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Charles Sturt University

# Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Edward/Kolety-Wakool River System Selected Area Technical Report 2020-21

FLOW Monitoring Evaluation Research

## Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Edward/Kolety-Wakool River System Selected Area Technical Report 2020-21

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**Cover photos:**
**Left:** Adult female Murray River short-necked turtle (Photo: James Van Dyke)
**Right:** Low water levels in Stevens Weir, 7th June 2021 (Photo: Paul Frazier)

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# Contents

# ACKNOWLEDGEMENTS


### *Core monitoring*

The authors of this report as well as the Commonwealth Environmental Water Office respectfully acknowledge the Traditional Owners of the Murray-Darling Basin, their Elders past and present, their Nations, and their cultural, social, environmental, spiritual and economic connection to their lands and waters. We are honoured to work on the ancestral lands of the Wamba Wamba or Wemba Wemba, and Perrepa Perrepa or Barapa Barapa People. We recognise their unique ability to care for Country and their deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices. We are committed to genuinely partner and meaningfully engage with Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

This project was funded by the Commonwealth Environmental Water Office with in-kind contributions from Charles Sturt University, NSW Department of Primary Industries, NSW Office of Environment and Heritage and La Trobe UNiversity. Project partners: Charles Sturt University, NSW Fisheries, NSW Department of Planning, Industry and Environment, La Trobe University, Streamology, Yarkuwa Indigenous Knowledge Centre, Edward-Wakool Anglers Association, Western Murray Land Improvement Group.

We extend our thanks to the Edward/Kolety-Wakool Environmental Water Reference Group, Wakool River Association, Edward/Kolety-Wakool Angling Association, Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation, the Colligen and Niemur Group, Western Murray Land Improvement Group, and landholders in the Edward/Kolety-Wakool River system for their keen interest in this project and for providing access to monitoring sites on their properties.

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Maps were prepared by Simon McDonald and Deanna Duffy (Charles Sturt University Spatial Analysis Unit). John Pengelly (CSIRO) processed carbon and nutrient samples. Larval and juvenile fish sampling was carried out under NSW Fisheries license (larval fish P19/0006-1.0, juvenile fish P19/0051). Projects were approved by the CSU Animal Care and Ethics Committee (larval fish surveys: A19260, recruitment surveys: A19384). Sampling in the Murray Valley National Park was permitted under the National Parks and Wildlife Act 1974 (Scientific License: SL101403). Adult fish surveys were conducted by DPI Fisheries under Fisheries NSW Animal Care and Ethics permit 14/10.

### *Turtle research*

We acknowledge the Traditional Owners of the lands in which the study took place, and pay respect to Elders past, present, and future. The wetlands and areas researched in this project are the on the lands of the Wamba Wamba and Perrepa Perrepa people.

We are grateful to Jeanette and David Crew and Yarkuwa Indigenous Knowledge Centre for their support of the project. We thank Jason Thiem and the La Trobe Centre for Freshwater Ecosystems for lending the acoustic receivers used in this project. We thank Katie Howard for helping to establish the telemetry network, and Joseph Briggs, John Trethewie, Emma Kynaston, and Angela Simms for fieldwork assistance. We thank Josh Campbell and Jamie Hearn from Murray LLS for additional troubleshooting and assistance. We are grateful to the following people for allowing us to access wetlands via their properties and work sites: Chris McBurnie (Billabong), Barry Doidge (Barratta Farm), Peter Landale (Dahwilly Farm), Ken and Jill Hooper (Moonahcullah property), and Mark Jeffery (Water NSW).

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# EXECUTIVE SUMMARY

## Introduction

The Commonwealth Environmental Water Office (CEWO) Monitoring, Evaluation and Research (Flow-MER) Program (2019 to 2022) is an extension of the Long-Term Intervention Monitoring (LTIM) and Murray-Darling Basin Environmental Water Knowledge and Research Project (EWKR) projects, with monitoring, evaluation and research activities undertaken within a single integrated program.

This report describes the monitoring, evaluation and research activities that were undertaken in the Edward/Kolety-Wakool system as part of the CEWO Flow-MER Program in 2020-21. This project was undertaken as a collaboration between Charles Sturt University, NSW DPI (Fisheries), NSW Department of Planning, Industry and Environment, and La Trobe University.

This report has eleven sections. This introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2019-20 (section 2). An overview of the monitoring, evaluation and research undertaken in this system for the Flow-MER Program and its relationship to LTIM monitoring is described in section 3. Summaries of the evaluation of responses of each indicator to Commonwealth environmental watering and unregulated flow events are presented in sections four to eight; hydrology (section 4), water quality and carbon (section 5), stream metabolism (section 6), riverbank and aquatic vegetation (section 7), and fish spawning, fish recruitment and fish community (section 8). Sections nine and ten report on the outcomes of several components of an integrated research program focused on the Edward/Kolety River. Section 9 reports on turtle research, and section 10 on social research. Recommendations to inform adaptive management of environmental water in the Edward/Kolety-Wakool system in the future is presented in section 11. A summary report (Watts et al. 2021b) provides an overview of the monitoring and key findings of the ecosystem responses to environmental watering actions in the Edward/Kolety-Wakool system in 2020-21 including findings across the seven years of the combined LTIM/Flow-MER Program.

## Monitoring and evaluation

The monitoring and research described in this report is undertaken using methods and approaches described in the Edward/Kolety-Wakool MER Plan (Watts et al 2019a). As the Flow-MER Program is a continuation of the LTIM Project, for some of the monitoring indicators we will evaluate long-term trends across the seven years of the LTIM/Flow-MER Program.

The Flow-MER Program includes monitoring in the following sites and river reaches:

- Monitoring sites in the upper and mid reaches of the Wakool-Yallakool system (zones 1, 2, 3 and 4) and zone 8 (Colligen Creek) that were established during the LTIM project for water quality, stream metabolism, vegetation and fish were retained for the Flow-MER Program.
- Twenty sites that were established for fish community surveys in 2010 and were monitored in year one (2015) and year five (2019) of the LTIM project were maintained for the Flow-MER Program and will be surveyed in year three of the project (2022).

- Additional water quality monitoring sites were added to the existing network of water quality monitoring sites established during LTIM project. For the MER Program there are now17 throughout the whole system.

An evaluation of the outcomes of Commonwealth environmental watering undertaken in 2020-21 was undertaken for the following indicators: Hydrology, Water quality and carbon, stream metabolism, aquatic and riverbank vegetation, and fish reproduction, recruitment, and community.

Responses to Commonwealth environmental water were evaluated in two ways:

i) Indicators that respond relatively quickly to flow (e.g., hydrology, water quality and carbon, stream metabolism, fish spawning) were evaluated for their response to specific watering actions. Hydrological indicators were calculated on the discharge data with and without the environmental water.

ii) Indicators that respond over longer time frames (e.g., riverbank and aquatic vegetation, fish recruitment, fish community) were evaluated for their response to the longer-term environmental watering regime. This was undertaken by comparing responses over multiple years, and/or comparing responses in reaches that had fewer environmental watering actions, such as the upper Wakool River that received minimal environmental water between 2014-21.

## Environmental watering in the Edward/Kolety-Wakool system 2020-21

This report describes responses to eight Commonwealth environmental watering actions in the Edward/Kolety-Wakool Selected Area from 1 July 2020 to 30 June 2021 (Table i). All eight actions are incorporated under Watering Action Reference number WUM10105-01 (CEWO 2021). Some of the environmental water during these actions was sourced as return flows from the Southern Connected Flow in the Murray River. With the exception of a number of water quality monitoring sites, watering actions undertaken in Tuppal Creek, Jimaringle-Cockrans Creek and Pollack Swamp are not included in this report as they are not Flow-MER monitoring sites.

Watering action number 1 was an 800 ML/day flow trial coordinated with wider Murray River actions to maximise benefit. Actions 1, 2, 3 in Yallakool-Wakool system and 5, 6 and 7 in the Colligen Niemur system were a sequence of spring fresh/elevated base flows/summer freshes that in combination aimed to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, and support pre-spawning condition of native fish and/or spawning in early spawning native fish. Watering action 4 was an autumn fresh in Yallakool Creek. Action 8 was a period of variable base flows in the upper Wakool River to improve water quality.

**Table i** Commonwealth environmental watering actions in 2020-21 in the Edward/Kolety-Wakool system.

| Watering Action | System | Name | Objectives (from CEWO) | Dates |
|---|---|---|---|---|
| 1 | Yallakool-Wakool system | Spring fresh | 800 ML/day flow trial to test inundation extent, coordinated with wider Murray River actions to maximise benefit. Slow recession for instream water plants to elevated base flow of 380 ML/d<br><br>To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish. | 20/10/20-30/11/20 *(Yallakool)*<br>23/10/20 - 27/11/20 *(Wakool)* |
| 2 | Yallakool | Elevated base flow | To maintain nesting habitat for Murray Cod, and inundation for aquatic vegetation growth | 30/11/20 - 15/12/20 |
| 3 | Yallakool | Summer freshes | To influence and encourage silver perch breeding and fish movement, may also assist with dispersal of larvae and juveniles of a number of fish species. Slow recession to support instream water plants.<br><br>Two freshes: 15/12/20 start peak 1/4.01/21 finish peak 1 start peak 2. 15/2/21 finish peak 2 and recession down to operational base levels of 170 ML/d | 15/12/20 – 15/2/21 |
| 4 | Yallakool | Autumn fresh | To influence/encourage fish movement. May also assist with dispersal of juveniles of a number of fish species. | 30/3/21 - 6/5/21 |
| 5 | Colligen-Niemur | Spring fresh | To provide early season rise in river level to contribute to connectivity, water quality, stimulating early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish | 21/10/20 - 6/12/20 |
| 6 | Colligen-Niemur | Elevated base flow | To maintain nesting habitat for Murray Cod, and inundation for aquatic vegetation growth. | 6/12/20 - 8/1/21 |
| 7 | Colligen-Niemur | Summer fresh | Summer fresh to influence and encourage fish movement, may be coordinated with wider Murray River actions to maximise benefit. May also assist with dispersal of larvae and juveniles of a number of fish species. | 8/1/21 - 26/1/21 |
| 8 | Upper Wakool | Variable base flows | To provide a proactive, longer-term approach to preventing a potential hypoxic water event. Enable a comparison to previous monitoring data to determine if a longer, higher flow rate is better at maintaining fish, plants, invertebrates and aquatic species. Improve ability to provide longitudinal connectivity, flow variability and potential refuge. Continue to build good social license among landholders and other stakeholders.<br><br>Variable cycling for WQ Ranging from 50 ML/d to 120 ML/d | 23/1/21 - 9/6/21 |

# Outcomes of monitoring and evaluation of environmental watering

Key results from environmental watering actions in 2020-21 are presented in Table ii.

**Table ii** Results for each indicator in response to environmental watering actions in the Edward/Kolety-Wakool system in 2020-21.

| Theme | Indicator | Key result |
|---|---|---|
| Hydrology | Maximum and minimum discharge | • All of the Commonwealth environmental watering actions increased the maximum discharge compared to operational flows.<br>• The maximum daily operating discharge of 600 ML/d in zone 4 was exceeded during watering action 1; the discharge peaked at 781 ML/d in zone 4 compared to operational flow of 225 ML/d on this date.<br>• The watering actions did not change the minimum discharge. |
| | Flow variability | • The watering actions increased the variation of discharge in all zones compared to operational flows. In the absence of the watering actions there would have been extended periods of low variability flows. |
| | Longitudinal connectivity | • The watering actions maintained longitudinal connectivity across the system.<br>• Watering action 1 increased longitudinal connectivity by initiating flow in Black Dog Creek, connecting the upper Wakool River and Yallakool Creek. |
| | Lateral connectivity | • Watering action 1, 3, 4, 5, 7, and 8 increased lateral connectivity compared to the modelled connectivity under operational flows. |
| Water quality and carbon | Dissolved oxygen concentration | • The expected seasonal variations of dissolved oxygen concentrations were observed in the Edward/Kolety-Wakool River in 2020-21 water year, generally were above the range of concern to fish populations. The 2020 800 ML/day flow trial did not result in any adverse water quality outcomes. Dissolved oxygen concentration remained normal for the period of watering action.<br>• Commonwealth environmental watering action 8 commenced in the upper reach of Wakool River during January to June 2021 resulting in higher discharge than other years and the variable base flows supported dissolved oxygen concentrations in this part of the system. It demonstrated that using Commonwealth environmental water in upper Wakool with extremely low flow in hot months could provide a proactive, longe- term approach to improve water quality and prevent potential hypoxic water events. |
| | Nutrient concentrations | • Nutrient concentrations in the Edward/Kolety-Wakool system remained in the acceptable range in 2020-21 water year.<br>• Total phosphorus and total nitrogen were slightly elevated during Commonwealth environmental watering actions, likely due to greater turbidity (particles suspended in the water column), bioavailable nutrients remained low. |
| | Temperature regimes | • None of the watering actions targeted temperature. Water temperatures in the system were primarily controlled by the prevailing weather conditions. |
| | Dissolved organic matter | • There was no detectable effect of environmental watering actions on dissolved organic matter and no adverse water quality outcomes.<br>• A pulse of dissolved organic carbon was detected in the Wakool-Yallakool system during the 800 ML/day flow trial and the concentration of dissolved organic carbon in the mid- Wakool River was outside the normal range observed in the system and almost reached a similar level to that observed during 2016-17 floods. This may have been influenced by return flows from MIllewa Forest during the Southern Connected Flow. |

| Theme | Indicator | Key result |
|---|---|---|
| Stream metabolism | Gross Primary Production (GPP) | • The environmental watering actions did not substantially affect areal rates of gross primary productivity (mg O2/m$^2$/day), which largely followed seasonal trends. However, when GPP was calculated as the amount of organic carbon ('fish food') produced per day (kg C/day) then watering actions had a beneficial effect (more 'food' is better). The size of the beneficial impact was largely related to the proportion of total flow that came from the watering action, with greater proportional effects of environmental water in lower-flow periods. Carbon production was enhanced by between 18% and 285% during the watering actions, with a median across all sites and watering actions of 117% more carbon produced during environmental watering actions compared to no environmental water. |
| | Ecosystem Respiration (ER) | • As with GPP, areal rates of ecosystem respiration (mg O2/m$^2$/day) were largely driven by seasonal trends. However, when ER was calculated as the amount of organic carbon consumed per day (kg C/day), then watering actions had a beneficial effect. A higher amount of organic carbon consumed means more nutrient recycling and hence greater nutrient supply to fuel GPP. Carbon consumption was enhanced by between 18% and 257% during the watering actions, with a median across all sites and watering actions of 113% more carbon consumed during environmental watering actions compared to no environmental water. |
| Riverbank and aquatic vegetation | Total species richness | • In general, the watering actions in 2020-21 maintained total species richness of riverbank and aquatic plants. There has been an increase in the mean total richness in the five monitored zones since the 2016 flood, especially in zones 1 and 4, however species richness has not yet recovered to the same as prior to the flood. The mean total number of taxa was higher in zones 1 ,3, 4 and 8, that have received more environmental watering actions compared to zone 2. |
| | Richness and percent cover of functional groups | • Since the 2016 flood there has been a reduction in richness and % cover of riverbank and aquatic plants. The patterns vary within functional groups.<br>• After the 2016 flood all submerged taxa were absent from monitored sites. Some submerged taxa have re-established in all zones, but the total richness has not yet reached levels observed prior to 2016.<br>• Since the 2016 flood the number of amphibious taxa has increased in all zones, but total richness has not recovered to that observed prior to the flood.<br>o Amphibious responder taxa have responded variably to flows. The 2016 flood had no impact on % cover of spiny mudgrass. In 2020-21 this species had higher % cover in all zones compared to prior to the flood, regardless of environmental watering. Floating pondweed, azolla, milfoil and water primrose were negatively impacted by the 2016 flood, with most of these absent after the flood. More amphibious responder taxa have re-established in zones 1, 3, 4, and 8 that have received more environmental watering actions than in zone 2.<br>o The number of amphibious tolerator taxa in zones 1, 3 and 8 continued to be lower than the number of taxa prior to 2016. Common spikerush tolerated the 2016 floods and has maintained % cover across years, but there is no relationship with watering regime. The patterns of Juncus percent cover do not appear to be related to environmental watering.<br>• Following the flood in 2016 there was a reduction in the mean total richness of terrestrial taxa in all zones, but the patterns were variable. Common sneezeweed increased in cover after the flood, especially at transects high up on the bank. Most other terrestrial taxa have very little change over time. |

| | | |
|---|---|---|
| | Other plant responses | • Watering actions 1 and 5 (spring fresh) in Yallakool-Wakool and Colligen-Niemur systems stimulated germination and early growth of riverbank and aquatic vegetation. Watering action 3 (summer fresh) supported the persistence and growth of seedlings on the riverbank in 2020-21. |
| Fish spawning | Larval abundance of periodic species | • There was no evidence of local golden or silver perch spawning in the Wakool River or Yallakool Creek.<br>• Carp benefited from the higher in-channel flows, which resulted in inundation and commence to flows in local distributary creeks such as Black Dog Creek and other low-lying areas. This was evidenced by an increase in carp larvae during the Spring pulse (watering action 1), and subsequent recruitment (as evidenced by Category 1 adult fish survey data). |
| Fish spawning | Larval abundance of opportunistic species | • Strong spawning and recruitment in flathead gudgeon were recorded in 2020-21, with higher catches of both larval and juvenile stages (Category 1 adult surveys) recorded compared to all previous years of monitoring. |
| Fish recruitment | Murray cod, silver perch and golden perch recruitment | • Despite low catch rates of Murray cod larvae in 2020-21, follow up recruitment surveys in summer 2021 captured 0+ (YOY) and 1+ recruits at a similar abundance to 2019-20, and across all study zones.<br>• Juvenile trout cod (1+) were captured in Yallakool Creek in February 2021.<br>• A higher abundance of silver perch, of all sizes except for YOY, were present in 2021 compared with previous years.<br>• No golden perch 0+ or 1+ fish were captured during recruitment surveys (but see below). |
| Fish populations | Adult fish populations | • All nine native fish species and three alien fish species caught in previous Category 1 adult surveys of the Edward/Kolety-Wakool Selected Area from 2014-2020 were detected in 2021.<br>• Murray cod, silver perch and golden perch increased in abundance and biomass in 2021 compared to the previous year. Although, excluding silver perch, levels remained below those prior to the flooding/hypoxic event in 2016-17.<br>• Golden perch sub-adults (100-300 mm), including one 0+ individual, were detected in 2021. This may have been due to fish immigrating into the Edward/Kolety-Wakool River system from the Murray River or fish stocked into the river from a hatchery. |

## Outcomes of research projects

There are considerable knowledge gaps that need to be addressed to inform the future delivery of environmental water to the Edward/Kolety River system.

The Edward/Kolety integrated research project includes physical, ecological, and social research that will address questions relating to how managed flows in the Edward/Kolety River and the operation of Stevens Weir. There are two research projects included in this 2020-21 report. The first project examines turtle movement and condition to answer the question *How does connectivity of wetlands along the Edward/Kolety River affect turtle distribution, movement and body condition?* In addition, social research was undertaken in 2020-21 to examine stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water. Some of the research components have different reporting timelines.

## *Turtle research: How does connectivity of wetlands along the Edward/Kolety River affect turtle distribution, movement and body condition?*

This project was undertaken in collaboration with Wamba Wamba and Perrepa Perrepa Traditional Owners from the Yarkuwa Indigenous Knowledge Centre. Through this project Traditional Owners were provided training and experience in turtle ecology and conservation methods that they will be able to apply in their own future conservation work in Werai forest. The project facilitated reciprocal learning, as the Traditional Owners also shared their perspectives and knowledge about turtles, wetlands, and conservation.

Freshwater turtles are an important component of Australian river ecosystems, and are culturally important to local Traditional Owners. As major scavengers, they are likely to be important regulators of nutrient cycling in river systems, at least at their historic densities. Despite their importance, about half of all Australian turtle species are currently listed as vulnerable, threatened, or endangered. Freshwater turtle populations may be threatened by winter drying of wetlands. As aquatic ectotherms (ie, cold-blooded), freshwater turtles substantially reduce their activity rates during the cold of winter. Thus, if they overwinter at a site that dries completely, they are likely to be exposed to mortality both as a result of environmental exposure and greater susceptibility to predators that they cannot escape.

Three freshwater turtle species are found in the Edward/Kolety River: the broadshelled turtle, *Chelodina expansa*, eastern long-necked turtle, *Chelodina longicollis*, and the Macquarie River, *Emydura macquarii.* In this project, we tested for how winter drying affects turtle populations in the Edward/Kolety River in two ways: i) We used repeated trapping surveys to compare turtle community, body condition and population structures among disconnected wetlands that were more likely to experience winter drying and connected wetlands that were unlikely to experience winter drying, and ii) We used acoustic telemetry to track a subset of tagged individual E. macquarii to determine individual movement patterns in relation to the wetting/drying regime of six wetlands.

Three of the study wetlands (Horseshoe, Moonahcullah, and Billabong) were disconnected, meaning that there is at least a small area of dry land between them and the Edward/Kolety River at normal flows. Three wetlands (Barratta, Yallakool, ad Dahwilly) all have a continuous open connection to the river, and their levels fluctuate with river levels.

During the study, we caught 195 *C. expansa*, with 37 recaptures; 265 *C. longicollis*, with 62 recaptures; and 303 *E. macquarii*, with 33 recaptures. Catch-per-unit-effort (CPUE) did not differ between disconnected and connected wetlands for any of the three turtle species present. Female *C. expansa* exhibited higher body conditions in disconnected wetlands than in connected wetlands, but males exhibited no difference. There was no difference in body condition of *C. longicollis* between connected and disconnected wetlands. Female *E. macquarii* exhibited higher body conditions in connected wetlands than in disconnected wetlands, but males exhibited no difference. In our body condition analysis, only female *E. macquarii* presented a pattern consistent with a potential risk in disconnected wetlands, because they had lower body conditions than females from connected wetlands.

Demographics of all three species followed similar trends at all six wetlands. We detected very few juveniles of all three species, and all populations were dominated by older, larger adults. This trend is widespread in the Murray-Darling Basin and indicates that turtles suffer from low recruitment rates. Juvenile *E. macquarii* were especially rare, with only one individual captured in Horseshoe Lagoon. More juvenile *C. longicollis* were present than in the other two species, but even these numbers only summmed to 29 out of 265 turtles, or about 10.9 %.

During the study, we detected 121 exit events, where tagged *E. macquarii* exited a wetland into the adjacent river. We also detected 107 entry events, where tagged *E. macquarii* entered a wetland from the adjacent river. Across the study, female turtles tended to stay close to 'home' even if they exited their home wetland, whereas males tended to either disappear completely, leave their wetland and reappear in the river adjacent to a different wetland, or re-appear at their home wetland weeks to months after disappearance. We found that tagged *E. macquarii* typically exited temporary wetlands prior to winter and overwintered in the adjoining Edward/Kolety river. Furthermore, all three species of turtles exited a drying wetland in summer, long before winter drying became a potential threat. *E. macquarii* rapidly re-entered 'home' wetlands (wetlands in which they were initially tagged) the following spring. At connected wetlands, females exited and re-entered their home wetlands repeatedly throughout the year. The majority of females spent the winter in the river adjacent to their home wetlands. All of these tagged females returned to their home wetlands by the start of spring. Males exited and re-entered their home wetlands several times, but three left for long periods of time. However, most males had disappeared from the receiver network by the start of winter so we cannot confidently state whether they overwintered in the river or in other wetlands.

Our results indicate that turtles that utilise wetlands on the floodplains of permanent river systems may be protected from winter wetland drying due to their behaviour of moving to the adjacent river to hibernate. By spending the winter in the river channel, they avoid the risks of being exposed in a drying wetland as temperatures drop in winter. Our research indicates that turtles can survive in wetlands susceptible to winter drying if a nearby waterway retains high water and can act as a winter refuge.

