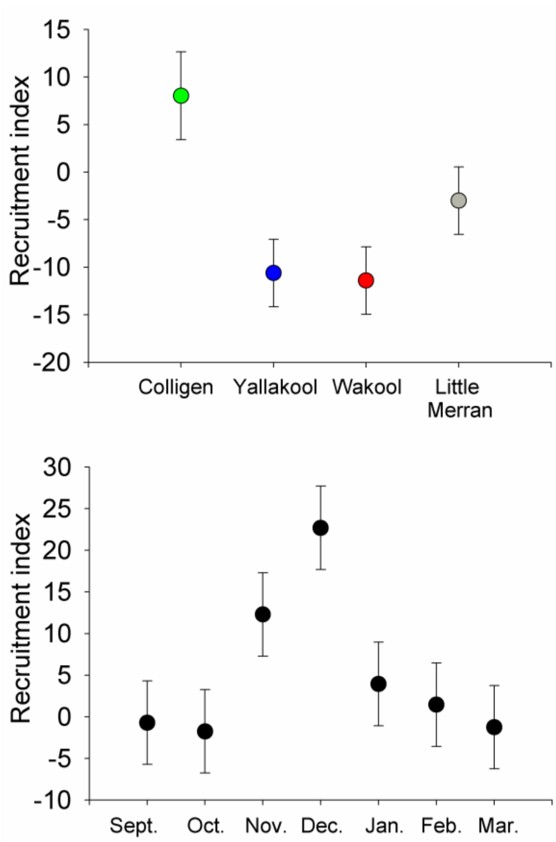


Figure 32. Recruitment index values for carp gudgeon in the Edward-Wakool system for 2013-14. Higher recruitment index values estimated by the Generalized Linear Mixed Model indicate more recruits hatched by river (top graph) or month (bottom graph).

The observation that environmental watering actions in Yallakool Creek during late spring 2013-14 had no effect on carp gudgeon recruitment is different to previous years, where changes in abundance of larvae and juveniles was detected in response to environmental watering in Colligen Creek in Spring (Watts et al. 2013a; 2013b). In 2011-12 an environmental watering action in Colligen Creek during November peaked at approximately 900 ML/d, and this resulted in elevated larval and juvenile carp gudgeon abundances (Watts et al. 2013a). Similar magnitude and timing of environmental watering actions in Colligen Creek in 2012-13 also resulted in changes in carp gudgeon recruitment or increased downstream dispersal from upstream sources (Watts et al. 2013b).

River discharge influences the size, timing and duration of slackwater habitat (Price et al. 2013) which is thought to be important to fish recruitment. One possible explanation for the lack of recruitment response in 2013-14 is that environmental watering actions did not provide adequate slackwater habitat in Yallakool Creek required to benefit native fish recruitment beyond that provided under normal regulated river discharge conditions. Previous two dimensional hydraulic modelling of discharge in these rivers showed that the relationship between discharge and wetted surface area differed between rivers, possibly due to differences in river geomorphology. A statistical analysis conducted across years, rivers, environmental attributes (eg. temperature, primary productivity, availability of slackwater habitat) and discharge patterns will be required to determine factors explaining recruitment success of carp gudgeon in relation to environmental watering actions.

6.5. Riverbank and instream vegetation

Photo: Charophyte growing in edge of water in Yallakool Creek, near Cumnock Park

Key findings

- Instream aquatic vegetation and riverbank vegetation surveys were undertaken from September 2013 to March 2014.

Aquatic vegetation

- There was a significant increase in the percent cover of submerged aquatic vegetation in Yallakool Creek between September and December 2013 during the cod maintenance flow and recession flows. The environmental watering enabled the submerged aquatic vegetation (in particular Characeae *sp*) to persist over an extended period of time. This is a different response to that observed in 2012-13 where the recession of the maintenance flow was rapid and Characeae *sp* was rapidly exposed and desiccated. The recession of future environmental watering actions should be managed with consideration to aquatic vegetation (see flow recommendations).
- The desiccated algae that remain on the surface of the riverbank sediment after the recession of flows could provide a nutrient source that would increase productivity during subsequent riverbank inundation. This may be important in the Edward-Wakool system, because previous monitoring has shown there is a low availability of nutrients in this system which may limit productivity.

Terrestrial vegetation

- There was no significant change in the percent cover of terrestrial riverbank vegetation in each river before, during and after the environmental watering, suggesting there was no response to environmental watering actions. However, the monitoring concluded in March 2014, a month after the end of the maintenance flow recession, and may not have continued long enough to detect terrestrial vegetation responses to the environmental watering. It is possible that terrestrial vegetation on the lower part of the riverbank may have increased after March. Longer term responses of riverbank vegetation to environmental watering will be examined as part of the Long Term Intervention Monitoring project in the Edward-Wakool system (Watts et al. 2014).

Background

Riverbank vegetation and aquatic vegetation play an important role in river ecosystems and provides habitat for fish, invertebrates, frogs and birds (Roberts and Marston 2011). The cover and composition of aquatic vegetation can determine the availability of oviposition sites for macro invertebrates calling and spawning locations for frogs (Wassens et al. 2010) and support wetland food webs and zooplankton communities (Warfe and Barmuta 2006). Furthermore, the response of aquatic and riverbank vegetation following a flow event can assist understanding the response of other biological indicators.

Riverbank plant survival and growth is affected by the frequency and duration of inundation (Toner and Keddy 1997; Johansson and Nilsson 2002). Frequent inundation can delay reproduction (Blom and Voesenek 1996), whilst long duration of inundation can reduce growth (Blom et al. 1994; Johansson and Nilsson 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). 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).

Instream aquatic vegetation and riverbank vegetation surveys were undertaken from September 2013 to March 2014 to evaluate the response to Commonwealth Environmental watering actions.

Hypotheses

- The percent cover of aquatic vegetation and riverbank vegetation will be higher in rivers receiving environmental water than in those not receiving environmental water.
- Recession flows of longer duration will result in greater response than those having a short recession.

Methods

A rapid habitat assessment was undertaken once per month at the four focus rivers (Colligen Creek, Wakool River, Yallakool Creek and Little Merran Creek) over the eight month survey period (September 2013 to March 2014). Overall river characteristics were recorded including surrounding land use, general assessments of the surrounding vegetation communities, soil type, continuity of fringing vegetation, percent open water and percent inundated vegetation cover.

Three sites within each focus river were surveyed monthly between September 2013 and March 2014. One hundred (100) metre long transects that ran along the water's edge of the river channel were surveyed to monitor changes in the percent cover of terrestrial and aquatic vegetation over time. Each transect was ten metres wide, which allowed for five metres on the riverbank side to represent terrestrial riverbank vegetation and 5m within the water representing submerged and emergent aquatic vegetation plus , in some cases, inundated riverbank vegetation. Measurements of percent cover along each 100m transect were taken visually at 5 m intervals. The riverbank transect was classed as grasses (tall and short), herbs (tall and short), logs and litter, and bare ground. Aquatic vegetation was classed as tall emergent, short emergent, broadleaf emergent, attached floating, or submerged and the percent cover of each class was recorded.

The aim of the monitoring was to assess vegetation responses to environmental watering action in two zones: 1) Aquatic vegetation within 5 m of water adjacent to the water's edge – representing shallow inundated terrestrial vegetation or submerged and emergent aquatic vegetation; and 2) Riverbank vegetation in a 5 m transect adjacent on the riverbank to the water's edge. This riverbank vegetation becomes inundated aquatic habitat when water levels rise during instream freshes.

A two-way nested ANOVA was conducted to look at the effect of environmental flow Cod maintenance and recession flow on aquatic vegetation. Here, mean percent cover was compared across Period (before, during and after environmental watering) and CI (control rivers, impact rivers). A significant p-value for interaction between the two fixed factors: Period (before, during sustained flow, recession) and CI (control rivers, impact rivers) indicates that the mean percent of aquatic vegetation changed in impact rivers as a result of the flow compared to rivers not receiving environmental water. Significant differences in CI only indicate differences in vegetation cover across control and impact rivers regardless of flow period (Period).The survey dates were used as follows: Before: September; During the maintainence flows: October and November surveys; After the maintainence flows (which was during the gradual recession): the December and January.

Results and discussion

Aquatic vegetation response to environmental watering

Overall, there was greater cover of submerged aquatic vegetation in Yallakool Creek compared to the control rivers, regardless of Period (before, during, after watering) (Figure 33, Figure 34). The higher amounts of submerged aquatic vegetation in Yallakool River at the start of the watering year may be due to the positive effects that environmental watering in 2012-13, such that there was dried macroalgae and nutrients on the riverbank that may have promoted a response in submerged vegetation in Yallakool Creek in 2013-14. There were significant differences in tall emergent vegetation among the control rivers (significantly more in the control rivers than in Yallakool Creek), but environmental flows did not have any effect on percent cover of these vegetation types.

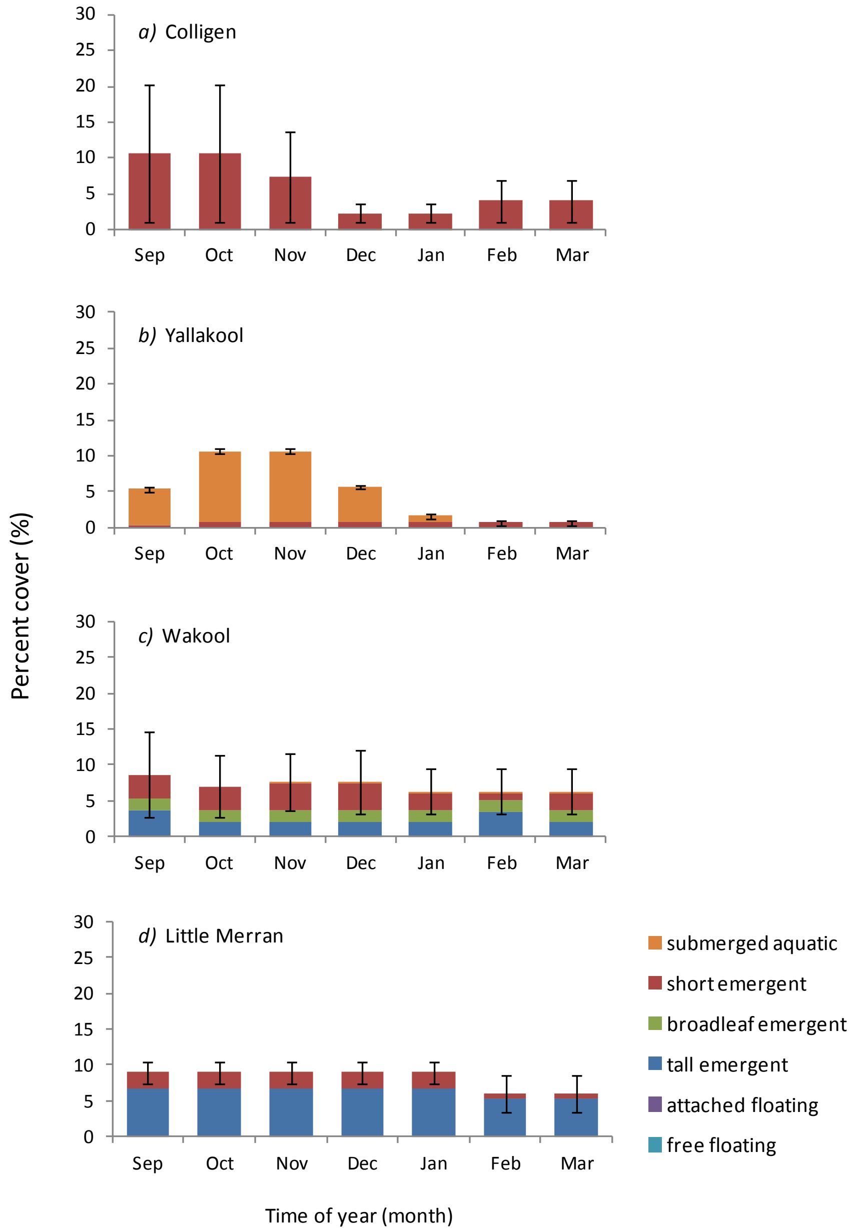


Figure 33. Mean percent cover (%) of aquatic vegetation across study sites in a) Colligen Creek, b) Yallakool Creek, c) Wakool River and d) Little Merran River during the 2013-2014 study period.

Figure 34. Characeae sp that increased in cover in the Yallakool Creek during the 2013-14 environmental watering action

Although significant differences between the impact and control rivers were apparent (Table 17, Figure 35), there was little variation in aquatic vegetation response within each focus river before the environmental watering actions, during and at recession of the actions (Figure 35). Each focus river responded differently in terms of aquatic vegetation cover and diversity over the survey period (Figure 33; Figure 35). Hydrological conditions, such as water depth and stability of water levels (Casanova and Brock 2000), and channel geomorphology can strongly influence both aquatic vegetation community response and structure (Brock et al. 2006; Thoms et al. 2006).

Table 17. Statistical results for 2 way mixed-effects Analysis of Variance (ANOVA) looking at the effect of environmental flows on aquatic vegetation. A significant p-value for interaction between the two fixed factors: Period (before, during sustained flow, recession) and CI (control rivers, impact rivers) indicates that the mean percent of aquatic vegetation changed in impact Rivers as a result of the flow compared to rivers not receiving environmental water. Significant differences in CI only indicate differences in vegetation cover across control and impact rivers regardless of flow period (Period).

Species	Main effect	d.f	F-test	p-value
Cod maintenance and recession flows: Yallakool creek				
Submerged aquatic	Period (B-D-R)	2,39	6.100	0.005
	CI (C-I)	1,39	157.59	<0.001
	Period*CI	1,39	21.890	<0.001
Tall emergent	Period (B-D-R)	1,39	0.218	0.805
	CI (C-I)	2,39	1.814	0.186
	Period*CI	1,39	0.109	0.897
Short emergent	Period (B-D-R)	1,39	0.045	0.955
	CI (C-I)	2,39	7.408	0.009
	Period*CI	1,39	0.053	0.948
Broadleaf emergent	n/a			

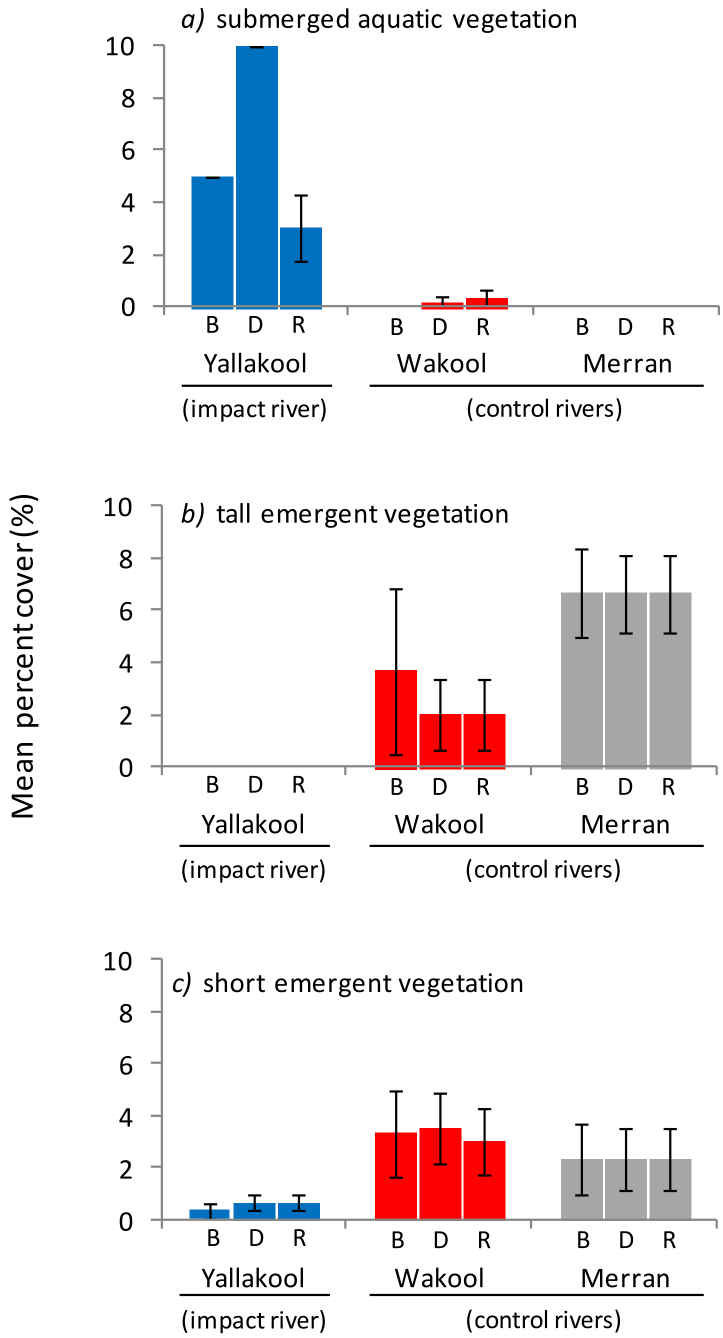


Figure 35. Mean percent cover (±1SE) of aquatic vegetation in the Edward-Wakool system before (B), during the Yallakool maintenenace flow (D) and during the recession of the flow (R) in 2014. The Wakool River and Little Merran Creek did not receive environmental water, and were used as controls.

The environmental watering had a significant effect on the submerged aquatic vegetation in Yallakool Creek. There was a significant increase in the percent cover of submerged aquatic vegetation in Yallakool Creek in response to the Cod maintenance and recession flows (Table 17). Submerged aquatic vegetation cover in Yallakool Creek was relatively low in September 2013, however doubled during October and November 2013 (Figure 33, 35) during the sustained environmental flow. The extended duration of inundation provided an opportunity for some submerged species, such as Characeae sp, to increase in area during the environmental watering action (Figure 34). This macroalgae provides habitat for invertebrates and small fish that in turn are preyed upon by fish, amphibians and birds and would be expected to benefit river productivity. The submerged aquatic vegetation reduced during December 2013 and was greatly reduced by January 2014, because the water levels receded at the end of the environmental watering in late January 2014 (Figure 35).

The slower recession of the environmental watering action in the Yallakool Creek extended the period for growth and duration of the submerged algae. In contrast, in 2012-13 the drawdown after the environmental watering was very rapid and all the new algal growth was exposed and desiccated. Although there was evidence of desiccated algae on the exposed sediment during the recession in 2013-14 (Figure 34), the slower draw down in 2013-14 enabled submerged algae to continue growing. Once desiccated, the algae could provide a nutrient source on the surface of the sediment that would likely assist productivity during subsequent riverbank inundation events. This may be important in the Edward-Wakool system, because monitoring over the past three years has shown there is a low availability of nutrients in this system which may limit productivity.

Terrestrial vegetation response

Colligen Creek had the highest cover of tall grasses and tall herbs; whereas Yallakool Creek contained the highest short herb cover and Little Merran Creek had the least percent cover of riverbank plant classes of all the focus rivers (Figure 36). There were no significant differences in tall herbs found across the focal rivers (Figure 37, Table 18).

Significant differences in vegetation were observed among rivers (Table 18, Figure 37). Yallakool Creek had significantly higher short herb cover and significantly less tall and short grasses than Little Merran Creek and the Wakool River (Figure 37, Table 18). However, these differences were not in response to the 2013-14 environmental watering actions because there were no significant changes in the percent cover of vegetation in each river before, during and after the environmental watering (Table 18).

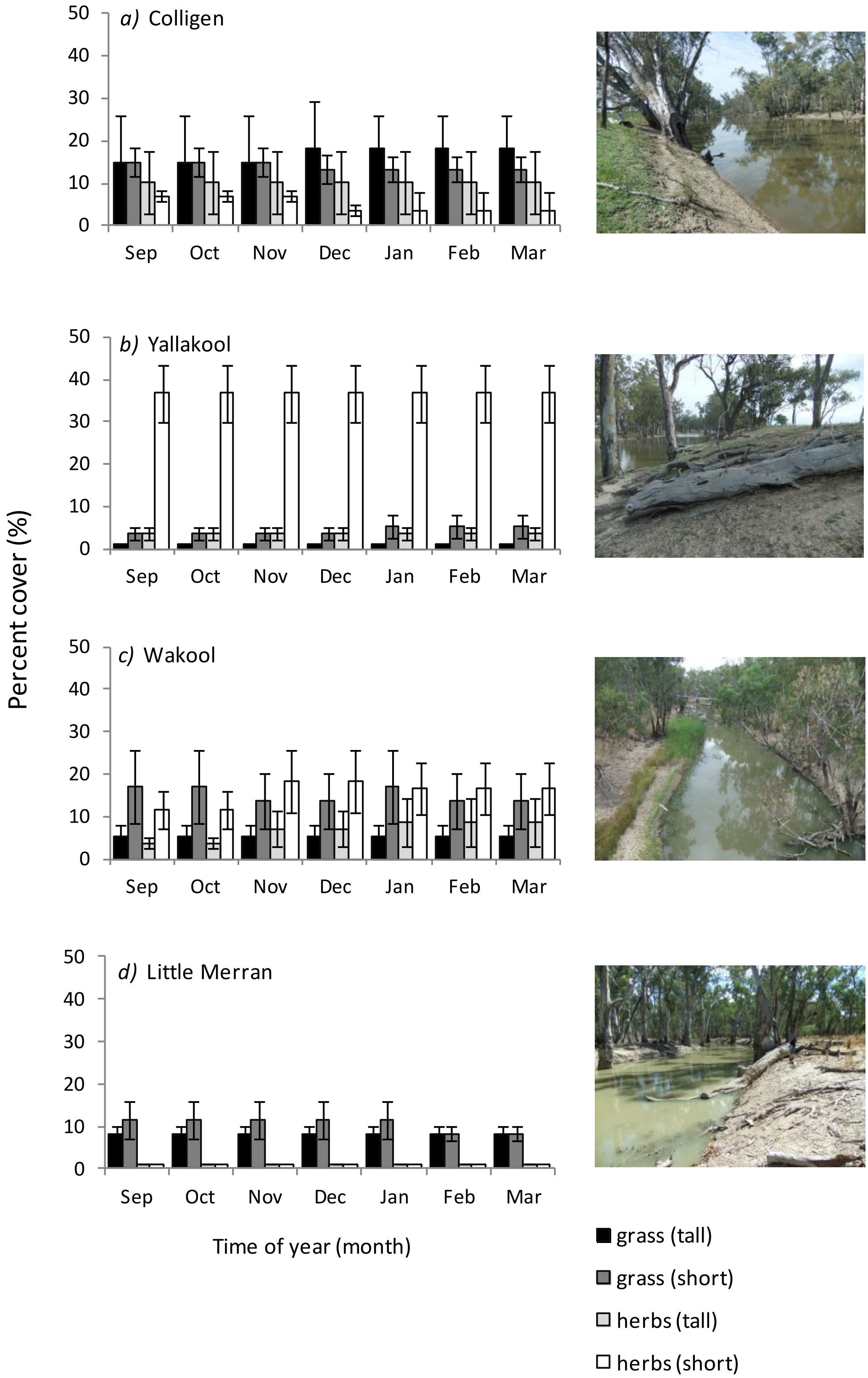


Figure 36. Mean percent cover (%) of riverbank vegetation across study sites in a) Yallakool Creek, b) Colligen Creek, c) Wakool River and d) Little Merran River during the 2013-2014 study period.

Table 18. Statistical results for 2 way mixed-effects Analysis of Variance (ANOVA) looking at the effect of environmental flows on terrestrial vegetation. A significant p-value for interaction between the two fixed factors: Period (before, during sustained flow, recession) and CI (control rivers, impact rivers) indicates that the mean percent of aquatic vegetation changed in impact Rivers as a result of the flow compared to rivers not receiving environmental water. Significant differences in CI only indicate differences in vegetation cover across control and impact rivers regardless of flow period (Period).

Species	Main effect	d.f	F-test	p-value
Cod maintenance and recession flows: Yallakool creek				
Tall grasses	Period (B-D-R)	2,39	0.000	1.000
	CI (C-I)	**1,39**	**5.041**	**0.030**
	Period*CI	1,39	0.000	1.000
Short grasses	Period (B-D-R)	2,39	0.014	0.985
	CI (C-I)	**1,39**	**7.787**	**0.008**
	Period*CI	1,39	0.029	0.971
Tall herbs	Period (B-D-R)	2,39	0.473	0.626
	CI (C-I)	1,39	0.001	0.969
	Period*CI	1,39	0.237	0.790
Short herbs	Period (B-D-R)	2,39	0.173	0.841
	CI (C-I)	**1,39**	**5.271**	**0.027**
	Period*CI	1,39	0.086	0.917

The lack of significant change in vegetation cover response to the 2013-14 environmental flows may be, in part, because minimal inundation of the riverbank occurred in Yallakool Creek during the environmental watering action (see hydraulic modelling in Watts et al 2013b). If environmental watering actions do not sufficiently increase the wetted surface area to facilitate a response of riverbank vegetation this may have negative consequences for instream productivity, because the inundation of riverbank vegetation following larger flow events can increase plant productivity and contribute to carbon and nutrient dynamics in aquatic and terrestrial ecosystems (Sims and Thoms 2002) and provide habitat for a range of organisms.

In addition, it may be that the monitoring in 12-13 did not extend not long enough to detect vegetation responses to the 2013-14 flow. The vegetation monitoring concluded in March 2014, a month after the end of the cod maintenance flow recession. It is possible that terrestrial vegetation may have subsequently increased in the section of the river bank that was wetted during the environmental watering and subsequently exposed. The longer term responses of riverbank vegetation will be examined in future years in the Long Term Intervention Monitoring (LTIM) project in the Edward-Wakool system (Watts et al. 2014).

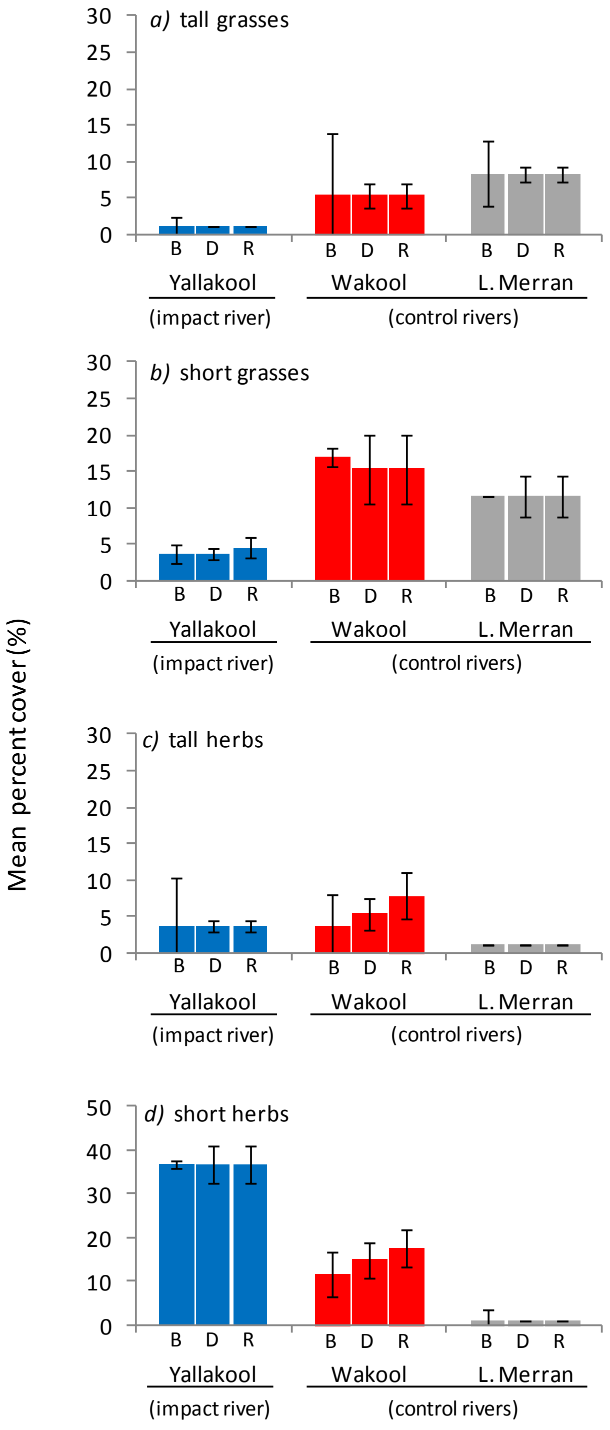


Figure 37. Mean percent cover (±1SE) of terrestrial vegetation in the Edward-Wakool system before (B), during the sustained Yallakool flow (D) and during the recession of the Yallakool flow (R) in 2014. The Wakool River and Little Merran Creek did not receive environmental water, and were used as controls. Planned comparisons with significant interactions between control-impact rivers (impact river; Yallakool, control rivers; Wakool River, Little Merran Creek) and Period (B, D, R) are marked with an asterisk, indicating that mean larval abundance changed significantly in Yallakool Creek either during the environmental watering.

6.6. Water quality and chemistry

Photos: left, filtering water for carbon analysis; right, Colligen Creek near Niemur River offtake, 11 February 2014

Key findings

- Water quality was monitored through a combination of continuous logging (dissolved oxygen and temperature) and fortnightly spot measurements (EC, pH, turbidity) and samples (nutrients and organic carbon).
- Commonwealth environmental watering met the objective of maintaining or supporting water quality outcomes as it did not trigger any adverse water quality outcomes or a blackwater event. Commonwealth environmental water should continue to be delivered to mitigate adverse water quality events (see flow recommendations).
- Environmental watering actions did not significantly alter dissolved carbon or total carbon in treatment rivers relative to control rivers. A moderate increase in dissolved organic carbon was recorded during unregulated flows in August and September, resulting in a small but statistically significant difference between rivers during the Yallakool maintenance flow.
- The strongest influence on dissolved oxygen concentrations was a period of very hot weather in January and February 2014. No hypoxic blackwater event was observed during the study period.
- While total nitrogen and total phosphorus frequently exceeded ANZECC (2000) trigger levels, bioavailable nutrients were routinely extremely low in these rivers. Some statistically significant differences in nutrient concentrations were found when assessing effects of watering actions, but these differences were extremely small and not ecologically important.

Background

Changes in flow in a river system can influence water quality both positively and negatively with the outcome dependent on initial water quality, size of the flow, time of year, duration and other hydrological and catchment conditions. A range of water quality parameters are monitored as indicators of these changes and may be directly or indirectly affected by alterations in flow. For example, 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. Nutrients and organic matter concentrations may be reduced by dilution with increased flows or increase under flow conditions that result in water contacting parts of the channel or floodplain which were previously dry and which have stores of nutrients and carbon in both plant materials and the soil (Baldwin, 1999; Baldwin and Mitchell, 2000).

Reconnection of the stream channel with backwater areas may also result in additional nutrients and organic carbon. The majority of these additions will 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 *et al.*, 1999). For example, the connection between the river and floodplain has been shown to generate essential carbon stores to sustain the system through drier periods (Baldwin *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 *et al.*, 2007; Hladyz *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 *et al.*, 2007; Whitworth *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.

Hypotheses

- Environmental watering is expected to stimulate ecosystem productivity by moving nutrients and carbon between the main channel, benches and low commence-to-flow floodrunners.
- Watering actions are expected to result in only very small increases in nutrient concentrations, unless there is significant inundation of the floodplain.
- There will be a short-term increase in dissolved organic carbon and particulate organic carbon levels following environmental watering, but the watering actions are not expected to trigger blackwater events.

Methods

Water temperature and dissolved oxygen were logged every ten minutes at two sites within each of the four focus river reaches, with loggers located approximately 3-5 km apart. Data were downloaded and loggers calibrated approximately once per month depending on access. Light and depth loggers were also deployed during the commencement phase of the 2013-14 monitoring period and data were downloaded on a monthly basis. The data collected by the loggers was used to calculate daily average temperature (Figure 38) and dissolved oxygen concentrations (Figure 39) for each of the rivers from August 2013 to April 2014. Gaps in dissolved oxygen data were the result of problems with the loggers (discussed in more detail in Section 6.8 on Stream Metabolism).

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 four sites within each river, and from Stevens Weir on the Edward River, and processed according to the methods detailed in Watts et al. (2013b) 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))

An asymmetrical BACI (before-after, control-impact) (Underwood, 1991) statistical design was used to test the effect of the Yallakool Creek Perch Pulse Flow and the Colligen-Niemur River continuation flow on water chemistry parameters in the Edward-Wakool system. Differences in mean values between control/impact rivers and before/during/after environmental freshes were evaluated statistically for each watering action using 2-way nested ANOVA (nesting sampling date in period (before or during) and nesting river in control-impact) on un-transformed data. Impact rivers received environmental freshes, while Control rivers were those that did not receive environmental water. The impact river was either Yallakool Creek or Colligen Creek (depending on the watering action), and the control rivers were Little Merran Creek and the Wakool River for all occasions. A significant interaction between Period and CI (Contol/Impact) would suggest a significant effect of the watering action. A significant 'Period' suggests temporal or seasonal changes in all rivers are alike, and a significant 'CI' results suggests that rivers are just naturally different, and not changing differently as a result of receiving environmental water.

For the Yallakool Creek Cod maintenance flow, instead of a BACI approach, we tested whether POC, DOC and nutrient concentrations were significantly higher in rivers that received environmental flows, using a one way ANOVA, with River as the fixed effect, and sampling trip was included as a random effect. A Tukey's post hoc test was run to examine the significant groupings of rivers based on mean DOC.

The monitoring results were assessed against ANZECC (2000) water quality guidelines trigger levels. Trigger levels are concentrations of key water quality parameters designed to provide guidance for ecological protection. Where it has been determined that the measured concentration of one or more parameters in the water body exceed this level (or for some parameters, fall outside the given range) the trigger levels are designed to 'trigger' further investigation to establish whether the concentrations are causing harm in that system. Exceedance of 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.

Results and Discussion

Water temperature was very consistent between sites and heavily influenced by ambient weather conditions (Figure 38). Particularly high water temperatures were recorded during mid January and early February, corresponding to prolonged heatwave conditions with air temperatures in excess of 40 ^{o}C. The dissolved oxygen concentrations recorded at these study sites remained at acceptable levels throughout the study period, indicating that no hypoxic blackwater event was associated with any of the environmental watering actions (Figure 39). The lowest recorded concentrations were associated with the heatwaves in summer, where high water temperatures act to both decrease oxygen solubility and increase the rates of microbial respiration, lowering the concentration of oxygen dissolved in the water column. The Niemur River continuation flow was delivered via Colligen Creek in February to reduce the impact of this process in that river.

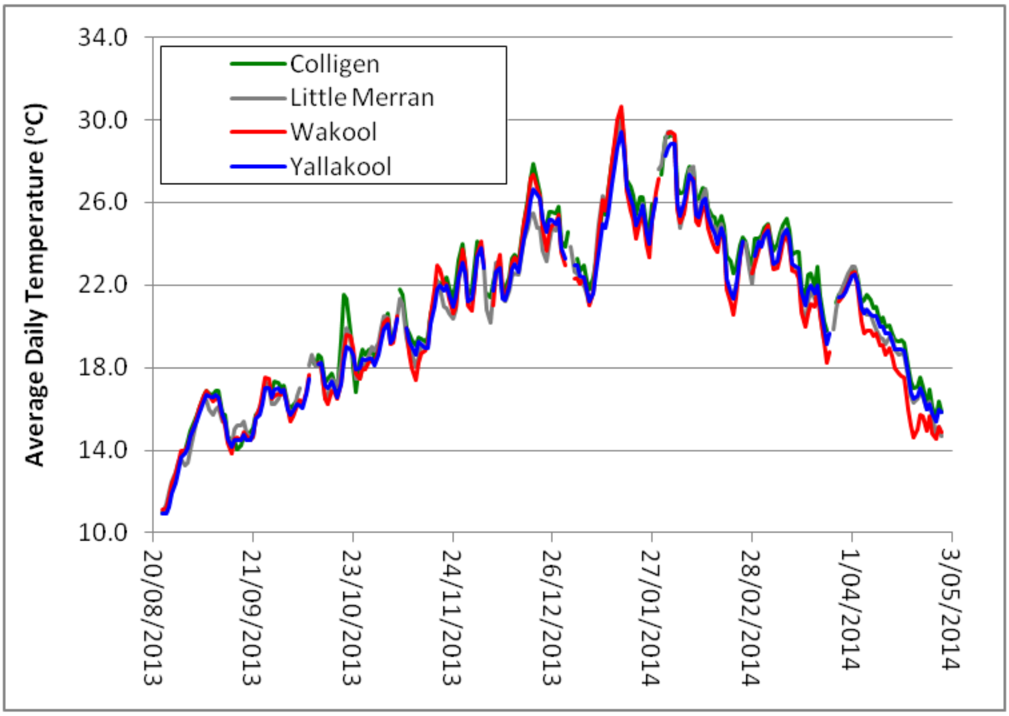


Figure 38. Average Daily Water Temperature (°C) in four rivers the Edward-Wakool system in 2013-14.

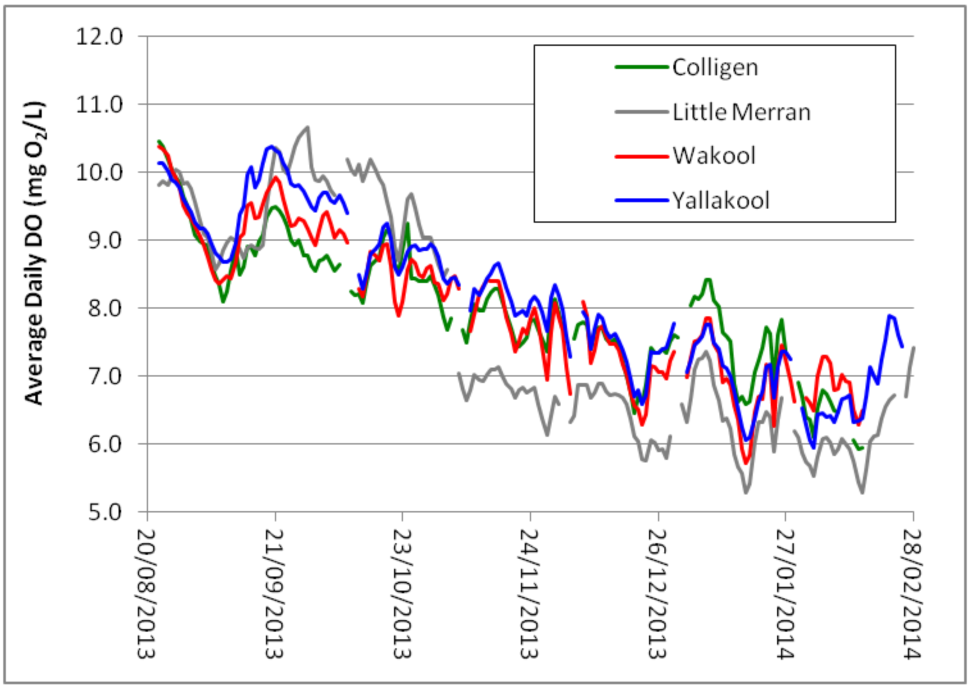


Figure 39. Average Daily Dissolved Oxygen concentrations (mg O_2/L) in four rivers the Edward-Wakool system in 2013-14. Data is omitted where loggers were out of the water or malfunctioning.

Dissolved and particulate organic carbon

Dissolved organic carbon (DOC) concentrations were moderately elevated but very similar between all sites during the unregulated flow in August and September. A substantial decline was observed in the Wakool, Yallakool and Colligen in late September, consistent with improved water quality in the Edward River (Figure 40). The water in Little Merran Creek is sourced from the Murray River and did not reflect this decrease in DOC to the same extent. A small increase in DOC was observed in all rivers in October and then concentrations steadily declined to the low range (2-4 mg/L) normally observed for this system. Declines in DOC were slower in Little Merran Creek, consistent with the trend observed in previous years (Watts et. al. 2013a, Watts et. al 2013b). At no point in the study did the concentrations reach the high levels (between 15-30 mg/L) observed during the unregulated flow event in March and April 2012 (Watts et al. 2013a). Particulate organic carbon (POC) concentrations remained low throughout the study period (Figure 40).

Statistical analysis indicated that neither POC nor DOC concentrations were altered as a result of environmental watering actions (Table 19, Figure 41). There were statistically significant differences in DOC between rivers at the time of the Cod maintenance flow in Yallakool Creek (sampling dates 23/10/2/13 to 4/12/13)(Table 19). Little Merran Creek had the highest DOC levels (4.15 mg C/L), followed by Wakool (3.75 mg C/L), while Yallakool and Colligen had the least (3.5 mg C/L) (Figure 41c). While statistically different, the difference between 3.5 and 4.1 mg C /L is not ecologically significant. The difference between Yallakool Creek, Colligen Creek, the Wakool River and Little Merran Creek can be explained by a combination of the slower decline in the hydrograph for Little Merran Creek following the spring unregulated flows and the considerably larger wetted surface area at relatively low flows due to the stream morphology of this river (Watts et al 2013b). The larger wetted surface area will result in greater contact between the water and both soil organic carbon and organic matter derived from leaf litter, resulting in leaching of DOC into the water column. In addition, Little Merran Creek receives water from the Murray River rather than the Edward River and carbon inputs may be influenced by transit through the Koondrook State Forest.

POC was not significantly affected by environmental watering for Yallakool perch pulse, maintenance, or Colligen-Niemur continuation flows (Table 19). The DOC significant 'period' ($p<0.001$) means that DOC concentrations changed in all rivers from before to during the time that Yallakool was experiencing the perch pulse flow. This decrease (Figure 41) affected all rivers alike and is a result of sampling across the period where the DOC was still declining following the earlier unregulated flows.

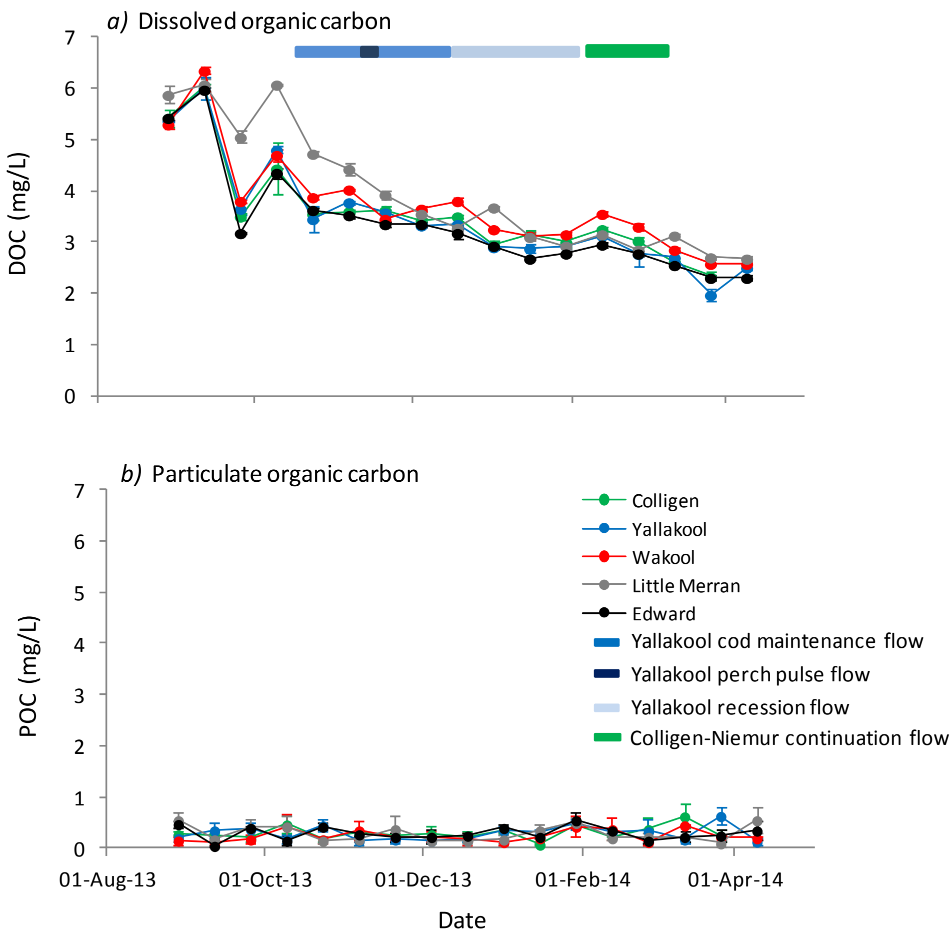


Figure 40. Mean (±SE) concentrations of *a)* dissolved organic carbon and *b)* particulate organic carbon in Yallakool Creek, Colligen Creek, Wakool River, Little Merran Creek and the Edward River between August 2013 and April 2014. Blue green bars represent the start and finish dates of environmental watering.

Table 19. Statistical results for 2 way mixed-effects Analysis of Variance (ANOVA) on DOC and POC results. A significant interaction between the two fixed factors: Period (before, during, after/recession) and CI (control rivers, impact rivers) indicates that the concentrations of DOC or POC within Impact Rivers and Control rivers responded different across time. A one way ANOVA was run for Cod maintenance flows to test for differences across Rivers. Results highlighted in bold were statistically significant.

WQ Parameter	Main effect	d.f	F-test	p-value
Perch pulse flow: Yallakool creek				
DOC	**Period (B-D)**	**1,44**	**14.014**	**<0.001**
	CI (C-I)	1,44	1.437	0.237
	Period*CI	1,44	2.976	0.091
POC	Period (B-D)	1,44	0.141	0.708
	CI (C-I)	1,44	0.001	0.964
	Period*CI	1,44	1.43	0.238
Cod maintenance: Yallakool creek				
DOC	**River**	**4,72**	**22.391**	**<0.001**
POC	River	4,72	0.266	0.897
Colligen-Niemur continuation flow				
DOC	Period (B-D)	1,43	0.780	0.382
	CI (C-I)	1,43	0.065	0.799
	Period*CI	1,43	0.039	0.843
POC	Period (B-D)	1,43	0.401	0.529
	CI (C-I)	1,43	0.112	0.738
	Period*CI	1,43	1.679	0.201

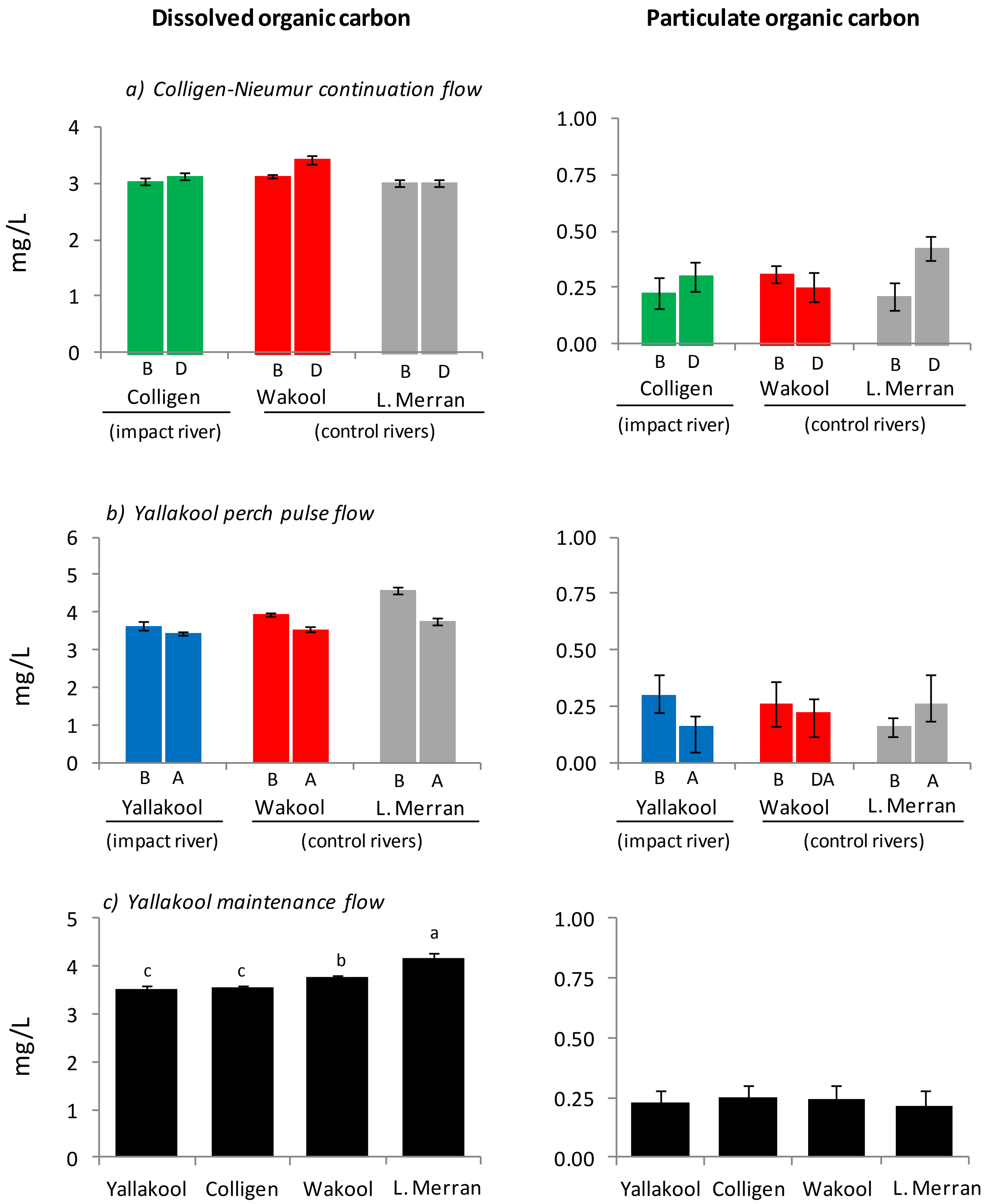


Figure 41. Statistical comparison of DOC and POC concentrations between treatment and control rivers for a) the Colligen-Niemur continuation flow (BACI), b) the Yallakool perch pulse flow (BACI), and c) the Yallakool maintenance flow. The letters above the bars indicate significant differences in DOC between rivers during the Yallakool maintenance flow.

Nutrients

Concentrations of Total Nitrogen, NO_x (nitrate plus nitrate) and ammonia (Figure 42) indicate that as observed in previous years (Watts et al 2013a, Watts et al 2013b) the nitrogen profile of Little Merran Creek is different to the other rivers during the spring, reflecting differences in both source water and flow regime (Figure 42). All forms of nitrogen were elevated in the Little Merran relative to the other rivers over August and early September. There was a slight increase in bioavailable nitrogen in the other rivers during the unregulated flow in August with a rapid decline in September. From October onwards, nitrogen concentrations in all rivers were similar to each other.

As shown in Figure 42, although the TN concentrations at times exceeded the ANZECC (2000) trigger value for lowland rivers of 0.5 mg N/L, the mean and median values were below the trigger level for all rivers. The bioavailable forms of nitrogen (NO_x and ammonia) were well below the trigger values on all occasions with the exception of Little Merran Creek, where NO_x exceeded the trigger value in August and early September and ammonia at the beginning of the sampling period in August. Median NO_x concentrations were at or below the limit of detection for all but Little Merran Creek.

This pattern is repeated with the concentrations of phosphorous (P) in the rivers: while Total P concentrations (Figure 43a) frequently exceeded the trigger value of 0.05 mg P/L with median and mean concentrations for all rivers at or above this trigger level, the filterable reactive P (the bioavailable fraction) was well below the trigger value of 0.02 mg P/L (Figure 43b). A slight increase in bioavailable P occured in August/September and was greatest in Little Merran Creek but FRP was not impacted by any of the environmental watering actions. The ANZECC Water Quality Guidelines recommend that in order to minimize the risk of algal blooms (and other adverse outcomes) in lowland rivers in south-eastern Australia, these bioavailable concentrations should be below 0.02, 0.02 and 0.04 mg/L for ammonia, FRP and NO_x respectively. The median concentrations were nearly an order of magnitude lower than these guidelines in most instances.

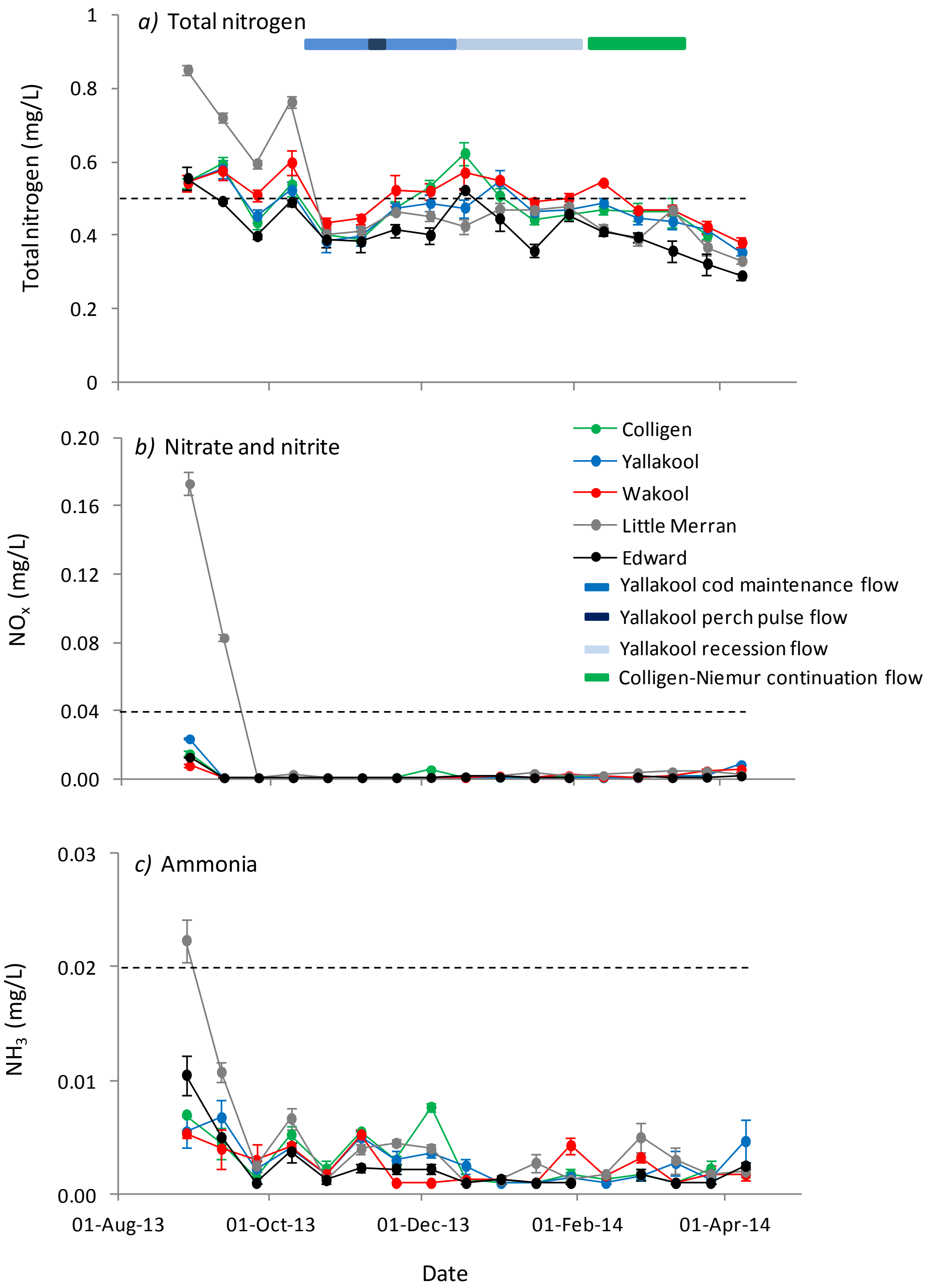


Figure 42. Mean (±SE) concentrations of *a)* total nitrogen, *b)* nitrate and nitrite, and c) ammonia in the Yallakool River, Colligen Creek, Wakool River, Little Merran Creek and Edward River between August 2013 and April 2014. Blue and green bars represent the start and finish dates of environmental watering. The dashed line indicates the AANZECC (2000) trigger levels for each nutrient.

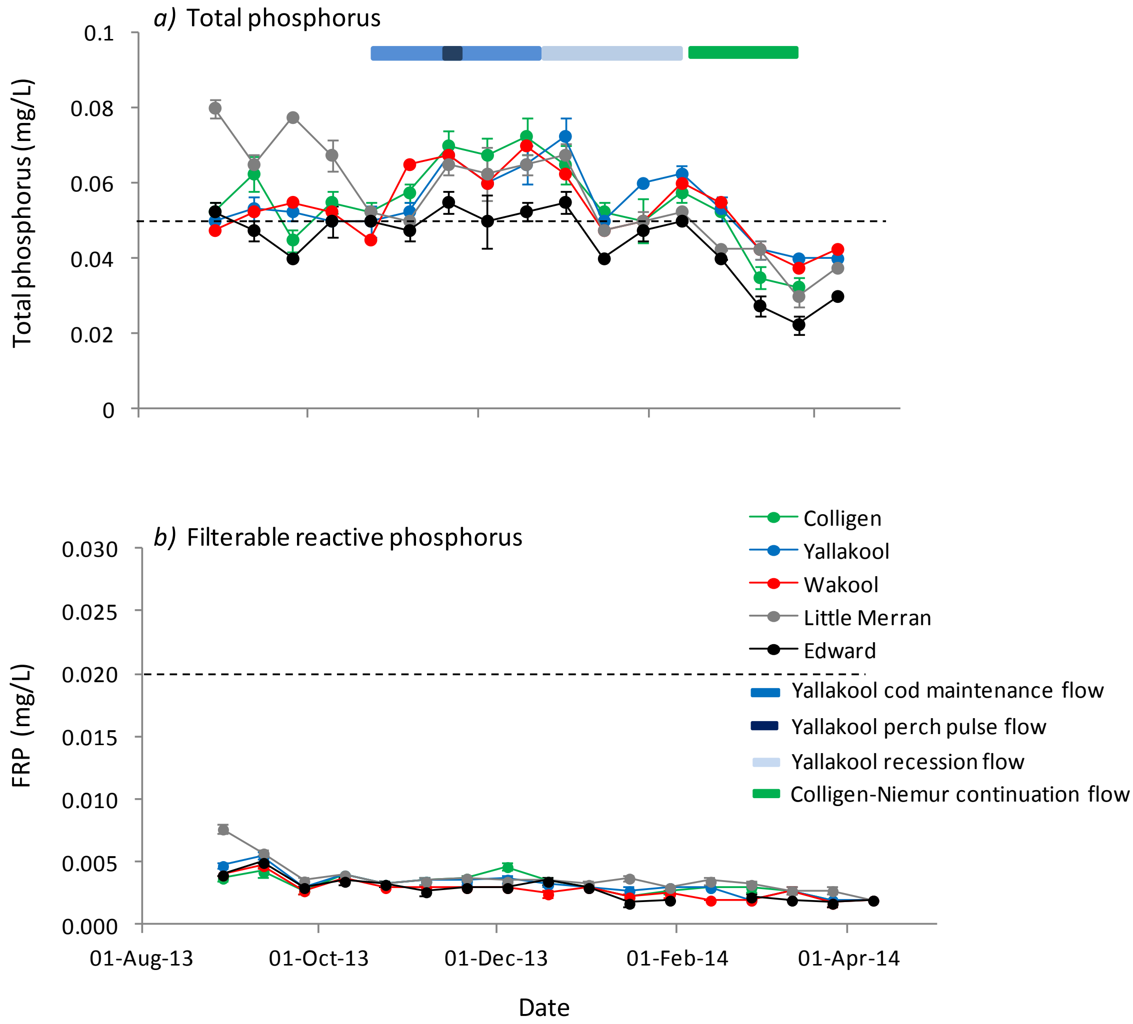


Figure 43. Mean (±SE) concentrations of *a)* total phosphorus, and *b)* filterable reactive phosphorus in the Yallakool River, Colligen Creek, Wakool River, Little Merran Creek and Edward River between August 2013 and April 2014. Blue and green bars represent the start and finish dates of environmental watering. The dashed line indicates the AANZECC (2000) trigger levels for each nutrient.

Table 20 summarizes the findings of the BACI analysis for the effects of environmental watering on. each nutrient for the Colligen-Niemur continuation flow, the Yallakool perch pulse flow and the Yallakool cod maintenance flow. The data used in these analyses is summarized in Figures 44 to 46.

There were no effects of the perch pulse flow on TP, NH_4^+, FRP, or NOX due to perch pulse flow (Table 20, Figure 44). TN levels changed from after the perch pulse flow, but that this happened in control and impact rivers alike suggesting the changes were due to seasonal factors (Table 20, Figure 44a).