### *Edward/Kolety River social research*

This research considered the knowledge, values and opinions of people with some form of 'stake' in the Edward/Kolety-Wakool in relation to environmental water and its use in that river system, specifically to address the following questions:

1. How are knowledge, information and learning (i.e., acting, adapting and accepting) understood and experienced by stakeholders in the Edward/Kolety-Wakool River system?
2. What are the current Edward/Kolety-Wakool River system stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water?
3. What institutional, social and/or cultural interventions could improve the acceptance and impact of Commonwealth environmental water for this and other sites?

An online questionnaire was developed that used a semi-standardised format that included pre-structured choices and opportunity for respondents to formulate their own responses. A list of themes, topic areas and potential questions were developed in consultation with willing stakeholders and piloted. Sections related to: the respondent population and their involvement in the Edward/Kolety-Wakool system; their knowledge and understanding of water in the Edward/Kolety-Wakool system; their understanding and perceptions of environmental water planning and management and their forms of communication and information sources.

Survey respondents in the Edward/Kolety-Wakool system monitoring area were predominately men over 40 years of age who have lived in the area, either on the river or in the towns, for most or all of their lives. All of the respondents, whatever age or gender, were clearly well connected to the river system. They are interested in all of the river system, not just parts of it and they are concerned not only about the health of the river but also with its relationship to personal livelihood and the local community.

All of the respondents agree that healthy rivers are necessary for healthy societies. It is rare to have 100% agreement to a value statement in such a contested area of activity, and this could, perhaps should, be a pivot point for information exchange in the future. What health means in each in instance will vary for each individual, group and organisation, but the common shared agreement of purpose can provide a solid foundation for working with those variances. Some, but not all, agree that water for the environment can play a role in achieving river health.

The respondents have a good understanding of the roles of various government agencies and groups that have a role in water management in the Edward/Kolety-Wakool system, while the trust in those groups is more varied. The qualitative data indicate that dissatisfaction relates to perceptions of low consultation and poor accountability around environmental water, and water in general.

This group of respondents want to know about the responses of animals, plants and water quality to the use of environmental water. They support the focus of existing monitoring programs.

The data from the survey suggests:

1. There is potential to use the results of this survey as an object for conversations within the communities (including scientists) associated with this river system and Flow-MER.
2. Reducing the narrow scientific focus on water for the environment that separates the program from the river system communities, who relate to all of the water.
3. More information about river health and water quality should be available in locally relevant and accessible ways. Detailed information about the Flow-MER Program is available on websites, but locally focused, locally accessible and even locally verified or voiced information is also needed. What this involves should form part of the discussions noted in 1, but could include, for example, one or two large, current water quality graphs in publicly accessible sites (see for example the Saltwatch program), regular columns on river health in the local newspapers, and or involvement of schools in water quality management.
4. Continuing to work with the expertise and passion that at local people have for the Edward/Kolety-Wakool River system.

This survey instrument appears to be valuable, and we recommend that it is used for further exploration of the social acceptability of the use of water for the environment in the Edward/Kolety-Wakool system. Involving specific social groups that are underrepresented in this report would be valuable. This includes women, Traditional Owners, and water planners/water managers. Mitchell and Allan (2018) found that over one-third of respondent groups in their NSW based survey took up the recommendation of completing a survey as a group exercise, and this may be needed to increase the number and range of responses if the survey is administered again. Engagement of these groups may also require paper-based survey, offers to assist in group settings, and targeted use of social media.

## Recommendations from previous annual reports (2014-2020)

A summary of recommendations from previous Edward/Kolety-Wakool LTIM annual reports (Watts et al. 2015, 2016, 2017b, 2018, 2019) and the 2019-20 Edward/Kolety-Wakool Flow-MER annual report (Watts et al 2020) is provided in Appendix 1. These recommendations relate to the use and/or contribution of Commonwealth environmental water to different types of watering actions including:

- Base flows
- Small freshes
- Medium and larger in- channel freshes
- Recession flows
- Winter flows
- Mitigate issues arising during hypoxic blackwater events
- Mitigate issues associated with managed flows operations, including constant regulated flows, (low variability), rapid recession of flows, and winter cease to flow.

Some of the flow recommendations in appendix 1 refer to specific targeted ecological objectives, such as fish movement, spawning of Murray cod, or river productivity. In previous LTIM/Flow-MER reports there are also some recommendations that have addressed more general aspects of environmental water management, such as the need to implement flow trials, the setting of flow objectives, and the need to improve sources of hydrological data to facilitate the evaluation of environmental watering actions.

## Recommendations for management of environmental water

The following ten recommendations are based on findings from this 2020-21 annual report, with some reference made to recommendations and findings in previous reports.

**Recommendation 1:**

Environmental water delivery in 2020-21 was the closest yet (since the LTIM/Flow-MER Program commenced in 2014) to achieving environmental flows that included the timing, magnitude, duration and extent and provided longitudinal connectivity with other flow freshes in the mid-Murray region required for spawning, recruitment and movement of juvenile golden perch and silver perch. The sequence of flows over spring/summer in 2020-21 also supported the germination and survivorship of riverbank plants that play an important role in stabilising riverbanks, riverine productivity and food webs, and provides habitat for fish, frogs, birds and invertebrates.

Recommendation: Deliver a sequence of flows over the period from late winter/spring/early summer to support the spawning, recruitment and movement of juvenile perch, support aquatic and riverbanks plants, riverine productivity, and provide habitat and food for other aquatic animals.

**Recommendation 2:**

Although small watering actions have provided a beneficial outcome for the riverine ecosystem productivity, the findings of the stream metabolism evaluation suggest that reconnecting backwaters and the floodplain to the river channel would result in much larger positive productivity outcomes.

Recommendation: Consideration be given to providing a more variable flow regime that reconnects low lying parts of the floodplain to the river channel.

**Recommendation 3:**

Positive spawning responses of Murray cod during elevated flows in the upper Wakool River were recorded in 2018-19, and record numbers of larvae were associated with the delivery of sustained 200 ML/day flows, which commenced from late September 2018 through to January 2019. In 2020-21, a similar increase from base flows was delivered, however this did not commence until 30 November 2020. Monitoring results have shown that the number of Murray cod larvae caught in 2020-21 was the second lowest since monitoring commenced in 2014-15 (second lowest to the 2016-17 during the 2016 flood).

Pre-spawning and nesting behaviour of Murray cod is likely to commence between September and October. In 2018-19 nest-building and spawning would have taken place under 200 ML/day flows, while in 2020-21 flows were still at base levels (50 ML/day) in September. The lower catch rates of Murray cod in the upper Wakool in 2020-21 compared to 2018-19 may have been due to difference in the timing of the two watering actions. The timing of watering action 2 (elevated base flow) in late November 2020 may have been too late for achieving the flow objective.

Consideration of future water delivery to tributaries of the Edward/Kolety-Wakool system that commences in September may be more successful in maximising the availability of suitable nesting areas during the Murray cod breeding season. As trout cod spawn at cooler water temperatures than Murray cod, it may be worth considering introducing an elevated baseflow through the Yallakool and Wakool systems as early as August to support nesting in this species. Consideration of future water delivery of elevated base flows (200 ML/day) to the Upper Wakool River from start of September to maximise nesting and spawning opportunities for Murray cod.

**Recommendation:** Deliver elevated base flows from the start of September to maximise nesting and spawning opportunities for Murray cod. Record catches of larvae have been recorded in 2018-19 when this type of watering action was delivered.

**Recommendation 4:**

The ‘2020 Southern Spring Flow’ (SSF) was a river pulse in the Murray River that was designed by timing releases of water for the environment in the Murray, Goulburn and Murrumbidgee rivers to deliver water to five wetlands of international significance, to provide a system-wide productivity boost and improve connectivity down the river to the Coorong and Murray Mouth (SCBEWC, 2021). CEWO (2020) states “Where possible, water for the environment will be managed to benefit multiple sites enroute and will be coordinated with other sources of water”.

Instead of commencing in mid-July, the water delivery for the SSF in 2020 was delayed until October 2020. Due to this delay, all of the planned watering actions in the Edward/Kolety-Wakool were also delayed, because there was an aspiration in CEWO to gain maximum benefit of water from the SSF returning from Millewa Forest to deliver the planned watering actions in the Edward/Kolety-Wakool system. Thus, watering action #1 (spring fresh) in Yallakool-Wakool commenced on 20 October 2020, and watering action #2 (elevated base flow in Wakool-Yallakool system that aimed to maintain nesting habitat for Murray cod) was delayed until 30 Nov to 15th December. The lower catch rates of Murray cod larvae in the upper Wakool in 2020-21 may have been due to the delayed timing of this watering action (see recommendation 3).

As environmental water delivery from Hume Dam to the Murray River can strongly influence outcomes in the anabranches and distributaries of the Murray River (e.g., the Edward/Kolety-Wakool system) there is a need for a more integrated, system-wide approach to the planning of environmental watering in the Murray River. The watering actions from Hume Dam need to be designed in a holistic manner, with expected outcomes for the anabranches and distributaries included in the planning, with consideration of the benefits and risks of coordinated actions. The planning should include options to enable watering actions to be ‘un-linked’ if circumstances change and the integrated actions cannot be delivered to achieve the planned outcomes. This would enable environmental watering actions to be independently implemented in parts of the river system, if necessary, to achieve outcomes. This holistic approach will require more complex and integrated planning than has been implemented in previous water years.

**Recommendation:** Undertake integrated, system wide planning of environmental water actions for the Murray River that includes watering of anabranches and distributaries, such as the Edward/Kolety-Wakool system. Planning should include options to ‘un-link’ watering actions in different parts of the Murray system if circumstances arise that prevent the integrated actions from being delivered in the way they were initially planned.

**Recommendation 5:**

In 2020-21 watering action 8 delivered variable base flows to the upper Wakool River to prevent a potential hypoxic water event, provide longitudinal connectivity, flow variability and potential refuge. This watering action produced positive outcomes.

**Recommendation:** Undertake watering actions to improve the connectivity and aquatic and riverbank vegetation outcomes in the Upper Wakool River. Deliver larger freshes with increased variability to enable riverbank vegetation to establish and be maintained.

**Recommendation 6:**

Some fish (e.g., flathead gudgeon) and plants may benefit from water delivery in the Edward/Kolety-Wakool system that targets inundation of a greater diversity of creek systems, including distributary ephemeral and intermittent creeks.

**Recommendation:** Undertake watering actions to improve the connectivity and other outcomes in intermittent and ephemeral streams and flood runners in the Edward/Kolety-Wakool system. Consideration of timing of delivery that reduces opportunities for carp spawning whilst minimising hypoxic blackwater may need to also be taken in account.

## Recommendations for future monitoring and research

We make the following four recommendation about communications, monitoring and research in the Edward/Kolety-Wakool system.

**Recommendation 7:**

The Southern Spring Flow in the Murray River in 2019-20 and 2020-21 resulted in flows returning from Millewa Forest to the Edward/Kolety-Wakool system. Results from 2020-21 monitoring suggest that these return flows had an impact on water quality, productivity and fish outcomes in the Edward/Kolety-Wakool system. At present there is no hydrological model that can provide estimates of daily discharge returns from the Murray watering actions.

**Recommendation:** Hydrological models be developed that will enable daily returns from Murray River environmental watering actions to be estimated in the Edward/Kolety River, so it is possible to evaluate all sources of environmental water that influence the Edward/Kolety hydrology.

**Recommendation 8:**

The social research found that more information and research about the social and cultural impacts of using water for the environment would be welcomed by the community. The research also suggested that more information about river health and water quality is sought that is presented in locally relevant and accessible ways. Detailed information about the Flow-MER Program is currently available on websites, but locally focused, locally accessible, and even locally verified or voiced information is also needed. The social research also found that community members considered that the information available about water delivery is disjointed.

**Recommendation:** Share more information with the community about social and cultural impacts of using water for the environment and present it in locally relevant and accessible ways. When developing communication products about environmental water for the non-technical community, present Information about environmental water in the context of all water in the system.

**Recommendation 9:**

Several social groups were underrepresented in the social research project undertaken in 2020-21. The under-represented groups were women, Traditional Owners, young people, and water planners/water managers. The current research was undertaken by online survey, and a paper option was available but not taken up. Future social research may require implementation of a different survey options survey, such as offers to assist in group settings, and targeted use of social media to engage these under-represented groups. The research should be co-designed with the community.

**Recommendation:** Undertake more social research about the social and cultural impacts of using water for the environment, and in particular co-design the research with the community to facilitate the engagement of previously under-represented groups in the community.

**Recommendation 10:**

The turtle research project was undertaken in collaboration with Wamba Wamba and Perrepa Perrepa Traditional Owners, via the Yarkuwa Indigenous Knowledge Centre. Through this project Traditional Owners were provided training and experience in turtle ecology and conservation methods that they will be able to apply in their own future conservation work in Werai forest. The project facilitated reciprocal learning, as the Traditional Owners also shared their perspectives and knowledge about turtles, wetlands, and conservation.

**Recommendation**: Future monitoring and research projects should, where possible, be undertaken in collaboration with Traditional Owners and other community groups to facilitate co-learning and engagement of the community in water planning, management, monitoring and research.

# 1 INTRODUCTION

## 1.1 Purpose of this report

The Commonwealth Environmental Water Office (CEWO) Monitoring, Evaluation and Research (Flow-MER) Program (2019 to 2022) is an extension of the Long-Term Intervention Monitoring (LTIM) and Murray-Darling Basin Environmental Water Knowledge and Research Project (EWKR) projects, with monitoring, evaluation and research activities undertaken within a single integrated program.

The LTIM Project was implemented over five years from 2014-15 to 2018-19 to deliver five outcomes:

- Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authorities (MDBA) Environmental Watering Plan.
- Evaluate the ecological outcomes of Commonwealth environmental watering in each of the seven Selected Areas.
- Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin (MDB) that are not monitored.
- Support the adaptive management of Commonwealth environmental water; and
- Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

The Flow-MER Program consists of evaluation, research and engagement at a Basin-scale and on ground monitoring, evaluation, research and engagement across seven Selected Areas, one of which is the Edward/Kolety-Wakool River system. The Flow-MER Program aims to provide the critical evidence that is needed to understand how water for the environment is helping maintain, protect, and restore the ecosystems and native species across the Murray–Darling Basin. The program will demonstrate outcomes of environmental watering actions, inform management of Commonwealth water for the environment and will help meet the CEWO's legislative reporting requirements through to June 2022.

This report describes the monitoring, evaluation and research activities that were undertaken in the Edward/Kolety-Wakool system as part of the CEWO Flow-MER Program from July 2020 to June 2021. This project was undertaken as a collaboration between Charles Sturt University, NSW DPI (Fisheries), NSW Department of Planning, Industry and Environment, and La Trobe University. The turtle research was undertaken in partnership with Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation. The monitoring and research described in this report is undertaken using methods and approaches described in the Edward/Kolety-Wakool Flow-MER Plan (Watts et al 2019a). As the Flow-MER project is a continuation of the LTIM Project, for some of the monitoring indicators we will evaluate long-term trends across the seven years of the LTIM/Flow-MER Program.

This report has eleven sections. This introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2020-21 (section 2). An overview of the monitoring, evaluation and research undertaken in this system for the Flow-MER Program and its relationship to LTIM monitoring is described in section 3. An evaluation of responses of each core indicator to Commonwealth environmental watering and unregulated flow events are presented in sections four to eight; hydrology (section 4), water quality and carbon (section 5), stream metabolism (section 6), Aquatic and riverbank vegetation (section 7), and fish spawning, fish recruitment and fish community (section 8). Sections 9 and 10 are reports from research projects; Section 9 reports on turtle research and Section 10 reports on social research. Recommendations to help inform adaptive management of environmental water in the Edward/Kolety-Wakool system in the future is presented in section 11. A summary report (Watts et al. 2020) provides an overview of the monitoring and key findings of the ecosystem responses to environmental watering actions in the Edward/Kolety-Wakool system in 2020-21.

## 1.2 Edward/Kolety-Wakool Selected Area

The Edward/Kolety-Wakool River system is a large anabranch system of the Murray River in the southern MDB, Australia. The system begins in the Millewa Forest and travels north and then northwest before discharging back into the Murray River (Figure 1.1). It is a complex network of interconnected streams, ephemeral creeks, flood-runners and wetlands including the Edward/Kolety River, Wakool River, Yallakool Creek, Colligen-Niemur Creek and Merran Creek. There are also many ephemeral or intermittent creeks in the Edward/Kolety-Wakool system, including Cockrans-Jimaringle Creek, Tuppal Creek, Bullatale Creek, Thule Creek, Murrain-Yarrien Creek, Yarrien Creek, Whymoul Creek, and Buccaneit-Cunninyeuk Creek. These Creeks have important ecosystem functions, enabling connectivity between the larger rivers and tributaries within the system.

Under regulated conditions flows in the Edward/Kolety River and tributaries remain within the channel, whereas during high flows there is connectivity between the river channels, floodplains and several large forests including the Barmah-Millewa Forest, Koondrook-Perricoota Forest and Werai Forest (Figure 1.1). These three forests make up the NSW Central Murray Forests Ramsar site (NSW Office of Environment and Heritage 2018), being one of the matters of national environmental significance to which the EPBC Act applies.

The Edward/Kolety-Wakool River system supports many flora and fauna listed as vulnerable or endangered under Commonwealth EPBC Act or NSW state legislation. The Commonwealth protects the matters of national environmental significance (e.g., Ramsar wetlands, Nationally listed threatened species and ecological communities, listed migratory species) under the EPBC Act and the State under their legislation.

The Edward/Kolety-Wakool Selected Area can be broadly divided into three aquatic ecosystem types:

1) The main semi-permanent flowing rivers including Yallakool and Colligen creeks and the Wakool, Niemur and Edward/Kolety rivers,

2) The floodplain forests and woodlands including the Niemur and Werai Forests, and

3) Several small intermittent and ephemeral creeks of ecological significance including Cockrans-Jimaringle Creek, Tuppal Creek, Bullatale Creek, Thule Creek, Murrain-Yarrien Creek, Yarrien Creek, Whymoul Creek, and Buccaneit-Cunninyeuk Creek.

*Edward/Kolety River, Colligen- Niemur, Yallakool Creek and Wakool River*

The permanent or seasonal rivers and creek support high regional biodiversity values and have significant value as drought refugia for native fish and other biota. The dominant vegetation is river red gum (*Eucalyptus camaldulensis*) with areas providing habitat for a number of threatened species.

*Floodplain – Werai and Niemur Forest*

Werai Forest is located downstream from Deniliquin along the Edward/Kolety River, and has cultural significance to the Wamba Wamba and Perrepa Perrepa Traditional Owners. Land use and occupancy mapping has identified over 12,000 sites of cultural significance to First Nations people in the Werai Forest (Weir et al 2013). Werai Forest is currently managed by the NSW National Parks and Wildlife Service. Since 2009 Traditional Owners have been working towards having Werai Forest established an Indigenous Protected Area (IPA) to be cared for by Traditional Owners through an Indigenous Land Use Agreement. The Yarkuwa Indigenous Knowledge Centre is developing a management plan for the Werai Forest Indigenous Protected Area as part of the process to transfer management and ownership to the Werai Land and Water Aboriginal Corporation.

Werai Forest is recognised regionally, nationally, and internationally as an important forest and wetland. The higher floodplain areas in Werai are dominated by river red gum with lower lying areas typically dominated by giant rush. The low-lying areas, floodrunners and backwaters in Werai may be important habitat for larval and juvenile fish and is a potential source of carbon to feed the lower Edward/Kolety River and Niemur River systems. The Werai Forest supports significant breeding colonies of several species of cormorants, whilst the Niemur Forest supports egrets and nankeen knight heron breeding colonies. Both forests support several listed species and migratory bird species.

In 2003, Werai Forest was listed as a wetland of international importance under the Ramsar convention, as one of three sites in the NSW Central Murray Forests Ramsar site. The two other sites in the NSW Central Murray Forests group are the Millewa Forest Group and the Koondrook-Perricoota Forest Group, all of which depend on flows in the Murray River. The Werai group of forests are also recognised as wetlands of national importance on the Australian Directory of Important Wetlands.

*Ephemeral and intermittent creeks (e.g., Tuppal, Bullatale, Jimaringle, Cockran, and Gwynnes Creeks)*

There are a large numer of intermittent and ephemeral creeks and floodrunners in the Edward/Kolety-Wakool system. For example, Tuppal Creek is an intermittent flood runner connecting the Murray River to the Edward/Kolety River and has a largely continuous riparian corridor which provides habitat connectivity for over 120 terrestrial native species and supports a number of Commonwealth and State listed threatened and vulnerable species (Brownbill and Warne 2010; CEWO 2012c). Jimaringle, Cockran and Gwynnes Creeks are all ephemeral creeks and are considered a biodiversity hotspot of significant regional value.

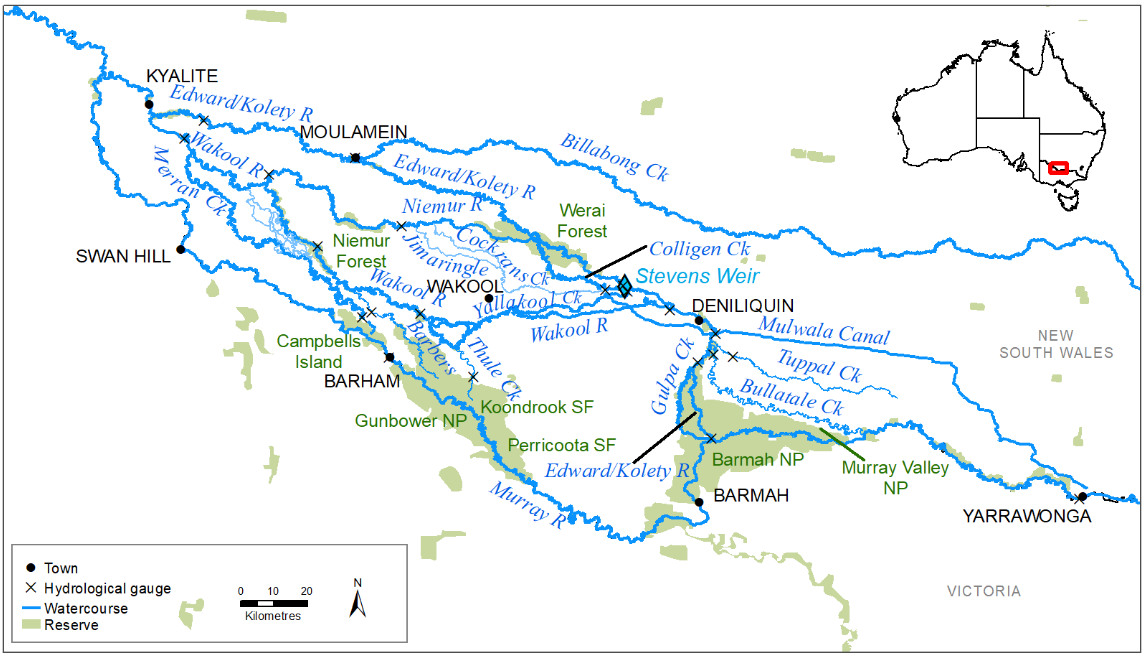


**Figure 1.1** Map showing the main rivers and creeks in the Edward/Kolety-Wakool River system.

The Edward/Kolety-Wakool River system is considered to be important for its 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. Threatened species include the Trout Cod, Freshwater catfish, Murray Cod, Australian Bittern, Australian Painted Snipe, Superb Parrot, and Swamp Wallaby Grass (Department of Environment and Energy 2019).

The area has a rich and diverse Indigenous history, supports a productive agricultural community and supports recreational uses such as fishing, birdwatching and bushwalking. Many First Nations including the Wamba Wamba (Wemba Wemba) and Perrepa Perrepa (Barapa Barapa), and Yorta Yorta, maintain strong connections to Country.