There were statistically differences in NO_x, ammonia and FRP (but not TN or TP) across rivers during the Yallakool cod maintenance flow (Table 20), but these differences arose due to slightly higher concentrations in Colligen Creek rather than Yallakool Creek (Figure 45 c, d, e). A change of ± 1-2 µg N or P/L is only slightly greater than the precision in the analytical chemistry method (0.5 µg N or P/L by Flow Injection Analysis) and certainly does not reflect a major new source of nutrients. As noted earlier, the concentration levels are extremely low and definitely a constraint on primary production in these streams (see Section 6.8 on Stream Metabolism).

There was a significant interaction effect between the control and impact streams for FRP (only) before and after the Colligen-Niemur continuation flow (Table 20, Figure 46). However, it was an increase in the control streams (Wakool River and Little Merran Creek) rather than the impact stream that caused this statistically significant difference (Figure 46d). Again, the actual concentration change was extremely small (<1 µg P/L), and not considered to be ecologically significant.

There was a significant difference between control and impact rivers for NH_3, in that control rivers had slightly more than the Colligen Creek, however the difference was not ecologically significant (Table 20, Figure 46).

Overall, there were no ecologically significant changes in carbon or nutrient concentrations in reponse to environmental watering actions, consistent with previous years (Watts et. al 2013a, Watts et al 2013b). Increases in carbon and nutrients in these rivers have been observed in response to unregulated flow events and stimulation of productivity through inputs of carbon and bioavailable nutrients in this system is expected to require either the import of these substances from upstream (requiring larger flows from upstream and the water having been in contact with the floodplain) or larger inundation events occurring locally which reconnect previously dry sections of the in-channel habitat with the water column.

Table 20. Statistical results for 2 way mixed-effects Analysis of Variance (ANOVA) on Nutrient Concentrations. A significant interaction between the two fixed factors: Period (before, during, after/recession) and CI (control rivers, impact rivers) indicates that the relevant nutrient concentration within Impact Rivers and Control rivers responded different across time. An effect due to the watering action could be determined if the significant interaction was due to the relevant mean concentration changing in the impact river as compared to the control river, not vice-versa (See accompanying Figures 44-46). A one way ANOVA was run for Cod maintenance flows (see methods) to test for differences across Rivers.

WQ Parameter	Main effect	d.f.	F-test	p-value	Significant effect due to watering action?
Perch pulse flow: Yallakool creek					
TN	**Period (B-D)**	**1,44**	**25.200**	**<0.001**	
	CI (C-I)	1,44	0.132	0.717	
	Period*CI	1,44	0.069	0.793	No
NO_X	Period (B-D)	n/a			
	CI (C-I)	n/a			
	Period*CI	n/a			No
NH_4^+	Period (B-D)	1,41	0.033	0.856	
	CI (C-I)	1,41	0.236	0.629	
	Period*CI	1,41	0.048	0.826	No
TP	Period (B-D)	1,44	0.000	0.985	
	CI (C-I)	1,44	0.250	0.619	
	Period*CI	1,44	0.073	0.832	No
FRP	Period (B-D)	1,41	1.491	0.229	
	CI (C-I)	1,41	0.255	0.615	
	Period*CI	1,41	0.045	0.832	No
Cod maintenance: Yallakool creek					
TN	River	3,57	2.081	0.112	No
NO_X	**River**	**3,53**	**5.147**	**0.003**	No
NH_4^+	**River**	**3,53**	**4.854**	**0.004**	No
TP	River	3,57	1.043	0.380	No
FRP	**River**	**3,53**	**5.536**	**0.002**	No
Colligen-Niemur continuation flow					
TN	Period (B-D)	*1,43*	*0.539*	*0.466*	
	CI (C-I)	*1,43*	*0.034*	*0.854*	
	Period*CI	*1,43*	*1.701*	*0.199*	No
NO_X	Period (B-D)	*1,43*	*0.000*	*0.987*	
	CI (C-I)	*1,43*	*1.398*	*0.243*	
	Period*CI	*1,43*	*0.077*	*0.781*	No
NH_4^+	Period (B-D)	*1,43*	*0.273*	*0.603*	
	CI (C-I)	***1,43***	***5.371***	***0.025***	
	Period*CI	*1,43*	*0.137*	*0.712*	No
TP	Period (B-D)	*1,43*	*1.216*	*0.276*	
	CI (C-I)	*1,43*	*0.345*	*0.560*	
	Period*CI	*1,43*	*0.000*	*0.981*	No
FRP	Period (B-D)	*1,43*	*1.435*	*0.237*	
	CI (C-I)	*1,43*	*0.000*	*0.989*	No
	Period*CI	***1,43***	***5.600***	***0.022***	**Yes**

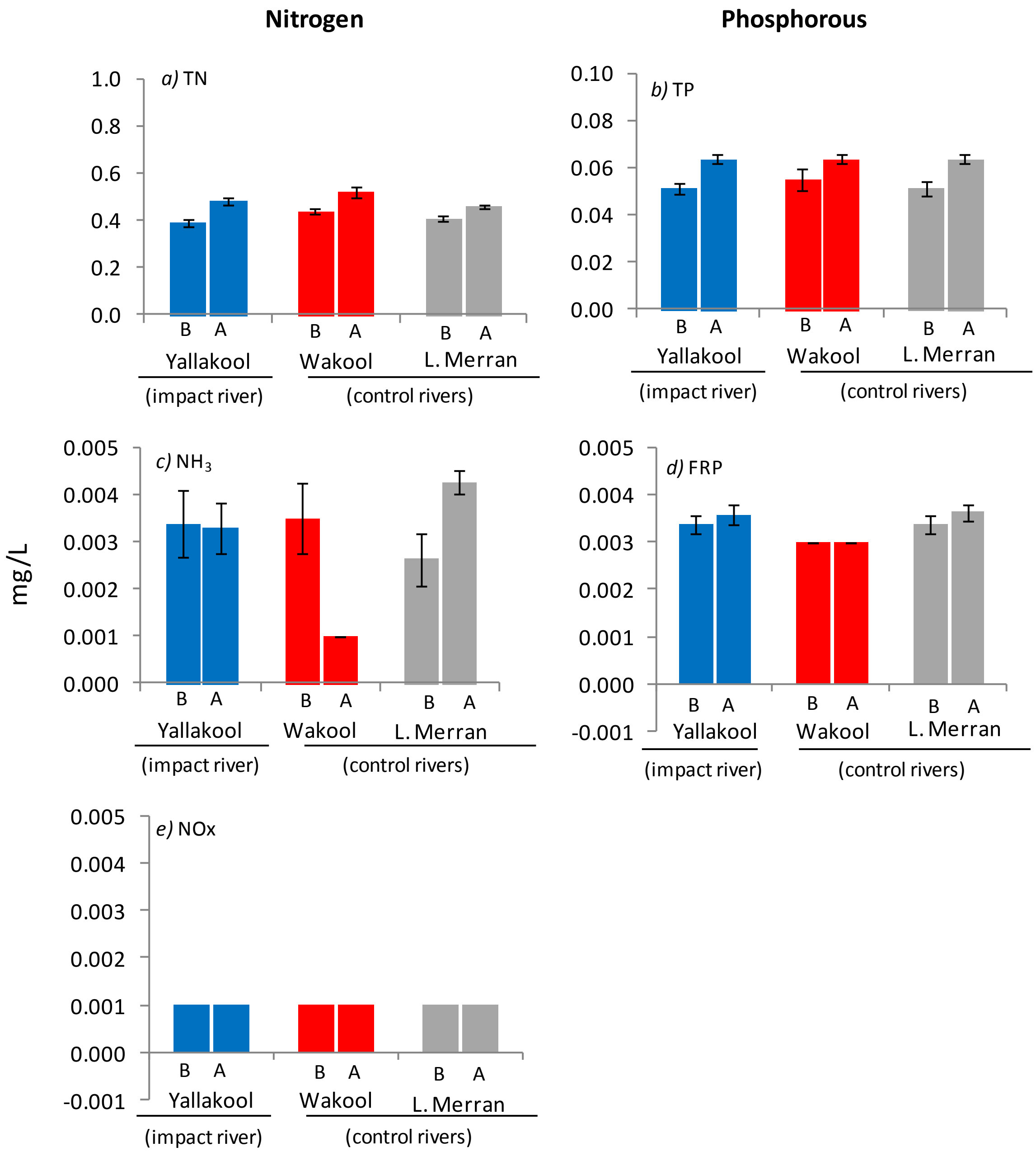


Figure 44. Yallakool Perch flow: BACI comparison of nutrient concentrations between treatment and control rivers before and after the watering action. Tthe first bar of each pair is before (B) the watering action, the second is after (A) the watering action.

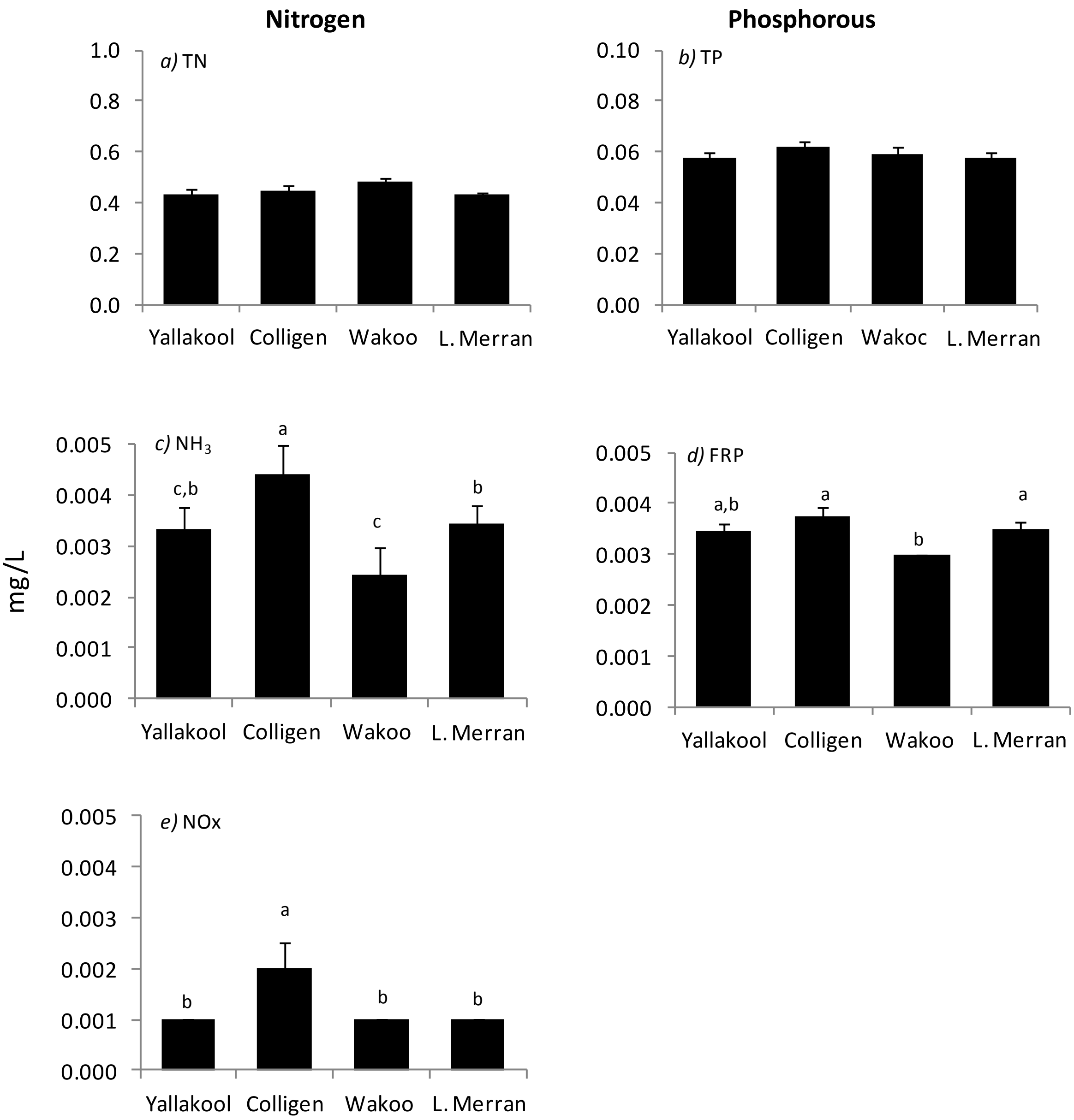


Figure 45. Yallakool maintainence flow: Comparison of nutrient concentrations between treatment and control rivers during the Yallakool sustained flow. The letters above the bars indicate significant differences between rivers.

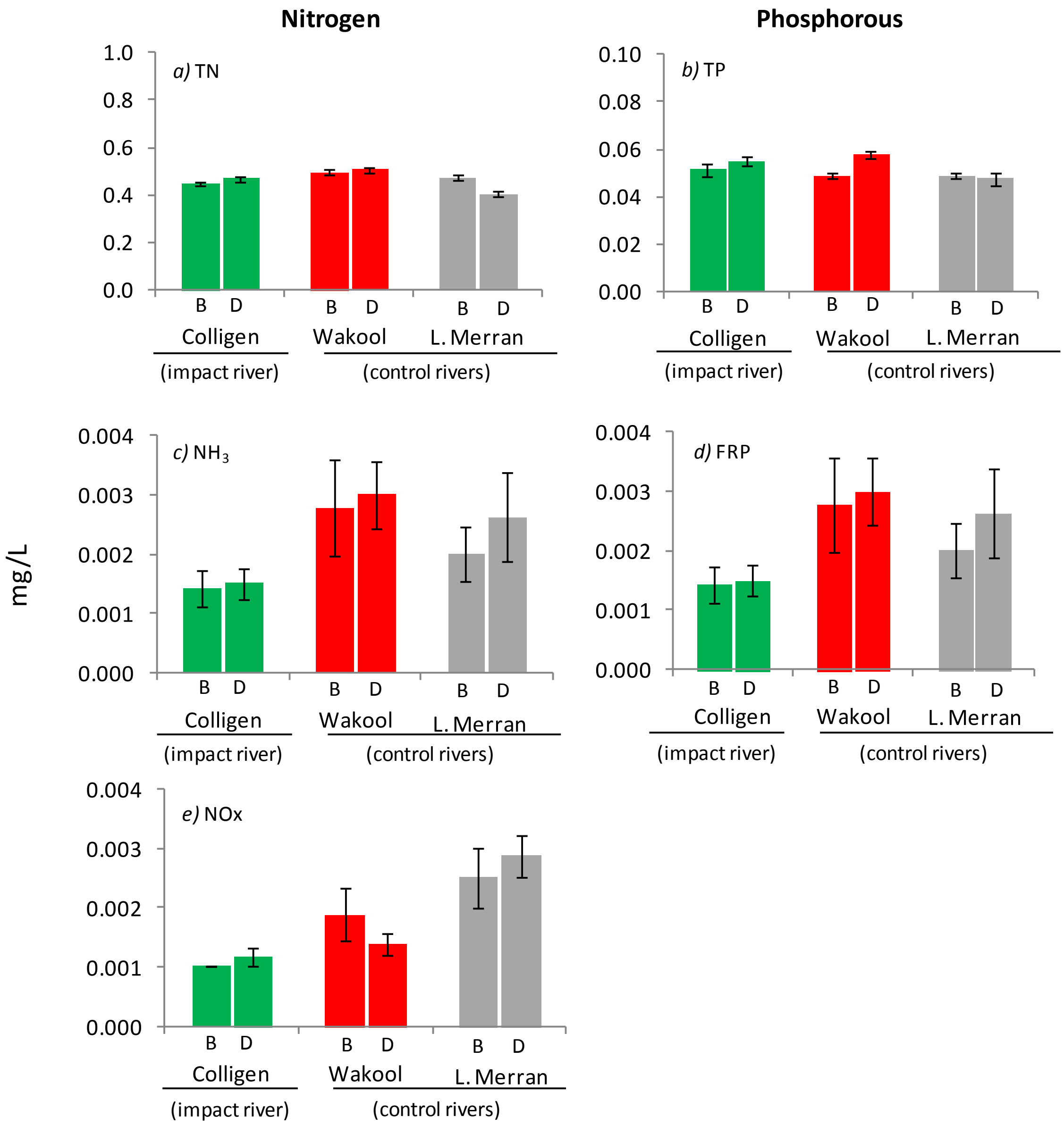


Figure 46. Colligen-Niemur continuation flow: BACI comparison of nutrient concentrations between treatment and control rivers for the Colligen-Niemur continuation flow – the first bar of each pair is before (B) the watering action, the second is after (A) the watering action.

6.7. Organic matter characterisation

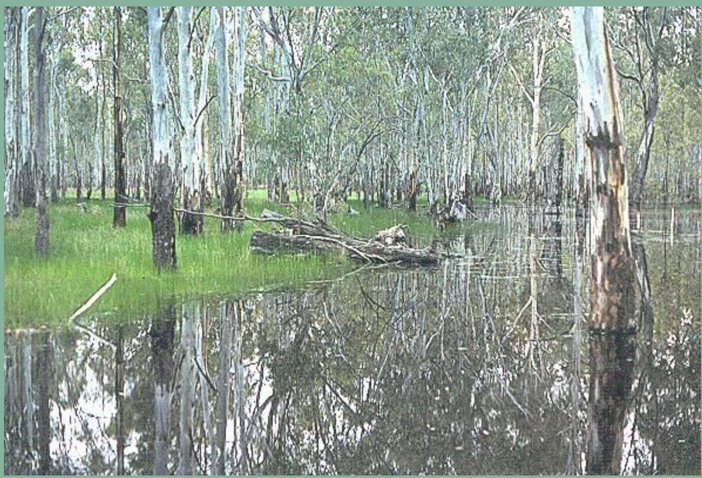


Photo: Example of blackwater in a redgum forest. This type of event did not occur n 2013-14 at the sites monitored in the Edward-Wakool system.

Key findings

- Water samples to facilitate the characterisation of organic matter were collected fortnightly from August 2013 until April 2014. The organic matter profiles of all river sites were generally very similar to each other for a given sampling date, with the exception of the Little Merran Creek during spring.
- Commonwealth environmental watering met the objective of maintaining or supporting water quality outcomes as it did not trigger any adverse water quality outcomes. No hypoxic blackwater event occurred during this study period and environmental watering actions did not result in changes to the organic matter profiles. Commonwealth environmental water should continue to be delivered to mitigate adverse water quality events (see flow recommendations).
- Organic matter composition was generally more complex early in the season and simplified over time, consistent with previous years, with the exception of some sites at the end of January where minor modification of the organic matter may have resulted from the prolonged heatwave.The fluorescence results indicate that the low levels of organic matter in these river systems over summer are generally weighted towards carbon of low bioavailability.

Background

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 et al., 2010). While water quality guidelines (ANZECC 2000) include trigger values (concentrations of concern) for a number of water quality parameters such as chlorophyll a, nutrients, dissolved oxygen and pH, no guidelines are given for organic matter and aquatic environments are expected to have quite varying dissolved organic matter concentrations.

Organic matter is made up of a complex mixture of compounds from a diverse range of sources. Microbial communities do not respond to all types of organic matter in the same way (Baldwin 1999; O'Connell et al. 2000; Howitt et al. 2008) although it has been shown that bacterial communities can respond to changes in organic carbon source quite rapidly. 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 (Howitt et al. 2008).

One way of examining the mixture of organic substances present is to measure the spectroscopic behaviour of the substances- i.e. to study which wavelengths of light they absorb, and to examine which wavelengths of light they emit (fluoresce) in response to this absorption of incoming light (Dahlen et al. 1996; Mobed et al. 1996, Baker and Spencer, 2004; Howitt et al. 2008). 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.

The consideration of changes in both the quantity and type of organic matter present in the system allows for a more detailed examination of the hypotheses around the movement of organic carbon and the creation of blackwater events.

Hypothesis

If environmental watering facilitates inundation of extensive new sources of organic matter it would result in changes to the spectroscopic responses of the organic matter through alteration of the mixture of compounds that make up dissolved organic matter.

Methods

Samples for organic matter characterisation were collected fortnightly from August 2013 until April 2014. Four samples were collected from each river reach on each sampling date. Samples from the early October field trip were compromised during transport and were not analysed. On one occasion samples from the Wakool sites were not available due to access issues (29/1/14) and water collected from the Wakool River futher upstream, immediately above the Mulwala Canal escape. No water was being released from the canal so these results are expected to be representative. Colligen Creek samples could not be collected in April.

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 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 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 contour plot is shown in Figure 47. 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.

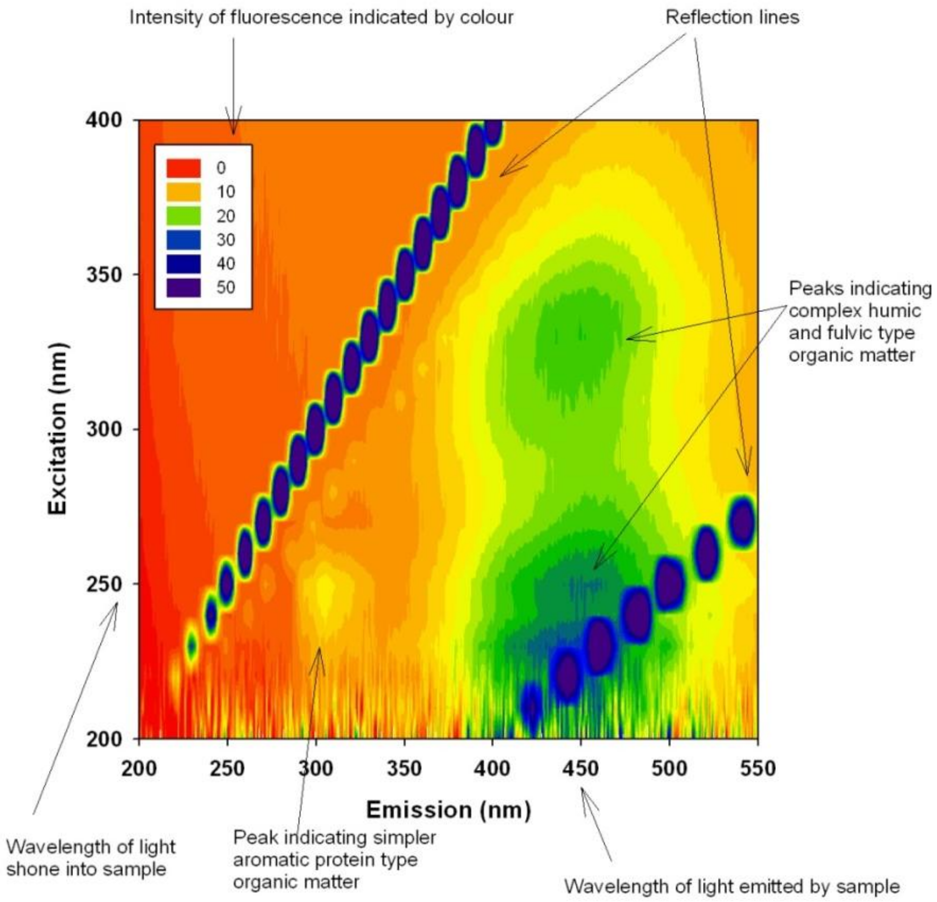


Figure 47. Sample excitation emission contour plot indicating key features of the data. (Watts et al. 2013a)

Results and discussion

Absorbance scans of representative water samples from each sampling trip are presented in Figure 48. The greatest variation between replicates for each river is expected at 200 nm and the range was commonly less than 5% of the measured absorbance for each river on most occasions, and the maximum range observed for each sampling trip is in Table 21. An exception to this pattern was observed in late January where the variation between replicates was increased in all rivers to between 9 and 25% with Colligen Creek and Little Merran Creek being the most affected. In general, these data indicate that the greatest influence on organic matter composition and concentration over the study period were the unregulated flows in August and September 2013, where all rivers have elevated organic matter compared to May 2013 (Watts et al. 2013b). Over the period from August to October 2013, the organic matter content of Little Merran Creek is generally slightly higher than that found at all the other sample sites, consistent with the DOC results, although the absorbance results imply a more gradual decline in organic matter than the DOC (the sharp dip in late September in the DOC results is less pronounced in the absorbance results). Throughout the study period the absorbance scans for the Wakool River, Colligen Creek and Yallakool Creek closely match the source water from the Edward River, where overbank flows through the Barmah-Millewa Forest can be a source of organic matter upstream. This pattern is consistent with that observed in previous years. The in-channel flows in both Yallakool Creek and Colligen Creek do not result in the absorbance scans at these sites becoming substantially different to the other sites, again supporting earlier conclusions that the areas of in-stream habitat that were re-wet during these flows did not have substantial amounts of accumulated organic material (such as leaf litter) (Watts et al. 2013b).

One method for assessing the relative size of the organic matter in a water sample is to compare the ratio of absorbances at shorter and longer wavelengths, as larger, more complex molecules absorb at longer wavelengths. Table 21 shows the ratio of absorbance at 250 nm to that at 340 nm, based on average value of three replicates for each river. The rivers generally have very similar ratios to each other, and the ratios are in the range previously reported for aged organic matter as found in billabongs (Howitt et al. 2008). There is a very gradual increase in ratio through the sampling season, indicating a relative loss of the larger humic and fulvic materials compared to the smaller molecules, and this trend commences earlier in the rivers with the lowest summer flows (Little Merran Creek and Wakool River), although it should be remembered that these changes are very small and that the overall DOC concentration is quite low by the time these changes are evident.

Representative fluorescence scans are shown in Figure 49. Being a more sensitive spectroscopic technique, the fluorescence results have more dramatically shown the reduction in organic matter between the two sampling dates in September, but also support the conclusion that the Colligen, Yallakool and Wakool sites have organic matter profiles that closely reflect the water quality entering from the Edward. It is noted that the humic peak in the Edward river samples is slightly weaker than the other rivers on the 11/9/13 and this is likely an indication that the decline in organic matter inputs had just commenced upstream. The fluorescence analysis indicates that by late November 2013 the amount and type of organic matter at all sites is very consistent and low, as has been observed in previous years. Consistent with the absorbance results presented above, there is no evidence that the freshes in the Colligen and Yallakool have resulted in changes in the organic matter load or the composition of the mixture of compounds making up the fluorescent dissolved organic matter. There are small increases in the aromatic protein region of the spectrum in all rivers during January and these persist through to April 2014, consistent with the change in absorbance ratios indicating an increased proportion of smaller molecules. This is a seasonal effect consistent with previous years (Watts et al. 2013a; Watts et al. 2013b). Increases in fluorescence in this region of the spectrum may indicate the presence of a more bioavailable fraction of organic matter and may be associated with breakdown of humic and fulvic components by sunlight (Howitt et al. 2008), however it should be noted that the concentrations of these substances remain in a low range. Peaks in this region have also been associated with bacterial metabolism (Elliott et al. 2006), and have been found in marine environments (Coble 1996) where their presence is likely of algal origin.

The reduced oxygen concentrations observed during the heatwave in January 2014 were not accompanied by increases in dissolved organic carbon, however, there was greater variability in the absorbance and fluorescence results for replicates from the same river during this period, and some fluorescence results had peaks in a region not normally present for this river system (see for example, Colligen and Wakool scans from 29/1/14). These additional peaks suggest localised algal production, or products of photochemical degradation of humic and fulvic materials

The patterns observed in the absorbance and fluorescence results are consistent with those observed in previous sampling seasons (Watts et al. 2013a; 2013b). Higher flows during early spring, associated with unregulated river rises, increase the amount and complexity of organic matter in the rivers. The rivers may be different from each other due to varying amounts of newly wetted habitat or where overbank flow may occur for the source rivers upstream, but long periods of in-channel flow result in a reduction and simplification of the organic matter signals and there is consistency across the study sites.

The small in-channel watering actions did not reconnect sufficient area of upper benches and floodrunners to result in substantial exchange of organic matter and nutrients. Therefore, the hypothesis that environmental watering would stimulate ecosystem productivity by moving nutrients and carbon between the main channel, upper benches and small, low commence-to-flow floodrunners was not upheld for the in-channel watering actions in 2013-14.

It was expected that dissolved organic carbon and particulate organic carbon levels would remain relatively unchanged following in-channel environmental watering or that small increases would occur. The environmental watering was not expected to trigger blackwater events in these systems. These hypotheses were supported: in-channel environmental watering did not result in large inputs of dissolved or particulate organic matter and no blackwater event was observed. Organic matter inputs associated with the unregulated flows in August and September 2013 did not result in a blackwater event, primarily due to the low water temperature at this time of year.

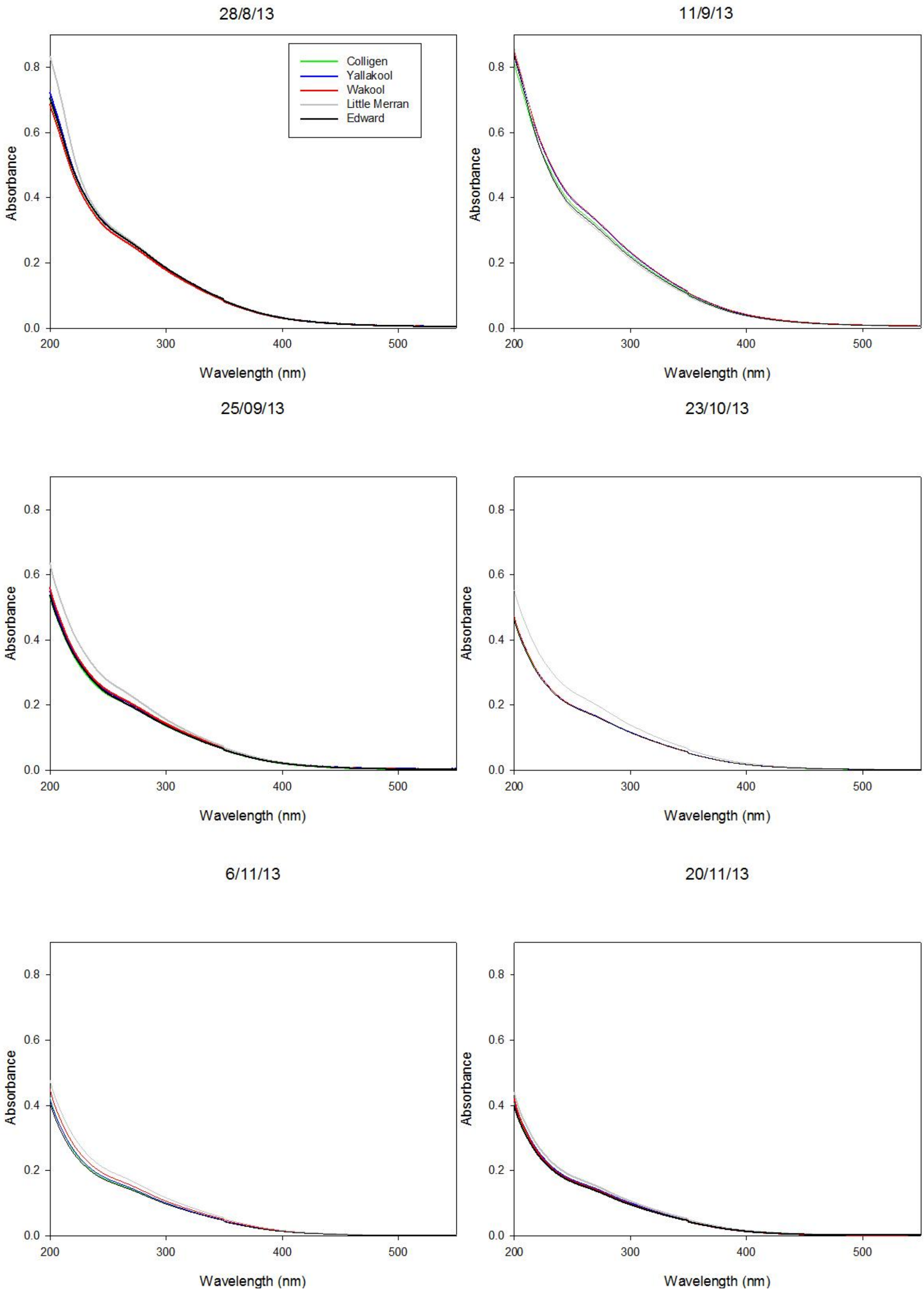


Figure 48a. Absorbance Scans for water samples from August to November 2013.