The Edward/Kolety-Wakool River system plays a key role in the operations and ecosystem function of the Murray River and the southern MDB, connecting upstream and downstream ecosystems in the mid-Murray River. The multiple streams and creeks in this system provide important refuge and nursery areas for fish and other aquatic organisms, and adult fish regularly move between this system and the Murray River. As some of the rivers in the Edward/Kolety-Wakool system have low discharge (compared to the Murray River) there is a risk of poor water quality developing in this system, particularly during warm periods or from floodplain return flows. Maintaining good water quality is crucial for both the river ecosystem, the communities that rely on water from this system, and downstream communities along the Murray River that are influenced by the water quality in this system.

# 2 ENVIRONMENTAL WATER USE OBJECTIVES AND WATERING ACTIONS IN 2020-21

The Australian Government owns entitlements to water in the Murray-Darling Basin and this water is used to keep rivers healthy, so they continue to support communities for future generations (CEWO, 2020a). The CEWO manages this water for the environment. The amount of available water changes from year to year and plans are adjusted accordingly. The CEWO follow an annual cycle of 'plan, deliver, measure and review' to manage water for the environment (Figure 2.1).

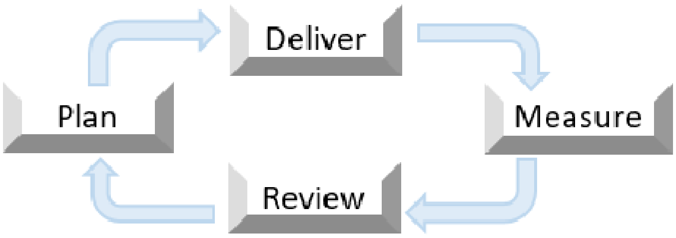


**Figure 2.1.** Annual cycle of 'plan, deliver, measure and review'. (Source CEWO 2020a)

Each year the CEWO prepare a Water Management Plan that considers how much water is expected to be available, the seasonal rainfall outlook, and current ecosystem health. The annual Water Management Plan scopes options for a range of weather scenarios (from dry to wet) so the watering actions can adapt to the seasonal conditions. The CEWO also consider the needs of communities and irrigators, physical limitations of the river, lessons learned from monitoring the response of plants and animals to previous environmental flows, and the Basin Plan annual and long-term objectives (CEWO 2020a).

In the Edward/Kolety-Wakool system the CEWO work closely with local communities, First Nations peoples, water managers, scientists, river operators and landholders through the Edward/Kolety-Wakool Environmental Water Reference Group to plan water use. Delivery of Comonwealth environmental water is coordinated alongside water for the environment managed by the NSW government.

## 2.1 Expected outcomes from Basin-wide Environmental Watering Strategy relevant to the Mid-Murray Region

Expected outcomes from the Basin-wide Environmental Watering Strategy (MDBA 2014) that are relevant to the Mid-Murray Region are listed below and in Table 2.1 and Table 2.2.

### River flows and connectivity

- Base flows are at least 60 % of the natural level
- Contributing to a 30 % overall increase in flows in the River Murray
- A 30 to 60 % increase in the frequency of freshes, bankfull and lowland floodplain flows

### Vegetation

- Maintain the current extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain
- Improve condition of black box, river red gum and lignum shrublands
- Improve recruitment of trees within black box and river red gum communities
- Increased periods of growth for non-woody vegetation communities that closely fringe or occur within the river and creek channels, and those that form extensive stands within wetlands and low-lying floodplains including Moira grasslands in Barmah–Millewa Forest

### Fish

- No loss of native species
- Improved population structure of key species through regular recruitment, including:
    - Short-lived species with distribution and abundance at pre-2007 levels and breeding success every 1–2 years
    - Moderate to long-lived with a spread of age classes and annual recruitment in at least 80% of years
- Increased movements of key species
- Expanded distribution of key species and populations

**Table 2.1** Important Basin environmental assets for native fish in the Mid Murray (Table sourced from MDBA 2014).

| Environmental asset | Key movement corridors | High Biodiversity | Site of other Significance | Key site of hydrodynamic diversity | Threatened species | Dry period / drought refuge | In-scope for Commonwealth water |
|---|---|---|---|---|---|---|---|
| Koondrook–Perricoota | * | * | * | * | * | | Yes |
| Gunbower | * | * | * | * | * | | Yes |
| Barmah–Millewa | * | * | * | * | * | * | Yes |
| Edward/Kolety–Wakool system | * | | * | * | * | * | Yes |
| Werai Forest | | | * | * | | | Yes |
| Billabong–Yanco–Columbo Creeks | | * | * | * | * | * | Yes |
| Lake Mulwala | * | | * | * | * | * | Yes |

**Table 2.2** Key species for the Mid Murray (Source: MDBA 2014)

| Species | Specific outcomes | In-scope for Commonwealth water in the Mid Murray? |
|---|---|---|
| Flathead galaxias (*Galaxias rostratus*) | Expand the core range in the wetlands of the River Murray | Yes |
| Freshwater catfish (*Tandanus tandanus*) | Expand the core range in Columbo-Billabong Creek and Wakool system | Yes |
| Golden perch (*Macquaria ambigua*) | A 10–15% increase of mature fish (of legal take size) in key populations | Yes |
| Murray cod (*Maccullochella peelii peelii*) | A 10–15% increase of mature fish (of legal take size) in key populations | Yes |
| Murray hardyhead (*Craterocephalus fluviatilis*) | Expand the range of at least two current populations. Establish 3–4 additional populations, with at least one in the Mid Murray conservation unit. | Yes |
| Olive perchlet (*Ambassis agassizii*) | Olive perchlet are considered extinct in the southern Basin. Reintroduction using northern populations is the main option for recovery. Candidate sites may result from improved flow that reinstates suitable habitat in the River Murray. | Restoration of flow to Murray River could support future reintroduction of the species |
| River blackfish (*Gadopsis marmoratus*) | Expand the range of current populations from the Mulwala canal | Yes |
| Silver perch (*Bidyanus bidyanus*) | Expand the core range within the River Murray (Yarrawonga–Euston) | Yes |
| Southern purple-spotted gudgeon (*Mogurnda adspersa*) | | Yes |
| Southern pygmy perch (*Nannoperca australis*) | Expand the range of current populations at Barmah-Millewa and other Mid Murray wetlands | Yes |
| Trout cod (*Maccullochella macquariensis*) | Expand the range of trout cod up the Murray upstream of Lake Mulwala and into the Kiewa River. For the connected population of the Murrumbidgee–Murray–Edward: continue downstream expansion. | Yes |
| Two-spined blackfish (*Gadopsis bispinosus*) | Establish additional populations (no specific locations identified) | Yes |

## 2.2 Water Quality targets

The water quality targets of the Basin Plan (2012) (the Plan) are outlined in Chapter 9, Part 4, sub-section 9.14(5) of the Plan. The targets for recreational water quality in Section 9.18 contains Guidelines for Managing Risks in Recreational Water. The target for dissolved oxygen (DO) in the Plan is to maintain DO at a value of at least 50% saturation and suggests this be determined at 25°C and 1 atmosphere of pressure (sea level). This equates to a DO concentration of approximately 4 mg/L. The CEWO has used a trigger of 4.0 mg/L for the potential provision of refuge flows into catchments like the Edward/Kolety-Wakool River system. The Guidelines for Managing Risks in Recreational Water also guide the green, amber and red alert levels issued by relevant state management agencies (e.g., in NSW – the Regional Algal Coordinating Committees) who are responsible for the catchment scale management of algal blooms. The CEWO has access to the alert advice issued by these state agencies and can adjust the use of Commonwealth environmental water accordingly.

## 2.5 Commonwealth environmental watering actions 2009-2020

Commonwealth environmental watering actions have been undertaken in the Edward/Kolety-Wakool River system since 2009 (Table 2.3). Between July 2009 and June 2020 Commonwealth environmental watering actions delivered base flows and freshes, contributed to the recession of flow events, delivered water from irrigation canal escapes to create local refuges during hypoxic blackwater events, and contributed to flows in ephemeral watercourses (Table 2.3). Many of the watering actions in ephemeral creeks were undertaken jointly with NSW DPIE. One Commonwealth watering action in 2009-10 for Werai State Forest (DEE 2017) was undertaken to deliver environmental water to Edward/Kolety-Wakool forests (Table 2.3).

The winter of 2017 was the first time in which a watering action was undertaken to maintain winter base flows during the period when the regulators to some of the smaller streams are usually shutdown in winter. A second winter flow trial was implemented in 2019-20.

It has not been possible to deliver large within channel freshes or overbank flows due to operational constraints in this system (e.g., operational constraint of 600 ML/d at confluence of the Wakool River and Yallakool Creek). However, in 2018-19 a flow trial was undertaken to deliver 800 ML/day at the confluence of the Wakool River and Yallakool Creek. In 2020-21 another flow trial was planned for the Wakool-Yallakool system, and the outcomes of that will be the discussed in this report.

In addition to watering actions specifically targeted for the Edward/Kolety-Wakool system, water from upstream Commonwealth environmental watering actions and actions that are targeted for downstream watering actions transit through the Edward/Kolety-Wakool system in some years. For example, in 2015-16 environmental water returning from Barmah-Millewa Forest influenced the hydrograph in the Edward/Kolety-Wakool system (Watts et al. 2016). Similarly, in 2019-20 the Southern Connected Flow in the Murray River influenced flows in the Edward/Kolety-Wakool system from 28 August to 9 September 2019, and 23 September to 1 October 2019. The return flows from Millewa Forest may have affected the water quality in the Edward/Kolety-Wakool system on these dates, and on later dates at sites further downstream. In 2020-21 another spring pulse was planned and delivered to the Murray River, and this report will discuss some of the implications of this watering action for the Edward/Kolety-Wakool system.

**Table 2.3** Summary of Commonwealth environmental watering actions and unregulated overbank flows in the Edward/Kolety-Wakool River system from July 2009 to June 2020.

| | In-channel environmental watering actions | | | | Environmental watering actions using irrigation infrastructure | | | Unregulated overbank flows |
|---|---|---|---|---|---|---|---|---|
| Water Year | Base flows and small freshes | Contribute to flow recession | Maintain winter base flows | Larger within channel freshes[1] | Flows from canal escapes during hypoxic events | Flows in ephemeral streams[2] | Watering forests | Flooding forests and/or floodplains |
| 2009-10 | | | | | | | ✓ | |
| 2010-11 | | | | | ✓ | ✓ | | ✓ |
| 2011-12 | ✓ | | | | | ✓ | | |
| 2012-13 | ✓ | | | | ✓ | ✓ | | |
| 2013-14 | ✓ | ✓ | | | | ✓ | | |
| 2014-15 | ✓ | ✓ | | | | ✓ | | |
| 2015-16 | ✓ | ✓ | | | | ✓ | | |
| 2016-17 | ✓ | ✓ | | | ✓ | ✓ | | ✓ |
| 2017-18 | ✓ | ✓ | ✓ | | | ✓ | | |
| 2018-19 | ✓ | ✓ | | | | ✓ | | |
| 2019-20 | ✓ | ✓ | ✓ | | | ✓ | | |

[1] Delivery of larger within channel freshes to the Wakool River and Yallakool Creek is not possible under current operational constraints (e.g., constrained to 600 ML/d at the confluence of the Wakool River and Yallakool Creek).
[2] Some of the watering actions in ephemeral creeks done jointly with NSW Office of Environment and Heritage

## 2.3 Environmental Watering Priorities for 2020-21

### *CEWO Portfolio Management Plan for the Mid-Murray in 2020–21*

Prior to the start of each new water year, the MDBA publishes Basin annual environmental watering priorities (Table 2.4). These articulate the environmental water needs (or demands) for the coming year. They are developed having regard to the annual environmental watering priorities developed by Basin States for each catchment. Commonwealth environmental watering actions will seek to contribute to the Basin annual environmental watering priorities, subject to conditions as they unfold throughout the year.

CEWO (2020b) states “The Basin annual environmental watering priorities establish both the context and key environmental water needs at a basin scale through describing the priority environmental values and the desired trend from a whole of basin perspective. The valley priorities provide local information on the key environmental demands in the coming year, under different climatic scenarios. They can provide details on the past and current environmental health of the valley, the objectives for the coming year, and the volumes and timing of desired environmental flows. Valley priorities are developed in close consultation with catchment management agencies, site managers, First Nations representatives, local landholders and community advisory groups.”

Table 2.5 sets out the objectives for environmental watering in the River Murray valley as stated in CEWO (2020b). These objectives are based on long-term environmental objectives in the Basin Plan, draft state long-term watering plans, site management plans (including Ramsar site ecological character descriptions), and best available knowledge. The objectives targeted in a particular year may vary depending on available water, catchment conditions, operational feasibility and demand for environmental water. These objectives will continue to be revised as part of the CEWO's commitment to adaptive management.

**Table 2.4**: Basin annual environmental watering priorities 2020-21 (Source: CEWO 2020b)

| | **Rolling, multi-year priorities** | **2020–21 annual guidance** |
|---|---|---|
| River flows and connectivity | • Support lateral and longitudinal connectivity along the river systems.<br>• Support freshwater connectivity through the Lower Lakes, Coorong and Murray Mouth | • Protect drought refuges.<br>• Build ecosystem resilience by providing or enhancing connectivity |
| Native vegetation | • Allow opportunities for growth of non-woody wetland vegetation<br>• Allow opportunities for growth of non-woody riparian vegetation<br>• Maintain the extent, improve the condition and promote recruitment of forests and woodlands<br>• Maintain the extent and improve the condition of lignum shrublands<br>• Expand the extent and improve the condition of moira grass in Barmah-Millewa Forest<br>• Expand the extent and improve resilience of ruppia in the southern Coorong | • Maintain core wetland vegetation and refuges<br>• Avoid critical loss and (where possible) improve vegetation condition in areas where drought conditions persist<br>• Support and build on watering events that have happened in previous years<br>• Provide follow-up watering to consolidate improvement in lignum communities at Narran Lakes<br>• Support growth of ruppia in the southern Coorong |
| Waterbirds | • Maintain the diversity and improve the abundance of the Basin's waterbird population<br>• Maintain the abundance of key shorebird species in the Lower Lakes and Coorong | • Provide follow-up watering to build resilience in the Narran Lakes system or to support waterbird breeding and recruitment<br>• Provide water to the Macquarie Marshes to support waterbird habitat<br>• Support productive shorebird habitat and foraging resource availability in the Coorong, Lower Lakes and Murray-Mouth |
| Native fish | • Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the Southern-connected Basin<br>• Improve flow regimes and connectivity in northern Basin rivers to support native fish populations across local, regional and system scales<br>• Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations | • Protect or provide flows that protect existing populations, support connectivity and sustain short-lived species recruitment<br>• Support recruitment from breeding events and subsequent dispersal of new recruits in the northern Basin<br>• Maintain existing populations and ensure hydrological integrity of flows in the southern Basin rivers |

**Table 2.5**. Summary of objectives for environmental watering in the River Murray valley. (Source: CEWO 2020b)

| Basin-wide Matters | In-Channel Assets | Off-Channel Assets | End of System |
|---|---|---|---|
| **Vegetation** | • Maintain riparian and in channel vegetation condition.<br>• Increase periods of growth for nonwoody vegetation communities that closely fringe or occur within river corridors. | • Maintain the current extent of floodplain vegetation near river channels and on low-lying areas of the floodplain, including Moira grass.<br>• Improve condition of black box, river red gum and lignum shrublands.<br>• Improve recruitment of trees within black box and river red gum communities.<br>• Maintain and improve condition of wetland vegetation. | • Ensure survival and promote growth and recruitment of *Ruppia tuberosa* in the south lagoon of the Coorong.<br>• Maintain or improve the diversity, condition and extent of aquatic and littoral vegetation at the Lower Lakes. |
| **Waterbirds** | • Provide habitat and food resources to support waterbird survival and recruitment and maintain condition and current species diversity. | • Provide habitat and food resources to support waterbird survival and recruitment and maintain condition and current species diversity.<br>• Complete seasonally appropriate bird breeding events that are in danger of failing due to drying.<br>• Support naturally triggered bird breeding events.<br>• Provide habitat for migratory birds. | • Maintain habitat and food sources to support waterbird condition and populations within the Lower Lakes and Coorong lagoons (including curlew sandpiper, greenshank, red-necked stint and sharptailed sandpiper).<br>• Complete seasonally appropriate colonial bird breeding events that are in danger of failing due to drying. |
| **Native Fish** | • Provide flows to support habitat and food sources and promote increased movement, recruitment and survival/condition of native fish. | • Provide flow cues to promote increased movement, recruitment and survival/condition of native fish (particularly for floodplain specialists). | • Maintain or improve diversity, condition and population for fish populations (including estuarine-dependent and diadromous fish) through providing suitable habitat conditions within the Coorong lagoons and maintaining migration pathways that supports species recruitment and survival/condition.<br>• Provide flow cues to promote increased movement, recruitment and survival/ condition of native fish. |
| **Invertebrates** | • Provide habitat to support increased microinvertebrate and macroinvertebrate survival, diversity, abundance and condition. | | |
| **Other vertebrates** | • Provide habitat to support survival, maintain condition and provide recruitment opportunities for frogs and turtles. | | |
| **Connectivity** | • Maintain baseflows and increase overall flows in the River Murray.<br>• Maintain longitudinal & lateral connectivity through contributing to an increase in the frequency of freshes, bankfull and lowland floodplain flows. | • Maintain latitudinal connectivity (within constraints) to wetlands, floodplains, creeks and anabranches by contributing an increase in the frequency of lowland floodplain flows. | • Improve the connection of the River Murray to the Coorong and the sea, through supporting increased barrage flows and Murray Mouth openness. |
| **Processes Water quality Resilience** | • Increase primary productivity, nutrient and carbon cycling, biotic dispersal and movement. Increase transport of organic matter, salt and nutrients downstream.<br>• Maintain water quality and provide refuge habitat from adverse water quality events. Increase mobilisation and export of salt from the River Murray system.<br>• Provide drought refuge habitat and maintenance/condition of native biota. | | |

Information sourced from: MDBA (2019); Department of the Environment (2011a and b); MDBA (2012a-i); DELWP (2015); Department of Environment, Water and Natural Resources (2015)

### *Water planning for the River Murray Valley in 2020-21*

The water planning for the southern Murray-Darling Basin in 2020–21 reflected the very dry conditions of the last three years. The CEWH commenced the new water year with low storages and the lowest volume of carryover in a decade (CEWO 2020c). The following summary from CEWO (2020c) indicates how they may manage Commonwealth environmental water deliveries under various scenarios.

**Very Dry (a year that is in the driest 10 per cent of years, in terms of inflows)**

- Maintain baseflows to support in-channel species (including native fish), provide drought refuge, maintain water quality and riverine functions:
    - in the main river channel in winter (4 000 ML/day at Yarrawonga), spring (8 000 ML/day at Yarrawonga) and summer (6 000 ML/day at the South Australian border)
    - through the creeks and key wetlands of Barmah-Millewa Forest over spring
    - through Gunbower Creek
    - through the Edward/Kolety-Wakool River system, including the Yallakool-Wakool and Colligen-Niemur Creek systems (subject decisions made by NSW agencies under the NSW Extreme Events Policy)
    - provide continuous connection through the Lower Lakes and into the Coorong and maintain water levels in the Lower Lakes above 0.4 m (to avoid the risk of acidification).
- Use infrastructure, pumps and/or weir pool manipulation to provide water to key wetlands throughout the valley that provide refuge habitat or are at risk of suffering irretrievable damage
- Respond to poor water quality events that may result from low flows

**Dry to Moderate (a year that is in the driest 25-50 per cent of years)**

As per very dry (above), with following additional events in scope:

- Provide a spring fresh down the River Murray to support a broad range of environmental outcomesThe timing, size and duration will be dependent water availability. Under drier scenarios, the fresh is likely to be of lower height and delivered later in spring to early summer. With increasing water availability, the targeted flow height and duration is likely to increase and may start earlier in spring. Even under a dry scenario, this may see flows travel through Barmah-Millewa Forest (reflecting the frequency in which this forest would naturally receive low-level flows).
- Provide spring fresh to Gunbower Creek.
- In the Edward/Kolety-Wakool River system provide a spring fresh and minimum flow target during fish nesting period, followed by increase flow variability in summer and autumn and winter flows from May- August 2021.
- Target minimum end-of-system flow targets to support salt export and improve conditions in the Coorong and the Lower Lakes for native fish and waterbirds.
- Increased scope (number of sites and volumes) of infrastructure-assisted water delivery to wetlands (including autumn watering).

**Natural bankfull or overbank flows**

- Extend the duration and recession of natural overbank flows.

**Wet (a year that is in the wettest 25 per cent of years)**

- Extend the duration and recession of natural overbank flows, including with ‘top-up’ watering for wetlands in autumn.
- Provide refuge flows in response to hypoxic blackwater events, support elevated end-of-system flows.

The environmental water demands and priorities for watering in the Edward/Kolety-Wakool system in 2020-21 (as stated in CEWO, 2020b) are shown in Table 2.6. CEWO (2020b) states that "The majority of flows listed below will be synchronised with flows in the River Murray" and "the capacity to contribute to many of these environmental demands is contingent on a substantial improvement in water availability in the catchment".

CEWO (2020b) states "Critical environmental demand for water have been identified for ameliorating hypoxic conditions in the Edward/Kolety Wakool System, which has suffered from multiple hypoxic events in recent years." In 2020 the CEWO aim to support recovery of native fish and river plants following low-oxygen blackwater event in 2016 and maintain habitat in low-lying wetlands and ephemeral creeks.

Commonwealth environmental water is planned for 2020-21 in the Wakool-Yallakool system and Colligen-Niemur system is summarised in Table 2.6 with specific noting of actions to support:

- Maintenance of native fish habitat and instream aquatic vegetation
- Longitudinal connectivity
- Fish spawning, recruitment and movement
- Nutrient cycling
- Water quality
- Recession flows for the maintenance of instream aquatic vegetation and native fish habitat
- Refuge Flows for habitat, water quality and the provision of refuges for native fish

CEWO (2020c) states "Where possible, water for the environment will be managed to benefit multiple sites enroute and will be coordinated with other sources of water. This will include other environmental water portfolios (such as The Living Murray program), consumptive and operational deliveries, natural flows and inflows from key tributaries such as the Ovens and Kiewa Rivers."