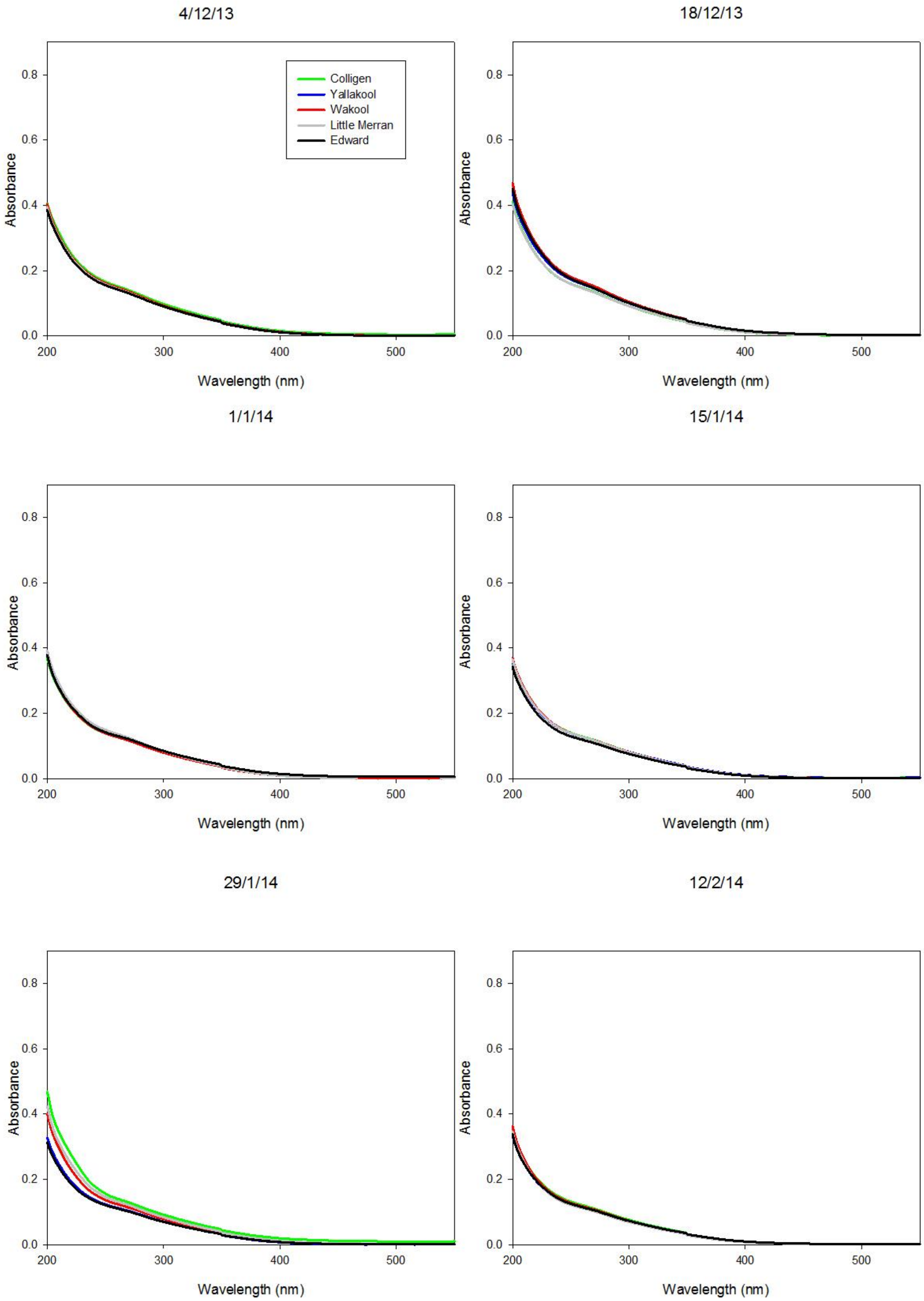


Figure 48b Absorbance Scans for water samples from December 2013 to mid February 2014.

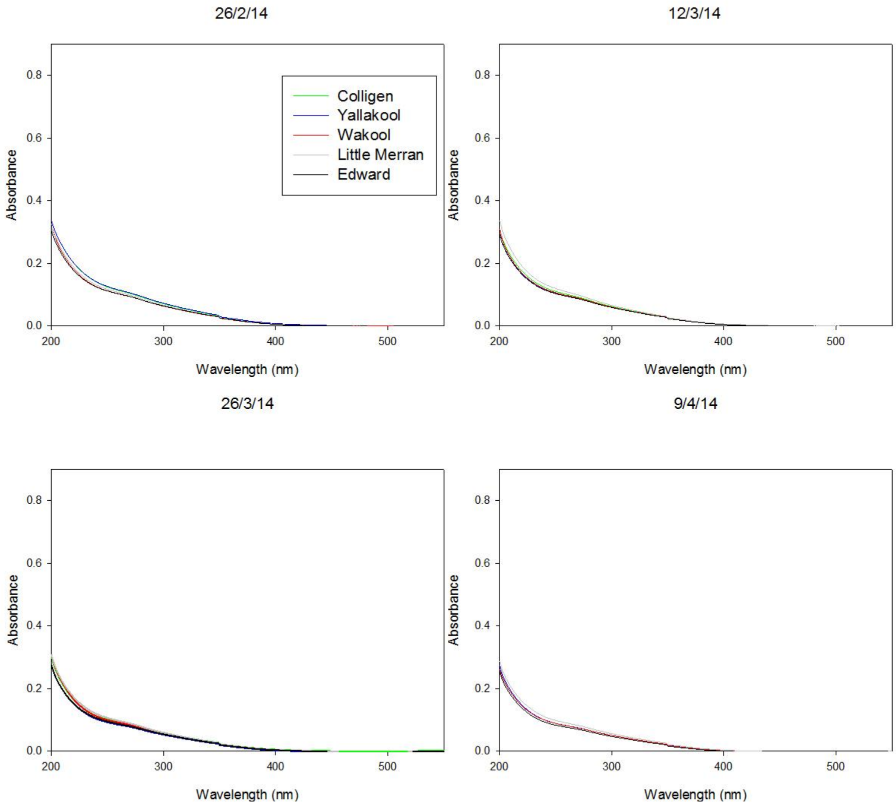


Figure 48c. Absorbance scans for water samples from late February to April 2014.

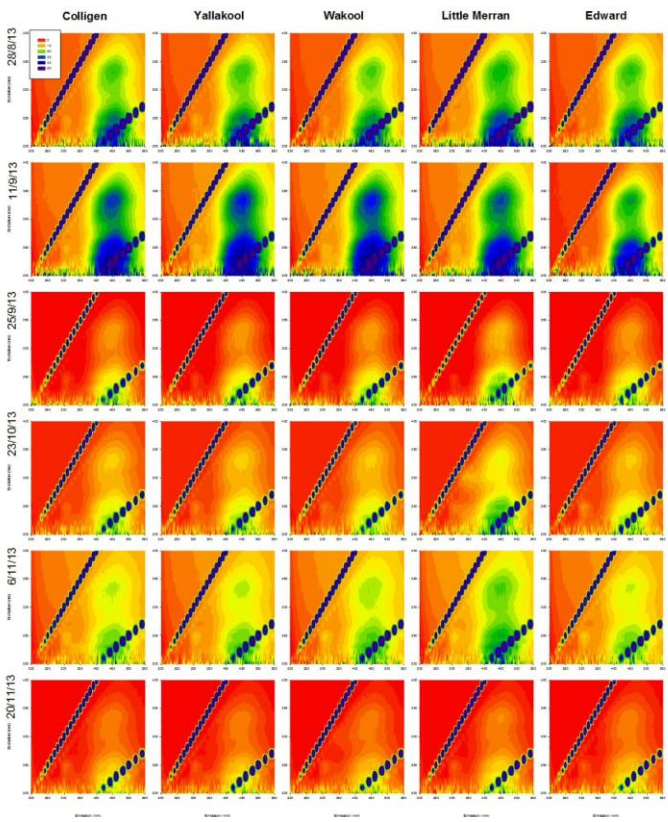


Figure 49a Representative fluorescence scans for water samples collected between August and November 2013.

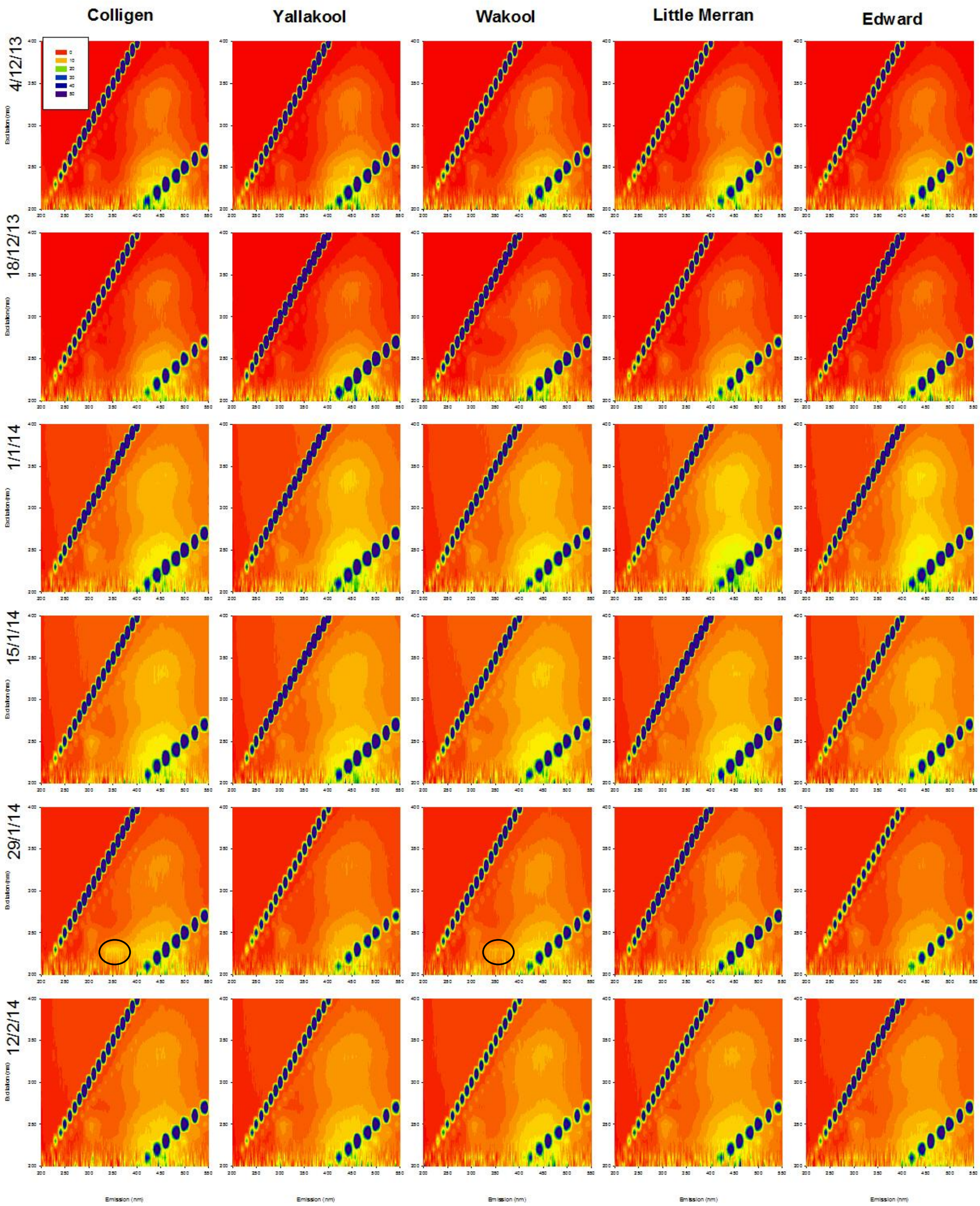


Figure 49b Representative fluorescence scans for water samples collected between December 2013 and mid February 2014. Additional peaks present in the Colligen Creek and Wakool River at the end of January are marked with black circles.

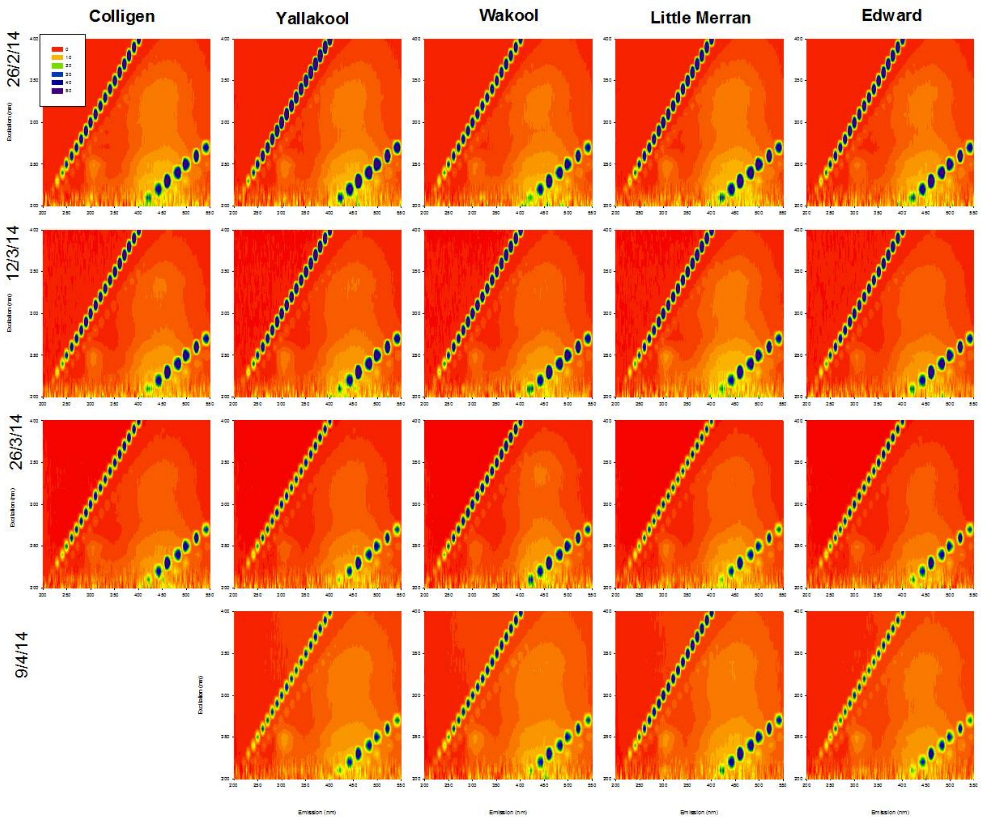


Figure 49c. Representative fluorescence scans for water samples collected between late February and April 2014.

Table 21. Average ratio of absorbance at 250 nm to 340 nm for 3 replicate samples for each river, and the maximum range in absorbances observed between replicates from a single river at 200 nm.

Date	Colligen	Yallakool	Wakool	Little Merran	Edward	Max range A200 (%)
29/08/13	2.95	3.00	3.00	3.06	3.00	7
11/09/13	3.01	3.02	3.00	3.07	3.02	4
25/09/13	3.03	3.01	3.02	3.20	3.02	5
25/10/13	3.01	3.00	3.02	3.09	2.99	3
6/11/13	3.07	3.05	3.06	3.05	3.03	5
20/11/13	3.03	3.01	3.09	3.05	3.03	5
4/12/13	3.01	2.99	3.12	3.15	3.04	6
18/12/13	3.00	3.09	3.11	3.14	3.04	13
1/01/14	3.18	3.12	3.19	3.22	2.85	8
15/01/14	3.12	3.06	3.09	3.12	3.03	7
29/01/14	3.06	3.21	3.18	3.17	3.10	25
12/02/14	3.13	3.10	3.19	3.18	3.05	5
26/02/14	3.15	3.10	3.25	3.21	3.12	12
12/03/14	3.17	3.01	3.18	3.27	3.18	6
26/03/14	3.12	3.26	3.18	3.31	3.22	10
9/04/13		3.21	3.22	3.25	3.32	5

6.8. Whole stream metabolism

Photo: Dissolved oxygen logger being calibrated in the field

Key findings

- Battery-powered loggers were deployed at either end of each of the four focus reaches and measure and loggged dissolved oxygen concentration and water temperature every 10 minutes. The metabolic parameters, gross primary production and ecosystem respiration were calculated for each day.
- Rates of primary production and ecosystem respiration during 2013-2014 were at the lower end of the normal range found in streams worldwide.
- Only very small increases in metabolic rates resulted from environmental watering actions, most likely because the flows were contained within the stream channel with little inundation of backwater areas or instream geomorphic features, such as benches. there is a need to increasing our understanding of interaction between instream flows and river productivity (see flow recommendations).
- Primary production and ecosystem respiration are constrained by the very low concentrations of bioavailable nutrients and organic carbon, respectively. This is both beneficial in that the risks of severe algal blooms or anoxic events are very low, but problematic if this lack of organic carbon input into the base of the aquatic foodweb is limiting maintenance and recovery of fish populations.

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 measuring metabolism provides a mechanism for assessing the energy base underpinning aquatic foodwebs. The relationships between these processes are shown in Figure 50.

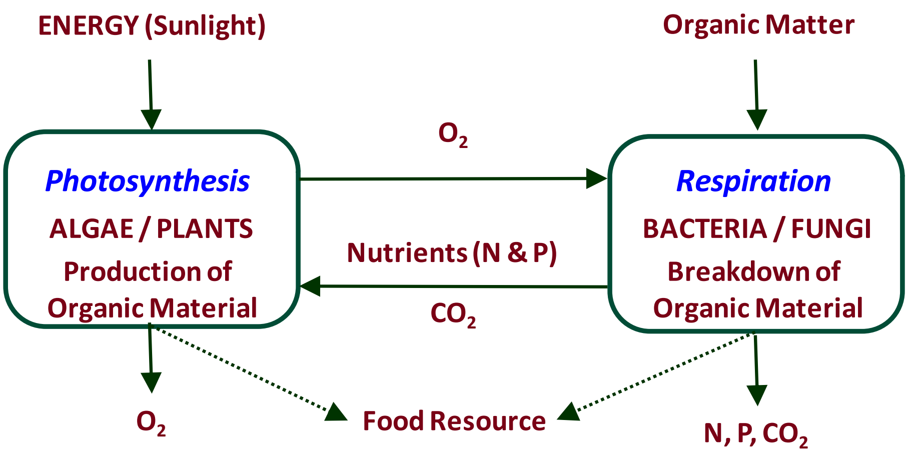


Figure 50. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

Rates of metabolism are typically expressed as the increase (photosynthesis) or decrease (respiration) of dissolved oxygen concentration over a given time frame. For stream metabolism studies, the most commonly used unit is (change in) milligrams of dissolved oxygen per litre per day (mg O_2/L/Day). Sometimes, photosynthetic and respiratory quotients are used to convert these oxygen-based measurements to carbon units, although that is not required here. 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 the rates of these processes are too low, this will limit the amount of food (in the form of bacteria, algae and water plants) available to organisms that consume these entities. This limitation will flow on up through the food web and constrain the 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 rates of these processes are too high. Greatly elevated primary production rates usually indicate probable algal bloom conditions (or excessive growth of plant species, including duckweed and azolla). Several deleterious effects can then occur – blocking of sunlight penetration into the water which can kill off other submerged plants, possible production of potent algal toxins and large swings in diel (over the course of 24 hours) DO. Although photosynthesizing algae can produce extremely high concentrations of DO during daylight hours, overnight, elevated respiration rates can drive the DO concentration very low, even to the point of anoxia (no dissolved oxygen in the water). Also, when an algal bloom eventually collapses, the very large biomass of labile organic material is then respired, often resulting in anoxia for extended periods. Very low (or no) DO in the water can be fatal to many organisms, resulting in fish kills and unpleasant odors. Bloom collapse is also often, but not always, coincident with release of algal toxins; hence the water becomes unusable for stock and domestic purposes as well.

After allowing for seasonal variability, sustainable rates of primary production for a given system will primarily depend on the characteristics of the aquatic ecosystem being considered. Streams with naturally higher concentrations of nutrients (e.g. arising from the geology), especially those with very open canopies (hence lots 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. The important point is that the ecology of each stream will develop based (partly) on the rates of these fundamental processes. 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.

Hypotheses

The following hypotheses were developed specifically related to the possible impact of environmental watering on the rates of stream metabolism and were derived from a combination of the work of Vink et al. (2005) on impacts of irrigation releases on the middle reaches of the Murrumbidgee River, the predictions of the 'Flood Pulse Concept' (Junk et al. 1989) and findings from previous measurements on these streams (Watts et al. 2013b):

i) Increased flow via an environmental watering action will result in an initial decline in Gross Primary Production (GPP) due to the enhanced turbidity from that higher flow causing light limitation of photosynthesis.

ii) Following that initial decline, GPP will increase to a higher rate than pre-watering action levels due to an influx of bioavailable nutrients.

iii) There will be an initial decline in Ecosystem Respiration (ER) followed by a rapid increase as more labile organic carbon is introduced into the stream channel during environmental watering.

iv) Changes in stream metabolism will be relatively small (< 5 mg O_2/L/Day) unless the increased flow results in inundation of backwaters and perhaps the floodplain.

Methods

Rates of primary production and respiration can readily be estimated by continuously recording DO, temperature and ambient light (known as *photosynthetically active radiation* or PAR) over periods of many months under a range of meteorological conditions and flows (Grace and Imberger, 2006). Rates are calculated for each day so that the influence of flow, cloud cover and season can be assessed. A typical daily DO trace is shown in Figure 51. The figure illustrates how DO changes in a sinusoidal pattern over 24 hours, with DO increasing after sunrise, reaching a peak in late afternoon (due to photosynthesis throughout daylight hours) and then declining overnight, as ecosystem respiration (which consumes DO) continues 24 hours a day. Estimation of these rates must also include one additional factor – reaeration, which is the physical movement of DO across the air water interface. If the water contains less DO than it can hold (100% saturation), such as overnight when respiration consumes DO, then more oxygen will diffuse from the atmosphere into the water.

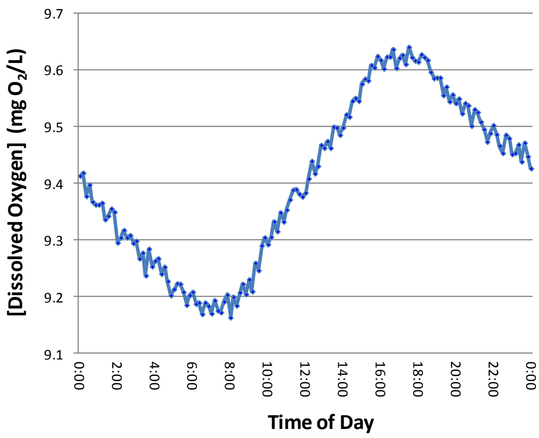


Figure 51. Typical Dissolved Oxygen Concentration Profile over a 24 hour period. This unsmoothed data was from Yallakool Creek on the 6th October, 2013. The signal may appear noisy but is actually very stable given the small diurnal change in concentration.

Battery-powered ZebraTech data sondes (DO Loggers) were deployed mid-stream, with one sonde at either end of each of the four focus reaches separated by 3-5 km of stream channel. Each sonde was set to measure and log dissolved oxygen concentration and water temperature every 10 minutes. Approximately every month, data were downloaded from the sondes, which were then recalibrated to ensure high quality data. PAR data were also recorded every 10 minutes on loggers placed in open fields near each of the stream sites. The metabolic parameters, gross primary production and ecosystem respiration, plus the reaeration rate were calculated for each day using the daytime regression method described by Atkinson et al. (2008), implemented in the Bayesian 'BASE' model (Grace et al. 2014). Only data where the diel curve reasonably matched the shape shown in Figure 51, and the 'BASE' model produced excellent fits to these diel curves, were included in the subsequent analysis of the metabolic rates.

Unlike previous deployments in 2011-2013, some major problems were experienced by many of the sondes post-Christmas 2013. Whilst still the subject of ongoing discussions between the project team and suppliers, it appears that a more 'vigorous' cleaning approach may be required to prevent buildup of biofilms on and near the membrane. This buildup is the likely cause of the highly erratic day-time DO signals recorded by many loggers. This meant that there were significant periods – especially from February through to the end of April – when there was almost no usable data. This unfortunate outcome constrained assessment of any 'after' effects from the watering actions.

Statistical analyses were performed to examine the hypotheses. As daily metabolic rates are affected by weather and water temperature, the potential impacts of environmental watering actions were assessed by determining whether there was a change in the *difference* in daily rates between the impacted streams (Yallakool or Colligen Creeks) and the control streams (Wakool River or Little Merran Creek). For example, the 'pre-watering action' difference in GPP between Yallakool Creek and Wakool River was calculated each day. This 'before' data was then compared to the differences in GPP in the same two streams 'during' the watering action. Unlike 2012-2013, the combination of the extended nature of the elevated flows in Yallakool Creek or the late summer watering action in Colligen Creek (as part of the Niemur River water quality improvement action) and the aforementioned difficulties with the DO sondes meant that there was no 'after' comparison possible.

For all planned comparisons, the Student t-test was used to test for statistically significant differences (at $p < 0.05$) between the 'before' and 'during' data sets assuming that the Shapiro-Wilk normality requirement was met in the two data sets (at $p < 0.05$). If normality conditions were not met, then a Mann-Whitney Non-Parametric Rank Sum Test was performed.

Results

Metabolic Rates in the four study streams

The rates of both primary production and respiration remain relatively constant over the entire study period (Figures 52 to 55). There were some longer term (seasonal) trends where both primary production and respiration rates increased during summer due to warmer water temperatures, and in the case of primary production, more hours of sunshine. At no stage between September and April did any of the loggers record very low dissolved oxygen concentrations (< 20% DO saturation), even during and immediately after the watering actions. For three of the four focus rivers (Colligen Creek, Wakool River and Yallakool Creek), the %DO saturation barely dropped below 70% saturation, while the other river (Little Merran Creek) only very occasionally fell below 60%. At no point in this period did any river fall below 50% saturation. These findings are consistent with the organic matter characterization results (section 6.7). None of these watering actions resulted in water spreading out onto the floodplain, remaining for days-weeks and then return, which is the most common scenario for development of 'black water' (high dissolved organic carbon and very low or no dissolved oxygen).

Table 22 provides summary data for the gross primary production (GPP) and ecosystem respiration (ER) rates for each river. The table lists the lowest and highest rates found, plus the median value. The P/R ratio refers to the balance between primary production rates and ecosystem respiration rates. A value for this ratio of < 1 indicates that more organic carbon is being consumed in the study reach than is being produced by primary production (photosynthesis).

Table 22. Summary of primary production (GPP) and ecosystem respiration (ER) rates for the four study rivers (combined upstream and downstream sonde data), September 2013 - April 2014.

	Colligen (n = 221)			Merran (n = 251)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.62	0.76	4.15	1.37	0.48	2.92
ER (mg O_2/L/Day)	2.36	0.92	7.45	2.36	0.56	8.09
P/R	0.66	0.28	1.35	0.56	0.15	2.48

	Wakool (n = 220)			Yallakool (n = 194)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.59	0.46	5.47	1.17	0.39	2.83
ER (mg O_2/L/Day)	2.71	0.65	12.10	1.85	0.58	10.06
P/R	0.53	0.25	1.76	0.48	0.17	2.63

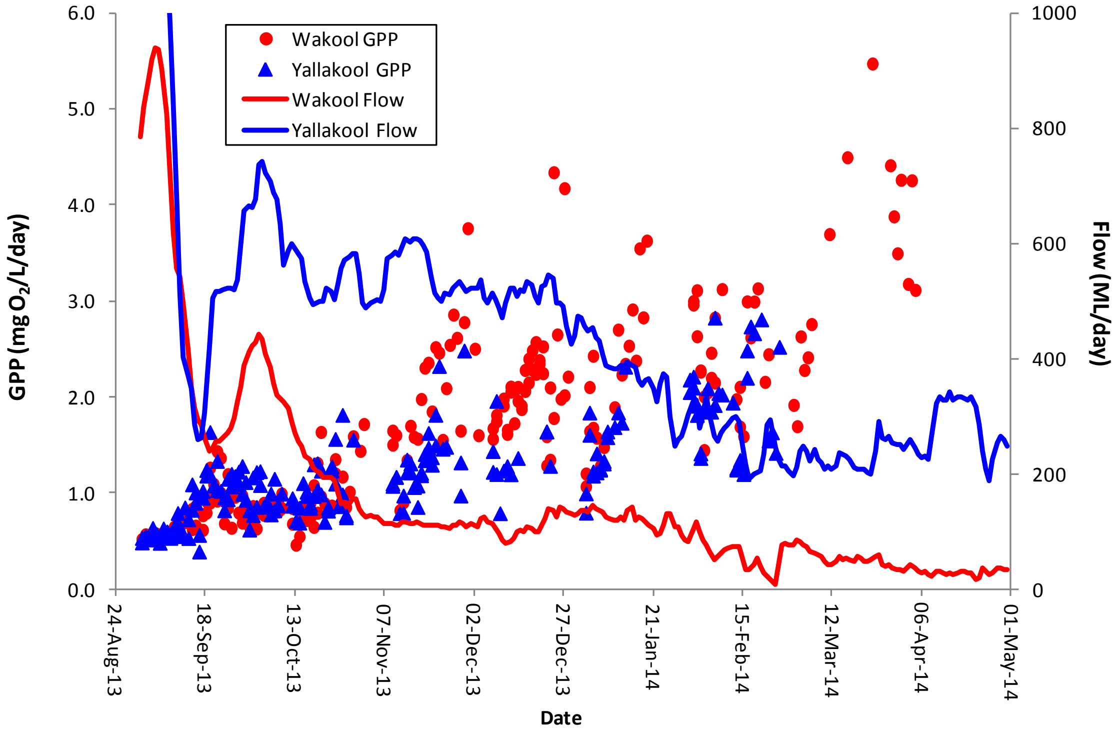


Figure 52. Gross Primary Production (GPP) rates and stream discharge for the Wakool River and Yallakool Creek from September 2013 through April 2014. The paucity of data from mid-February onwards is due to problems with the DO sondes.

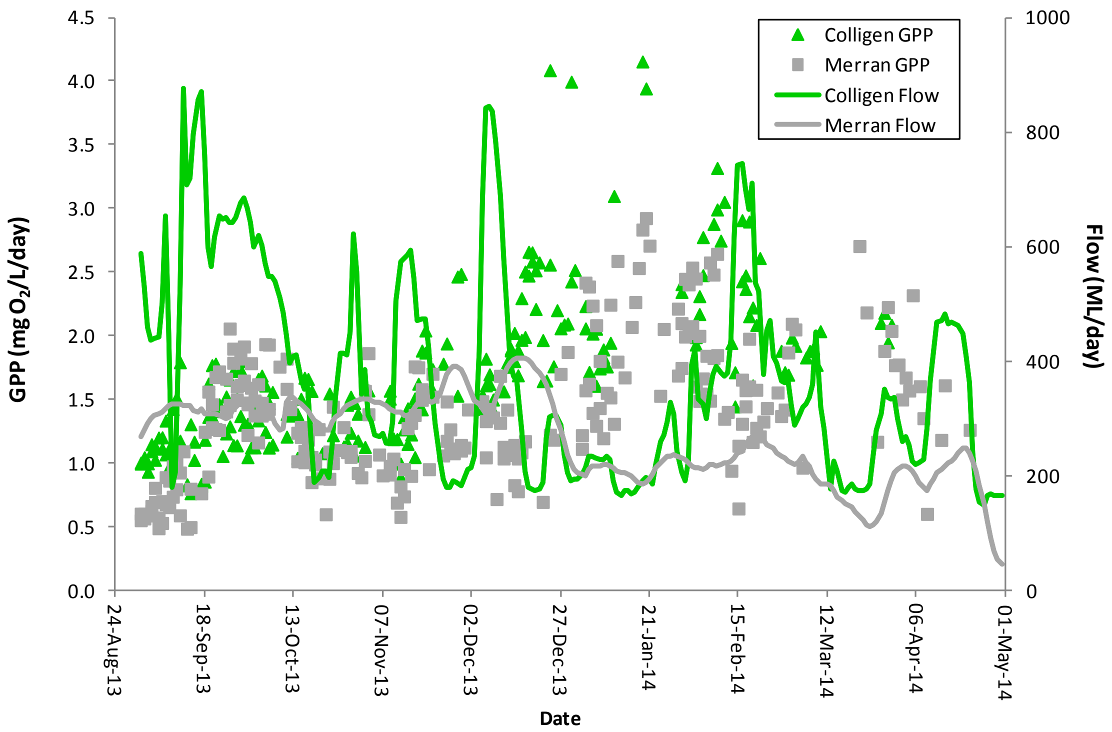


Figure 53. Gross Primary Production (GPP) rates and stream discharge for Colligen and Little Merran Creeks from September 2013 through April 2014. The paucity of data from Colligen Creek from mid-February onwards is due to problems with the DO sondes.

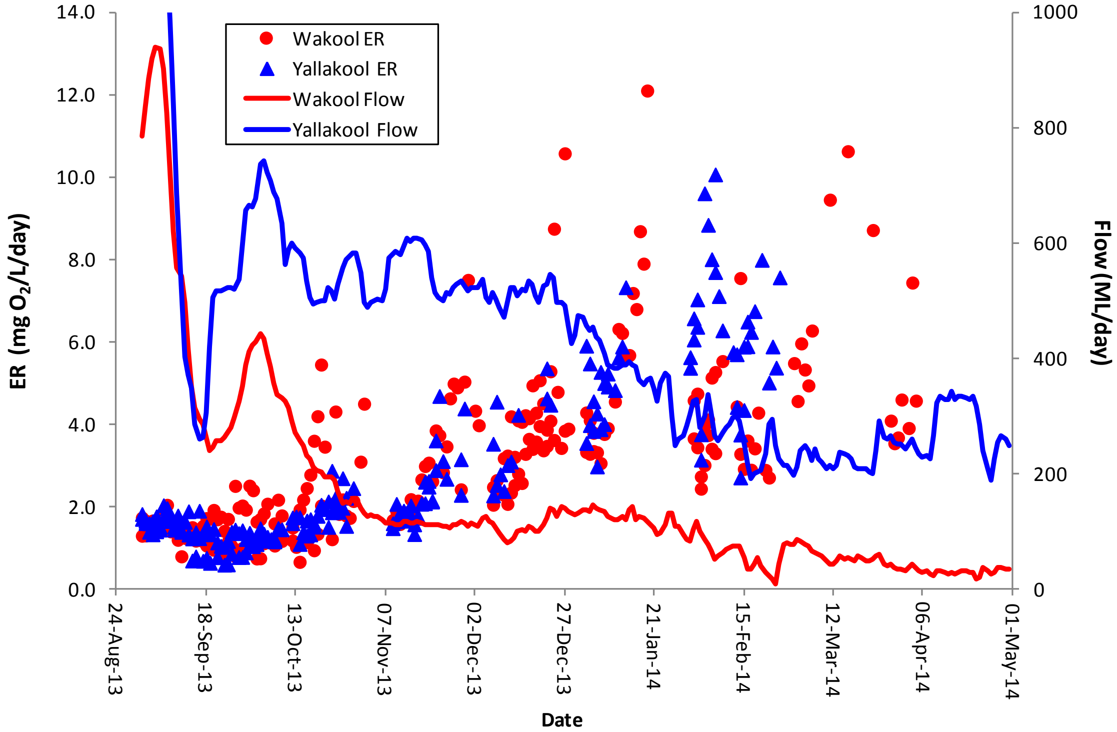


Figure 54. Ecosystem Respiration rates and stream discharge for the Wakool River and Yallakool Creek from September 2013 through April 2014. The paucity of data from mid-February onwards is due to problems with the DO sondes.

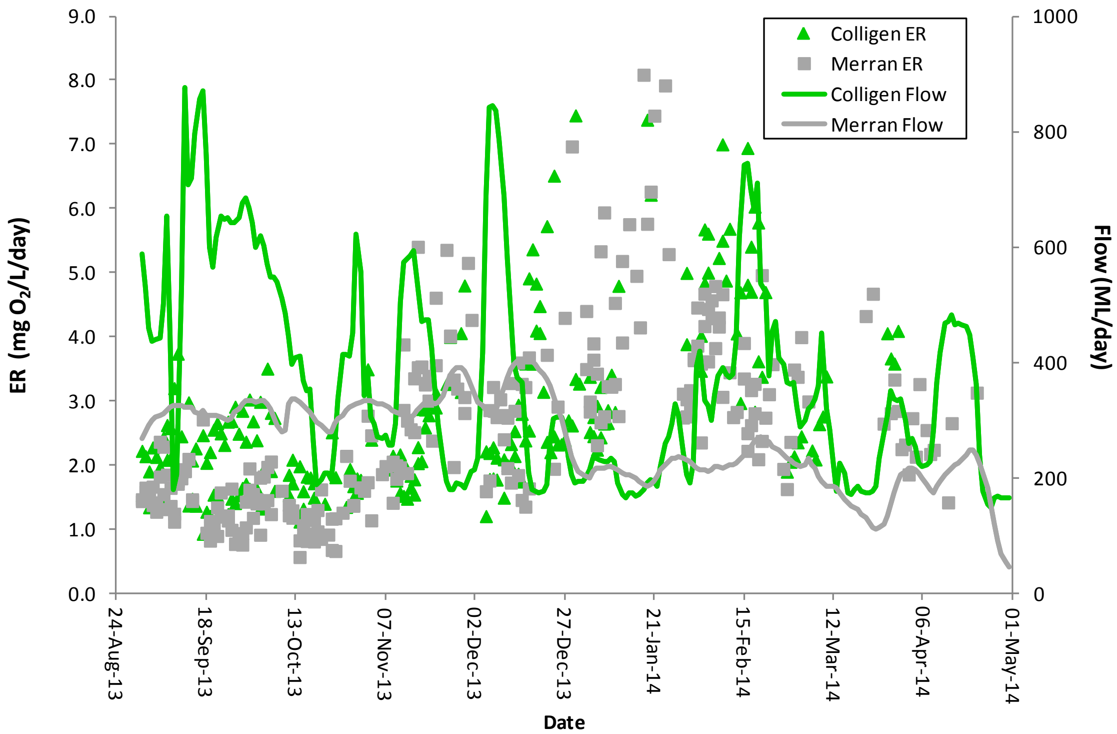


Figure 55. Ecosystem respiration rates and stream discharge for Colligen and Little Merran Creeks from September 2013 through April 2014. The paucity of data from Colligen Creek from mid-February onwards is due to problems with the DO sondes.

The gross primary productivity and ecosystem respiration rates in the four focus rivers (Table 22) are extremely similar between the four rivers, with median primary production rates and median respiration rates differing by less than a factor of 2 between the four rivers. This is largely unsurprising given the similarity in land forms, land use, the sizes of the rivers and that they are all in the same region. The median values for the P/R ratio (0.48 – 0.66; 0.44 – 0.77 in 2012-2013) indicate that for most of the time, these rivers are net heterotrophic (P/R < 1) implying that there must be another source of organic carbon fuelling respiration. Such carbon additions generally come from further up in the catchment or have fallen in/been washed in from riparian vegetation. It is pertinent to note though that primary production within the stream channel, as measured here by GPP, is also an extremely important contributor to organic carbon supply (which is the food sustaining higher organisms in the food web).

Figure 56 clearly demonstrates that there was also a very large variation in GPP at any particular light value, coupled with the expected increase in GPP with increasing daily light flux. Similar results were obtained for GPP-PAR relationships for Colligen Creek (slope = 0.055, R^2 = 0.28, p(slope) < 0.0001) and Little Merran Creek (slope = 0.025, R^2 = 0.14, p(slope) < 0.0001) over the same period. Consistent with the findings from 2012-2013, this variability indicates that although sunlight is obviously essential for photosynthesis, it is generally not the major factor limiting primary production in these streams. If that were the case, a much stronger (and less scattered) relationship would be expected between Daily PAR and GPP. This finding suggests another factor or factors must be contributing to the measured GPP rates. One of these important factors is the biomass of organisms capable of photosynthesis. These are typically divided into three major groups: the macrophytes, biofilms and floating algae (phytoplankton). Biofilms are likely to be the dominant primary producer in most reaches of these streams, especially in the shallow, marginal zones of the stream where sunlight easily penetrates through the water. In the water column, photosynthesis can only occur when there is sufficient light. When the water is turbid ('cloudy' from suspended colloidal particles), this limits how far into the water light can penetrate. The point at which photosynthesis is no longer biologically viable is known as the 'euphotic depth', Z_{eu}. This parameter can also be estimated from simple relationships derived from empirical data. As a relationship is not available for these rivers, we used information for the Darling River, a larger, turbid, lowland river in northern NSW (Oliver et al. 1999). This empirical equation is $Z_{eu} = 4.6 / (0.04 \times \text{Turbidity} + 0.73)$. Table 23 lists the euphotic depth for each river based on the regular, fortnightly measurements of turbidity taken during this project. For each trip turbidity was measured at 5 locations. Data has been pooled for each site. The euphotic depths indicate that for all reaches deeper than Z_{eu}, insufficient light will reach the sediment surface to allow macrophytes and biofilms to grow. Hence biofilms will be restricted in range to shallower regions on the edges of the stream. This will decrease the overall primary productivity of the rivers. For example, in Little Merran Creek, the stream with the highest median turbidity (83 NYU), all areas with water depth greater than 1.14 m lack light at the sediment surface, hence preventing benthic plant growth, even assuming all other factors (substrate, nutrient concentrations, lack of scour) are conducive to such growth. The lack of biofilms and plants in these still relatively shallow reaches will result in depressed primary production compared to the same stream environment with less turbidity. In turn, this will result in less organic matter in the surficial sediments, thereby diminishing ecosystem respiration rates.

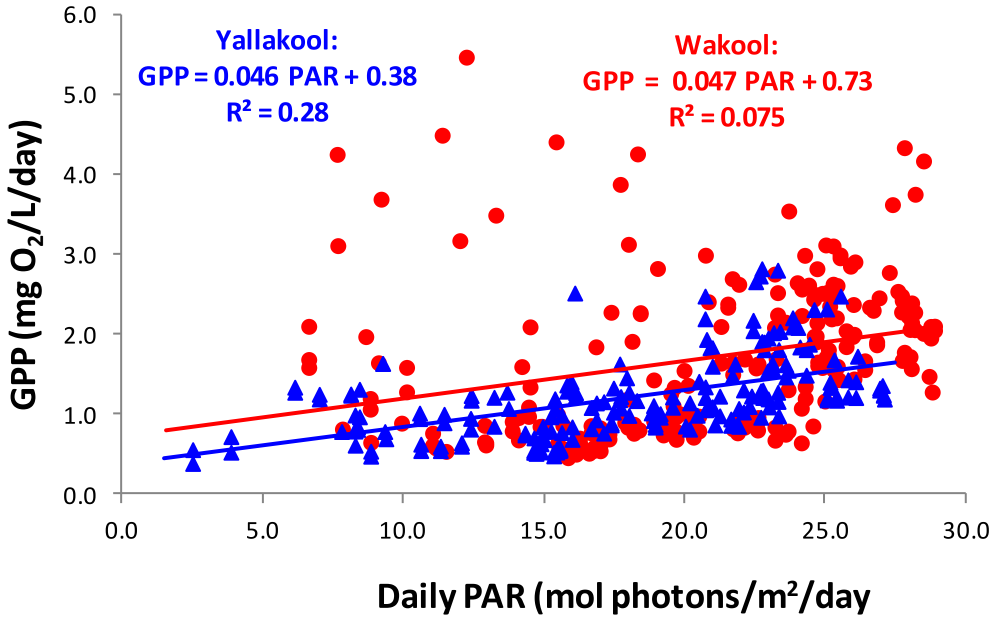


Figure 56. Linear relationships between daily light (as PAR) and gross primary production for the Wakool River and Yallakool Creek. Collated data from September 2013 through April 2014. P-values for the slope term: Wakool < 0.0001; Yallakool < 0.0001

Table 23. Summary of stream turbidity (NTU) plus the median euphotic depth, Z_{eu}, for the four study rivers, August 2013 - April 2014.

	Colligen	Little Merran	Wakool	Yallakool
n	80	85	85	77
Median	57	83	51	58
Min	7	41	15	7
Max	109	151	109	131
Z_{eu} (m)	1.53	1.14	1.66	1.51

It was expected that increasing water temperatures associated with seasonal change would result in faster physiological rates in organisms and hence greater rates of GPP and ER. The relationship between mean daily water temperature and the rate of daily gross primary productivity (Figure 57) confirms this hypothesis. The figure shows data for Colligen Creek, but the other three streams were similar. Also not shown, but displaying similar positive relationships with mean daily water temperature, are the rates of ecosystem respiration in the four rivers. The slopes and coefficients of variation (R^2) for all eight plots are given in Table 24. All four coefficients of variation (R^2 = 0.43 - 0.71) indicated a moderately strong, positive relationship between ecosystem respiration and mean daily water temperature, but again suggesting that other factors are also important in determining these rates.

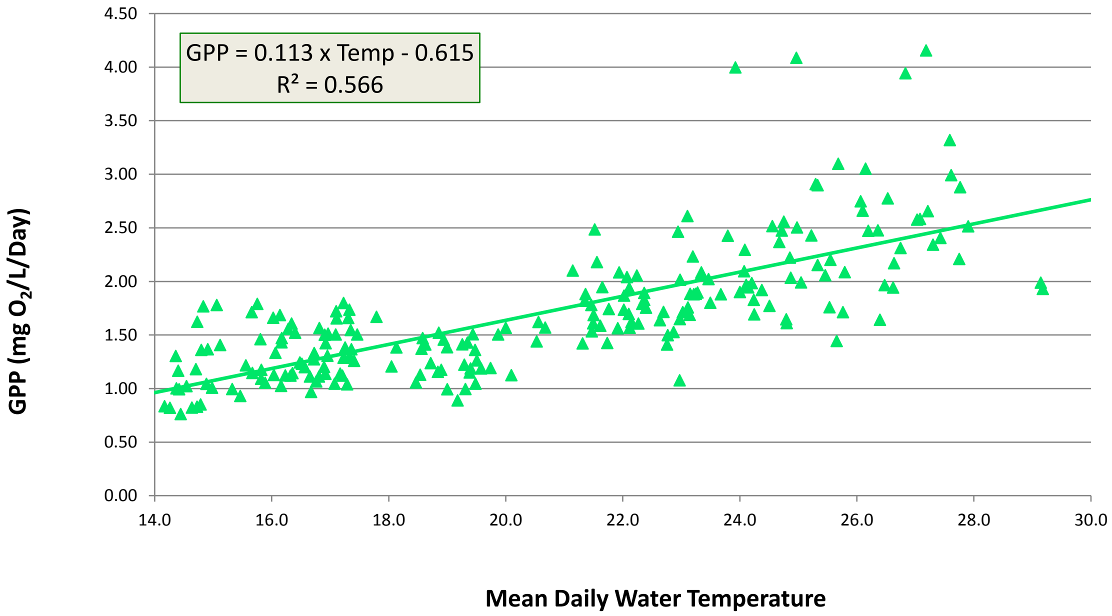


Figure 57. Linear relationship between daily mean water temperature and gross primary production for Colligen Creek. Collated data from September 2013 to April 2014. P-value for slope < 0.0001.

Table 24. Temperature Dependence of GPP and ER Rates for the four study streams.

		GPP *vs* Temperature		ER *vs* Temperature	
Stream	**n**	**Slope**	**R^2**	**Slope**	**R^2**
Colligen	221	0.113	0.57	0.213	0.43
Little Merran	251	0.069	0.30	0.233	0.46
Wakool	220	0.161	0.51	0.316	0.46
Yallakool	194	0.092	0.52	0.427	0.71

Note: All slopes were significantly different from 0 (p-value < 0.0001)

The temperature dependence of the GPP and ER rates exemplified in Figure 57 and determined by linear regression (Table 24) indicates a potential problem during hot, dry summers (although not realised in this past summer). Higher water temperatures automatically mean lower dissolved oxygen solubilities. By itself this is rarely problematic as solubility is 6.4 mg O_2/L at a water temperature of 40^{o}C, well above the ANZECC trigger value of 4.0 mg O_2/L. However, as temperature increases, the net drawdown of O_2 also increases as respiration rates increase more rapidly with temperature than GPP (Table 24). This net drawdown exacerbates the lower O_2 solubility and increases the likelihood of suboxic, even anoxic conditions (this occurrence was the trigger for the water quality watering action conducted for the Niemur River with flows via Collagen Creek in February 2014). Fortunately, physical reaeration by diffusion of O_2 from the atmosphere will partially counteract this potential for developing very low dissolved oxygen concentrations. It is highly pertinent to note that reaeration across the air-water interface is significantly higher from a moving water column than from a still one, especially if the current increases water turbulence. Thus maintenance of even slow flow rates, for example by periodic watering actions, is far preferable to standing water in the streams as a means of addressing potential anoxia during hot, dry spells. Note that this is a different scenario to blackwater events, where rapid oxygen drawdown is brought about by direct contact of water with high levels of organic carbon on the floodplain during the warmest times of the year.

Another key factor controlling the rate of photosynthesis is the concentration of nutrients in the water. As was also found previously in 2011-2013, the bioavailable nutrient concentrations in the water column of each of the streams in this study were very low (see section 6.6). In most cases, the nitrate (NO_x) concentration was below the detection limit of 1 µg/L (to enable statistical analyses, those samples with concentrations less than this detection limit were assigned a nominal concentration of half that amount i.e. 0.5 µg/L). These very low nutrient concentrations are the major constraint on the overall primary productivity of the rivers. This nutrient limitation means that large algal blooms are unlikely in these streams. As seen regularly with algal blooms in rivers such as those in the Darling River system in northern NSW, high turbidity and hence low light penetration into the water is *insufficient* to prevent large blooms if nutrient concentrations are high. The high turbidity simply favours species such as the toxic cyanobacteria (blue-green algae) *Anabaena*, which can alter its position in the water column to move to the surface and obtain sufficient light to grow prolifically. The major difference between the rivers in the Edward-Wakool system and those in the Darling and other regions, is the very low nutrient concentrations which greatly limit algal proliferation. Hence management focus in the study region should continue to include nutrient minimization strategies.

When considering possible nutrient limitation, the form of the nutrient is critically important. Measurements of total concentrations of nitrogen and phosphorus include all N and P in that sample. However, only the bioavailable fractions, nominally FRP for phosphorus and the sum of ammonia and NO_x for nitrogen, are in the form readily taken up by primary producers, whereas other N and P species can be relatively recalcitrant (not suitable for assimilation into plant biomass). Table 25 shows several salient features of the nutrient concentrations in the study streams over the period August 2013 to April 2014: i) the median concentrations of the bioavailable forms are extremely low by both national and international standards for lowland rivers; ii) As noted in the Water Quality section of this report (section 6.6), the Total P and Total N concentrations are frequently above the ANZECC Water Quality Guidelines; and iii) typically only 5-6% of the phosphorus in the water column is bioavailable and just 1% (or less) of the nitrogen is bioavailable. This highlights a general finding in turbid waters, that the use of total nutrient concentrations, rather than bioavailable concentrations, can provide extremely misleading information about the potential of a water body to suffer adverse effects from ostensibly high nutrient levels.

Table 25. Median Bioavailable and Total Nutrient Concentrations and the fraction of Bioavailable P & N in the four study streams from August 2013 through April 2014.

	Nutrients (µg/L of N or P)							
River	**n**	**Ammonia**	**FRP**	**NO_x**	**Total P**	**Total N**	**% Bioavailable P**	**% Bioavailable N**
Colligen	17*	2.0	3.0	< 1	50	480	6.0	0.6
Little Merran	17*	2.5	3.0	2.0	55	460	6.0	1.1
Wakool	17*	2.0	3.0	1.0	50	485	5.0	0.6
Yallakool	17*	2.0	3.0	< 1	50	470	5.0	0.7

* Sampled on 17 separate occasions with typically 4 replicates in each sample.

The narrow range of ecosystem respiration rates identified in Table 24 can be largely explained by a combination of two factors: i) the remarkably constant concentrations of TOC (and DOC) in the water column (shown in Table 26) resulting largely from the constraint of elevated flow levels to within the main channels; and ii) the constancy of the gross primary productivity rates, which would yield an approximately constant supply of leachate material for microbial respiration.

Table 26. Summary statistics for Total and Dissolved Organic Concentrations in the four study streams from August 2013 through April 2014.

Parameter		Colligen Ck	Little Merran Ck	Wakool R	Yallakool Ck
DOC (mg C/L)	Median	3.4	3.5	3.6	3.3
	Mean	3.6	4.0	3.7	3.5
	Std Dev	1.0	1.2	1.0	1.0
	n	64	68	68	63
	Max	6.1	6.3	6.5	6.4
	Min	2.1	2.6	2.5	1.8
TOC (mg C/L)	Median	3.6	3.75	3.8	3.5
	Mean	3.9	4.2	4.0	3.8
	Std Dev	1.0	1.2	1.0	1.0
	n	63	68	68	63
	Max	6.4	7.1	6.7	6.5
	Min	2.5	2.7	2.7	2.5

The Effect of Watering Actions on the Metabolic Rates in the four focus rivers

The influence of watering actions on the rates of GPP and ER has been determined by examining these rates *before* and *during* each of these events. As noted earlier, the extended duration of the combined Cod and Perch watering actions in Yallakool Creek, and the late summer water quality action in Colligen Creek, coupled with sonde misbehaviour meant that there was insufficient 'after' data to make any assessment of 'post action' impacts. The rationale behind this 'before' and 'during' approach is to isolate the effect of the watering action from weather, seasonal and water temperature effects, all of which are assumed to act equally on both the 'Impact' rivers (Yallakool or Colligen Creeks) and the 'Control rivers' (Wakool River or Little Merran Creek). The results of all comparisons are presented in Table 27. For illustrative purposes, two sets of results from this Table are presented as Box Plots in Figures 58 and 59.

Previous studies over the period 2011-13 have provided different perspectives on the effects of watering actions on rates of ecosystem respiration and gross primary productivity. During 2011-12, there was an indication of enhanced rates of GPP and ER after watering actions, but this behaviour was not strongly evident during 2012-2013, in contrast to the initial hypotheses.

Although the statistical analysis summarized in Table 27 indicate that there were statistically significant differences in metabolic rates between the control and impact streams induced by the watering actions on several occasions, the direction of the change was variable for GPP and in all cases the magnitude of these differences was very small. From this table, all *statistically* significant changes were < 1 mg O_2/L/Day. This finding is consistent with the fourth hypothesis that predicted changes would be < 5 mg O_2/L/Day unless there was significant inundation of backwaters and the floodplain.

Of the four comparisons of ecosystem respiration in Table 29, both Yallakool Creek results showed an enhanced rate of ER in this stream compared to the controls during the extended watering action. ER appeared to be enhanced in Colligen Creek as well, but these changes were either exceptionally small or highly variable, resulting in a lack of statistical significance (using the conventional $p < 0.05$ as the significance criterion). This preponderance of ER enhancement is largely in line with the hypothesis that a fresh would increase ER by introducing new organic matter. The very small magnitude of the enhancements is entirely consistent with the DOC (and TOC) measurements and the finding that the organic carbon that was measured was relatively non-labile (hence more difficult, and slower, to respire).

The results were less consistent for GPP and seemed to depend on which stream was used as the control. With the Wakool River as the control, both Yallakool Creek and Colligen Creek exhibited a suppression of GPP during the watering actions, whereas with Little Merran Creek as the control, there was an enhancement on GPP. The key point however, is that these differences, although statistically significant, were all extremely small (< 1 mg O_2/L/Day). A difference of e.g. 3-5 mg O_2/L/Day would indicate an *ecologically* important change in rates.

The most important finding of this statistical analysis is that any suppression or enhancement of GPP or ER was very small; typically limited to within the range ± 1 mg O_2/L/Day (Figures 58 and 59). It was noted earlier that the metabolic rates in these streams are relatively low (but 'normal') compared to other streams around the world and it is apparent that these freshes are sometimes causing small fluctuations in these 'low' rates. Freshes that result in water moving onto the floodplain and then returning to the stream channel may have a much larger impact on gross primary production and ecosystem respiration, but this was unable to be examined during the 2013-14 period as there were no bankfull or overbank flows due to the need for water managers to limit the risk of potential third party impacts.

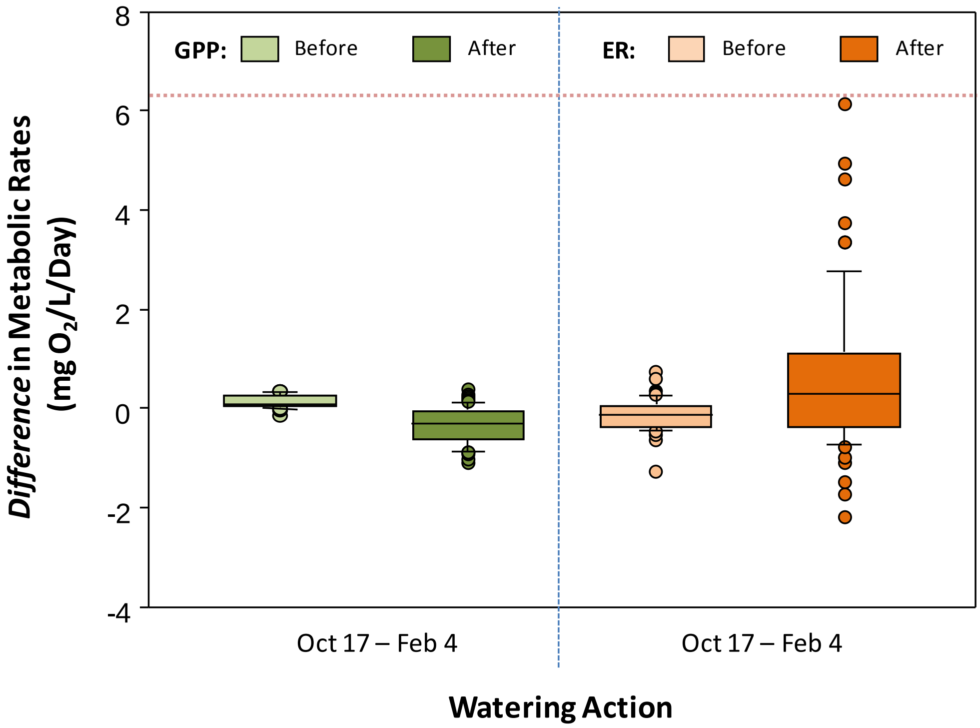


Figure 58. Box plots showing the effect of the combined watering action on metabolism in Yallakool Creek. A negative value on the Y-axis indicates that the rate in the control stream (Wakool River) was higher than in Yallakool Creek. The boxes represent the data range 25th to 75th percentile, with the 'middle' line in the box being the median. The "whiskers" indicate 10th and 90th percentiles in the data. Outliers are shown as circles.