**Table 2.6.** Environmental demands, priority for watering in 2020–21 and outlook for coming year in the Edward/Kolety-Wakool River system. The majority of flows listed below will be synchronised with flows in the River Murray (Source: CEWO, 2020, Table 4).

| Environmental assets | Indicative demand (for all sources of water in the system) | | Watering history | 2020-21 | | Implications for future demands |
|---|---|---|---|---|---|---|
| | Flow/Volume | Required frequency (maximum dry interval) | (from all sources of water) | Environmental demands for water | Potential Commonwealth environmental water contribution? | Likely environmental demand in 2021–22 if watering occurred as planned in 2020-21 |
| **Yallakool - Wakool**<br><br>Maintenance of native fish habitat and instream aquatic vegetation<br>Longitudinal connectivity<br>Fish spawning, recruitment and movement<br>Nutrient cycling<br>Water quality | ~200 ML/day base flow for ~304 days during late winter to late Autumn (~61 GL). Note: winter base flows are a separate flow component and is included below. | Annual | Has been met 5 out of the past 5 years | Low | Likely to be met by operational flows except in a very dry year when CEW may be use to prevent system from being cut off subject to NSW Extreme Events Policy | Low |
| | ~600 ML/day peak for 4 days pulse/fresh over 20 days in spring with gradual recession (~10 GL, includes ~200 ML/day base flow). | Annual | Has been met 5 out of the past 5 years | High | Priority for Commonwealth environmental water to continue ecosystem recovery | High |
| | ~430 ML/day for 41 days to maintain minimum flow for fish nesting habitat, and inundation for aquatic vegetation growth (~17 GL in total, includes ~200 ML/day base flow) | Annual | Has been met 5 out of the past 5 years | High | Priority for Commonwealth environmental water to continue ecosystem recovery | High |
| | ~600 ML/day peak for 4 days undertaken 1-3 times in late spring/early summer with a gradual recession at end of fish nesting period (~10.61 GL, includes ~200 ML/day base flow). | Annual | Has been met 2 out of the past 5 years | Moderate | Option to be considered under a moderate to high water resource availability. | Moderate |
| | ~470 ML/day peak for 3 days over 25 days pulse/fresh in autumn with a gradual recession (~7.3 GL, includes ~200 ML/day base flow). | 2 in 3 years (2 years) | Has been met 2 out of the past 5 years | Moderate | Option to be considered under a moderate to high water resource availability. | Moderate |
| | ~170 ML/day winter base flow from early-May (irrigation shut down) until last week of July (system restarts) (~10 GL). Needs minimum of 4,000 ML/day at Yarrawonga to meet all Edward/Kolety system winter base flow requirements. | Annual | Has been met 2 out of the past 5 years. | High | Priority for Commonwealth environmental water to continue ecosystem recovery. | High |
| **Colligen - Niemur**<br>As per Yallakool-Wakool above | The potential flow components for the Colligen-Niemur during 2020-21, and related assessment of demands & urgency of demands are like the flow components outlined for the Yallakool-Wakool above. The primary difference is that the flows planned for the Colligen-Niemur have been scaled to fit within its constraint for environmental flows of up to 450 ML/day. | | | | | |
| **Edward/Kolety River** downstream of Stevens Weir | Up to 2 700 ML/day (constraint downstream of Stevens Weir) spring-pulse (~15 GL). Will need to align with delivery of flows into Yallakool-Wakool and Colligen-Nimeur systems. | Annual | Has been met 5 out of the past 5 years. | Low | Likely to be met by operational flows | Low |
| **Tuppal Creek** | Spring pulse with variability flows during the year (~3 GL of CEW + ~3 GL NSW). | Annual | Has been met 5 out of the past 5 years | Moderate | Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW. | Moderate |
| **Merran Creek** | ~ 460 ML/day preferably in spring and comprised of: Merran Creek at Franklings Bridge (~250 ML/day), Waddy Cutting (~150 ML/day) and St Helena Creek (~60 ML/day). | Annual | Has been met 5 out of the past 5 years | High | Priority for Commonwealth environmental water to continue ecosystem recovery. | High |
| **Jimaringle, Cochrans** and **Gwynnes Creeks** | Total flow of ~3 000 ML deliverable preferably in spring. May also require high flows in receiving Niemur system to dilute potential poor water quality outflows from these systems. | 1 in 2 years (2 years) | Last significant flow was the 2016 flood event. | Moderate | Use of CEW in these systems suspended pending further advice from NSW re acid sulphate soils and salinity issues. | Moderate |
| **Werai Forest** | Flows greater than ~2 100 ML/day downstream of Stevens Weir (with forest regulators open) in late autumn-early spring when water temp is below 16 degrees (~15 GL). Will need to align with delivery of flows into Yallakool-Wakool and Colligen-Nimeur systems. | 2-3 in 5 years (2 years) | Has been met 5 out of the past 5 years | Moderate | Use of CEW, including pumping, could be considered subject to stakeholder support, operational delivery infrastructure, third party impacts and accounting being addressed. | Moderate |

**Table 2.6** (continued)

| Environmental assets | Indicative demand (for all sources of water in the system) | | Watering history | 2020-21 | | Implications for future demands |
|---|---|---|---|---|---|---|
| | Flow/Volume | Required frequency (maximum dry interval) | (from all sources of water) | Environmental demands for water | Potential Commonwealth environmental water contribution? | Likely environmental demand in 2021–22 if watering occurred as planned in 2020-21 |
| **Koondrook-Perricoota Forest** | Annual watering proposals for this site are developed by Forestry NSW and can be contributed to by a number of water holders. Flow objectives may include maintaining habitat for aquatic vegetation, stimulate wetland vegetation response and the provision of carbon (productivity) during cooler times of the year. | 2-3 in 5 years (2 years) | Has been met 1 in 5 years (minimum flow provided in 2019-20, similar to 2014-15 commissioning event). | High | Commonwealth environmental water could be considered in future years, subject to stakeholder support, third party impacts and return flows being addressed. | High |
| **Pollack Swamp** | ~2 GL per year watering proposals for pumping to this site during late spring and summer developed by Forestry NSW and DPIE. Flow objectives may include provide water to water stressed red gums, encourage the recruitment of terrestrial species (i.e. red gums and benefits to waterbirds and frogs) and aquatic flora (i.e. amphibious and mudflat). | Annual | Has been met 5 out of the past 5 years | High | Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW. | High |
| **Edward/Kolety Wakool System – Recession Flows**<br>Maintenance of instream aquatic vegetation and native fish habitat | ~15 GL within constraints to provide more natural recession flows off rain rejection and unregulated events in the system. | As required - usually triggered via advice from NSW agencies re anticipated flow rates in the system. | Has been met when required | Moderate | Commonwealth environmental water may be used to manage flow recessions associated with natural or rain-rejection events. | Moderate |
| **Edward/Kolety Wakool System - Refuge Flows**<br>Habitat flows<br>Water quality<br>Provision of refuges for native fish | ~30-120 GL a year to manage hypoxic water quality events and other critical habitat needs. | As required - usually triggered once dissolved oxygen levels reach 4.0 mg/l in line with Basin Plan water quality requirements. | Has been met when required | Critical once trigger is met | High priority for Commonwealth environmental water to abate the impact of potential fish kills if triggers are met. | Critical once trigger is met |

**Key - potential watering in 2020-21**

- High priority for Commonwealth environmental watering (likely to receive water even under low water resource availability)
- Secondary priority for Commonwealth environmental watering (watering to occur only if natural trigger is met, or under moderate - high water resource availability); or water demand likely to be met via other means
- Low priority for Commonwealth environmental watering (under high - very high water resource availability)
- Unable to provide Commonwealth water because of constraints or insufficient water

**Key - environmental demands**

- Critical demand i.e. urgent need for water in that particular year to manage risk of irretrievable loss or damage
- High demand for water i.e. needed in that particular year
- Moderate demand for water i.e. water needed that particular year and/or next
- Low demand for water i.e. water generally not needed that particular year
- Very low demand for water i.e. water generally not needed that particular year or the following year

Note that demand is considered at a generalised scale; there may be specific requirements that are more or less urgent within the flow regime

**References for Table 4:**

Edward-Wakool indicators compiled from multiple sources (Hale & SKM 2011; Watts et al. 2013; Watts et al. 2014; Watts et al. 2015; Watts et al. 2016; Watts et al. 2017; Webster 2010). Previous watering actions and their outcomes have also been used for all indicators.

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## 2.4 Practicalities of environmental watering in the Edward/Kolety-Wakool system

The main source of Commonwealth environmental water for the Edward/Kolety-Wakool River system is from the Murray River through the Edward/Kolety River and Gulpa Creek. The main flow regulating structures within the Edward/Kolety-Wakool River system are the Gulpa Creek Offtake, Edward/Kolety River Offtake (both located on the Murray River), and Stevens Weir, located on the Edward/Kolety River downstream of Colligen Creek (Figure 1.1). This structure creates a weir pool that allows Commonwealth environmental water to be delivered to Colligen Creek-Niemur River system, Yallakool Creek, the Wakool River, the Edward/Kolety River and Werai Forest.

Environmental watering actions delivered for the Murray River channel from Hume Dam delivers water to Millewa Forest via Barmah-Millewa Forest regulators. Some of this water exits via creeks and flood runners in Millewa Forest or via Tuppal Creek and Bullatale Creek. Thus, the environmental watering actions for th Murray indirectly contribute to flows in the Edward/Kolety River.

Water diverted into the Mulwala Canal from Lake Mulwala can also be delivered into the Edward/Kolety-Wakool system through ‘escapes’ or outfalls managed by the irrigator-owned company Murray Irrigation Limited (MIL). During a hypoxic blackwater event in 2010, environmental water was released from the Mulwala Canal escapes to lessen the impact of hypoxia and create localised refugia with higher DO and lower DOC (Watts et al. 2017a). There are numerous smaller escapes throughout the MIL network that can also be used to deliver small flows to the river system. Escapes were also used to deliver environmental water as refuge flows in response to the 2016 hypoxic blackwater event (Watts et al. 2017b).

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

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

Delivery of instream flows to the Edward/Kolety River, Wakool River, Yallakool Creek, Colligen-Niemur system and Merran River system are managed within regular operating ranges as advised by river operators to avoid third party impacts (MDBA 2020). For example, in the Wakool-Yallakool system the operational constraint is 600 ML/d at the confluence of the Wakool River and Yallakool Creek. Thus, the types of flow components that can be achieved under current operating ranges are in-channel baseflows and freshes. Environmental watering may also be constrained due to limitations on how much water can be delivered under regulated conditions. At times of high irrigation demand channel capacity will be shared among water users. If the system is receiving higher unregulated flows, there may not be enough capacity to deliver environmental water (Gawne et al. 2013). Environmental water may be delivered to contribute to the slower recession of freshes, delivered during low flow periods to provide refuge habitat, or delivered to manage water quality issues, such as hypoxic events (Gawne et al. 2013; Watts et al. 2017a).

## 2.5 CEWO planned watering actions for the Edward/Kolety-Wakool in 2020–21

In the Yallakool-Wakool system an 800 ML/day flow trial in Wakool-Yallakool system was proposed to commence 1 August. The aim was for this trial to deliver combined flows via Yallakool Creek and the Wakool River that would exceed the 600 ML/d operational constraint downstream of the Wakool Reserve.

In Yallakool Creek, the flow trial would be followed by four variable flows during spring/summer and an autumn fresh (Figure 2.2).

In the Wakool River, following the flow trial there were plans to deliver environmental water to create variability in base flows (Figure 2.2).

In Colligen Creek the 2020-21 plans were to provide a spring fresh, elevated spring baseflow and two smaller freshes in spring/summer (Figure 2.3).

Environmental watering actions in the Edward/Kolety-Wakool River system were also proposed for Tuppal Creek, Pollack Swamp, and Cockran's/Jimaringle Creek commencing in September (CEWO 2021). These watering actions were not monitored as part of the Flow-MER Program.

As per Water Use Minute WUM 101105, the proposed watering actions sought to achieve the following expected outcomes:

<u>Primary expected outcomes</u>

- support the recovery of instream aquatic vegetation and large bodied native fish for three years following the 2016 hypoxic blackwater event.
- maintain the diversity and condition of native fish and other native species through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit.
- maintain health of riparian and in-channel aquatic native vegetation communities.
- maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.
- maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.
- support inundation of low-lying wetlands/floodplains habitats within the system.

<u>Secondary expected outcomes</u>

- maintain habitat quality in ephemeral watercourses.
- support mobilisation, transport and dispersal of biotic and abiotic material (e.g., sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity.

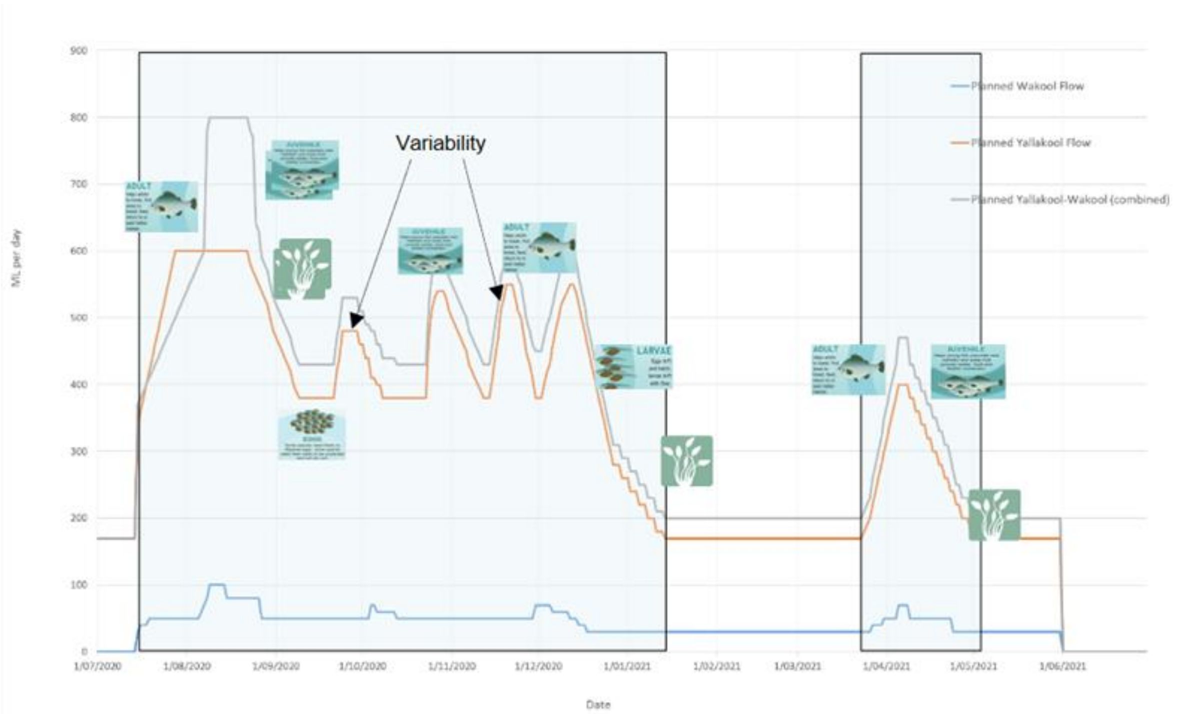



**Figure 2.2** Annual hydrograph planned for Yallakool-Wakool at start of 2020-21 action. Shaded area shows period of potential use of CEW. Operational base flows are usually around 170 ML/day except in winter when they are zero unless provided via unregulated flows. From mid-January to mid-March there was a return to base flows followed by an autumn fresh. (Source: CEWO 2021).

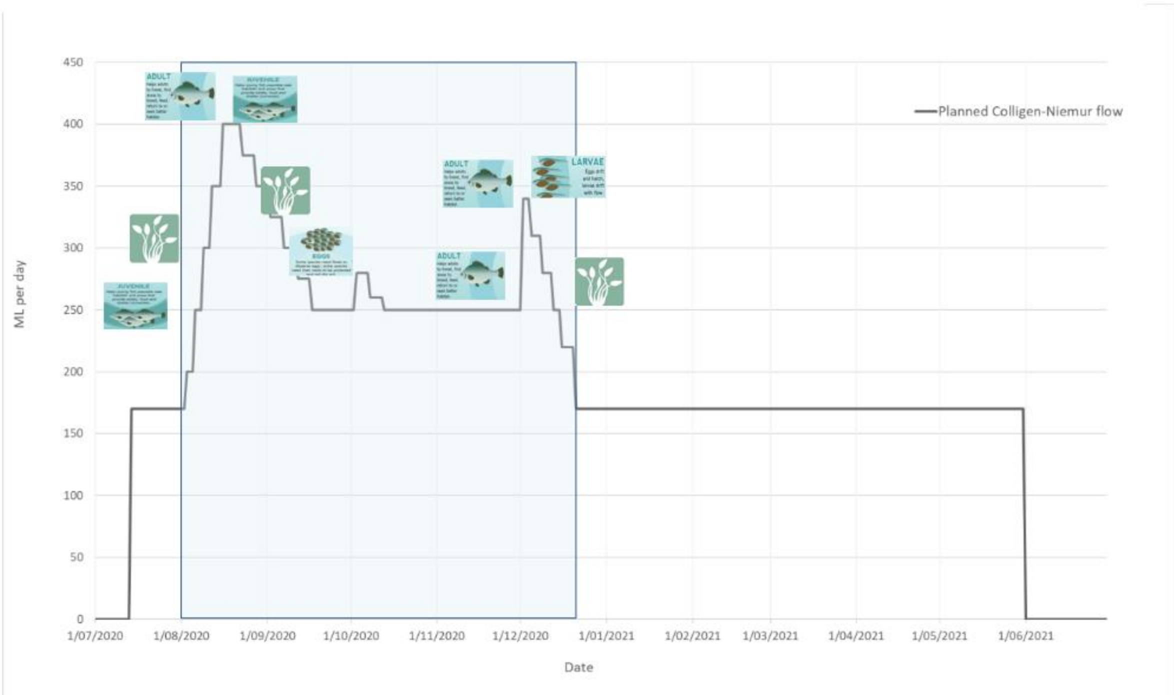



**Figure 2.3**. Annual hydrograph planned for Colligen-Niemur at start of 2020-21 action. Shaded area shows period of potential use of CEW. Operational base flows are usually around 170 ML/day except in winter when they are zero unless provided via unregulated flows. (Source: CEWO 2021).

## 2.6 Commonwealth watering actions in Edward/Kolety-Wakool system 2020-21

Eight watering actions were undertaken by the Commonwealth Environmental Water Office for the 2020-21 water year in the Wakool-Yallakool system and the Colligen-Niemur system (Table 2.7, Figures 2.4 and 2.5). All eight actions are incorporated under Watering Action Reference number WUM10105-01 (CEWO 2021). Some of the water during these actions was sourced as return flows from the Southern Spring Flow in the Murray River (section 2.6). Analysis of the environmental water component of these watering actions is described later in this report (see section 4, hydrology).

**Table 2.7** Commonwealth environmental watering actions in 2020-21 in the Edward/Kolety-Wakool system.

| Watering Action | System | Name | Objectives (from CEWO) | Dates |
|---|---|---|---|---|
| 1 | Yallakool-Wakool system | Spring fresh | 800 ML/day flow trial to test inundation extent, coordinated with wider Murray River actions to maximise benefit. Slow recession for instream water plants to elevated base flow of 380 ML/d<br>To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish. | 20/10/20-30/11/20 *(Yallakool)*<br>23/10/20 - 27/11/20 *(Wakool)* |
| 2 | Yallakool | Elevated base flow | To maintain nesting habitat for Murray Cod, and inundation for aquatic vegetation growth | 30/11/20 - 15/12/20 |
| 3 | Yallakool | Summer freshes | To influence and encourage silver perch breeding and fish movement, may also assist with dispersal of larvae and juveniles of a number of fish species. Slow recession to support instream water plants.<br>Two freshes: 15/12/20 start peak 1/4.01/21 finish peak 1 start peak 2. 15/2/21 finish peak 2 and recession down to operational base levels of 170 ML/d | 15/12/20 – 15/2/21 |
| 4 | Yallakool | Autumn fresh | To influence/encourage fish movement. May also assist with dispersal of juveniles of a number of fish species. | 30/3/21 - 6/5/21 |
| 5 | Colligen-Niemur | Spring fresh | To provide early season rise in river level to contribute to connectivity, water quality, stimulating early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish | 21/10/20 - 6/12/20 |
| 6 | Colligen-Niemur | Elevated base flow | To maintain nesting habitat for Murray Cod, and inundation for aquatic vegetation growth. | 6/12/20 - 8/1/21 |
| 7 | Colligen-Niemur | Summer fresh | Summer fresh to influence and encourage fish movement, may be coordinated with wider Murray River actions to maximise benefit. May also assist with dispersal of larvae and juveniles of a number of fish species. | 8/1/21 - 26/1/21 |
| 8 | Upper Wakool | Variable base flows | To provide a proactive, longer-term approach to preventing a potential hypoxic water event. Enable a comparison to previous monitoring data to determine if a longer, higher flow rate is better at maintaining fish, plants, invertebrates and aquatic species. Improve ability to provide longitudinal connectivity, flow variability and potential refuge. Continue to build good social license among landholders and other stakeholders.<br>Variable cycling for WQ Ranging from 50 ML/d to 120 ML/d | 23/1/21 - 9/6/21 |

### *Watering action 1: Yallakool-Wakool Spring fresh – 800 ML/day trial*

Due to the lack of forecast rainfall eventuating and reduced outflows from Yarrawonga, the 800ML/day early season fresh was postponed until the required flow rates at Yarrawonga were achieved so the wateing actions could be delivered as part of the planned Murray spring pulse. There were no Commonwealth environmental watering actions between July and September 2020. Updated plans for Wakool-Yallakool and Colligen-Niemur show first watering actions commencing to align with the Murray SSF.

Instead of commencing in mid-July, the spring flow in the Yallakool-Wakool was delayed and commenced on 20 October 2020, with environmental water delivered via the Yallakool offtake, Wakool offtake and the Wakool escape from Mulwala Canal to create a combined flow pulse with a peak of approximately 800 ML/day in the Wakool River downstream of Wakool Reserve (Table 2.7). The objective of this watering action was to support the recovery of the river system following the low-oxygen blackwater event in 2016, and to contribute to connectivity, water quality, promote growth of in-stream aquatic vegetation, improve the condition of native fish and promote spawning of some species of native fish. This flow commenced in Yallakool Creek and progressed down the Wakool River.

A stated by CEWO (20210) in the 2020-21 Watering aquital report "The initial spring fresh in the Yallakool-Wakool was planned to go up to 800ML/d. This could not be achieved without supplementation from the MIL's Wakool escape. Commencing on 22 October 2020, the Wakool escape was used to provide additional water for 24 days up to ~200ML/d. This resulted in a maximum flow rate on 4 November 2020 at 828.25 ML/d with the remaining 23 days below 800ML/d.

### *Watering actions 2 and 3: Yallakool elevated base flows and summer freshes*

Environmental watering actions 2 and 3 in Yallakool Creek (Table 2.7) commenced in December 2020. The objective of this watering action was to promote silver perch spawning, influence and encourage fish movement, assist with dispersal of larvae and juveniles of a number of fish species, and support instream water plants.

### *Watering actions 4: Yallakool autumn fresh*

The autumn fresh in Yallakool Creek commenced 30 March and ended 6 May 2021. This watering action was to provide connectivity, to influence/encourage fish movement and assist with dispersal of juveniles of a number of fish species.

### *Watering actions 5 to 7: Colligen-Niemur spring fresh, elevated base flows and summer freshes*

The objectives of watering actions 5 to 7 in Colligen-Niemur system were similar to those for watering actions 1 to 3 in the Yallakool-Wakool system.

### *Watering action 8: Upper Wakool River variable base flows*

Due to the decline in Wakool River water quality in January reported to CEWO by CSU scientists, additional environmentalwater was provided up to 100ML/d with ± 30ML/d on two-weekly cycles for flow variability. Watering action 8 (Table 2.7) was added to the watering plans part way through the water year as a proactive, longer term approach to preventing a potential hypoxic water event.

Watering action commened in January and continued through to early May. This action provides flows of 50, 75, 100, 75, 50 in two weekly intervals for variability to the end of the watering year. They also included a two-week 25 ML/d cycling interval changing the flows from 23/1/21 to 9/6/2021 ranging from 50 ML/d to 100 ML/d with an autumn pulse up to 120 ML/d (Figure 2.4).


**Figure 2.4** Annual hydrograph for Yallakool-Wakool at end of 2020-21 action, showing the change made to the planned flows due to greater water availability in the Murray system. Operational flows were provided from October – June following initial unregulated flows wetting up in the system. Shaded area shows period of CEW use. (Source: CEWO 2021).

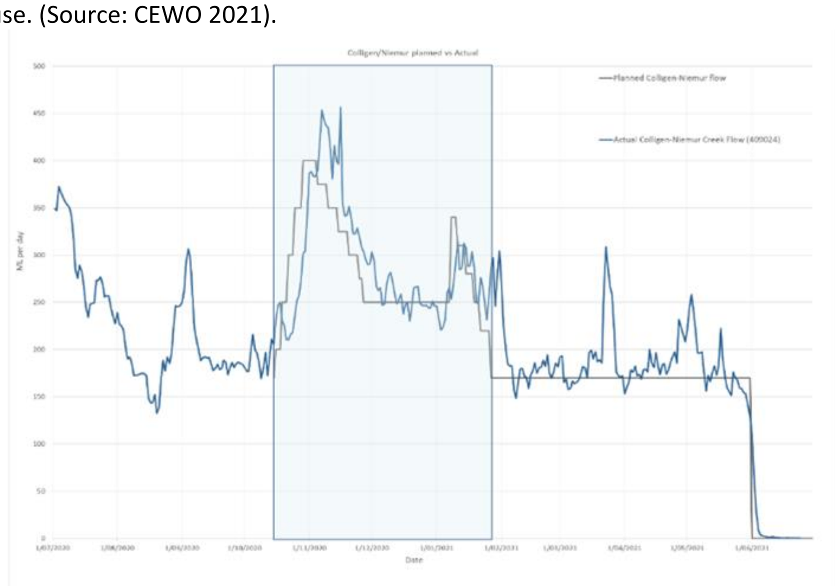


**Figure 2.5** Annual hydrograph for Colligen-Niemur at end of 2020-21 action, showing the changes made to the planned flows due a late start of the Murray spring flows in the system. Operational flows were provided from October - February. Unregulated flows events provided flows during July to mid-October 2020 and again from end of January to watering year end providing variable flows. Shaded area shows period of CEW use. (Source: CEWO 2021).

## 2.6 Southern Connected Flow in Murray River 2020-21

The '2020 Southern Spring Flow' was a river pulse in the Murray River that was designed by carefully timing releases of water for the environment in the Murray, Goulburn and Murrumbidgee rivers to deliver water to five wetlands of international significance, provide a system-wide productivity boost and improve connectivity down the river to the Coorong and Murray Mouth (SCBEWC, 2021).

The coordinated Southern Spring Flow delivered water from Hume Dam between September and December 2020 (SCBEWC 2021) (Figure 2.6). *This was our largest coordinated water for the environment event ever*" (SCBEWC, 2021). The SCBEWC report states "*Return flows were used at multiple environmental sites as the water flowed down the river including spring pulses in the Edward-Wakool system in NSW, Gunbower Forest in Victoria and Chowilla, Pike and Katarapko floodplains in South Australia" (2021)* (Figure 2.7).

The outcomes of this action have been evaluated at sites along the main Murray channel, however the outcomes of the return flows to the Edward/Kolety-Wakool system are poorly understood. SCBEWC (2021) estimates that 14.2 GL of environmental water from the Southern Spring Flow was delivered to the Edward/Kolety-Wakool system to the Niemur River and Yallakool-Wakool system, and the primary ecological target was fish. It is not clear what method or model was used to estimate this volume. There is a need for more transparent hydrological modelling to document the daily discharge of return flows to the Edward/Kolety-Wakool system. However, in the absence of that modelling in this report we will qualitatively consider how the Southern Connected Flow in 2020-21 may have influenced outcomes in the Edward/Kolety-Wakool system.

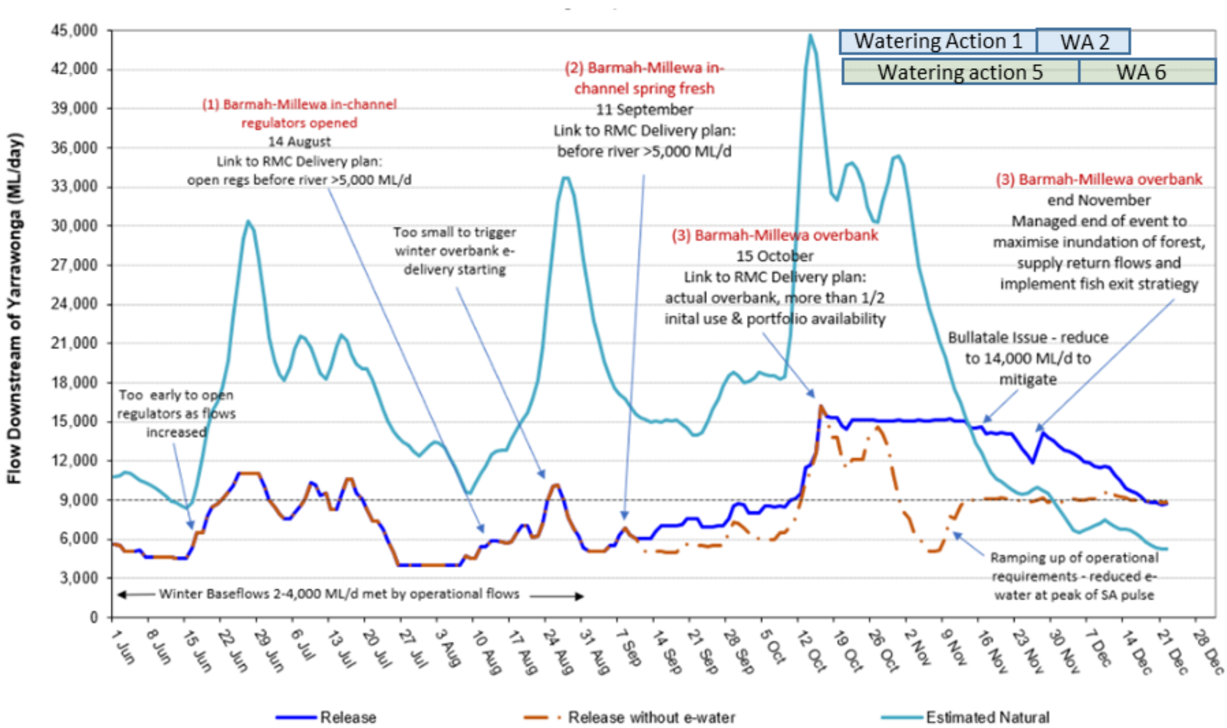



**Figure 2.6**. Southern Spring Flow – end of event hydrograph 2020. Flow downstream of Yarrawonga gauge and the probable release without environmental water (Source CEWO). Shaded bars were added to the original figure to approximate the timing of the Yallakool-Wakool spring fresh (Watering Action 1), Colligen-Niemur spring fresh (Watering Action 5), Yallakool elevated base flow (Watering Action 2), and Collien-Niemur elevated base flow (Watering Action 6).

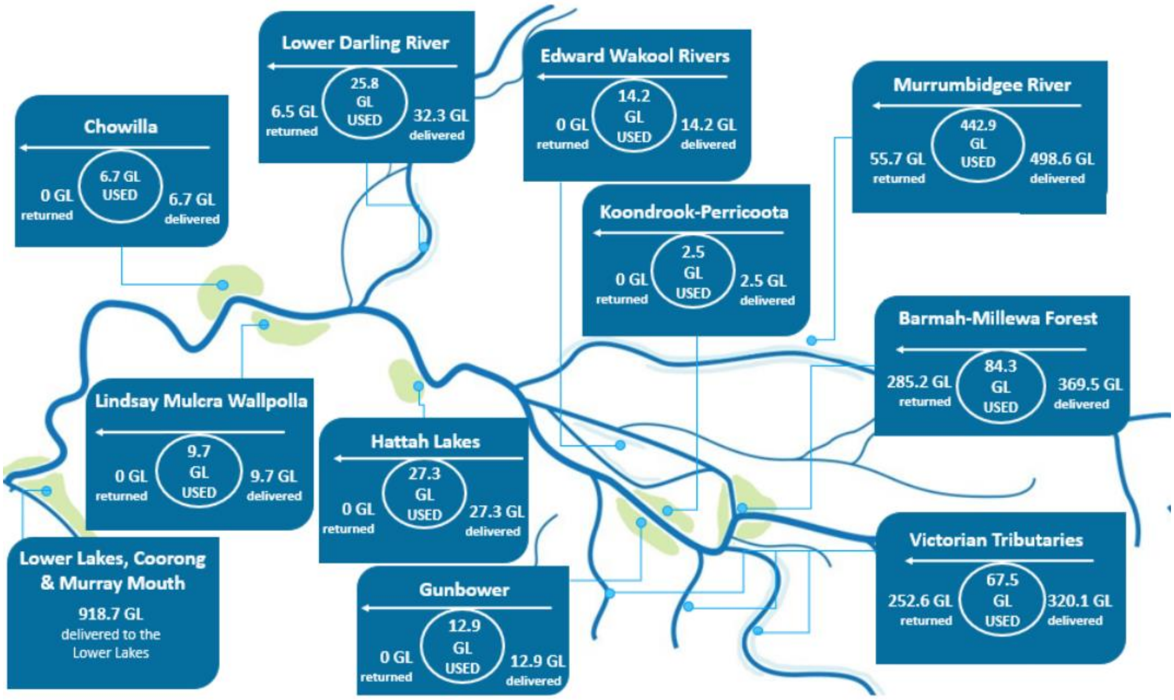



**Figure 2.7** Other environmental sites that received water in the Southern Connected Basin: Vic wetlands 9.9 GL (no return flows); NSW wetlands and creeks 31.8 GL (no return flows); SA wetlands and River Murray Channel use from upstream e-water 68.8 GL (no return flows). Delivery of water for the environment through the river system supported the River Murray Channel from Hume Dam to the Coorong (Source SCBEWC 2021)
flow

# 3 MONITORING, EVALUATION AND RESEARCH

## 3.1 Approach to monitoring, evaluation and research

The overarching principle that underpins this monitoring, evaluation and research in the Edward/Kolety-Wakool Selected Area is that we are taking an ecosystem approach to evaluate the responses to Commonwealth environmental watering. Monitoring indicators have been selected that each have clear linkages to other components of the MER Program (Figure 3.1). The monitoring and research has a strong focus on fish (including reproduction, recruitment and adult populations) and water quality. The Edward/Kolety-Wakool River system is recognised as a priority area for fish diversity in the Murray-Darling Basin, and outcomes for fish and water quality have been the main focus of environmental watering actions in the Edward/Kolety-Wakool system since 2010. Some of the other indicators (e.g., stream metabolism and aquatic vegetation) strongly influence the health of the ecosystem, and thus a key goal of this Flow-MER Plan is to improve our understanding and interpretation of these interdependencies. Research projects will complement the monitoring and evaluation and where possible be undertaken collaboratively with the local community to address physical, ecological, and social questions that are key for supporting future environmental watering actions in the Edward/Kolety-Wakool system.

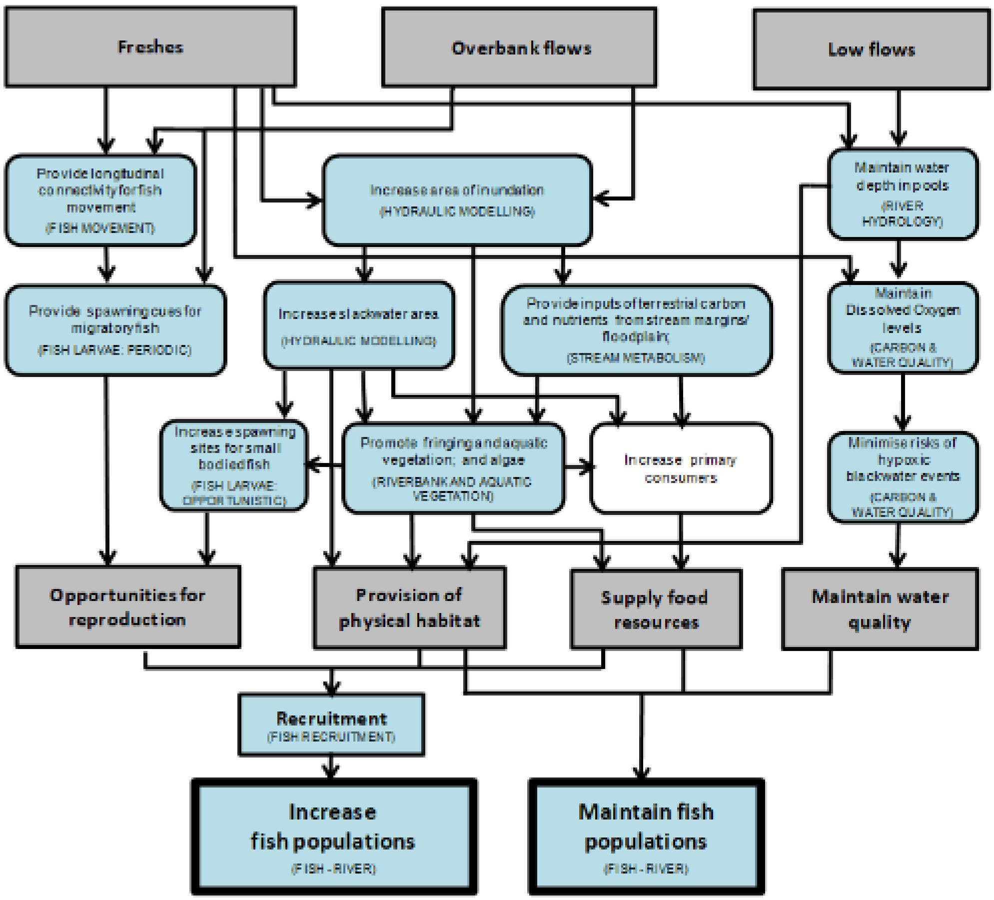



**Figure 3.1** Conceptual diagram illustrating three main flow types (low flows, freshes, overbank flows) and their influence on ecosystem components and processes that, in turn, influence fish population dynamics. Indicators included in the Edward/Kolety-Wakool Flow-MER Plan are shown in brackets in boxes shaded blue.

## 3.2 Monitoring zones and sites

The monitoring of ecosystem responses to Commonwealth environmental watering in the Edward/Kolety-Wakool River system in 2020-21 was undertaken following the methods outlined in the Edward/Kolety-Wakool Flow-MER Plan (Watts et al. 2019a).

At the commencement of the LTIM program daily discharge data from 14 hydrological stations in the Edward/Kolety-Wakool River system were analysed along with information on geomorphology and location of major distributaries to classify the system into distinct hydrological zones (Watts et al. 2014). Sixteen distinct hydrological zones were identified (Figure 3.2, Table 3.1). Transitions between these zones occur where there are major inflows or outflows to a river or at locations where there are significant changes in geomorphology. The zones range from ephemeral watercourses (e.g., Jimaringle, Cockran and Gwynne's Creeks), to smaller creeks and rivers (Wakool River, Yallakool Creek, Colligen-Niemur system, and Merran Creek) to the larger Edward/Kolety River system.

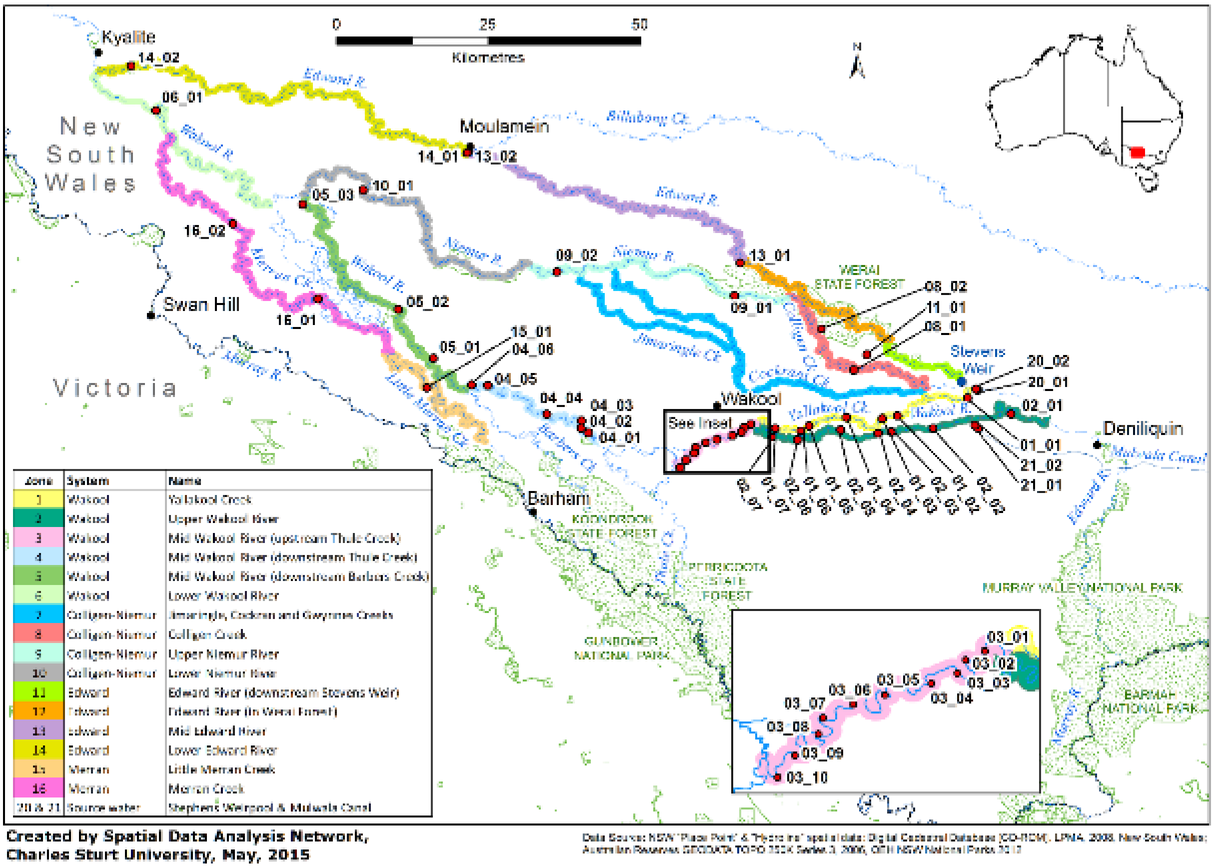



**Figure 3.2** Map showing 16 hydrological zones within the Edward/Kolety-Wakool River system. Site names are listed in Table 3.1.

**Table 3.1** List of site codes and site names for the CEWO Flow-MER Program in the Edward/Kolety-Wakool Selected Area.

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

Due to funding constraints, it was not possible to undertake monitoring and evaluation in all sixteen of the hydrological zones identified in the Edward/Kolety-Wakool system (Figure 3.2). The following factors were considered when prioritising the zones to include in the Flow-MER Plan:

- Likelihood of hydrological zones receiving Commonwealth environmental water or serving as a comparison zone (i.e., not receive Commonwealth environmental water)
- Location of hydrological gauging stations
- Availability of historical monitoring data in each zone and existing arrangements for access, including maintaining continuity of monitoring established during the LTIM project
- Ease of access for undertaking fieldwork under a range of weather conditions
- Need for a number of zones that experience a range of flows to facilitate predictive ecosystem response modelling
- Capacity to inform on specific objectives aligned with values and needs of local community, including First Nations.

Taking all of these factors into account, the Flow-MER Program includes monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward/Kolety-Wakool system in the following hydrological zones:

- Monitoring sites established during the LTIM project that focus on the upper and mid reaches of the Wakool-Yallakool system (zones 1, 2, 3 and 4) were maintained for the Flow-MER Program. This includes monitoring of sites (e.g. Stevens Weir and Mulwala canal, Figure 3.3) that are sources of environmental water.
- Twenty sites that were established for fish community surveys in 2010 and were monitored in year one (2015) and year five (2019) of the LTIM project were maintained for the Flow-MER Program and will be surveyed for fish community indices in year three of the Flow-MER Program (2022).
- Additional sites were added to the existing network of water quality monitoring sites established during LTIM project. For the Flow-MER Program there are 17 water quality monitoring sites throughout the whole system, including ongoing sites in Yallakool Creek, Wakool River (Zones 2 to 4), and source water sites in the Mulwala Canal (Figure 3.3) and the Edward/Kolety River at Stephens Weir. New sites for Flow-MER Program expanded the water quality monitoring to further downstream in the Wakool River as well as in Tuppal Creek (Figure 3.3), the Edward/Kolety River and the Colligen-Niemur system to enable an evaluation of environmental water across the broader system.

The focus of the integrated research project is the Edward/Kolety River downstream of Stevens Weir to inform the adaptive management of environmental water in this River. The Edward/Kolety River was not monitored as part of LTIM program. The research questions that will be addressed will inform future monitoring and delivery of environmental water in the Edward/Kolety-Wakool system.

The Milewa Forest and Koondrook-Perricoota Forest (including Pollack Swamp) are not included in the Flow-MER Program because they are currently monitored by other programs such as the MDBA Living Murray Program. The ephemeral creeks, Jimaringle, Cockran and Gwynnes Creek, have not been included in the Flow-MER Program to avoid duplication of monitoring, as environmental watering actions in these ephemeral creeks have previously been monitored by the NSW DPIE.

Upper Wakool River (zone 2)

Wakool River near Wakool Reserve (zone 3)

Wakool River near Moulamein Road bridge (zone 4)

Wakool River at Stoney Crossing (zone 6)

Colligen Creek, near Calimo (zone 8)

Edward/Kolety River (zone 13)

Mulwala Canal

Tuppal Creek

**Figure 3.3** Photos of rivers in the Edward/Kolety-Wakool system

## 3.2 Indicators for monitoring and evaluation

Table 3.2 provides a summary of the monitoring and evaluation activities for this Flow-MER Plan and provides a summary of the changes or additions relative to the Edward/Kolety-Wakool LTIM project (2014-2019). One of the main changes is that carbon and water quality monitoring has been extended so that evaluation can be undertaken across the entire Edward/Kolety-Wakool system (Table 3.2).

There are three categories of indicators for LTIM/Flow-MER monitoring:

- **Category I** –Mandatory indicators and standard operating protocols that are required to inform Basin-scale evaluation and may also be used to answer Selected Area questions. Category 1 indicators monitored in the Edward/Kolety-Wakool system (Table 3.2) are: river hydrology, stream metabolism, nutrients and carbon, fish reproduction (larvae) and fish (river).
- **Category 2** –Optional indicators with mandatory standard protocols that may be used to inform Basin-scale evaluation and may be used to answer Selected Area questions. Fish movement is the only category 2 indicator monitored in the Edward/Kolety-Wakool system, and this work ceased at the end of 2019.
- **Category 3** – Selected Area specific monitoring protocols to answer Selected Area questions. Category 3 indicators monitored in the Edward/Kolety-Wakool system (Table 3.2) are: hydraulic modelling, water quality and carbon characterisation, riverbank and aquatic vegetation, fish reproduction (larvae), fish recruitment, and fish community survey (year 3 of the Flow-MER Program).

The rationale regarding the selection of indicators is outlined in the Edward/Kolety-Wakool Flow-MER Plan (Watts et al. 2019a). Indicators are monitored to contribute to the Edward/Kolety-Wakool Selected Area Evaluation and/or the Whole of Basin-scale evaluation Flow-MER Program that is led by CSIRO. Some indicators are expected to respond to environmental watering in short time frames (< 1 year), but others (e.g., fish community assemblage) are expected to respond over longer time frames (e.g., 2 to 5 years).

A summary of the long-term and short-term evaluation questions is provided in Table 3.3. Category 1 monitoring and evaluation questions follow those outlined in the CEWO LTIM Standard methods (Hale et al. 2014).