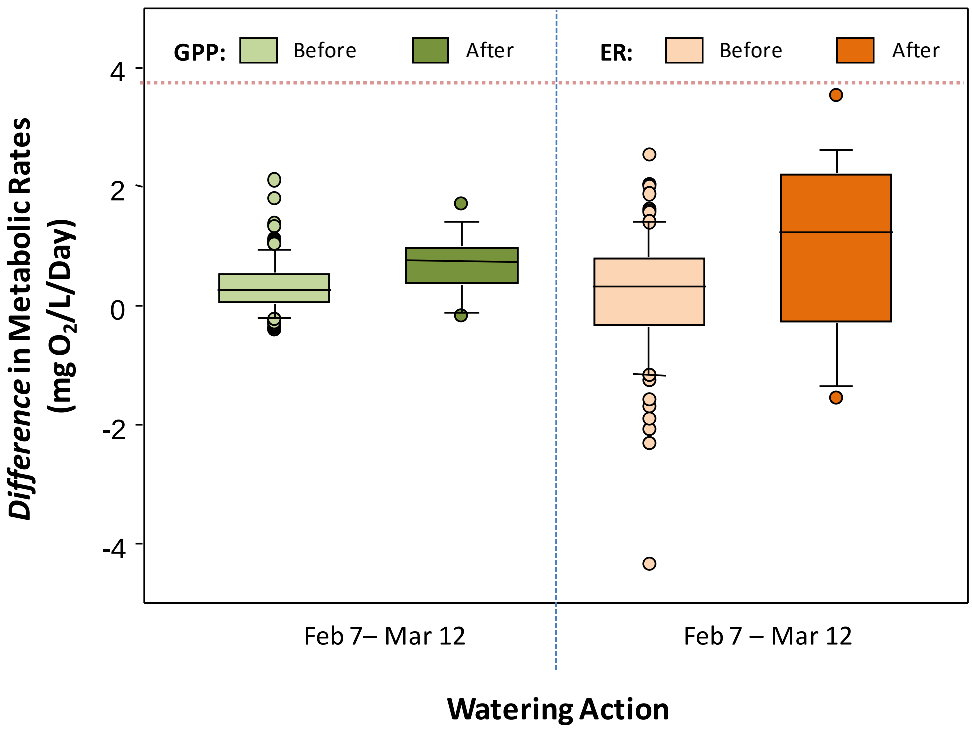


Figure 59. Box plots showing the effect of the watering action on metabolism in Colligen Creek. A negative value on the Y-axis indicates that the rate in the control stream (Little Merran Creek) was higher than in Colligen Creek. The boxes represent the data range 25th to 75th percentile, with the 'middle' line in the box being the median. The "whiskers" indicate 10th and 90th percentiles in the data. Outliers are shown as circles.

It is clear that GPP is strongly constrained by bioavailable nutrient concentrations and that the watering actions were not of sufficient magnitude to entrain higher nutrient concentrations (e.g. from rewetting the floodplain). Neither of the streams receiving environmental water (Yallakool Creek nor Colligen Creek) contained higher nutrient concentrations at any stage (before, during and after the watering action) than the other streams being monitored. One caveat to this statement is that water quality sampling, including nutrient and organic carbon measurements, was performed fortnightly (which provides an excellent synopsis of water quality), but any significant increase in concentrations after inundation of previously disconnected waters would almost certainly occur over a period of only a few days (the 'first flush' phenomenon).

Figure 60 depicts the difference in GPP and ER between Yallakool Creek, which experienced the watering actions, commencing on October 17, and Wakool River, representing the control site. The first hypothesis suggests that there will be an immediate decline in GPP following the additional water (marked by the edge of the blue shading in the figure). GPP did decline (the purple circles falling below '0' on the Y axis) but not for at least 10 days after the onset of the watering action. From about three weeks into the action, GPP was suppressed compared to the control for at least two months. This finding contradicts hypothesis two, which suggested that there would be a subsequent increase in GPP following the initial decline, brought about by higher nutrient concentrations.

The third hypothesis that there would be a rapid decline in ER followed by an increase due to the influx of labile organic carbon is partially supported by the data shown in Figure 60. The brown diamonds representing the ER difference between Yallakool Creek and the Wakool control did rapidly fall below 0 (over a few days) as the watering action commenced; following this initial decline, ER rates were on average above those in the control stream for the duration of the period shown. However, these small changes were not associated with any dramatic increase in lability of the organic carbon in the stream. In support of these hypotheses, but with too few data points to test statistically with any confidence, it is interesting to note that both the GPP and ER differences dropped below zero and remained there for a week following the additional water in Yallakool Creek associated with the perch pulse flow starting on the 9th November.

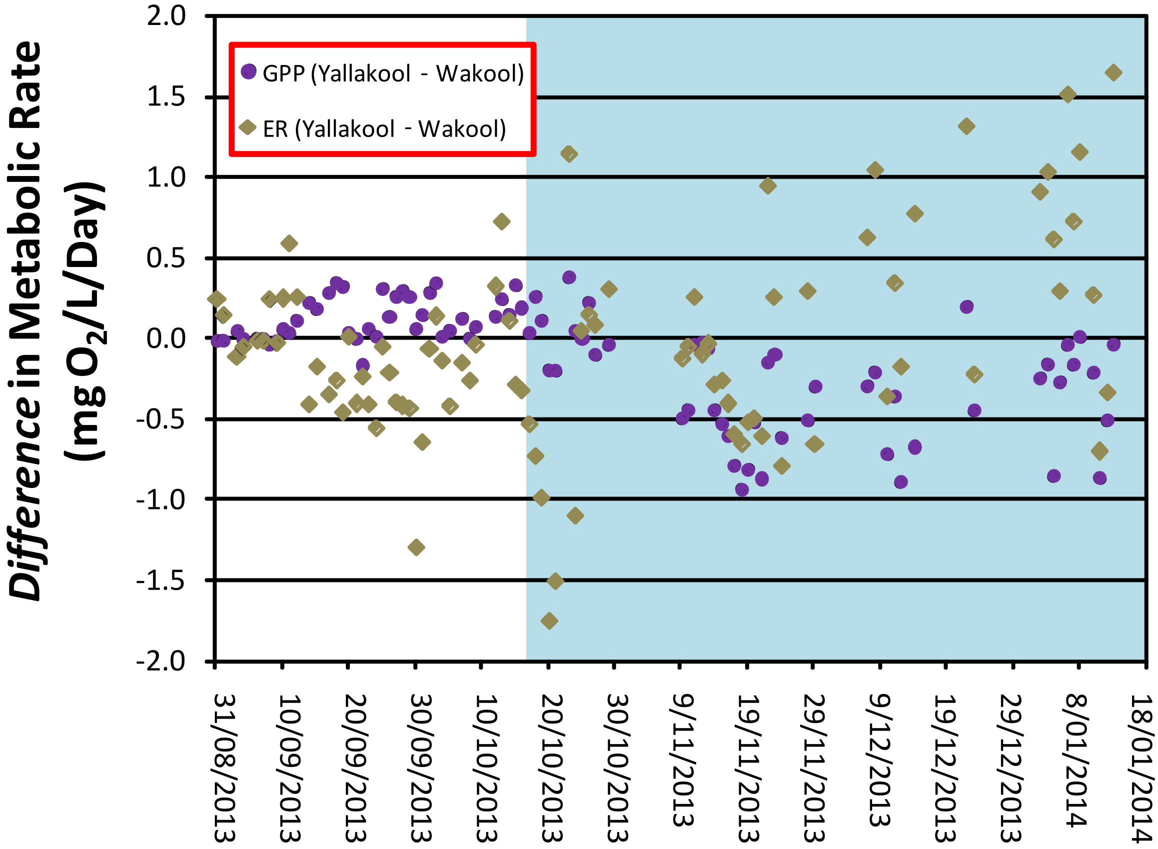


Figure 60. The differences in metabolic rates between Yallakool Creek experiencing the watering actions for cod and perch (over the period designated by the light blue shading) and Wakool River as the control site.

The rationale behind the first hypothesis is that a new source of water, which includes through a watering action, will result in elevated in-stream turbidity. Turbidity data from the routine monitoring program are plotted for the four streams used in metabolism measurements in Figure 61. Contrary to the hypothesis, the advent of additional flow in Yallakool Creek and then in Colligen Creek did not result in any large increase in turbidity, especially when compared to the behaviour in the control streams.

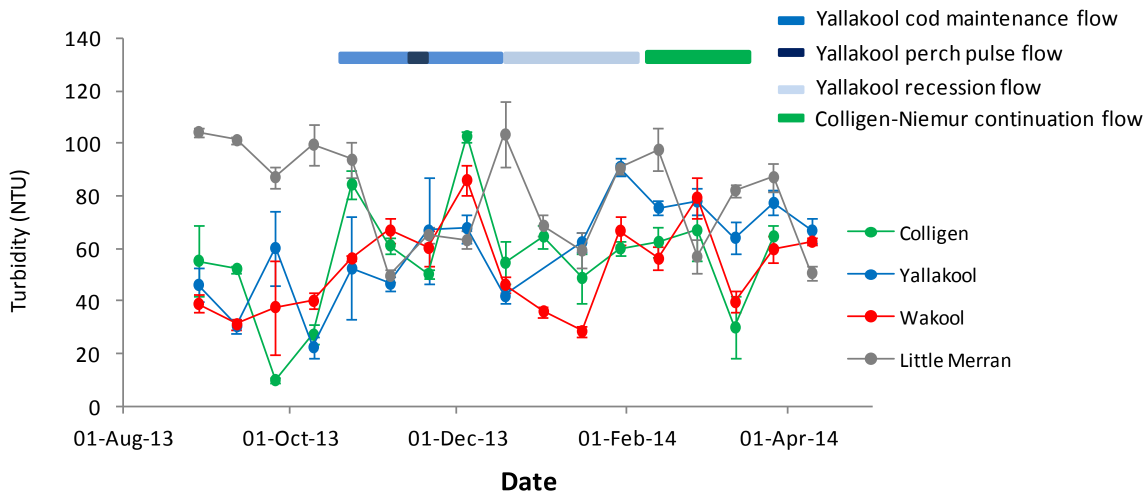


Figure 61. Mean (±SE) Turbidity values (NTU) in Yallakool Creek, Colligen Creek, Wakool River and Little Merran Creek between August 2013 and April 2014. Blue and green bars represent the start and finish dates of environmental watering actions.

These outcomes, including the lack of a major response in metabolic parameters to watering actions, could be seen as largely positive, as these watering actions did not increase the risk of either algal blooms or anoxic events. However, given these very small, and probably ecologically insignificant, changes in metabolic rates, it is not yet possible to determine whether the current rates of organic carbon (i.e. food) production are sufficient to help re-establish the fish populations to those prior to the devastating black water event in late 2010. As noted in the 2012-2013 report (Watts et al. 2013b) and further in 2013-14, there has been some recovery in the apex (fish) predators, but whether this recovery is constrained by food resources is not yet clear. In addition, the effects of an overbank flow on subsequent organic matter production remains unknown. It is expected that such an event would yield much higher nutrient and organic carbon concentrations to stimulate metabolism, but this needs to be assessed when such an event occurs. Consequently, it is strongly recommended that there is continued monitoring of discharge – metabolism – 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.

Table 27. Statistical Summary of Effects of Watering Actions on Stream Metabolism. Green shading = rate enhancement, pink = rate suppression, compared to control.

Impact River	Control River	Watering Action	Data Periods in Relation to Action		Effect on Metabolic Rates*	
			Before	***During***	**GPP**	**ER**
Yallakool	Wakool	17/10/2013 to 4/2/2014	31/8/2013 to 16/10/2013	17/10/2013 to 4/2/2014	M-W, suppression of Yallakool GPP, $p < 0.001$. 'before' median = 0.10, n = 40, 'during' median = -0.30, n = 63.	M-W, enhancement of Yallakool ER, p =0.010. 'before' median = -0.14, n = 40, 'during' median = 0.28, n = 63.
	Little Merran	17/10/2013 to 4/2/2014	31/8/2013 to 16/10/2013	17/10/2013 to 4/2/2014	M-W, enhancement of Yallakool GPP, $p < 0.001$. 'before' median = -0.23, n = 39, 'during' median = 0.04, n = 48.	M-W, enhancement of Yallakool ER, p =0.005. 'before' median = -0.05, n = 39, 'during' median = 0.58, n = 48.
Colligen	Wakool	7/2/2014 to 12/3/2014	31/8/2013 to 6/2/2014	7/2/2014 to 12/3/2014	M-W, suppression of Colligen GPP, p = 0.001. 'before' median = 0.27, n = 94, 'during' median = -0.27, n = 12.	M-W, no sig. effect on Colligen ER, p =0.932. 'before' median = -0.02, n = 94, 'during' median = 0.02, n = 12.
	Little Merran	7/2/2014 to 12/3/2014	31/8/2013 to 6/2/2014	7/2/2014 to 12/3/2014	M-W, enhancement of Colligen GPP, p =0.006. 'before' median = 0.26, n = 95, 'during' median = 0.74, n = 15.	M-W, no sig. effect on Colligen ER, p =0.050. 'before' median = 0.32, n = 95, 'during' median = 1.23, n = 15.

* 'T' = Student's two-tailed t-test; performed if the Shapiro-Wilk normality test was passed (at p = 0.05). 'M-W' = Mann-Whitney, Non-parametric Rank Sum Test; performed when normality requirements for t-test not met.

6.9. Shrimp

Photo: Freshwater shrimp *Paratya australiensis*

Key findings

- Shrimp larvae were sampled from August 2013 to March 2014 to determine if the environmental watering actions in 2013-2014 influenced the relative abundance of larval and juvenile shrimp in the Edward-Wakool river system.
- The spawning of shrimp occurred independently of the environmental watering actions.
- The rivers that received Commonwealth environmental water had fewer shrimp than the rivers that did not receive environmental water. In particular, the abundance of juvenile *P. australiensis* was significantly lower in Yallakool Creek compared to the control rivers during the Yallkool perch flow event. Thus, it appears that the abundance of *Paratya australiensis* larvae may have been negatively affected by environmental watering during their spawning season.
- Based on hydraulic modelling undertaken for a range of flow discharges, it is likely that the magnitude and timing of environmental flows watering during the 2013-2014 watering actions decreased the available slackwater habitat in Yallakool Creek that is necessary for shrimp recruitment.
- There is a need to increase the understanding of interaction between instream flows and instream habitat (see flow recommendations)

Background

Shrimp often occur in very large numbers in the Edward-Wakool system and are likely to be an important component of the food web. These shrimp are opportunistic omnivores feeding on algae, detritus and small invertebrates (Burns and Walker, 2000) and their foraging activities can play a key role in processing of organic material and nutrient cycling (Covich et al. 1999; Crowl et al. 2001, March et al. 2001). As well as being important to ecosystem function, shrimp are an important food source for native fish particularly the larger species such as Golden Perch *Macquaria ambigua*, Murray cod *Maccullochella peelii peelii* and trout cod *Maccullochella macquariensis* (Ebner 2006; Baumgartner 2007). One of the objectives of the watering Option 1 in the Edward-Wakool system is to support the condition of native fish. Given that shrimp are an important food source for native fish, an understanding of the impact of environmental watering actions on shrimp recruitment and production in the Edward-Wakool system would be invaluable.

In the Murray-Darling Basin there are two atyid species of shrimp, *Paratya australiensis* and *Caridina mccullochi*, and one palaemonid species, *Macrobrachium australiense*. Previous studies have shown that the distribution and abundance of *C. mccullochi* and *M. australiense* may be affected by altered flow regimes, whereas *P. australiensis* seems to be more tolerant (Richardson et al. 2004). This relationship is thought to be linked to the availability of suitable slackwater habitats during their spawning period (Richardson et al. 2004). Slackwaters act as an important nursery habitat for larval shrimp by providing refuges from current and energetic advantages during a key stage of their development (Humphries et al. 2006; Price and Humphries 2010). Flow regime has the ability to alter the size, availability and permanence of slackwaters (Bowen et al. 2003; Price et al. 2013), thus environmental watering has the potential to affect the recruitment success of shrimp.

The aim of this component of the study was to determine if the environmental watering actions in 2013-2014 influenced the relative abundance of larval and juvenile shrimp in the Edward-Wakool river system.

Hypothesis

The abundance of shrimp larvae and juveniles in the rivers that received environmental water will differ from the rivers that did not receive environmental water. The effects of the environmental watering on shrimp abundance will be influenced by how the environmental freshes influence the availability of slackwaters. Shrimp abundance will be higher in rivers that have more permanent and larger areas of slackwater.

Methods

Shrimp larvae and juveniles were sampled in addition to larval and juvenile fish using quatrefoil perspex traps containing bioluminescent light sticks (see larval fish methods in section 6.3). Three traps were set at five sites within each of the four rivers (15 traps in total per river). Traps were deployed at random along the littoral edge at each site at dusk, and retrieved the following morning (7:00-9:00am). All shrimp collected from the light traps were preserved in 90% ethanol and returned to the laboratory for processing.

Data analysis

The distribution of the shrimp abundance data was examined and a generalised linear model with negative binomial distribution and a log-link function was used to determine whether abundances of larvae, juveniles of each species differed between rivers and among sampling occasions. Pairwise tests based on estimated marginal means were conducted to determine where significant differences occurred. Generalised linear models were performed using SPSS Version 17 (SPSS Inc., Chicago, IL, U.S.A.).

An asymmetrical BACI (before-after, control-impact) (Underwood 1991) statistical design was used to test the effect of specific 2013-2014 environmental water actions on larval and juvenile shrimp abundance in the Edward-Wakool system. Differences in mean number of shrimp between control/impact rivers and before/during/after environmental freshes were evaluated statistically for each watering action using two-way mixed effects analysis of variance (ANOVA). Because there were multiple sampling times used to represent before, during and after environmental flows, and multiple rivers used as 'Control' and sometimes 'Impact' rivers, sampling trip (random effect) was nested within Period (fixed effect, three levels: before, during and after), and river (random effect) was nested in Treatment (fixed effect, two levels: control rivers, impact rivers). Impact rivers received environmental freshes, while Control rivers were those that did not receive environmental water. For this analysis particular interest is in the Period x Treatment interaction term, which indicates a significant effect of the environmental watering action.

The null hypothesis for all watering actions was that mean larval and juvenile abundance of shrimp in the rivers which received environmental water would not be significantly different to the control rivers. All BACI analyses were carried out using the freeware R and the R package NLME (R Development Core Team 2013).

Results and discussion

Abundance and seasonal timing in appearance of larval and juvenile shrimp

A total of 49,343 larval and juvenile shrimp were collected over the 2013-2014 monitoring period. Of these, 21,037 were *P. australiensis* and 28,306 were *M. australiense* (Table 28). The duration and timing of the spawning period was similar across the four rivers (Figures 62 and 63). *P. australiensis* larvae were found earliest in the spawning season, and were collected as larvae from late September to March, except in the Yallakool Creek where larvae did not appear until early October (Figure 62). Peaks in abundance of *P. australiensis* larvae occurred at different times in each River. Numbers peaked in October in both Colligen Creek and Little Merran Creek, whereas peak abundance in Yallakool Creek occurred in March in the Wakool River occurred in January (Figure 62). Numbers of *M. australiense* larvae peaked late January and early February in all four rivers (Figure 62). Peaks in abundance of *P. australiensis* juveniles occurred in December in Little Merran Creek, January in Yallakool Creek and in February in both Colligen Creek and Wakool River. Peaks in abundance of *M. australiense* juveniles occurred in February in all four Rivers (Figure 63).

Table 28. Total abundance of larval and juvenile *Paratya australiensis* and *Macrobrachium australiense* collected with light traps from the four focus rivers in the Edward-Wakool system during 2013-2014.

Species	*Colligen*	*Yallakool*	*Wakool*	*Little Merran*	Total
P. australiensis	3946	2245	5387	9459	21037
M. australiense	4907	6273	7734	9392	28306
Total	**8853**	**8518**	**13121**	**18851**	
%	17.9	17.3	26.6	38.2	

Environmental watering event-based analysis

The Cod maintenance and recession flows in the Yallakool creek coincided with the beginning of the spawning season for *P. australiensis and M. australiense* (Figure 62). The spawning of *P. australiensis* occurred independently of the environmental watering (d.f=1, 114, *F*-test=2.27, p>0.05) with the most significant results due to time period (before, during or after) (Table 29) which suggests that the changes in abundance are simply due to seasonal factors that affect all rivers. The spawning of *M. australiense* also occurred independently of environmental watering (d.f=1, 114, *F*-test=1.13, p>0.05) (Table 29, Figure 64). The Perch pulse flow in Yallakool creek had no significant impact on larval shrimp numbers however the abundance of juvenile *P. australiensis* was significantly lower in Yallakool compared to the control rivers during this flow event (d.f=1, 44, *F*-test=1.67, $p<0.05$) (Figure 65). The Colligen-Neimur continuation flow also had no significant impact on shrimp numbers (Figure 66) with no significant changes in abundance of *P. australiensis* larvae or juveniles. Changes in abundance of *M. australiense* can be attributed to seasonal changes (Table 29).

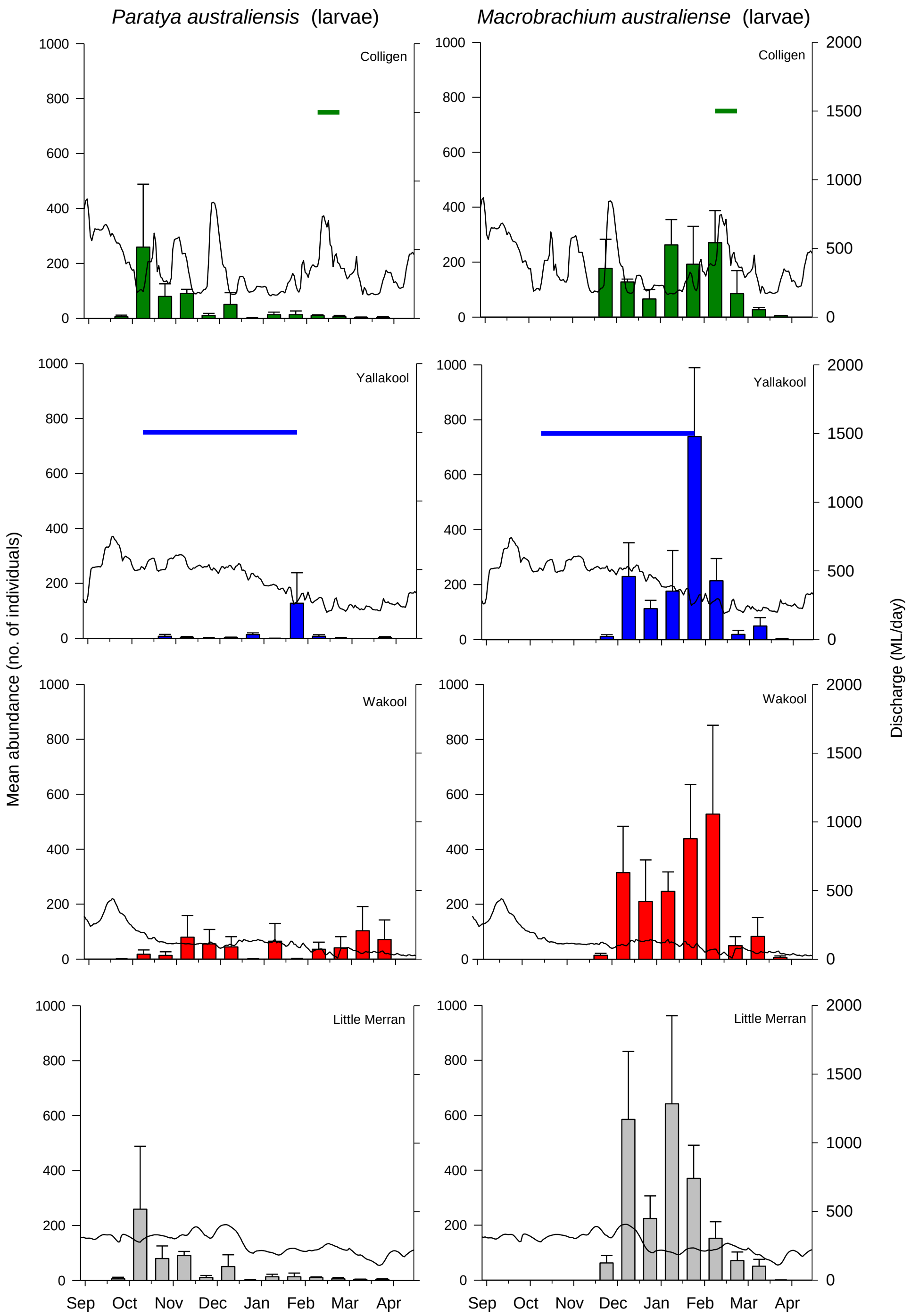


Figure 62. Temporal tends in mean abundance (±1SE) of larval *Paratya australiensis* and *Macrobrachium australiense* in the Edward-Wakool system during 2013-2014. Horizontal bars indicate duration of environmental watering actions in the treatment rivers, Colligen Creek and Yallakool Creek.

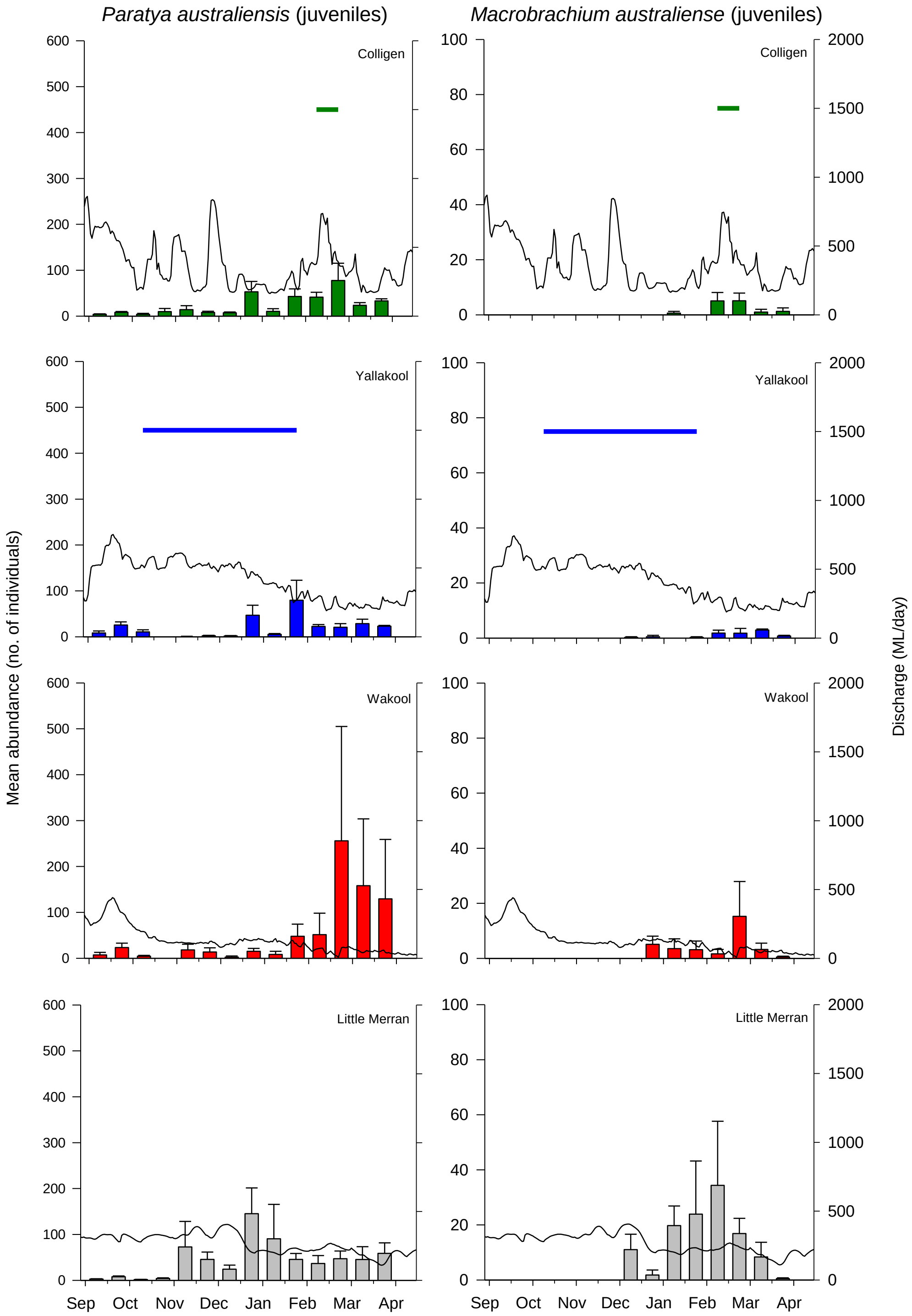


Figure 63. Temporal trends in mean abundance (±1SE) of juvenile *Paratya australiensis* and *Macrobrachium australiense* in the Edward-Wakool system during 2013-2014. Horizontal bars indicate duration of environmental watering actions in the treatment rivers, Colligen Creek and Yallakool Creek.

Table 29. Statistical results for 2-way mixed-effects Analaysis of Variance (ANOVA) looking at the effect of Commonwealth environmental watering actions on Larval and juvenile shrimp abundance. A significant interaction between the two fixed factors: Period (Before (B), During (D), After(A)) and CI (control rivers, impact rivers) indicates that the mean abundance of shrimp within Impact Rivers was significantly different to changes that occurred over the same period of time within the Control Rivers.