**Table 3.2** Summary of monitoring and evaluation to be undertaken in the Edward/Kolety-Wakool system for the CEWO Monitoring, Evaluation and Research (Flow-MER) Program from 2019 to 2022. Changes and additions relative to the Edward/Kolety-Wakool LTIM project (2014-2019) are described. Zones and sites are described in Figure 3.2 and Table 3.1. Category 1 and 2 indicators are monitored using standard operating protocols to inform Basin-scale evaluation and may be used to answer Selected Area questions. Category 3 indicators are those monitored to answer Selected Area questions.

| Theme | Cat | Zones | Changes or additions to the Flow-MER Program compared to the LTIM project (2014-19) |
|---|---|---|---|
| Monitoring and Evaluation | | | |
| River hydrology | 1 | system | No changes to monitoring or evaluation from LTIM project. Discharge data will be obtained from WaterNSW website. |
| Hydraulic modelling | | | Hydraulic modelling was undertaken in zones 1, 2, 3, 4 and 8 as part of the LTIM project. These models will continue to be used as part of Flow-MER evaluation but no new hydraulic modelling will be undertaken in these zones. Modelling of reaches in zones 11 and 12 will modelled as part of the integrated Edward/Kolety River research project. |
| Carbon and water quality | 3 | system | No changes in methods from LTIM. New sites have been added for the Flow-MER Program so that the evaluation of this indicator will be undertaken across the whole Edward/Kolety-Wakool system. |
| Stream metabolism | 1 | 1,2,3,4,8 | For LTIM DO and light were logged continuously in 4 zones between August and April each year. Flow-MER logging will be continuous across the whole year and additional dissolved oxygen logger site was established in Colligen Creek. |
| Riverbank and aquatic vegetation | 3 | 1,2,3,4,8 | No changes in methods from LTIM. The composition and percent cover of riverbank and aquatic vegetation will be monitored monthly. Four reaches in Colligen Creek will be added to the Flow-MER Program These sites in Colligen Creek were previously monitored 2015-2019 through a project funded by Murray Local Land Services |
| Fish movement | 2 | system | Golden perch movement will be monitored from June-Sept 2019 to evaluate the 2019 winter environmental watering action. No fish movement will be monitored as part of the Flow-MER Program after September 2019. |
| Fish reproduction | 1 | 3 | No changes to monitoring or evaluation from LTIM project. The abundance and diversity of larval fish will be monitored fortnightly between September and March using light traps and drift nets. |
| Fish reproduction | 3 | 1,2,3,4, | No changes in methods from LTIM. Research on fish spawning will be undertaken in the Edward/Kolety River as part of the integrated research project |
| Fish recruitment | 3 | 1,2,3,4 | Minor changes to monitoring methods from LTIM project. No changes to monitoring sites. |
| Fish river (Cat 1) | 1 | 3 | No changes to monitoring or evaluation from LTIM project. Cat 1 fish community surveys will be undertaken once annually in zone 3 between March and May. |
| Fish community survey | 3 | system | No changes from LTIM project. Fifteen sites (in addition to the Cat1 fish sites) from throughout the system will be surveyed in 2022 only (year 3 of the Flow-MER Program) |

**Table 3.3** Summary of the long-term and short-term evaluation questions for the Edward/Kolety-Wakool Flow-MER Program.

| Indicator | Evaluation questions |
|---|---|
| **Hydrology** | *Short and long-term questions*<br>• What was the effect of CEW (Commonwealth environmental water) on the hydrology of the rivers in the Edward/Kolety-Wakool system?<br>• What did CEW contribute to longitudinal connectivity? |
| **Carbon and water quality** | *Short and long-term questions*<br>• What did CEW contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat?<br>• What did CEW contribute to dissolved oxygen concentrations?<br>• What did CEW contribute to nutrient concentrations?<br>*Question for contingency monitoring*<br>• What did CEW contribute to reducing the impact of hypoxic blackwater or other adverse water quality events in the system? |
| **Stream metabolism (Cat 1)** | *Short and long-term questions*<br>• What was the effect of CEW on rates of GPP, ER and NPP<br>• What did CEW contribute to total GPP, ER and NPP?<br>• Which aspect of CEW delivery contributed most to productivity outcomes? |
| **Riverbank and aquatic vegetation** | *Long-term questions*<br>• What has CEW contributed to the recovery (measured through species richness, plant cover and recruitment) of riverbank and aquatic vegetation that have been impacted by operational flows and drought and how do those responses vary over time?<br>• How do vegetation responses to CEW delivery vary among hydrological zones?<br>*Short-term questions*<br>• What did CEW contribute to the percent cover of riverbank and aquatic vegetation?<br>• What did CEW contribute to the diversity of riverbank and aquatic vegetation taxa? |
| **Fish movement** | *Short term questions*<br>• Does CEW facilitate longitudinal connectivity for periodic species during winter? |
| **Fish reproduction (Cat 1)** | *Long term questions*<br>• What did CEW contribute to native fish populations?<br>• What did CEW contribute to native fish species diversity?<br>*Short term questions*<br>• What did CEW contribute to native fish reproduction?<br>• What did CEW contribute to native fish survival |
| **Fish reproduction** | *Short and Long-term questions*<br>• What did CEW contribute to the spawning of 'Opportunistic' (e.g., small bodied fish) species?<br>• What did CEW contribute to spawning in ‘flow-dependent’ spawning species (e.g., golden and silver perch)? |
| **Fish recruitment** | *Short and Long-term questions*<br>• What did CEW contribute to native fish recruitment to the first year of life?<br>• What did CEW contribute to native fish growth rate during the first year of life? |
| **Fish river (Cat 1)** | *Long term questions*<br>• What did CEW contribute to native fish populations?<br>*Short term questions*<br>• What did CEW contribute to native fish reproduction?<br>• What did CEW contribute to native fish survival? |
| **Fish community** | *Long-term question*<br>• How does the fish community in the Edward/Kolety-Wakool system vary over 3-5 years, and does this link with sequential flow characteristics? |

## 3.3 Evaluation of monitoring outcomes

The outcome of Commonwealth environmental watering undertaken in 2020-21 was undertaken for the following indicators:

- Hydrology (Section 4)
- Water quality and carbon (Section 5)
- Stream metabolism (Section 6)
- Aquatic and riverbank vegetation (Section 7)
- Fish reproduction, recruitment, and community (Section 8)

Responses to Commonwealth environmental water were evaluated in two ways:

iii) Indicators that respond quickly to flow (e.g., hydrology, water quality and carbon, stream metabolism, fish movement, fish spawning) were evaluated for their response to specific watering actions. Hydrological indicators were calculated on the discharge data with and without the environmental water.

iv) Indicators that respond over longer time frames (e.g., riverbank and aquatic vegetation, fish recruitment, fish community) were evaluated for their response to the longer-term environmental watering regimes. This is typically undertaken by comparing responses over multiple years, and/or comparing responses in reaches that have received environmental water to zones (e.g., upper Wakool River zone 2) that has received none or minimal environmental water.

## 3.4 Research

As part of the Edward/Kolety-Wakool Flow-MER Program there are several research projects undertaken through contingency funds. The research projects aim to address knowledge gaps and improve the delivery, monitoring and evaluation of environmental water in the Edward/Kolety-Wakool system. Several of the projects focus on Werai Forest where there are considerable knowledge gaps that need to be addressed to inform the future delivery of environmental water to the Edward/Kolety River and the management of Werai Forest.

The research projects will address questions relating to how managed flows in the Edward/Kolety River and the operation of Stevens Weir influence physical aspects (e.g., lateral connectivity and physical form) and ecological processes, (e.g., productivity, wetland plant emergence and survival, and turtle movement and condition) (Table 3.4). In addition, in 2019-20 a project used targeted e-DNA analysis to determine the presence and spatial distribution of threatened, uncommon and iconic or rare taxa at sites throughout the system. Integrated with these biophysical research themes, social research was undertaken in 2020-21 to examine stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water. Some of the research components have different reporting timelines (Table 3.4). Yarkuwa Indigenous Knowledge Centre is a collaborative partner on the research on turtles and understorey and groundcover vegetation in Werai Forest.

**Table 3.4** Summary of research questions for the Edward/Kolety integrated research project, and timeline for reporting for each theme

| Research Area | Research Question | Research timeframe | Final report |
|---|---|---|---|
| **Physical condition of riverbanks** | What are the features of the flow regime in the Edward/Kolety River that drive erosion and deposition? | 2019-2020 | Completed. Outcomes published in 2019-20 report |
| **Biodiversity (e-DNA)** | Can a targeted single-species e-DNA approach be used to identify the presence and spatial distribution of threatened, uncommon and iconic species of crustacean, turtles, fish and aquatic mamals in the Edward/Kolety river system | 2019-2020 | Completed. Outcomes published in 2019-20 report |
| **Turtles** | How does connectivity of wetlands along the Edward/Kolety River affect turtle distribution, movement and body condition? | 2019-2021 | **2021 This report** |
| **Social research** | This will be a co-designed research project, with questions to be developed during the first phase in collaboration with community and managers. Focus may include: knowledge, information and learning; stakeholder attitudes to and acceptance of the concept and use of environmental water | 2020-2021 | **2021 This report** |
| **Werai Forest inundation modelling** | Inundation models will be developed to link with the research questions relating to the Edward/Kolety River and Werai Forest | 2019-2022 | In progress. Reporting due in 2022 |
| **Understorey and groundcover vegetation in Werai** | How do understorey and groundcover vegetation species in low lying parts of Werai Forest respond to small inundation events via Tumudgery Creek? | 2019-2022 | In progress. Reporting due in 2022 |
| **Werai Forest primary productivity** | Does connectivity of flows into Werai Forest contribute to primary productivity outcomes in the Edward/Kolety River? | 2019-2022 | In progress. Reporting due in 2022 |

# 4 HYDROLOGY

Author: Robyn Watts

| Key findings | |
|---|---|
| **Maximum and minimum discharge** | • All of the Commonwealth environmental watering actions increased the maximum discharge compared to operational flows.<br>• The maximum daily operating discharge of 600 ML/d in zone 4 was exceeded during watering action 1; the discharge peaked at 781 ML/d in zone 4 compared to operational flow of 225 ML/d on this date.<br>• The watering actions did not change the minimum discharge. |
| **Flow variability** | • The watering actions increased the variation of discharge in all zones compared to operational flows. In the absence of the watering actions there would have been extended periods of low variability flows. |
| **Longitudinal connectivity** | • The watering actions maintained longitudinal connectivity across the system.<br>• Watering action 1 increased longitudinal connectivity by initiating flow in Black Dog Creek, connecting the upper Wakool River and Yallakool Creek. |
| **Lateral connectivity** | • Watering action 1, 3, 4, 5, 7, and 8 increased lateral connectivity compared to the modelled connectivity under operational flows. |

## 4.1 Background

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

The Edward/Kolety-Wakool system has experienced a wide range of flow conditions over the past 15 years, and these antecedent conditions will influence the way in which the ecosystem responds to Commonwealth environmental watering. From 1998 to 2010 south-eastern Australia experienced a prolonged drought (referred to as the Millennium drought) and flows in the MDB were at record low levels (van Dijk 2013; Chiew et al. 2014). During this period the regulators controlling flows from the Edward/Kolety River into tributary rivers such as Yallakool Creek and the Wakool River were closed for periods of time. Consequently, between February 2006 and September 2010 there were periods of minimal or no flow in the Wakool River and localised fish deaths were recorded on a number of occasions including in 2006 and 2009. At the break of the drought, a sequence of unregulated flow events between September 2010 and April 2011 triggered a widespread hypoxic (low oxygen) blackwater event in the mid-Murray (MDBA 2011; Whitworth et al. 2012; Watts et al. 2017a). In late 2016 there was a widespread flood in the southern-MDB associated with record-breaking rainfall in the catchment. Some areas of the floodplain were inundated that had not been flooded for more than 20 years. The unregulated flows from the Murray River inundated the floodplain including forests and agricultural land and resulted in a very large flood event in the Edward/Kolety-Wakool system (BOM 2017). In association with the floods there was a hypoxic blackwater event that extended throughout the Murray River system, including the Edward/Kolety-Wakool system. Since the 2016-17 flood, flows in the system have been regulated and remained within channel. This chapter reports on the hydrology of the system from 1 July 2020 to 30 June 2021.

## 4.2 Environmental watering actions targeting hydrology outcomes

Eight watering actions were undertaken by the CEWO for the 2020-21 water year (Table 4.1). Some of the water during these actions was sourced as return flows from the Southern Connected Flow in the Murray River.

**Table 4.1** Commonwealth environmental watering actions in 2020-21 in the Edward/Kolety-Wakool system. Hydrological objectives of watering actions are in bold.

| Action | System | Name | Objectives (from CEWO) | Dates |
|---|---|---|---|---|
| 1 | Yallakool-Wakool system | Spring fresh | **800 ML/day flow trial to test inundation extent**, coordinated with wider Murray River actions to maximise benefit. **Slow recession** for instream water plants to elevated base flow of 380 ML/d. **To provide early season rise in river level to contribute to connectivity**, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish. | 20/10/20-30/11/20 *(Yallakool)*<br>23/10/20 - 27/11/20 *(Wakool)* |
| 2 | Yallakool | Elevated base flow | To maintain nesting habitat for Murray Cod, **and inundation** for aquatic vegetation growth | 30/11/20 - 15/12/20 |
| 3 | Yallakool | Summer freshes | To influence and encourage silver perch breeding and fish movement, may also **assist with dispersal** of larvae and juveniles of a number of fish species. **Slow recession** to support instream water plants. Two freshes: 15/12/20 start peak 1/4.01/21 finish peak 1 start peak 2. 15/2/21 finish peak 2 and recession down to operational base levels of 170 ML/d. | 15/12/20 – 15/2/21 |
| 4 | Yallakool | Autumn fresh | To influence/encourage fish movement. May also **assist with dispersal** of juveniles of a number of fish species. | 30/3/21 - 6/5/21 |
| 5 | Colligen-Niemur | Spring fresh | To provide **early season rise in river level to contribute to connectivity**, water quality, stimulating early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish | 21/10/20 - 6/12/20 |
| 6 | Colligen-Niemur | Elevated base flow | To maintain nesting habitat for Murray Cod, and **inundation** for aquatic vegetation growth. | 6/12/20 - 8/1/21 |
| 7 | Colligen-Niemur | Summer fresh | Summer fresh to influence and encourage fish movement, may be coordinated with wider Murray River actions to maximise benefit. May also **assist with dispersal** of larvae and juveniles of a number of fish species. | 8/1/21 - 26/1/21 |
| 8 | Upper Wakool | Variable base flows | To provide a proactive, longer-term approach to preventing a potential hypoxic water event. Enable a comparison to previous monitoring data to determine if a longer, higher flow rate is better at maintaining fish, plants, invertebrates and aquatic species. **Improve ability to provide longitudinal connectivity, flow variability** and potential refuge. Continue to build good social license among landholders and other stakeholders. **Variable cycling** for WQ Ranging from 50 ML/d to 120 ML/d | 23/1/21 - 9/6/21 |

## 4.3 Selected Area evaluation questions

- *What was the effect of Commonwealth environmental water on the hydrology of the Edward/Kolety-Wakool system?*
- *What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?*
- *What did Commonwealth environmental water contribute to lateral connectivity?*

## 4.4 Methods

Daily discharge data for automated hydrometric gauges (Table 4.2) were obtained from the New South Wales Office of Water website (https://realtimedata.waternsw.com.au/water.stm). Daily discharge data for non-automated sites, such as the Wakool escape from Mulwala Canal, and daily usage of Commonwealth environmental water were obtained from WaterNSW.

Some of the study reaches do not have hydrometric gauging stations. The daily discharge data for sites in the Wakool River zone 2 was estimated by adding the discharge from gauge 409019 Wakool River offtake regulator to the discharge data from the Wakool escape from Mulwala canal. The daily discharge data for Wakool River zone 3 was estimated by adding daily discharge data from Yallakool Creek offtake (gauge 409020), the Wakool offtake regulator (gauge 409019) and the Wakool Escape from Mulwala Canal with an adjustment during regulated flows to account for travel time (4 days) and estimated 20% losses (V. Kelly, WaterNSW pers. comm.) between the offtakes and the confluence of Yallakool Creek and the Wakool River.

**Table 4.2** Details of Water NSW hydrometric gauges used to obtain discharge data. Zone codes are as described in Figure 3.1 and Table 3.1.

| River | LTIM zone | Gauge number | Name of gauge |
|---|---|---|---|
| Yallakool Creek | 1 | 409020 | Yallakool Creek @ Offtake |
| Wakool River | 2 | 409019 | Wakool River Offtake regulator |
| Wakool River | 4 | 409045 | Wakool @ Wakool-Barham Road |
| Wakool River | 5 | 409062 | Wakool River Gee Gee Bridge 2 |
| Wakool River | 6 | 409013 | Wakool @ Stoney Crossing |
| Colligen Creek | 8 | 409024 | Colligen Creek B/L regulator |
| Niemur River | 10 | 409086 | Niemur at Mallan School |
| Edward/Kolety River | | 409008 | Edward River Offtake |
| Edward/Kolety River | 11 | 409023 | Edward River DS Stevens weir |
| Edward/Kolety River | 13 | 409104 | Edward River at Moulamein |
| Edward/Kolety River | 14 | 409035 | Edward River at Liewah |

Details of the daily volume of water (ML/d) accounted for as Commonwealth environmental water was provided by WaterNSW and the CEWO. These data were used to produce hydrographs showing the daily discharge and the proportion of that flow that is Commonwealth environmental water for the four hydrological zones.

Modelled natural daily discharge for Toonalook Gauge and Downstream Stevens Weir gauge were produced by MDBA using MSM-Bigmod with natural model settings and actual natural inflows to storage and tributary inflows up to the day of the model run. Natural conditions are representative of the scenario with no dams, weirs and consumptive diversions from the river but does not exclude impact of land use changes or levees in the river system. The natural estimates are indicative only and meant to provide some guidance regarding the magnitude, timing and duration of natural watering to assist with watering actions.

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

The extent of riverbank inundation under operational flows and the Commonwealth environmental watering actions was estimated using 2-dimensional hydraulic modelling as described in Watts (2015). A 2D hydraulic model was created for nineteen river reaches each 4 km in length; five reaches in Yallakool Creek, five in the Wakool River (zone 2), four in Wakool River upstream of Thule Creek (zone 3) and five in the Wakool River downstream of Thule Creek (zone 4). Between ten and twelve discharge scenarios were modelled for each reach, with the majority of the discharge scenarios being in the range of 30 ML/day to 1200 ML/day and one discharge scenario in each reach being just less than bankfull. The models can be used to estimate the extent of wetted benthic surface area. The relationship between discharge and wetted benthic area for each study reach was determined using cubic smoothing spline regression modelling. The modelled curve for each reach used to estimate the daily wetted area due to operational discharge and discharge including Commonwealth environmental water.

## 4.5 Results

### *Overview of hydrology over 7 years of LTIM/Flow-MER from July 2014 to June 2021*

The five-year hydrograph (1 July 2014 to 30 June 2021) for the Downstream Stevens Weir gauge in the Edward/Kolety-Wakool system is dominated by the large unregulated flow in late 2016 (Figure 4.1).

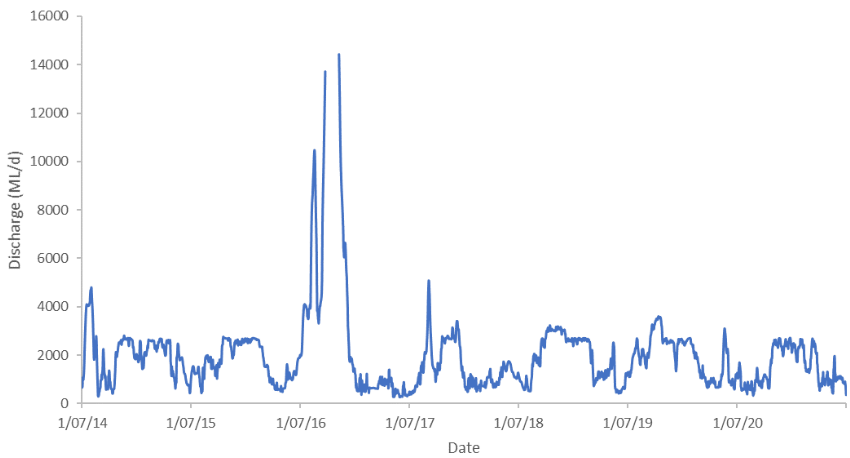



**Figure 4.1** Hydrographs of discharge at the downstream Stevens Weir gauge from 1 July 2014 to 30 June 2021. Note: the there are missing data at the peak of the 2016 unregulated flood event.

### *Edward/Kolety River MDBA Natural Flow Models 2020-21*

The figures showing modelled natural daily discharge for Toonalook and DS Stevens Weir gauges were produced by MDBA using MSM-Bigmod with natural model settings and actual natural inflows to storage and tributary inflows up to the day of the model run. In 2020-21 water year there were four freshes in the modelled natural discharge models: three freshes in spring/early summer in July 2020, Sept 2020, Nov/Dec 2021, and a late summer smaller fresh in February 2021.

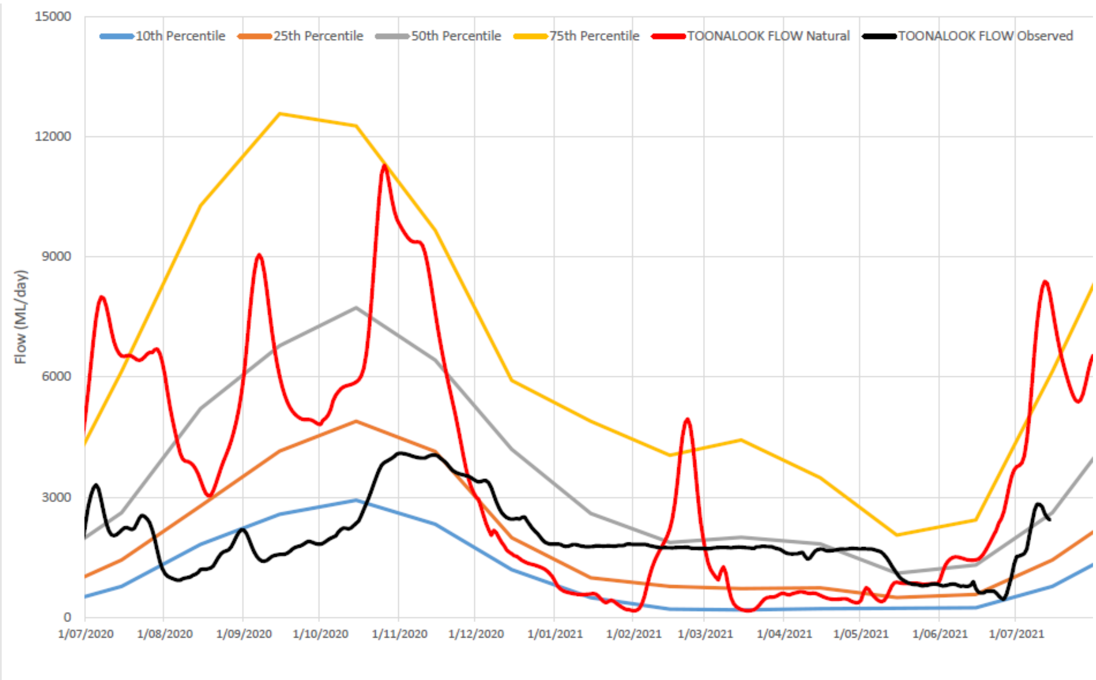



**Figure 4.2** Hydrograph showing observed and modelled natural daily discharge in the Edward/Kolety River from 1/6/2020 to 1/8/2021 at the Toonalook gauge. (Source: MDBA).

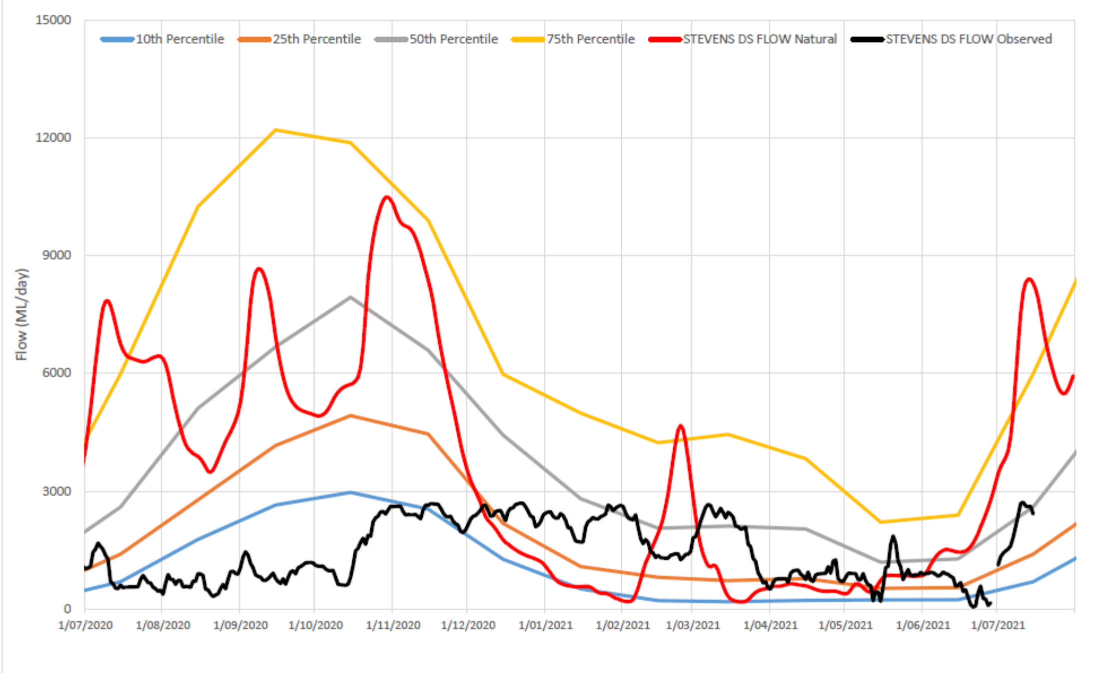



**Figure 4.3** Hydrograph showing observed and modelled natural daily discharge in the Edward/Kolety River from 1/6/2020 to 1/8/2021 at the Downstream Stevens Weir gauge. (Source: MDBA).

### *Edward/Kolety River hydrology 2020-21 – upstream to downstream gauges*

The four modelled natural events in the Edward/Kolety River (Figures 4.2 and 4.3) were highly regulated in the Edward/Kolety River. There was a small amount of variability in the hydrograph at the Edward Offtake regulator coinciding with the first two freshes (July and September). However, there was no evidence of the third larger October fresh because the discharge was controlled and held steady at approximately 1500 ML/day from September 2020 to April 2021 (Figure 4.4). In contrast, the flows in the Edward/Kolety River at Flow at Toonalook includes a large fresh from mid October to mid December peaking at approximately 4000 ML/d that includes return flows from Millewa forest from the Southern Spring Flow watering action in the Murray River. The fresh was re-regulated at Stevens Weir so the discharge downstream of Stevens Weir did not exceed 2700 ML/day.

Although return flows from Barmah-Millewa did not translate into a flow pulse downstream of Stevens Weir, the carbon rich water returning from Millewa Forest may have influenced water quality and productivity in the Edward/Kolety River, Yallakool Creek, Wakool River and Colligen Creek from late October to Early December 2020 (see section 5, Water Quality and Carbon).

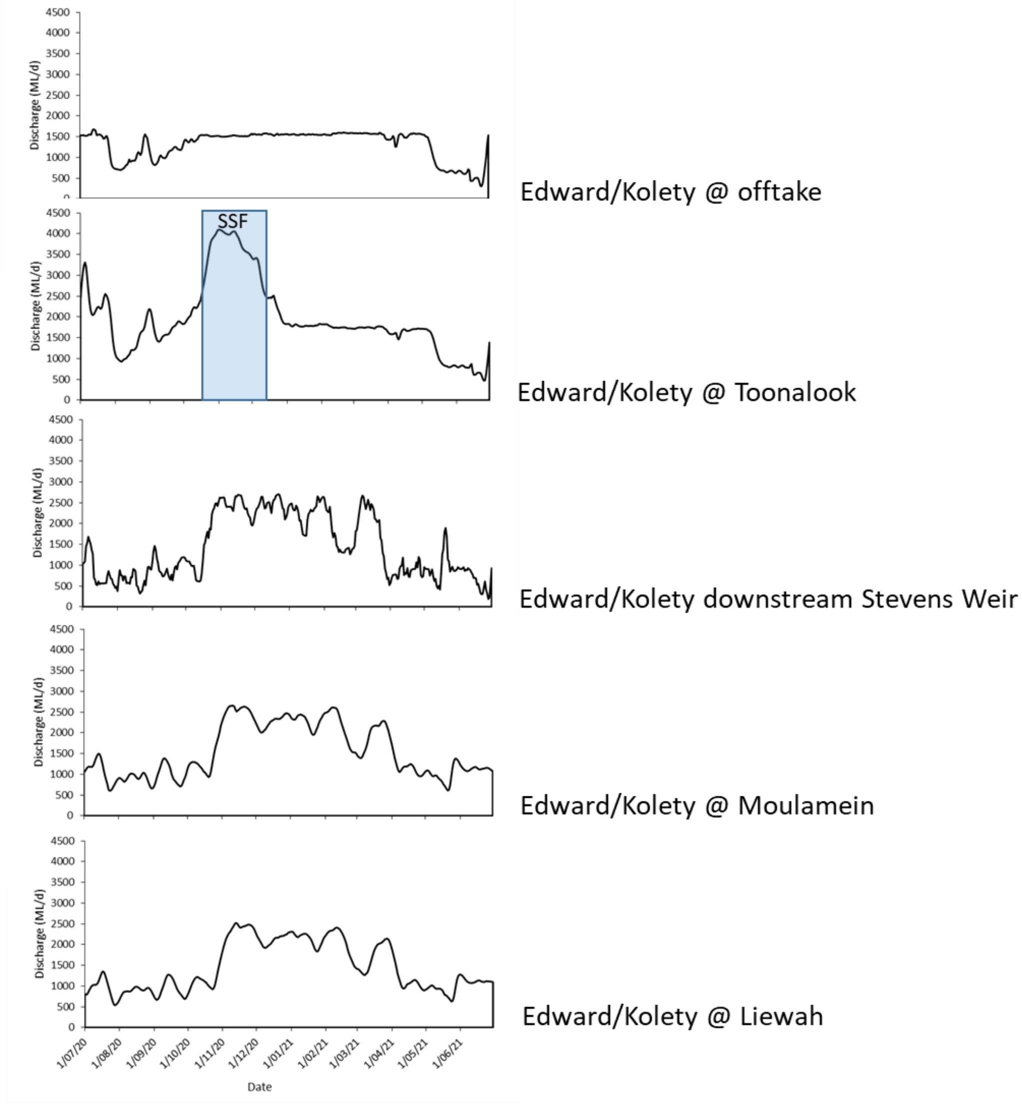



**Figure 4.4** Hydrographs for the Edward River at the Edward River offtake (gauge 409008), Toonalook (gauge 409047), downstream of Stevens Weir (gauge 409023), Moulamein (gauge 409014), and at Liewah (gauge 409035) from 1 July 2020 to 30 June 2021. The timing of the Southern Spring Flow is shown as the blue shaded area on the Toonalook hydrograph.

### *Environmental watering action 1: 800 ML/d flow trial in Yallakool-Wakool system*

The discharge in Yallakool Creek during watering action 1 peaked at 530 ML/day on 12 Novemmber 2020, which is slightly higher than the 488 ML/d peak during the previous 800 ML/d flow trial in 2018-19 (Watts et al. 2019).

The combined delivery of environmental water from the Wakool offtake regulator and the Wakool Escape resulted in a peak of approximately 350 ML/day at zone 2 site 4 on 1 November 2020 (Figure 4.5), slightly lower than the pek of 398 ML/d during the flow trial in 2018-19. However, the peak of this action was considerably higher than normal operational flows in this zone (40 to 80 ML/d).

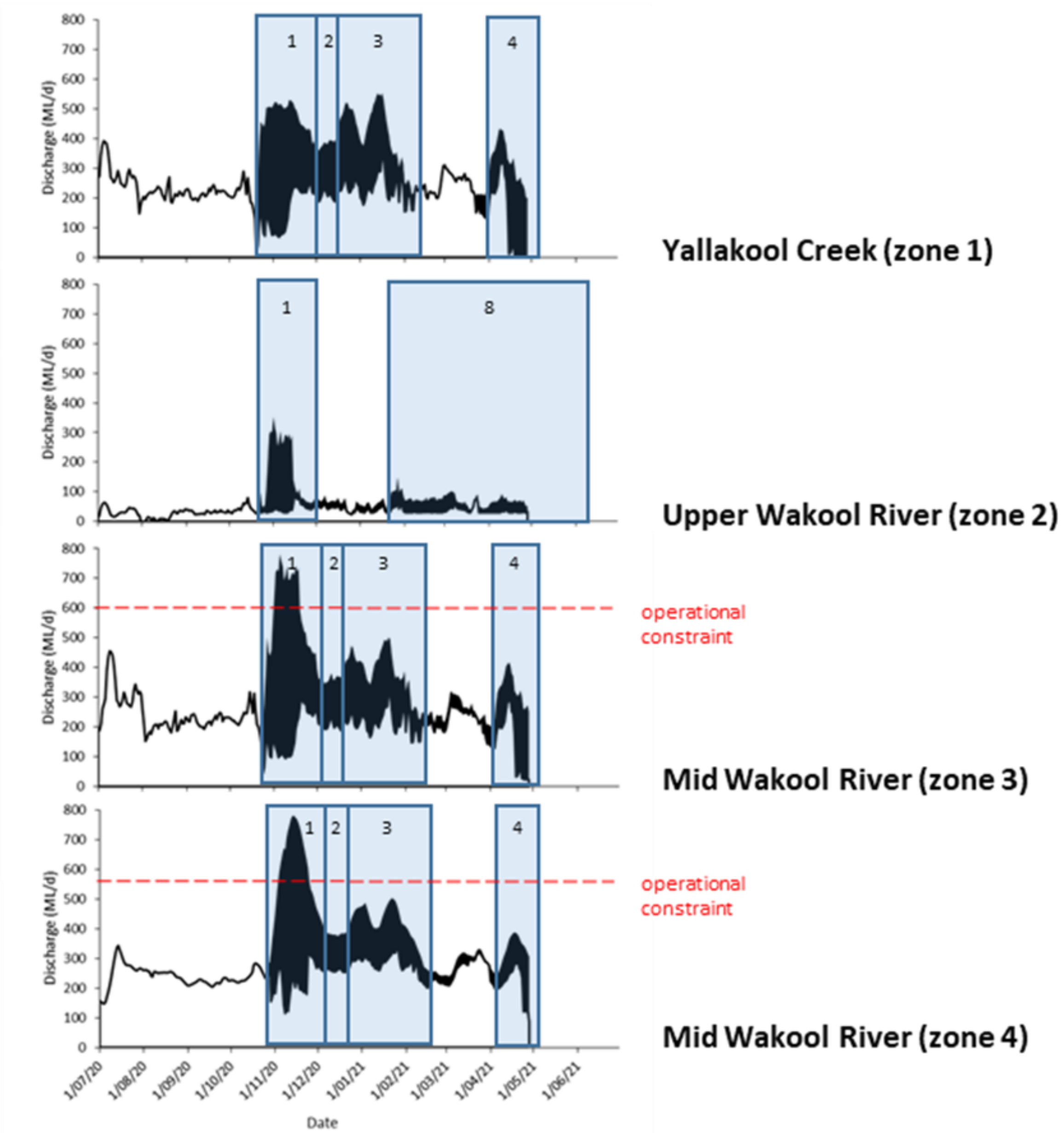



**Figure 4.5** Hydrographs of zones 1 Yallakool Creek (gauge 409020), and Upper Wakool zone 2 flows calculated at 'Widgee', zone 3 calculated at Wakool Reserve, and zone 4 in the mid-Wakool River at Wakool-Barham Rd (gaguge 409045) from 1st July 2020 to 30th June 2021. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. The blue shaded sections relate to the environmental watering actions listed in Table 4.1. Watering action 1 was the 800 ML/day flow trial that exceeded the operational constraint in Wakool River zones 3 and 4.

Although the total volume ordered from the Yallakool offtake, Wakool Offtakes and Wakool escape in 2020 totalled to more than 800 ML/d, when losses and travel time were taken into account the environmental water delivered from these three sources combined to create a peak at 781 ML/d in the Wakool River at Wakool Barham Rd (Gauge 409045) on 14th November 2020 in zone 4 (Figure 4.5). This was considerably higher than the peak of 225 ML/d that was the operational flow in zone 4 on this date. This was higher than the peak of 652 ML/d on 19 September 2018 during the previous flow trial (Watts et al. 2019).

Figure 4.6 shows the hydrograph of the 800 ML/d flow trial from 2018-19 for comparison to the 2020-21 event. Note that the duration of the peak flow during watering action 1 in 2020-21 had a longer peak than the peak flow during the 2018-19 flow trial action (Figure 4.6).

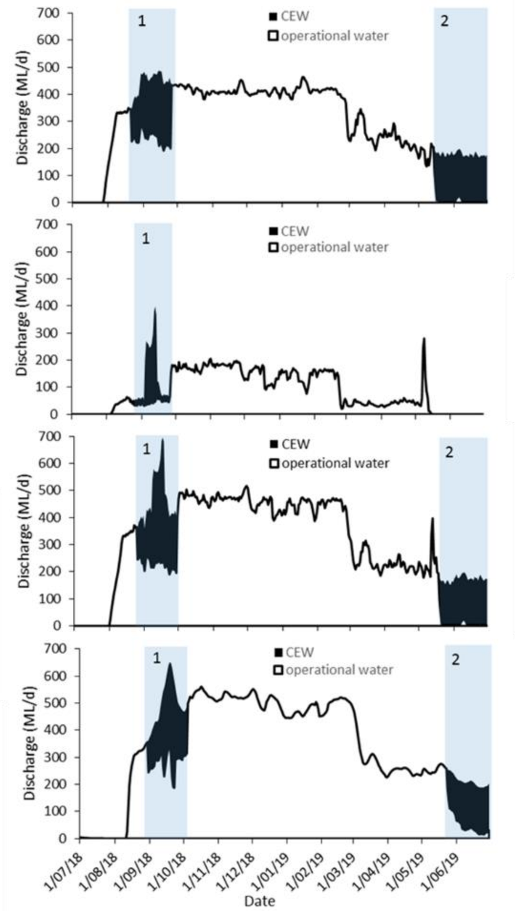



**Figure 4.6** Hydrographs of zones 1 Yallakool Creek (top), and zones 2, 3 and 4 (bottom) in the Wakool River from 1st July 2018 to 30th June 2019. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. The blue shaded sections relate to the environmental watering actions listed in Table 4.1. Watering action 1 was an 800 ML/day flow trial. (Source: Watts et al. 2019)

The higher flows in zone 2 initiated flow in Black Dog Creek, a runner that flows from the upper Wakool River near 'Widgee' (zone 2 site 4) and across to Yallakool Creek to 'Windra Vale' near zone 1 site 5. Two low level crossings over Black Dog Creek were inundated for a short period of time during the 2020 spring fresh (Figure 4.7). Black Dog Creek flows from the upper Wakool near 'Widgee' across to Yallakool Creek. Both of these crossings were inundated in the 2018 flow trial, but the water level was slightly higher during the peak of the 2020 flow.

Cameras installed near several bridges on Bookit Island recorded changes in water levels during the 800 ML/d flow trial (Figure 4.8). Bookit Island Bridge #1 was inundated for a short period of time in 2020 during the spring fresh. This bridge was also inundated in the 2018 flow trial, but the water level was slightly higher during the peak of the 2020 flow. The landholder said the inundation did not affect planned activities because they were given a lot of notice and involved in planning of the watering action.


**Figure 4.7** Changes in water level in Black Dog Creek during the 800 ML/d flow trial in 2020. Black Dog Creek is a runner that flows from the Wakool River near 'Widgee" across to Yallakool Creek.


**Figure 4.8** Changes in water level near three bridges during the 800 ML/d flow trial in 2020. The camera installed at Bookit Island Bridge was knocked by stock and so the photo points were taken on angle for part of the flow trial.

### *Environmental watering actions 2 and 3: Yallakool elevated base flow and summer fresh*

Watering action 2 (Figure 4.5) was an elevated base flow that was similar to previous years actions to maintain nesting habitat for Murray Cod and inundation for aquatic vegetation growth. Stable flows were achieved over this short period.

Watering action 3 (Figure 4.5), two summer freshes in Yallakool Creek, was delivered to encourage silver perch breeding, fish movement, and assist with dispersal of larvae and juveniles of a number of fish species, and create a slow recession to support instream water plants. These pulses did not exceed the operational constraint in Yallakool Creek. The peak flows for this action in Yallakool Creek were similar to the peak flow in action 1. However, in zones 3 the flow peaks were 475 ML/d on 25 December 2020 and approximately 500 ML/d on 21 January 2021. These peaks were considerably lower than the 781 Ml/d of watering action 1 in zone 3.

### *Environmental watering action 4: Yallakool Creek autumn fresh*

Watering action 4 created a fresh in autumn in Yallakool Creek that peaked at 250 ML/d on 18 May 2021.

### *Routing of flow peaks from watering actions 1, 2 and 4*

The flow peaks from watering action 4 were transmitted the whole way down the Wakool River system to end of system (Figure 4.9). This freshes from each of these actions were evident in Wakool River (zones 3 and 4), Gee Gee Bridge and at Stoney Crossing (Figure 4.9).

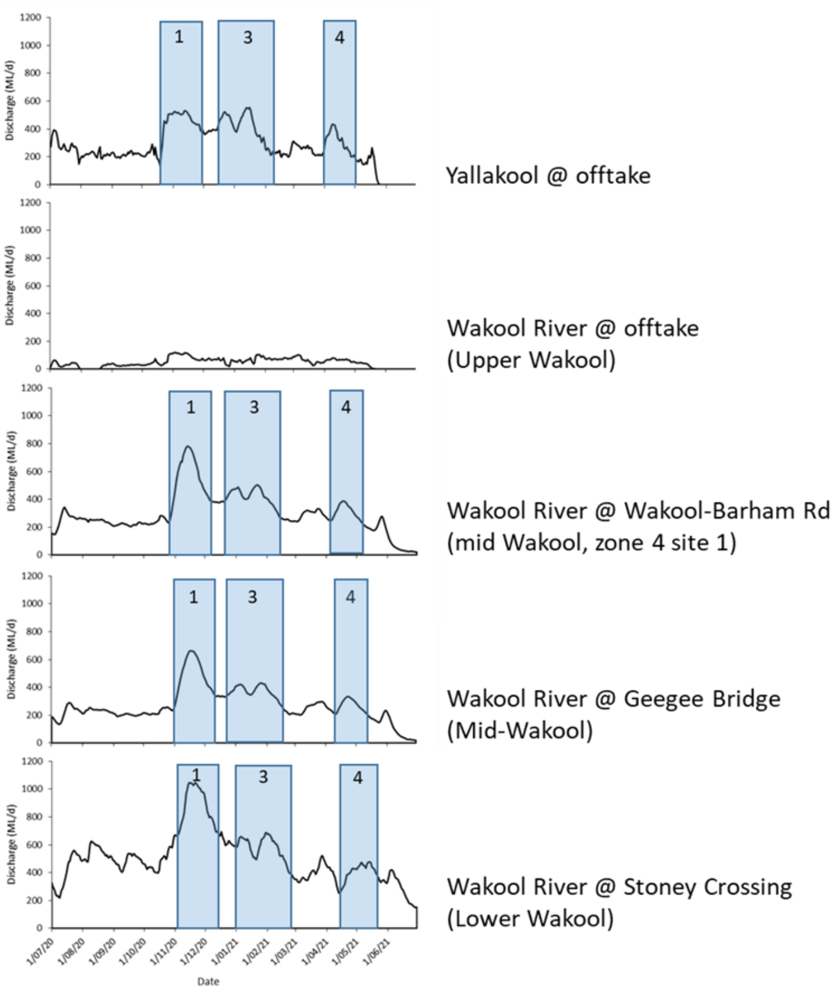



**Figure 4.9** Hydrographs of zones 1 Yallakool Creek, zone 4 Wakool River at Wakool-Barham Rd, and Wakool River at Stoney Crossing from 1 October to 31 December 2020 showing the routing of the flow peak of wateing action 1 (800 ML/d trial) from upstream to downstream reaches. The blue shaded sections relate to the environmental watering actions listed in Table 4.1. Watering action 1 was the 800 ML/day flow trial that exceeded the operational constraint in Wakool River zones 3 and 4.

### *Environmental watering actions 5, 6 and 7: Colligen Creek spring fresh, elevated base flow, and summer fresh*

The flow peak of watering action 5 (maximum discharge 456 ML/day) was similar to watering actions implemented in previous years. The flow peak of watering action 7 was smaller (maximum discharge 304 ML/day) than action 5 (Figure 4.10). The two freshes from thee wateing actions were evident throughout the Colligen-Niemur River system to end of system.

The hydrograph for the Niemur River very very similar to the Colligen hydrograph (Figure 4.11). Flows in the Niemur River were not augmented with flows from the Niemur regulator or Reed-Beds regulators in 2020-21 because flows downstream of Stevens Weir were highly regulated. In contrast, the flows in this system in Oct/Nov 2019 were augmented by flows through these two regulators, with peaks over 200 ML/day recorded in the system.

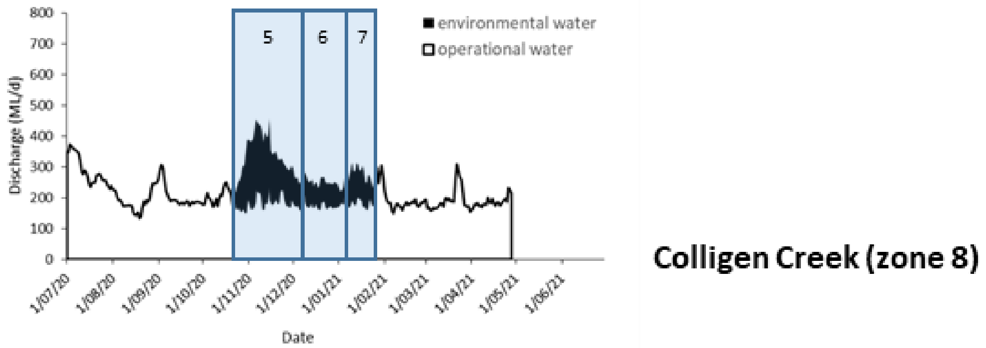



**Figure 4.10** Hydrographs of watering actions 5, 6 and 7 at the Colligen Creek Offtake showing the contribution of Commonwealth Environmental Water in black. The blue shaded areas relate to the environmental watering actions listed in Table 4.1.

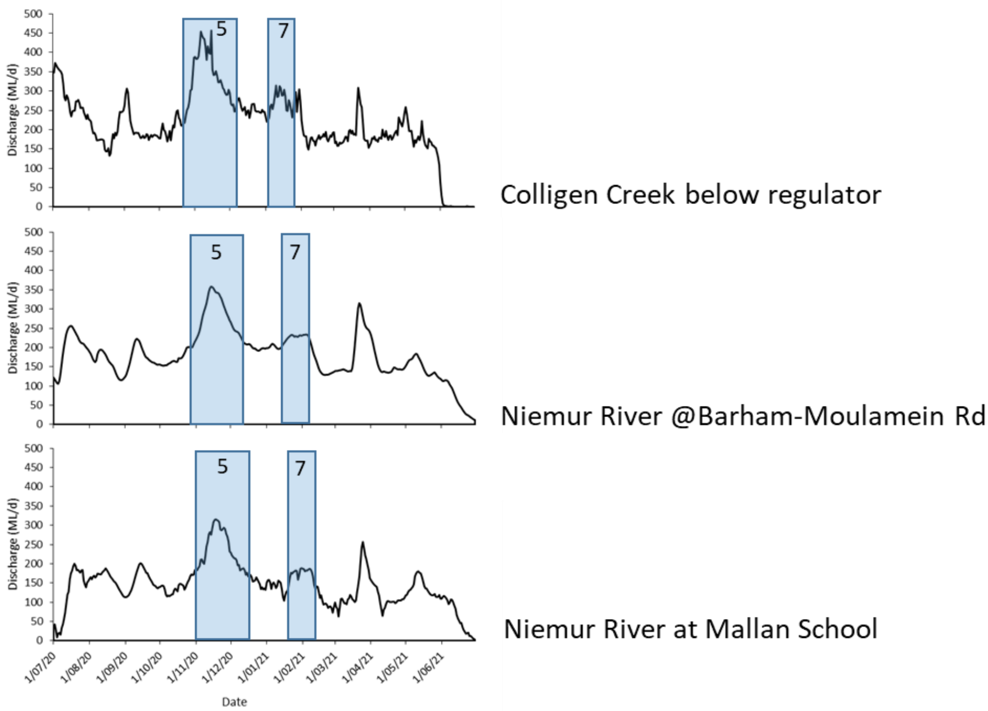



**Figure 4.11** Hydrographs of Colligen Creek from 1/7/2020 to 30/6/2021. The blue shaded sections relate to the environmental watering actions listed in Table 4.1.