Species	Main effect	d.f	F-test	p-value	Significant effect of watering action?
Cod maintenance and recession flows: Yallakool creek					
P. australiensis (larvae)	**Period (B-D-A)**	**2,114**	**3.675**	**0.028**	
	CI (C-I)	1,114	0.546	0.461	
	Period*CI	1,114	2.269	0.109	
P. australiensis (juveniles)	Period (B-D-A)	2,114	1.634	0.199	
	CI (C-I)	1,114	0.235	0.628	
	Period*CI	1,114	1.716	0.184	
M. australiense (larvae)	**Period (B-D-A)**	**2,114**	**33.842**	**<0.001**	
	CI (C-I)	1,114	0.829	0.364	
	Period*CI	1,114	1.133	0.3255	
M. australiense (juveniles)	n/a				
Perch pulse flow: Yallakool creek					
P. australiensis (larvae)	Period (B-A)	1,44	2.022	0.162	
	CI (C-I)	1,44	0.980	0.327	
	Period*CI	1,44	0.358	0.552	
P. australiensis (juveniles)	Period (B-A)	1,44	3.832	0.056	
	CI (C-I)	1,44	1.228	0.273	
	Period*CI	**1,44**	**6.768**	**0.013**	**Significant effect (-)**
M. australiense (larvae)	Period (B-A)	1,44	1.000	0.322	
	CI (C-I)	1,44	0.339	0.563	
	Period*CI	1,44	0.461	0.500	
M. australiense (juveniles)	n/a				
Colligen-Neimur continuation flow					
P. australiensis (larvae)	Period (B-D-A)	2,66	0.032	0.968	
	CI (C-I)	1,66	0.431	0.513	
	Period*CI	1,66	0.237	0.789	
P. australiensis (juveniles)	Period (B-D-A)	2,66	0.136	0.872	
	CI (C-I)	1,66	0.173	0.678	
	Period*CI	1,66	0.794	0.456	
M. australiense (larvae)	**Period (B-D-A)**	**2,66**	**3.365**	**0.040**	
	CI (C-I)	1,66	0.633	0.429	
	Period*CI	1,66	1.508	0.228	
M. australiense (juveniles)	**Period (B-D-A)**	**2,66**	**3.533**	**0.035**	
	CI (C-I)	1,66	0.619	0.434	
	Period*CI	1,66	1.034	0.361	

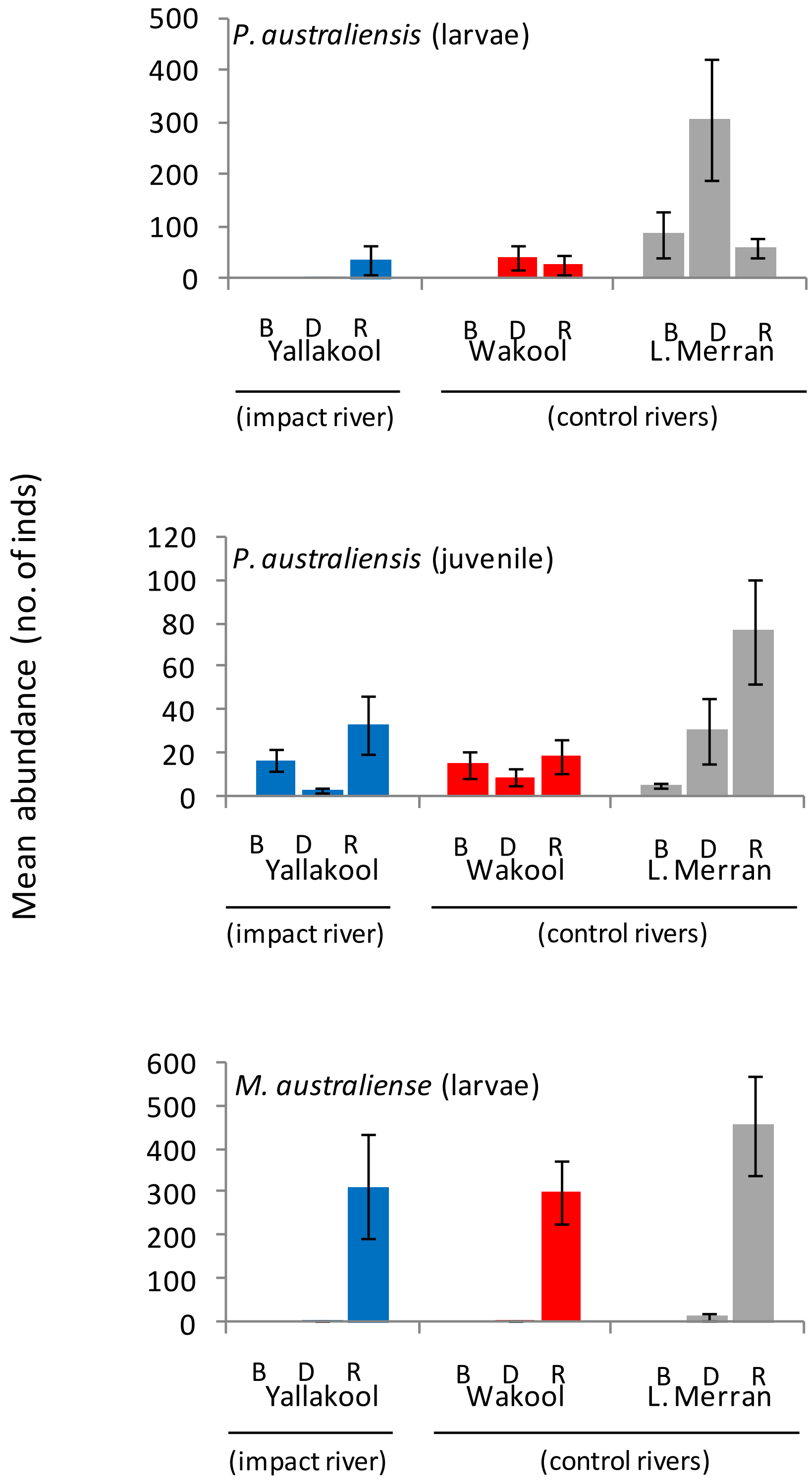


Figure 64. Mean abundance (±1SE) of shrimp present in the Edward-Wakool system before, during and after the Cod maintenance and recession flows in Yallakool creek between October 2013 and January 2014. The Wakool River and Little Merran Creek did not receive environmental water, and were used as controls. There were no significant interactions (see Table 29).

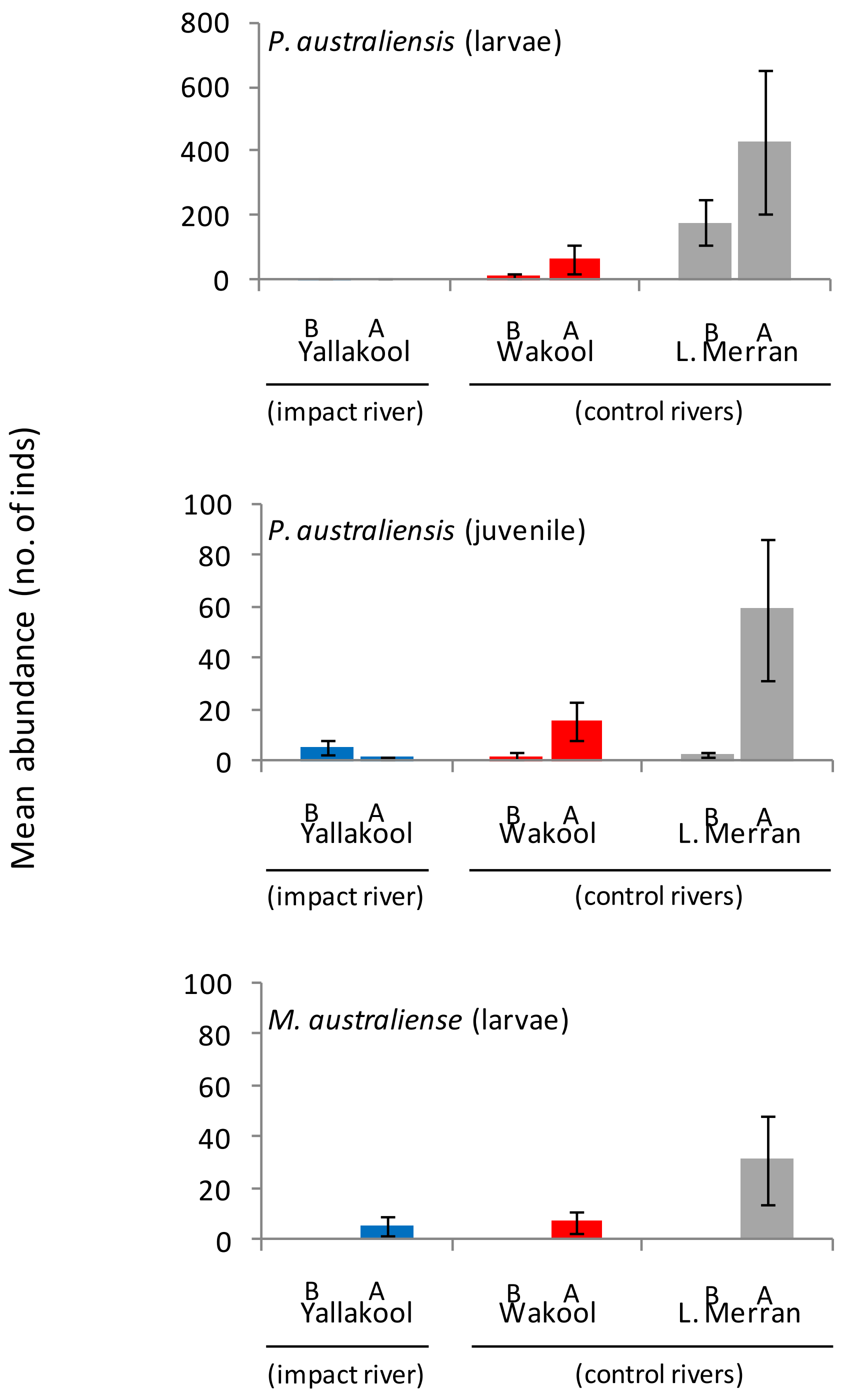


Figure 65. Mean abundance (±1SE) of shrimp present in the Edward-Wakool system before and after the Perch pulse flow in the Yallakool creek in Yallakool creek in November 2013. The Wakool River and Little Merran Creek did not receive environmental water, and were used as controls. The abundance of juvenile *P. australiensis* was significantly lower after the flow compared to the control rivers (see Table 29).

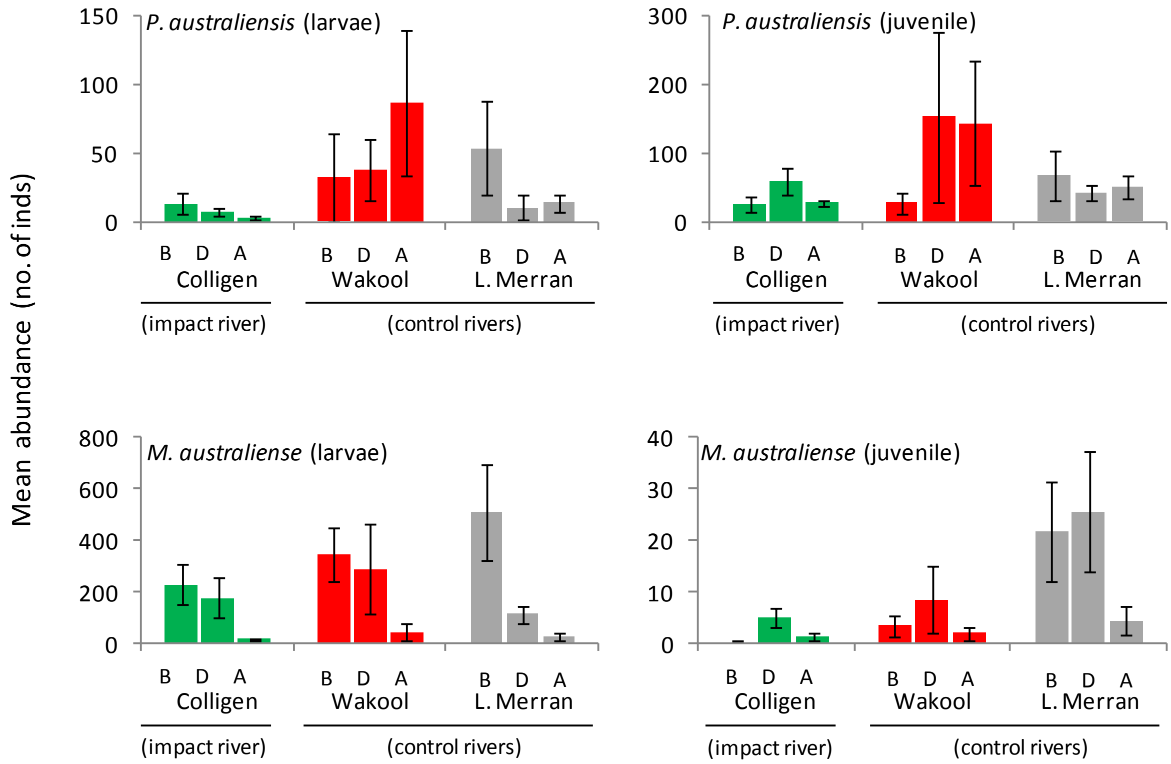


Figure 66. Mean abundance (±1SE) of shrimp present in the Edward-Wakool system before, during and after the Colligen-Neimur continuation flow between January and March 2014. The Wakool River and Little Merran Creek did not receive environmental water and were used as controls. There were no significant interactions (see Table 29).

Difference in total larval and juvenile production across rivers

The abundance of larvae sampled over the entire sampling period was not significantly different across the four rivers (d.f=3, Wald chi-square=2.96, $p>0.05$). Mean (±SE) numbers of larvae sampled from Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek were 126 (±26), 123 (±45), 173 (±41) and 275 (±55), respectively. The abundance of *P. australiensis* larvae was significantly lower in Yallakool Creek compared to the other three rivers (d.f=3, Wald chi-square=45.5, $p<0.001$), in addition the abundance *P. australiensis* larvae in the Wakool River was significantly lower than in Little Merran Creek (Figure 67). The abundance of *M. australiense* larvae was not significantly different between rivers (d.f=3, Wald chi-square=1.169, $p>0.05$) (Figure 67).

The abundance of juvenile shrimp was significantly greater in Wakool River than in Colligen Creek (d.f=3, Wald chi-square=8.0, $p<0.05$). Mean (±SE) numbers of Juveniles sampled from Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek were 25 (±4), 20 (±4), 55 (±22) and 53 (±10), respectively. *P. australiensis* juveniles were in significantly higher numbers in the Wakool River (d.f=3, Wald chi-square=17.53, $p<0.01$), there was no significant difference between the other rivers (Figure 67). The abundance of *M. australiense* juveniles was significantly higher in Little Merran Creek compared the other three rivers (d.f=3, Wald chi-square=69.5, $p<0.001$) (Figure 67).

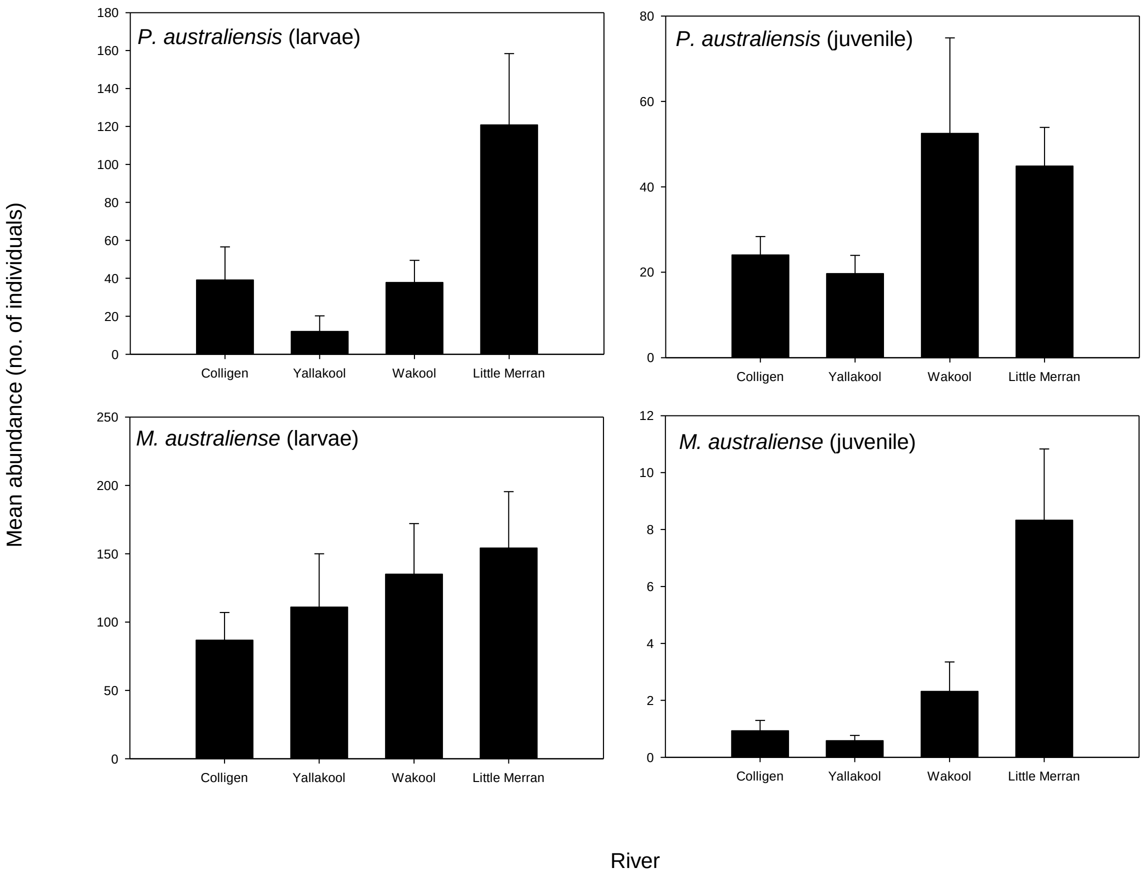


Figure 67. Mean total abundance of Shrimp larvae and juveniles in Colligen Creek, Yallakool Creek, Wakool River and Little Merran Creek during the 2013-2014 sampling season.

Conclusion

The aim of this component of the study was to determine if the environmental watering actions in 2013-2014 influenced the relative abundance of larval and juvenile shrimp in the Edward-Wakool system. Similar to the results in 2012-13, the rivers that received environmental water had fewer larval and juvenile shrimp overall compared to the two control rivers. In particular, there were fewer *P. australiensis* in Yallakool Creek compared to the other rivers. It is possible that the sustained flows received in Yallakool River during the shrimp spawning season reduced the overall availability of slackwaters required for *P. australiensis* spawning (Price and Humphries 2010). In addition, both Yallakool Creek and Colligen Creek had fewer juvenile *P. australiensis* than Wakool River, and both Colligen Creek and Yallakool Creek had fewer *M. australiense* juveniles than Little Merran Creek. This is interesting as the variation in flow was much greater in Colligen Creek and Yallakool Creek compared to Wakool River and Little Merran Creek.

It is possible that the recruitment success of both species may be negatively affected by in-channel flows during spring and summer that do not create slackwater habitat, as shrimp recruitment occurs during the normally low flow summer period (Humphries et al. 2006). Sharp increases in flow may result in higher larvae mortality as a result of displacement and catastrophic drift from slackwater habitats (Humphries et al. 2006; Price and Humphries 2010). Indeed, Hancock and Bunn (1997) found that high flow events limited the recruitment of *P. australiensis.*

Preliminary hydraulic modelling undertaken for these reaches in the Edward-Wakool system shows the environmental flows were likely to have decreased the size and availability of slackwaters relative to base flows (Watts et al. 2013b; Kingsford and Watts 2014). Only at discharges when benches begin to be inundated inundated, do large slackwaters start to develop and result in a general increase in slackwater area. Veitz et al. (2013) also found that in the Broken River there was a general decrease in the area of slackwaters as flow increased and slackwaters became available only at the channel margins. Therefore, it is likely that the magnitude and timing of environmental flows delivered during the 2013-2014 water actions resulted in a decrease in available habitat for shrimp recruitment. Understanding the relationship between flow and instream features such as woody instream habitat, geomorphological features (such as benches, backwaters) and anabranch systems will allow managers to identify critical thresholds and maximise the benefits of environmental water delivery.

6.10. Frogs

Photo: Peron's Tree frog *Litoria peronii*

Key findings

- Frogs were not the main focus of the environmental watering in Yallakool Creek. Commonwealth environmental water was also provided to Tuppal Creek in 2012-13 to achieve frog outcomes, but that area was not monitored by this project.
- Monitoring of the calling activity of adult frogs and the abundance of egg masses, tadpoles and metamorphs was undertaken in the focus rivers from September 2013 to March 2014 to evaluate the breeding response of frogs to Commonwealth Environmental watering actions.
- Whilst a lot of frog activity was observed during the September and October 2013 surveys at Yallakool Creek, frog numbers were similar across all focus rivers. However the Peron's tree frog abundances differed significantly between rivers with higher numbers of calling adults recorded at Yallakool Creek (received environmental water), and Little Merran Creek (control) compared to Wakool River (control), which had the lowest abundances and did not receive environmental water.
- There was no evidence that the 2013–14 environmental watering actions in Yallakool Creek and the Colligen Creek resulted in frog recruitment, as no egg masses, tadpoles or metamorphs were observed during surveys.
- In channel environmental watering actions did not inundate major in-channel geomorphological features (e.g. benches and backwaters), so may not have provided adequate or suitable habitat to support breeding and recruitment of frogs or adequate refuge from predators. There is a need to increase the understanding of interaction between instream flows and instream habitat (see flow recommendations)

Background

Riverine frogs have a range of life history strategies which allow them to utilise and occupy riverine habitats. In south-eastern Australia nine frog species are wholly dependent on flowing water for reproduction, (Gillespie and Hines 1999) whilst five others use streams for breeding only under certain flow conditions (Gillespie and Hines 1999; Heard et al. 2006). Many generalist riverine frog species utilise a range of habitats created during overbank events, such as back-waters and ground-water pools (Bateman et al. 2008; Wassens and Maher 2011). Permanently inundated systems may not necessarily support frog breeding due to their high predator densities; rather they may be used as refuge habitats during dry periods (Wassens and Maher 2011). Seasonally or intermittently inundated wetland systems, such as the Edward Wakool system, may be important for breeding by species with longer development times (Wassens et al. 2010; Wassens and Maher 2011) therefore in-channel environmental watering is most likely to lead to an increase in frog abundance and calling activity if intermittent and seasonal habitats are created adjacent to the main channel. For example Wassens and Maher (2011) found that temporary water bodies created during environmental flows were preferentially utilised for breeding over the more persistent habitat within the stream channel. Monitoring of the calling activity of adult frogs and the abundance of egg masses, tadpoles and metamorphs was undertaken from September 2013 to March 2014 to evaluate the breeding response of frogs to Commonwealth Environmental watering actions.

Hypotheses

- Frog activity (number of individuals calling and observed) will increase in rivers that receive environmental water relative to rivers that do not receive environmental water.
- Frog breeding (by presence of egg masses, tadpoles and metamorphs) will be observed more often in rivers that receive environmental water relative to rivers that do not.

Methods

Tadpoles were surveyed monthly from September 2013 to March 2014 during the day within a 50 m transect at three locations within each focus river using a large D-bottom sweep net. Tadpoles caught in the net were identified to species level if possible and their developmental stage recorded according to Anstis (2002). Once identified, all tadpoles were released at the point of capture.

Three replicate audio and visual surveys were undertaken at each focus river at monthly intervals, to detect distinct calls of resident frog species and record the number of individuals calling. The number of individuals was estimated when calling frog numbers exceeded the ability of the recorder to differentiate between calling individuals. Frogs were surveyed at night along a 200 m long and 5 m wide transect running parallel to the water's edge for 30 minutes on each survey occasion. A spotlight was used to search along the water's edge and within terrestrial habitats. Each individual encountered was identified to species level.

To test if frog activity (number of adult frogs) was greater in rivers that received environmental water, a series of one-way Anovas were run on each frog species, with total mean abundance of adult frogs as the response variable, and river as the grouping variable. Adult frog data did not meet the assumptions for parametric testing, so a Kruskal-Wallace non-parametric ANOVA was run instead. Statistics were run in SPSS.

Results and discussion

Six frog species were recorded across the four focus rivers over the seven month survey period (September 2013 to March 2014) (Table 30). The eastern banjo frog, was not spotted visually, rather it was only identified via calling activity (Table 30). Little Merran Creek initially supported the highest frog diversity which included the only record of the eastern banjo frog (*Limnodynastes dumerilii*) (Table 30). Colligen Creek contained the highest number of adult frogs, followed by Little Merran Creek, Yallakool Creek and the Wakool River (Figure 68). No frogs listed as vulnerable or endangered under the EPBC Act 1999 were observed or heard calling. No egg masses, tadpoles or metamorphs were observed for any of the frog species during the survey period (Table 30).

Frog community composition was similar across the rivers over the survey period, with the Barking marsh frog (*L. fletcheri)* being the most commonly visually encountered species followed by the plain's froglet (*Crinia parinsignifera,* spotted marsh frog (*L. tasmaniensis*) and Peron's tree frog (*Litoria peronii*) respectively (Figure 68). Significant differences in adult Peron's tree frog numbers across the four focus rivers were detected (Kruskal-Wallace $H=13.88$, df 3, $p>0.03$; Table 31), however this was not observed for *L. tasmaniensis, L. fletcheri, C. parinsignifera, or C. signifera* (Table 31). Peron's tree frog was most abundant at Little Merran Creek (*n*=35), Yallakool Creek (*n*=24) and Colligen Creek (n=19), while only several individuals were collected in the Wakool River (*n=3)* (Figure 68).

Table 30. Total abundance of frogs observed in the Edward-Wakool River system during the 2013-2014 study period, for each life history stage.

Common name	Frog species	Adults	Calling	Eggs	Tadpoles	Metamorphs
Peron's tree frog	*Litoria peronii*	81	Y	0	0	0
spotted marsh frog	*Limnodynastes tasmaniensis*	118	Y	0	0	0
barking marsh frog	*Limnodynastes fletcheri*	155	Y	0	0	0
eastern banjo frog	*Limnodynastes dumerili*	0	Y	0	0	0
plain's froglet	*Crinia parinsignifera*	120	Y	0	0	0
eastern common froglet	*Crinia signifera*	10	Y	0	0	0

Table 31. Results of non-parametric one-way anovas (Kruskal-Wallis) comparing adult frog abundance across the four focus rivers in the Edward-Wakool river system. *p* <0.05 (highlighted in bold) indicates that a significance difference was found in adult frog abundance across rivers in the 2013-2014 study period.

Frog species	Kruskal-Wallace statistic H	d.f	*P*
Peron's tree frog *Litoria peronii*	13.88	3	**0.003**
spotted marsh frog *Limnodynastes tasmaniensis*	3.79	3	0.285
barking marsh frog *Limnodynastes fletcheri*	6.11	3	0.106
plain's froglet *Crinia parinsignifera*	6.94	3	0.074
eastern common froglet *Crinia signifera*	2.31	3	0.511

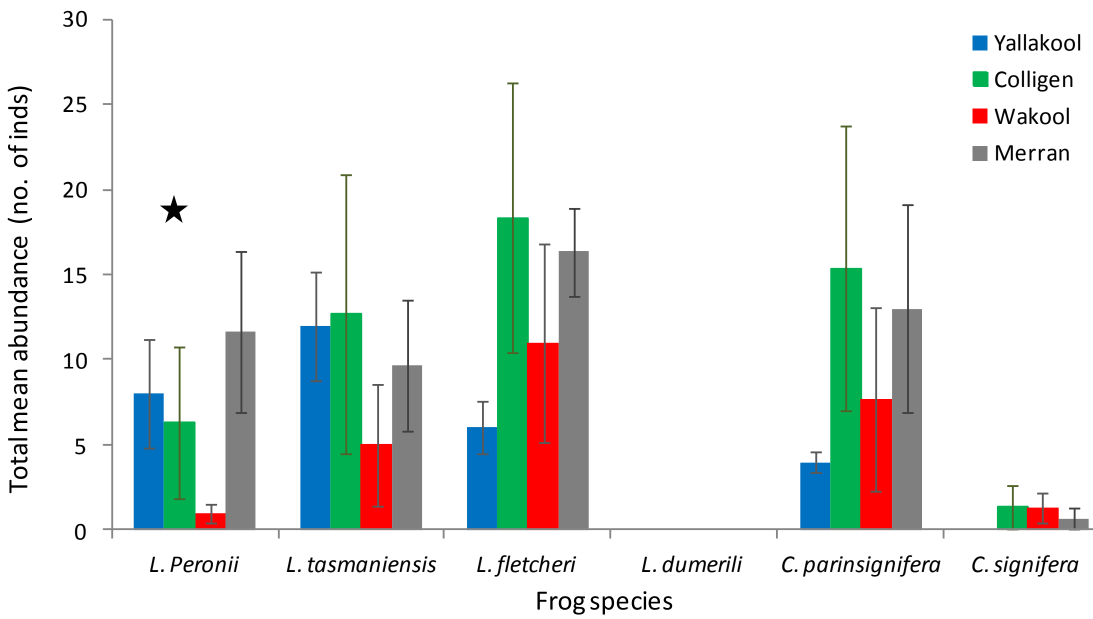


Figure 68. Total mean abundance (± 1SE) of adult frogs identified during visual frog surveys within each focus river between September 2013 and March 2014. The black star indicates there was a significant difference in the abundance of *L. Peronii* across rivers.

Our findings are comparable to frog diversity and numbers observed along the Murray River between Lock 15 and the South Australian border during an environmental watering action in 2005-06 (Val et al 2007), to environmental flow events along the Murray River (Wassens et al. 2011) and to more recent environmental watering actions in the intermittent Darling Anabranch in 2010-12 which detected 292 individuals during a three year survey period (Bogenhuber et al. 2013) and 449 individuals in 2013-14 (Bogenhuber et al. 2014).

Response to environmental watering

It was hypothesised that frog activity (measured as an increase in the number of individuals observed) would increase in the Yallakool Creek in response to the environmental watering action. Whilst a lot of frog activity was observed during the September and October 2013 surveys at Yallakool Creek, frog numbers were similar across all focus rivers. However the Peron's tree frog abundances differed significantly between rivers (Table 31), with higher numbers of calling adults recorded at Yallakool Creek (received environmental water), Colligen Creek and Little Merran Creek (control) compared to Wakool River (control), which had the lowest abundances and did not receive environmental water (Figure 68; Figure 69).

There were unregulated flows that achieved above estimated half bankfull levels (Watts et al. 2013b) within the Edward Wakool system prior to the commencement of the environmental watering action and may have accounted for the higher abundances of most frogs observed during the September and October 2013 surveys. An increase in activity at this time was also expected as most frogs that were identified are generally actively calling from September and during the warmer months (Wassens 2011; Wassens and Maher 2011).

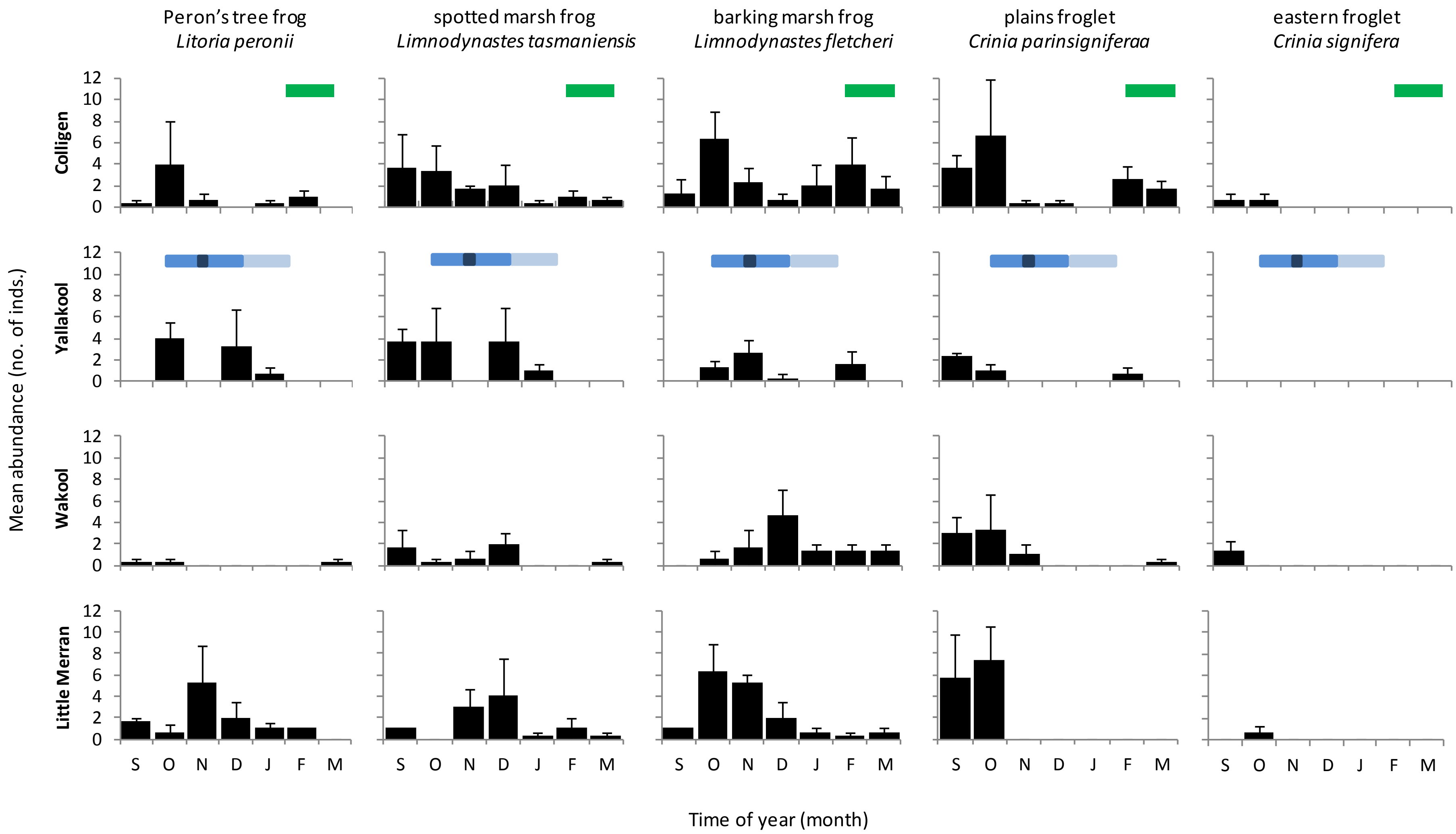


Figure 69. Mean abundance (±1SE) of *the five frogs visually identified* in the Edward-Wakool system during 2013-2014. Coloured bars represent when Commonwealth environmental water was delivered to Yallakool Creek (blue bars) and Colligen Creek (green bars). The Wakool River and Little Merran Creek did not receive environmental water.

Although flows during the Yallakool Creek environmental watering action averaged less than half bankfull, the flows endured for several months, which promoted submerged aquatic vegetation (Section 6.5). Inundated vegetation is used by frogs as calling and spawning locations (Wassens et al. 2010) and as habitat for adults and tadpoles (Healey et al. 1997). Inundated vegetation also acts as substrate for biofilm which is an important food source for tadpoles (Gillespie 2002; Mokany 2007). Notwithstanding, riverbank vegetation cover and aquatic vegetation cover was generally low in each study river, which potentially reduced suitable habitat for frogs. Concurrent frog surveys found no evidence of increase or decrease in frog numbers, or evidence of breeding (via egg masses, tadpoles or metamorphs) at focus rivers that received environmental watering actions, rather there was little difference in frog numbers between focus rivers during the survey period. The availability of inundated vegetation was generally low across all focus rivers, possibly because environmental watering actions occurred only in channel and did not inundate major in-channel geomorphological features such as backwaters and large benches. This can significantly influence the available wetted surface area available for fauna to inhabit (Watts et al. 2013b). As a consequence, a lack of newly wetted vegetated habitats during environmental watering actions may be an important factor influencing the lack of response of frogs to environmental watering.

High predator densities in the main channel from low flows may also inhibit frog breeding activity and could explain why no tadpoles were caught in-channel during the survey period. Exotic predatory fish including gambusia (*Gambusia holbrooki*), known to predate upon tadpoles (Anstis 2002; Ralph et al. 2011) and the common carp (*Cyprinus carpio*), also known to impact frog recruitment (Spencer and Wassens 2009), were present in all focus rivers. The occurrence of these predators, combined with small environmental freshes, may have resulted in reduced suitable inundated habitat being available to provide refuge from predators or support breeding and recruitment of frogs (Wassens and Maher 2011).

7. SUMMARY AND SYNTHESIS

Ecosystem responses to environmental watering in 2013-14

Objective 1. Increase movement, condition, reproduction and recruitment of native fish

- *There is a general trend towards improvement of the native fish community in the Edward-Wakool system*, although this improvement is species and location-specific. Some of the changes may be due to fish migration into the system because recruitment of some species is poor. There was an increase in the abundance of small bodied generalist species (primarily Australian smelt and carp gudgeon) in 2014 compared to 2013. There was an increase in the biomass of Murray cod, goldfish and bony herring and decrease in the biomass of common carp and golden perch in 2014 compared to 2013.
- The Sustainable Rivers Audit measure of expectedness and nativeness were calculated for fish community data collected from 2010 to 2014. All zones were in poor condition in 2014 in terms of nativeness, an improvement over the very poor condition from 2013. In 2014 all zones were in poor to moderate condition in terms of SRA recruitment index.
- Some individuals of acoustically tagged Murray cod, golden perch and common carp dispersed from the refuge pool into new habitats during early season unregulated flows. *Based on two years of monitoring data, Murray cod demonstrated a consistent preference for movement into the upper Wakool River over Yallakool Creek during delivery of environmental water.* The reasons for this are unknown, although it highlights the importance of maintaining habitat in both the Wakool River and Yallakool Creek. Factors such as loading of woody habitat, overhanging cover, depth of pools or physical or hydraulic barriers may have an influence on this preference.
- *The majority of tagged golden perch remained in the refuge pool throughout the environmental watering actions. Those individuals that did move, went both upstream and downstream from the refuge pool, with most movements occurring at the peak of flows or on the recession.* It is not known whether these movements resulted in spawning, and this can be evaluated in a future assessment of recruitment by the Long term Intervention Monitoring project. However, combined with results from fish community sampling and fish spawning the results suggest that the 2013-14 environmental watering did not trigger spawning in this species.

- *All acoustically tagged golden perch and some Murray cod returned to the refuge pool at the completion of the recession flows, indicating that these flows were appropriately managed to enable native species to return to refuge habitat*.
- Nine of the 13 fish species known to occur in theEdward-Wakool River system successfully spawned in 2013-14. *Spawning patterns of the Edward-Wakool fish community were independent of the environmental watering actions*.
- *The environmental watering in Yallakool Creek during the Murray cod spawning season did not result in a significantly greater number of larvae in Yallakool Creek compared to rivers that did not receive environmental water*. These findings support the results observed in 2012-13 and the body of knowledge that shows that Murray cod spawn at peak times in November-December, regardless of flow conditions.
- Back-calculated spawning dates indicate that golden perch has spawned in all years from 2004–2010. However, the dominant cohort of golden perch and silver perch was spawned in 2009 during periods of low in-flows into the Edward-Wakool system.
- *The Yallakool Creek perch flow did not trigger a golden and silver perch spawning response in the monitored reaches, as evidenced by the absence of larvae or eggs*. It is possible that these species spawned elsewhere in the system but were undetected by the current monitoring. Future assessment of fish recruitment undertaken as part of the Long Term Intervention Monitoring project may determine if these species spawned in 2013-14.
- *Juvenile golden perch, silver perch and Murray cod recruits were not sampled in large enough numbers to detect whether environmental watering actions influenced recruitment of these species*. Recruitment of carp gudgeon occurred between August 2013 and March 2014, peaking in November-January, in all rivers regardless of receiving environmental water. In 2013-14 annual recruitment of carp gudgeon was not positively or negatively affected by environmental watering actions in Yallakool Creek and Colligen Creek. This result is different to previous years, where an increase in the abundance of larvae and juveniles was detected in response to environmental watering in Colligen Creek (Watts et al. 2013a; 2013b). Dissimilar recruitment responses to environmental watering actions among years may be related to differences in the peak magnitude of flows or differences in the relationship between discharge and area of inundation in different rivers. This will require an evaluation of spawning responses across multiple years.

Objective 2. Provide end of system flows and increase hydrological connectivity in ephemeral streams

Monitoring of end of system flows and ephemeral streams was not undertaken in this project.

Objective 3. Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants

- *There was a significant increase in the percent cover of submerged aquatic vegetation during the Yallkool Creek cod maintenance flow*. The environmental watering enabled the submerged aquatic vegetation (in particular Characeae *sp*) to persist over an extended period of time. This is a different response to that observed in 2012-13 where the recession was rapid and submerged vegetation was rapidly exposed and desiccated.
- *There was no change in the percent cover of terrestrial riverbank vegetation in each river before, during and after the environmental watering, suggesting there was no response to environmental watering actions.* However, the monitoring concluded in March 2014, a month after the end of the maintenance flow recession, and may not have continued long enough to detect terrestrial vegetation responses to the environmental watering. Longer term responses of riverbank vegetation to environmental watering will be examined as part of the Long Term Intervention Monitoring project in the Edward-Wakool system (Watts et al 2014).

Objective 4. Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH

- *Commonwealth environmental watering met the objective of maintaining or supporting water quality outcomes as it did not trigger any adverse water quality outcomes or a hypoxic blackwater event.* Environmental watering actions did not significantly alter dissolved carbon, total carbon or the organic matter profiles in treatment rivers relative to the control rivers. Bioavailable nutrients were extremely low in these rivers. Some statistically significant differences in nutrient concentrations were found when assessing effects of watering actions, but these differences were extremely small and were not ecologically important.
- *Very small increases in metabolic rates that were not ecologically significant resulted from environmental watering actions*, most likely because the flows were contained within the stream channel, with little inundation of backwater areas or instream benches. Rates of primary production and ecosystem respiration during 2013-2014 were at the lower end of the normal range found in rivers worldwide.

Objective 5. Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs.

- The spawning of shrimp occurred independently of the environmental watering actions. *The rivers that received Commonwealth environmental water had fewer shrimp than the rivers that did not receive environmental water*. In particular, the abundance of juvenile Paratya shrimp during the Yallakool Creek perch flow was significantly lower in Yallakool Creek compared to the control rivers. The abundance of Paratya larvae may have been adversely affected by environmental watering during their spawning season, because hydraulic modelling has shown that the magnitude of the environmental watering actions in Yallakool Creek decreased the availability of slackwater habitat that is necessary for shrimp recruitment.
- Frogs were not the main focus of the environmental watering in Yallakool Creek. (Note, Commonwealth environmental water was also provided to Tuppal Creek in 2012-13 to achieve frog outcomes, but that area was not monitored by this project). Whilst a lot of frog activity was observed during the surveys, t*he environmental watering actions in Yallakool Creek and Colligen Creek did not result in frog recruitment, as no egg masses, tadpoles or metamorphs were observed during surveys*.
- In channel environmental watering actions did not inundate major in-channel geomorphological features (e.g. benches and backwaters), so may not have provided adequate or suitable habitat to support breeding and recruitment of frogs or adequate refuge from predators. There is a need to increase the understanding of interaction between instream flows and instream habitat (see flow recommendations).

Synthesis of responses to Commonwealth environmental watering

The responses to Commonwealth environmental watering observed in 2013-14 were largely consistent with those observed in previous years. In general, Commonwealth environmental water delivered to the Edward-Wakool system has contributed to the maintenance of water quality, provided opportunities for longitudinal connectivity and fish movement (such as the return movement of fish to the Wakool Reserve refuge pool during recession flows), promoted instream aquatic vegetation, and created a small increase in wetted benthic area. Importantly, the long-term benefits of the Commonwealth environmental watering actions during blackwater events in 2010, 2011 and 2012 are still being realised. The environmental watering during these blackwater events mitigated extreme low dissolved oxygen concentrations (Watts et al. 2013) and thus created an area of refuge habitat and avoided critical loss of fish in the upper reaches of the Wakool River and Yallakool Creek. The benefits of those watering actions are evident, with fish populations in upper part of the Edward-Wakool system maintaining higher biomass than the populations in the lower reaches. The long-term recovery of fish populations in this system is still occurring. However, some of the changes in the fish community in the middle and lower sections of the system are possibly due to other factors, such as immigration of fish into the system.

Some of the expected outcomes of Commonwealth environmental watering actions were not observed in the focal rivers, with no detectable response (positive or negative) to Commonwealth environmental watering observed for several indicators. Although fish reproduction is occurring in this system (nine of the 12 species were collected as larvae in 2013-14), the spawning response in these species could not be attributed to Commonwealth environmental watering. So although there is evidence of some recovery in the fish community in areas impacted by the blackwater events in 2010-2012, recruitment has been limited and the recovery of the fish population has been slow, especialy for large bodied long lived species. There have also been only very small increases in river productivity resulting from environmental watering actions. Hydraulic modelling has shown that Commonwealth environmental watering actions have created small increases in wetted benthic area (Watts et al. 2013b), but this has not been sufficient to trigger an increase in gross primary productivity. The delivery of environmental water is constrained by a limited capacity to deliver higher volumes of water in this system without having impacts on third parties. The CEWO has sought to maximize the flows to a level that is acceptable to third parties in the catchment area. Constraints that limit the delivery of environmental watering actions should be examined further and managers collaborate with the community to minimise factors that may limit the benefits of Commonwealth environmental watering actions (see recommendations).

In addition to the positive and and neutral responses associated with Commonwealth environmental watering there was one negative response observed in 2013-14. There was a lower abundance of juvenile paratya shrimp in Yallakool Creek captured during the perch flow and an overall lower abundance of shrimp larvae in Yallakool Creek. This is thought to be due to a reduction in the area of slackwater during watering actions compared to area of available slackwater during base flows (see hydraulic modelling in Watts et al 2013b, Kingsford and Watts 2014). Slackwater habitat is of vital importance for many organisms including larval fish, macroinvertebrates and frogs and there is a need to increase our understanding of the interaction between instream flows and instream habitat to help managers identify critical thresholds and maximise the benefits of environmental water delivery (see flow recommendations).

A summary of the responses to Commonwealth environmental watering is presented in Table 32. The responses were classified as:

- positive, resulting in improved outcomes (dark green)
- positive, resulting in maintenance of outcomes (light green)
- negative response resulting in adverse outcomes (red)
- no detectable response (neither positive or negative) (white)
- response not assessed by this project (grey)

If we revisit the ecological objectives for the Edward-Wakool system outlined in the water use minute (CEWO, 2013b) we can conclude:

- Objective 1 (Increase movement, condition, reproduction and recruitment of native fish) has been partially achieved, but an increase in reproduction and recruitment has not occurred.
- Objective 2 (Provide end of system flows and increase hydrological connectivity in ephemeral streams (this objective was not assessed in this project) was not assessed by this project
- Objective 3 (Maintain/improve vegetation condition, including fringing vegetation and emergent/submerged aquatic plants) was partly achieved, with an increase in submerged plants but not terrestrial riverbank plants.
- Objective 4 (Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH) was achieved.
- Objective 5 (Support breeding, recruitment and habitat requirements of a range of native animals, in particular frogs) was not achieved.

Table 32. Summary of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2013-14. Dark green shading indicates improved outcomes, Light green indicates positive outcome resulting in maintenance, red shading indicates adverse outcome, white shading indicates no detectable response (neither positive or negative). Grey boxes are where no evaluation was undertaken. N/A = not evaluated.

Indicators	**Responses to unregulated flows in Aug and Sep**	**Short-term responses to Commonwealth environmental water (responses to individual watering events or flows)**			**Annual response (Comparison among rivers across year)**	**Longer-term responses (across multiple years)**
		Yallakool cod maintenance flow and recession	**Yallakool perch flow**	**Colligen-Niemur continuation flow**		
Fish community	N/A	N/A	N/A	N/A	N/A	Improvement of the native fish community over time
Fish movement	Movement of Murray cod and golden perch out of refuge pool	Preference by Murray cod for Wakool R compared with Yallakool Creek Return movements of golden perch to refuge pool during recession	No change in habitat occupation detected in golden perch	N/A	Preference by Murray cod for Wakool River compared with Yallakool Creek	N/A
Fish spawning and reproduction	N/A	No response detected	No response detected	N/A	9 species spawned but was not related to e-watering. More smelt, gudgeon in Edward R	N/A
Fish recruitment	N/A	N/A	N/A	N/A	No effect of e-watering on recruitment in carp gudgeon	N/A
Riverbank and instream veg	N/A	Increase in % cover of submerged aquatic veg. No response in riverbank terrestrial vegetation	N/A	N/A	Significant differences in veg between rivers but not related to e-watering	N/A
Water quality and chemistry	HIgher DOC, slower decline in Little Merran Creek	Maintain water quality, no advserse response observed	Maintain water quality, no advserse response observed	Maintain water quality, no advserse response observed	N/A	N/A
Organic matter characterisation	Inc in amount and complexity of organic matter	Maintain water quality	Maintain water quality	Maintain water quality	N/A	N/A
Stream metabolism	N/A	Maintain productivity. There were very small changes in gross primary production and ecosystem respiration that are not ecologically important (< 1 mg O2/L/Day)			N/A	N/A
Shrimp	N/A	No response detected	Significantly lower numbers of juvenile Paratya shrimp in Yallakool Creek	No response detected	Abundance of *P. australiensis* larvae lower in Yallakool Creek.	N/A
Frogs	N/A	No response detected	No response detected	No response detected	No breeding response detected	N/A

8. Recommendations

Recommendation 1. Use Commonwealth environmental water to manage the recession of unregulated flows and environmental watering actions

The rate of recession under regulated flows in the Edward-Wakool system is likely to be much faster than the rate of change under natural flow conditions. Slowing down the rate of recession can provide ecological benefits by creating conditions that the biota in these systems would be more adapted to. Commonwealth water contributed to a recession flow in 2013-14, and this promoted the growth and longer duration of instream aquatic vegetation in Yallakool Creek compared to 2012-13 when rates of recession were much faster. In 2013-14 all acoustically tagged golden perch and some Murray cod returned to the refuge pool at the completion of the recession flows, indicating that these flows were appropriately managed to enable native species to return to refuge habitat. Commonwealth environmental water should continue to be allocated to manage recession flows following unregulated flow events or at the end of environmental watering actions.

Recommendation 2. Continue to use Commonwealth environmental water to mitigate adverse water quality events

Commonwealth environmental water has been used on several occasions to mitigate the advserse outcomes of poor water quality events. Monitoring results have demonstrated that these actions have been successful in maintaining water quality. Rapid action and coordination of information by the Edward-Wakool e-flows Group and the Water Murray and District Dissolved Oxygen Group are a vital part of this action.

Recommendation 3. Focus timing of Commonwealth environmental watering on late winter/spring

Available hydrological modelling suggests that the flow regime of the Edward-Wakool system has been significantly altered by river regulation, with changes to the timing and volume of flows. Natural flows in the system would have been high in winter/spring and low in summer and autumn. Late winter/spring flows were a key feature in these systems and biota are likely to be adapted to this regime. Monitoring results have shown that early season unregulated flows in 2013-14 enabled all fish species to disperse from the refuge pool into new habitats. Environmental watering in winter/spring also minimises risks of adverse water quality outcomes. In the absence of natural or regulated flows in late winter or early spring, Commonwealth environmental water should be targeted at this time of the year to enhance dispersal opportunities and maximise growth and reproductive opportunities. Winter/spring flows can be delivered to complement other watering actions delivered at other times of the year targeting other ecological outcomes (e.g. fish spawning).

Recommendation 4. Introduce flow variability into environmental watering actions

The Edward-Wakool river ecosystems have evolved in the presence of flow variability, and there is good evidence to suggest that flow variability can lead to healthy and resilient populations. It is recommended that some of the natural levels of variability should be incorporated within managed environmental watering actions. In general, long periods of constant flow and rapid flow recession should be avoided. One approach to achieve this is to use a whole of system approach to manage flows in the Murray system, using upstream triggers to guide variability. Recent flow events could provide a baseline to enable this approach to be tested to determine its benefits. See flow recommendation 7 for a recommended approach to help guide these decisions.

Recommendation 5. Deliver a variety of flows over time to improve understanding of responses to environmental watering

Some results from monitoring and evaluation of environmental watering are difficult to interpret, as it is not always possible to disentangle the responses to flow from responses related to a specific river. For example, Murray cod have demonstrated a consistent preference for the upper Wakool River over Yallakool Creek based on the past two years of monitoring, however it is unclear whether this is due to a general preference for the Wakool River over Yallakool Creek, or is related to delivery of environmental water. Future targeted watering of the upper Wakool River to maintain or maximise nest site inundation should be considered, as this would improve our understanding of responses to flows by disentangling the factors of river and flow. In addition, the upper Wakool River has not been the target of environmental watering actions over the past three years.

Recommendation 6. Increasing understanding of interaction between instream flows and instream habitat

There is a need to identify and quantify the instream geomorphological features in the rivers likely to receive Commonwealth environmental water to help better target environmental watering actions, especially decisions around the magnitude of water delivery. Understanding the relationship between flow and instream features such as large woody instream habitat, geomorphological features (such as benches, backwaters) and anabranch systems will allow managers to identify critical thresholds and maximise the benefits of environmental water delivery.

Recommendation 7. 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, considering the breadth of geomorphological and ecological responses. While there has been some modelling undertaken for the Edward River, there is currently a lack of hydrological modelling on 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. The flows assessment would need to 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 low flow periods. Based on the flows assessment, it would be possible to consider which aspects of the flow regime are most or least affected by regulation, and consider how these changes are likely to affect ecological features or assets of the Edward-Wakool system (eg vegetation, bench inundation, flow requirement for fish and birds etc). This would guide decisions and operating guidelines for future environmental watering actions. The flows recommendations should not be single species or group focussed, but consider all aspects of the river ecosystem. This information would underpin environmental watering plans and actions and maximise the benefit for the whole ecosystem.

Recommendation 8. Examine constraints that limit the delivery of environmental watering actions. Collaborate with other management agencies and the community to minimise factors that may limit the benefits of Commonwealth environmental watering actions

There were no observable increases in gross primary productivity, food resources or fish spawning in response to the Commonwealth environmental watering in 2013-14. If the proposed flows assessment (see recommendation 7) recommends that higher discharges are required to provide these instream benefits, then a comprehensive examination of flow constraints and a concurrent community consulation process will required to examine constraints to the delivery of larger in-channel environmental watering events. 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 illicit ecosystem responses to flows. There are other factors (e.g. small instream barriers) that may limit how the ecosystem responds to Commonwealth environmental watering. The CEWO should actively work with other agencies and the community to reduce the impacts of these other factors to produce better ecosystem responses to environmental watering.

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11. Appendices

Appendix 1. Watering option 1 – Edward-Wakool River system instream flows (from CEWO 2013)

Catchment: Murray Catchment	
Complex: Edward-Wakool River System	
Site: Edward River, Yallakool Creek, Wakool River, Colligen Creek-Niemur River, Gulpa Creek and the Merran System.	
Applicable level(s) of resource availability: Low to Very High	
Relevant flow component: ☒ Base flows ☒ Fresh ☐ Bank-full flows ☐ Over-bank flows	**Expected inundation extent:** ☐ Floodplain inundation ☐ Wetland inundation
Summary of watering option: • The purpose of this option is to support the condition and reproduction of native fish, which may involve contributing to instream flows to maximise available breeding habitat, create flow conditions favourable for reproduction (e.g. freshes), or contribute to the survival of native fish. • Environmental water may contribute to base flows, freshes and the recession of bankfull and overbank flows. Replicating a more natural rate of recession is beneficial as it may cue native fish to vacate off-stream and floodplain habitats, avoiding stranding and death. • Given the current water availability outlook, it is unlikely that very low flow periods will be experienced in the coming year. However, should they eventuate, the focus of environmental watering will be on the delivery of base flows to provide refuge habitat for native fish. • Hydrographs based on the reproduction requirements of different functional groups of native fish (small bodied in-stream generalists, medium and large bodied fish) will inform flows to support native fish reproduction. These will be considered along with recent monitoring results and prevailing flow conditions.	
Timing	September 2013 to April 2014
Volume of Commonwealth environmental water	Up to 60 GL
Operational considerations and feasibility: • The Edward-Wakool River System is a complex network of interconnecting rivers and creeks. The system is highly regulated. Environmental flows can be managed to individual creeks and rivers using regulating infrastructure including Stevens Weir, Yallakool offtake regulator and Colligen offtake regulator. Additionally, Murray Irrigation Limited irrigation channels span this region, and provide another mechanism to supplement instream flows. During the irrigation off-season regulating/irrigation systems are shut down. • NSW State Water Corporation is responsible for managing flows in the Edward-Wakool River System. The Commonwealth Environmental Water Office will seek advice from river operators on plausible target flow rates for this option with regard to demands on the delivery system, flow constraints, operational procedures and the risk of downstream impacts. Flows will be managed within-channel. • Environmental water may be delivered to the Edward-Wakool River System as a result of watering in the Murray River, if delivery in the Murray River causes overbank flows into the Millewa Forest. These additional flows to the Edward-Wakool River System may be directed into the target creeks and rivers using regulating structures. Alternatively, freshes could be managed discretely within the Edward-Wakool River System. • Implementing this option will build on past environmental watering actions in the Edward River, Yallakool Creek, Wakool River, and Colligen Creek-Niemur River. Consideration may also be given to undertaking watering in other creeks/rivers in the Edward-Wakool region not previously targeted by Commonwealth environmental water, such as Gulpa Creek and in the Merran Creek system. In the past two years, the Little Merran Creek has been used as a control site for monitoring ecological responses to environmental flows. • Under high and very high inflow conditions, delivery may not be feasible because natural flows would meet environmental demand and channel capacity would limit the ability to use environmental water at that time. However, higher inflow conditions are most likely in spring/early summer, and there may be opportunities to deliver environmental water outside of this time. • Environmental water delivery may be constrained by other demands on the system, especially during the irrigation season. • This option would be implemented in conjunction with local delivery partners, who will play a key role in engaging with the local community and third parties to manage potential inconveniences from environmental water delivery. The Murray Catchment Management Authority and NSW Office of Environment and Heritage will obtain any water delivery approvals/landholder consent required for this option.	

Appendix 2. Watering option 3 – Mid-Murray region water quality and habitat (from CEWO 2013)

Option 3 – Mid-Murray region water quality and habitat

Catchment: Murray Catchment	
Complex: Murray Catchment River Flows	
Site: Murray River Channel, Edward-Wakool River System (instream)	
Applicable level(s) of resource availability: Low to Very High	
Relevant flow component: ☒ Base flows ☒ Fresh ☐ Bank-full flows ☐ Over-bank flows	**Expected inundation extent:** ☐ Floodplain inundation ☐ Wetland inundation
Summary of watering option: • The purpose of this option is to contribute to managing water quality issues within instream environments in the Mid-Murray catchment. This option will contribute to the maintenance or improvement of water quality, to support the condition and reproduction of native fish, other vertebrates (frogs) and macroinvertebrates. This option will also contribute to growth and survival of native fish. Where water quality issues are wide-spread, this option may include providing environmental water to create localised refuge habitat. • Examples of scenarios where this option may apply include a flooding event that results in low dissolved oxygen within the instream environment, or a return to extended low-flow conditions which contributes to a reduction in water quality, and the availability and condition of instream habitat. • This option is contingent on site conditions throughout the year, but is more likely to be required during warmer months. The volume of environmental water required and duration of delivery for this option will vary significantly depending on water quality and flow conditions at the time.	
Timing	Dependent on site conditions and water quality
Volume of Commonwealth environmental water	Up to 150 GL
Operational considerations and feasibility: • Target flows will be dependent on the prevailing flow conditions, the nature of the water quality issue, and operational considerations. • Environmental water would be delivered in the Murray River from Hume Dam and Yarrawonga Weir. The Murray-Darling Basin Authority's River Murray Operations are responsible for managing flows from these storages. This option may have impacts on downstream systems and works projects. The Commonwealth Environmental Water Office will seek advice from river operators on plausible target flow rates for this option, taking into consideration potential downstream impacts. • Environmental water may be delivered to the Edward-Wakool River System as a result of watering in the Murray River, if delivery in the Murray River causes flows through the Millewa Forest. This would result in inflows through to the Edward-Wakool River System, which could be directed into the target creeks and rivers using regulating structures. Alternatively, delivery could be managed discretely within the Edward-Wakool River System; this may utilise releases from the Murray Irrigation Limited escapes. Delivery via escapes may be particularly useful in the scenario where hypoxic blackwater is returning from floodplain environments into the Edward-Wakool River System. • Environmental water delivery may be constrained by other demands on the system, especially during the irrigation season. Additionally, during periods of higher flows the capacity to deliver environmental water in addition to the existing flows may be limited. • This option would be implemented in conjunction with local delivery partners, who will play a key role in engaging with relevant landholders and other third parties to manage potential inconveniences from environmental water delivery.	

Appendix 3. Overall expected outcomes from the use of Commonwealth environmental water in the mid-Murray region (source: CEWO 2013).

Flow type	Expected outcomes for 2013-14	Contributions to longer term outcomes	Contribution to the following Basin Plan objective
Base flows and freshes	End of system flows	Connectivity	Ecosystem function
	Primary production	Process	
	Resistance	Population resilience	Resilience
	Dissolved oxygen	Chemical	Water Quality
Overbank	Dissolved organic carbon	Chemical	Water Quality
All flow types	Within ecosystem diversity	Landscape ecosystem diversity	Biodiversity
	Vegetation condition and reproduction	Landscape vegetation diversity	
	Fish reproduction Fish condition	Landscape fish diversity Fish larval growth and survival	
	Waterbird survival and condition. Waterbird reproduction. Waterbird fledging	Landscape bird diversity	
	Other vertebrate condition Other vertebrate reproduction	Other vertebrates	
	Hydrological connectivity Biotic dispersal Sediment transport	Connectivity	Ecosystem function
	Refuge Avoidance	Landscape refuge	Resilience