### *Watering action 8: Upper Wakool River variable base flows summer/autumn 2021*

Variable base flows in the upper Wakool River resulted in higher and more variable discharge over summer and autumn in this zone than in previous years (Figure 4.5)

### *Longitudinal connectivity*

Continuous flows in Yallakool Creek and Wakool River in winter 2020 (reported in 2019-20 report, Watts 2020) maintained refuge habitat during what would usually have been the operational irrigation shut-down period. This means there has been two consecutive years of continuous winter flows facilitating connectivity between the Murray River and the Edward/Kolety River.

Flow peaks from watering actions 1, 3, 4, flowed unabated down the Yallakool-Wakool system (Figures 4.9 and 4.12) and flow peaks from watering actions 5 and 7 flowed unabated down the Colligen-Niemur system (Figure 4.11), showing longitudinal connectivity outcomes for all of these watering actions.

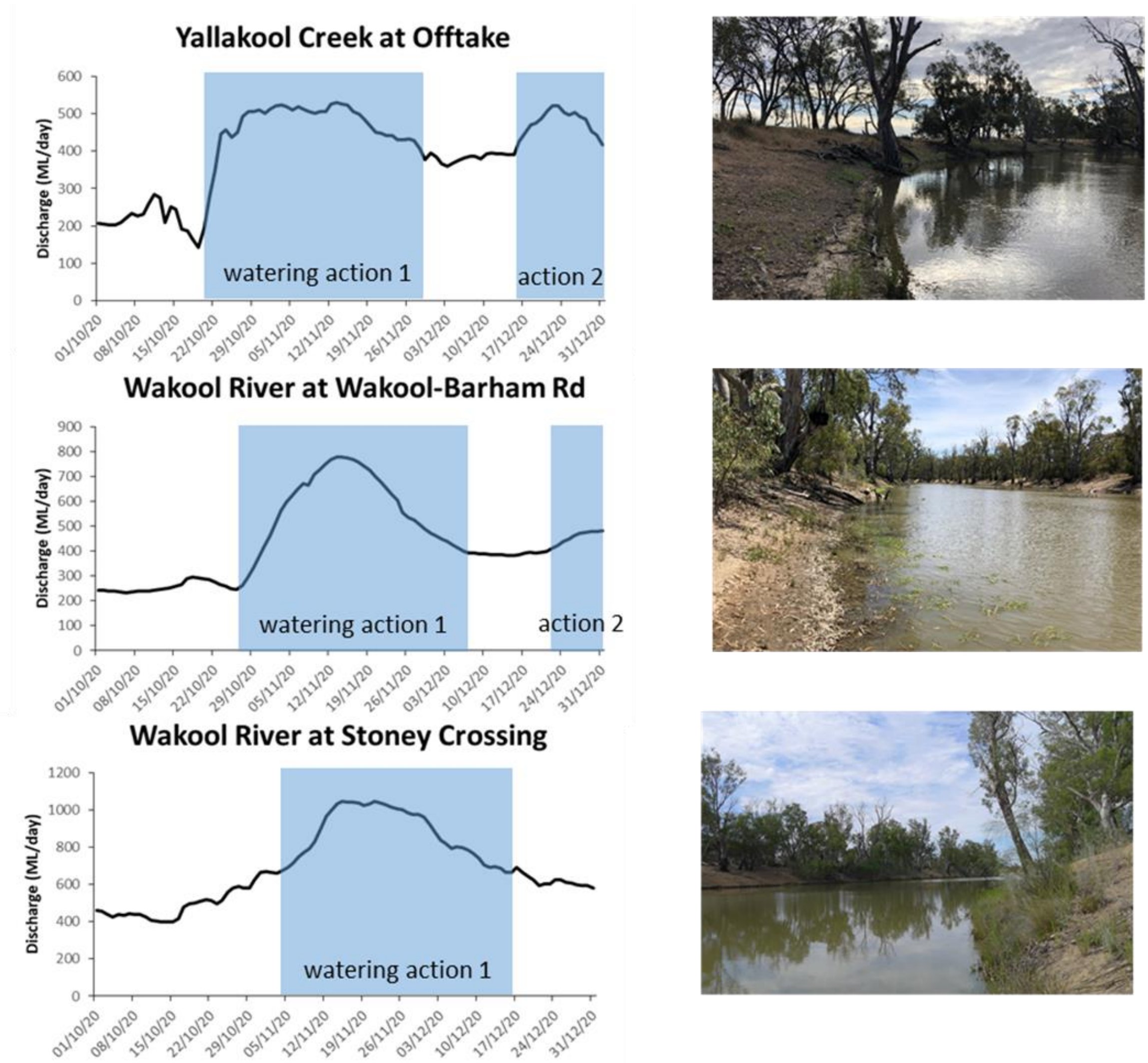



**Figure 4.12** Hydrographs of Yallakool Creek and the Wakool River at Wakool-Barham Road and Soney Crossing during watering action 1 showing the routing of the flow peak down the Wakool River in November and December 2020. The blue shaded sections relate to the environmental watering actions listed in Table 4.1.

## 4.6 Discussion

### *What was the effect of Commonwealth environmental water on the hydrology of the Edward/Kolety-Wakool system?*

Hydrological modelling of natural daily discharge shows that under natural flow conditions there would have been three large freshes in the system between July and December 2020 (Figures 4.2, 4.3). Under operational flow conditions there would not have been any flow peaks in the Yallakool-Wakool system over this period (Figure 4.5).

Watering action 1 (800 ML/day flow trial) increased the maximum discharge compared to operational flows. Furthermore, watering action 1 (800 ML/d flow trial) increased the peak of the spring fresh in the Yallakool-Wakool system beyond the current operational constraint of 600 ML/d, thus increasing the impact of this watering action to contribute to the objectives (Table 4.1) *"to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish."* From a water accounting perspective, although the total volume ordered from the Yallakool and Wakool Offtakes and Wakool escape in 2020 totalled more than 800 ML/d, when losses were taken into account the environmental water delivered from the three sources (Wakool offtake, Yallakool offtake, Wakool escape) were combined, they created a peak at 781 ML/d in the Wakool River at Wakool Barham Rd on 14$^{th}$ November 2020 in zone 3. This was considerably higher than the peak of 225 ML/d that was the operational flow at zone 4 on this date. The peak flow at zone 2 site 4 (305 ML/d on 6/11/2020) was also considerably higher than the discharge would have been on that day under operational flows (37.6 ML/d).

The two summer freshes (watering action 3) in summer and the autumns fresh (watering action 4) provided variability to the hydrograph to support the ongoing ecosystem outcomes. In the absence of environmental watering there would have been very little variability in the discharge over this period.

Similar to watering action 1, watering action 5 in Colligen Creek also increased the maximum discharge and variability of flows in this river compared to operational flows.

Watering action 8 in the upper Wakool River (Variable base flows) achieved the objective to *Improve ability to provide longitudinal connectivity and flow variability.* This would have potential benefits for water quality, stream metabolism and riverbank plants, that will be discussed in later sections in this report (sections 5 to 7).

### *What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?*

Flow peaks from watering actions 1, 3, 4, flowed unabated down the Yallakool-Wakool system (Figure 4.9 and 4.12) and flow peaks from watering actions 5 and 7 flowed unabated down the Colligen-Niemur system (Figure 4.11), showing longitudinal connectivity outcomes for all of these watering actions.

Due to the delivery of environmental water from the Wakool escape from the Wakool escape, the flows in the Wakool River (zone 2) were high enough to initiate flow in Black Dog Creek, that exits the Wakool River near ‘Widgee’ (zone 2 site 4) and flows across to Yallakool Creek to ‘Windra Vale’ near zone 1 site 5. This example of increased longitudinal connectivity resulting from the flow trial would provide increased opportunities for fish movement, dispersal of seeds and vegetation. This connectivity would not have occurred under operational flows.

### *What did Commonwealth environmental water contribute to lateral connectivity?*

Hydrological modelling of natural daily discharge shows that under natural flow conditions there would have been much larger freshes in the system and considerably more lateral connectivity than was observed under operational flows or the environmental watering actions.

Watering action 1, the 800 ML/day flow trial, increased lateral connectivity within the river system. There was considerable variation in wetted area among the study reaches, with some of this variability due to the local geomorphology of the reaches.

Watering actions 3,4,5,7,8 also increased the lateral connectivity in the river system. Increasing the extent and duration of lateral connectivity can play an important role in river productivity, increasing the opportunity for dissolved carbon inputs to the stream from the sediment or organic materials (e.g., leaves, biofilms, grasses and other inundated plants). The outcomes of this will be explored in chapter 5 and 6 of this report. The slower recession also provides opportunities for growth and increased cover of submerged and amphibious macrophytes (see chapter 7) which can increase habitat for invertebrates, frogs and fish.

# 5 Water Quality and Carbon

Authors: Xiaoying Liu and Nicole McCasker

| Key findings | |
|---|---|
| **Dissolved oxygen concentrations** | The expected seasonal variations of dissolved oxygen concentrations were observed in the Edward/Kolety-Wakool River in 2020-21 water year, generally were above the range of concern to fish populations. The 2020 800 ML/day flow trial did not result in any adverse water quality outcomes. Dissolved oxygen concentration remained normal for the period of watering action.<br><br>Commonwealth environmental watering action 8 commenced in the upper reach of Wakool River during January to June 2021 resulting in higher discharge than other years and the variable base flows supported dissolved oxygen concentrations in this part of the system. It demonstrated that using Commonwealth environmental water in upper Wakool with extremely low flow in hot months could provide a proactive, longer-term approach to improve water quality and prevent potential hypoxic water events. |
| **Nutrient concentrations** | Nutrient concentrations in the Edward/Kolety-Wakool River system remained in the acceptable range in 2020-21 water year.<br><br>Total phosphorus and total nitrogen were slightly elevated during Commonwealth environmental watering actions, likely due to greater turbidity (particles suspended in the water column), bioavailable nutrients remained low. |
| **Temperature regimes** | None of the watering actions targeted temperature. Water temperatures in the system were primarily controlled by the prevailing weather conditions. |
| **Type and amount of dissolved organic matter** | There was no detectable effect of environmental watering actions on this indicator in 2020-21 water year. The watering actions in 2020-21 did not specifically target the transport of dissolved organic matter. Dissolved organic carbon in the Edward/Kolety River and Colligen-Niemur River were similar remaining in the acceptable range.<br><br>A pulse of dissolved organic carbon was detected in the Wakool-Yallakool system during the 800 ML/day flow trial and the concentration of dissolved organic carbon in the mid-Wakool River was outside the normal range observed in the system and almost reached a similar level to that observed during 2016-17 floods. This may have been influenced by return flows from MIllewa Forest during the Southern Connected Flow. |

## 5.1 Background

Water quality describes the condition of the water, including physical, chemical and biological characteristics relating to its suitability for environmental uses. Water quality is a key indicator of aquatic ecosystem health, and flow plays an important role in the maintenance of water quality in lowland rivers. Water quality parameters will often respond to changes in flow regimes very quickly. Changes in flow in a river system can influence water quality both positively and negatively with the outcome dependent on the source of the water, magnitude and duration of the flow, time of the year, other hydrological and catchment conditions. High flow events caused increases in wetted benthic areas can result in exchange of nutrients and carbon between the river and the adjacent floodplain, and/or previously disconnected in-channel areas (Baldwin 1999; Baldwin and Mitchell 2000; Robertson et al. 2016) and environmental flows play a key role in restoring carbon exchange that has been lost due to extensive river regulation and modification of channel and bank features (Baldwin et al. 2016).

A range of parameters can be measured as indicators of water quality in river systems and many of these parameters as water quality targets in the Murray-Darling Basin Plan 2012 are directly or indirectly influenced by alterations in flow. For example, dissolved oxygen (DO) can be influenced by flow through changes in water volume and turbulence, and through indirect processes such as alterations in rates of bacterial metabolism and photosynthesis. This, in turn, will directly influence the suitability of the water quality for aquatic organisms, such as fish. Nutrients and organic matter concentrations may be influenced by flow, either by dilution or through inputs associated with 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 bare soil (Baldwin 1999; Baldwin and Mitchell 2000).

Aquatic environments naturally have quite variable dissolved organic matter concentrations and there are no optimal concentrations or trigger values provided for organic matter (ANZECC 2000). 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). Organic matter is made up of a complex mixture of compounds with different properties and variable availability to the microbial population. This mixture contains many different types of compounds with a diverse range of sources and the most fundamental use of broad categories of organic matter in natural waters are non-humic substances and humic substances (Choudhry 1984). Non-humic substances include relatively simple compounds belonging to recognised groups such as carbohydrates, proteins, peptides, fats and other low molecular weight organic compounds (Choudhry 1984). Humic substances can be further classified into two groups (including humic and fulvic acids) and are predominantly derived from the processing of plant residues and can involve complex chains and aromatic rings which contribute to their strong yellow-brown colour.

Microbial communities do not respond to all types of organic matter in the same way (Baldwin 1999; O'Connell 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 (Wehr et al. 1999). The very large, complex type of organic matter referred to as humic substances has been shown to be less available to bacterial communities than simpler non-humic carbon (Moran and Hodson 1990) although this can be altered over time with exposure to ultraviolet light (Moran and Zepp 1997; Howitt et al. 2008). These differences in microbial response to different types of organic matter mean that it is important to consider not just the total amount of dissolved organic matter in the rivers but to monitor changes in the type of organic matter present. Both absorbance and fluorescence spectra are used to examine the organic matter in this study. As a general guide, absorbance at longer wavelengths indicates larger, more complex organic matter (Bertilsson and Bergh 1999). Absorbance at a particular wavelength may be increased by increasing concentration of organic matter or a change in the type of organic matter.

Reconnection of the stream channel with backwater areas and dry sections of the floodplain and channel may result in additional nutrients and organic carbon. 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) and 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).

The 2020-21 sampling year was characterised by the in-channel flows more commonly observed in this system. There were two clear examples during 2020-21 where the CEWO acted in response/regard to water quality targets and requirements in the Murray-Darling Basin Plan 2012. The first example was in January and February 2021 in response to a hypoxic blackwater event observed in the upper Wakool River. Variable base flows were provided to improve water quality and prevent a potential hypoxic water event. The second example was the spring fresh (800 ML/d trial) that commenced from mid-October to late-November 2019 in the Wakool-Yallakool system. The objective of this watering action was to support the recovery of the river system following the low-oxygen blackwater event in 2016, and to contribute to connectivity and improve water quality.

This chapter reports on changes in water quality (nutrients, algal biomass, temperature, and DO) in response to flows from 1 July 2020 to 30 June 2021 and will consider changes in both the quantity and type of organic matter present in the system. Specifically, this work will address the evaluation questions in section 5.3.

## 5.2 Environmental watering actions targeting water quality outcomes

Eight Commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2020-2021 water year (Table 5.1). This report will cover water quality data from July 2020 to June 2021.

**Table 5.1** Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2020-21 water year. Commonwealth environmental watering actions 2020-21 for that had water quality objectives are shaded in grey.

| Watering Action | Type of action | Rivers | Dates |
|---|---|---|---|
| Action 1 | Spring fresh | Wakool-Yallakool | 20/10/20 – 30/11/20 (Yallakool)<br>23/10/20 – 27/11/20 (Wakool) |
| Action 2 | Elevated base flow | Yallakool | 30/11/20 – 15/12/20 |
| Action 3 | Summer freshes | Yallakool | 15/12/20 – 15/2/21 |
| Action 4 | Autumn fresh | Yallakool | 30/3/21 – 6/5/21 |
| Action 5 | Spring fresh | Colligen-Niemur | 13/10/20 – 6/12/20 |
| Action 6 | Elevated base flow | Colligen-Niemur | 6/12/20 – 8/1/21 |
| Action 7 | Summer fresh | Colligen-Niemur | 8/1/21 – 26/1/21 |
| Action 8 | Variable base flows | Upper Wakool | 23/1/21 – 9/6/21 |

## 5.3 Selected Area evaluation questions

As described above, the relationship between flow and water quality is complex and can be influenced by how changes in flow influence wetted benthic area, water depth, rate of flow and connectivity to the floodplain. Water quality parameters may be affected in different ways due to the direct effects of changes in flow, or due to interactions between the parameters. In order to obtain an understanding of the impact of environmental water deliveries to the Edward/Kolety-Wakool system on the water quality in a broader range of sites (the Wakool-Yallakool system, Edward/Kolety River, the Colligen-Niemur River system and Tuppal Creek), we monitor a number of water quality parameters at each site through a combination of continuous logging, spot readings on site and water sample collection for laboratory analysis. Water quality will generally respond very rapidly to changes in flow, but trends may also develop over a longer period, so the questions below are considered on a 1-3 year basis.

In 2020-21 the key questions relating to the CEW actions were:

- What did Commonwealth environmental water contribute to DO concentrations?
- What did Commonwealth environmental water contribute to nutrient concentrations?
- What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat?

The remaining question was not addressed as the watering actions did not seek to influence water temperature in the system:

- What did Commonwealth environmental water contribute to temperature regimes?

## 5.4 Methods

### *Monitoring sites*

The core carbon fluorescence and water quality data were collected at sites shown in Table 5.2 and Figure 5.1 and include ongoing monitoring at established sites in Yallakool Creek (Zone 1), Wakool River (Zones 2 to 4), and source water for these sites from the Mulwala Canal and the Edward/Kolety River at Stevens Weir. Sites added for water quality monitoring for the Flow-MER Program include further downstream in the Wakool River and Tuppal Creek, the Edward/Kolety River, and the Colligen-Niemur River to better capture the impact of environmental water in the broader system. Sites 5 and 6 (Edward/Kolety River) together with 9, 10 and 11 (the Colligen-Niemur River system) may be used in combination to assess carbon and nutrient exchange between the river systems and the Werai Forest should an appropriate overbank flow occur.

The focus of the annual monitoring is the assessment of organic matter inputs and water quality changes during in-stream flows. Sampling consists of water samples collected from each site on a monthly basis throughout the year.

**Table 5.2** Sites for water quality and carbon routine monitoring.

| No. | Site name | River system | Gauge number | LTIM DO logger | WaterNSW DO logger | New Flow-MER DO logger | Sites labels on figures |
|---|---|---|---|---|---|---|---|
| 1 | Tuppal Creek | Tuppal Creek | 409056 | | | ˇ | Aratula_Rd |
| 2 | Mulwala Canal | | | | | | Canal |
| 3 | Four Post | Edward River | 409047 | | ˇ | | Four_post |
| 4 | Stevens Weirpool | Edward River | 409101 | | | | Weir |
| 5 | Downstream Stevens Weir | Edward River | 409023 | | | ˇ | Eastman_bridge |
| 6 | Downstream Werai Forest | Edward River | | | | ˇ | Balpool_rd_bridge |
| 7 | Moulamein | Edward River | 409014 | | ˇ | | Moulamein |
| 8 | Liewah | Edward River | 409035 | | | ˇ | Liewah |
| 9 | Colligen | Colligen-Niemur River | 409024 | | | ˇ | Colligen-Old Morago Rd |
| 10 | Niemur Barham Road | Colligen-Niemur River | 409048 | | ˇ | | Niemur-Moulamein Rd |
| 11 | Niemur Mallan School | Colligen-Niemur River | 409086 | | ˇ | | Niemur-Mallan School |
| 12 | Zone 1 site 5 | Yallakool Creek | | ˇ | | | Zone 1 |
| 13 | Zone 2 site 4 | Wakool River | | ˇ | | | Zone 2 |
| 14 | Zone 3 site 5 | Wakool River | | ˇ | | | Zone 3 |
| 15 | Wakool Barham Road | Wakool River | 409045 | ˇ | | | Zone 4 |
| 16 | Zone 4 site 5 | Wakool River | | ˇ | | | Zone 4 |
| 17 | Gee Gee Bridge | Wakool River | 409062 | | ˇ | | Zone 5 |
| 18 | Stony Crossing | Wakool River | 409013 | | ˇ | | Zone 6 |

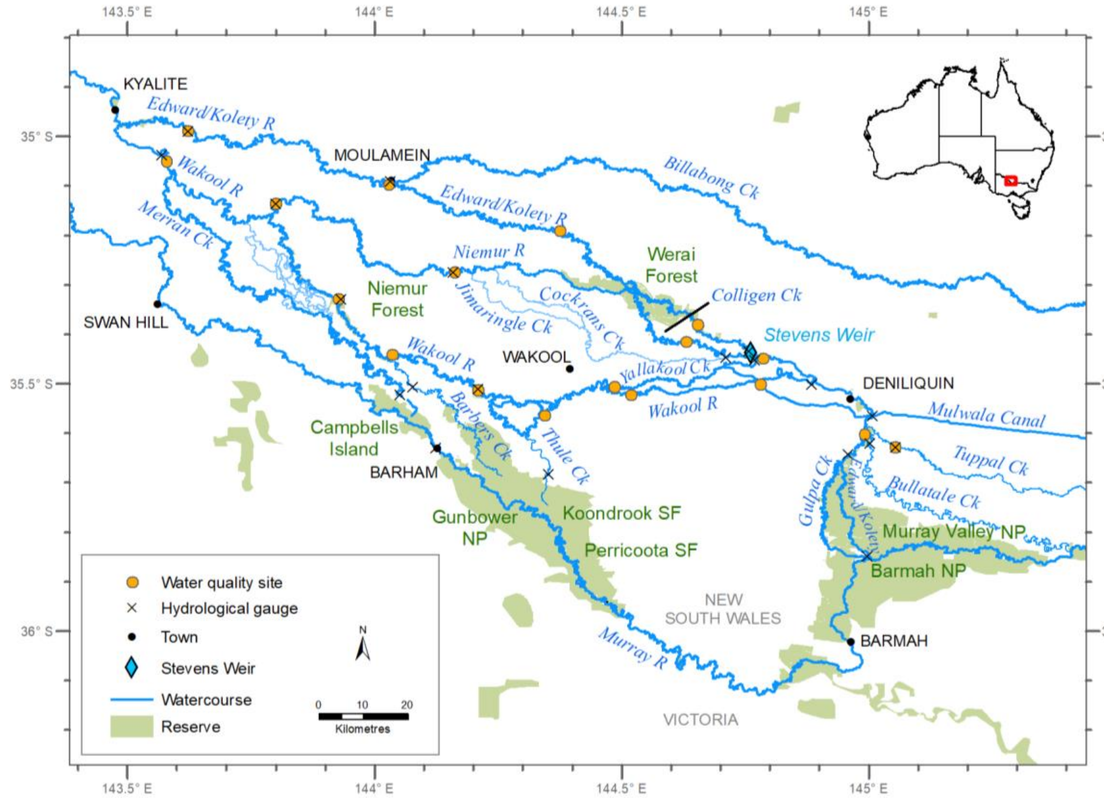



**Figure 5.1** Map of the Edward/Kolety-Wakool Selected Area showing existing LTIM sites that are continued (red), sites where water quality sampling are supplemented with data from WaterNSW loggers (green), sites where new loggers are installed (yellow).

### *Water quality data collection and analysis*

Water temperature and DO were logged every ten minutes at ten monitoring sites including Tuppal Creek, downstream Stevens Weir, downstream Werai Forest, Colligen, Zone 1 Site 5, Zone 2 Site 4, Zone 3 Site 5, Zone 4 Site 1, Zone 4 Site 5 and Liewah (see Figure 5.1). Data were downloaded and loggers calibrated approximately once per month depending on access to survey sites (e.g., high rainfall may prevent access). Light and depth loggers were also deployed, and data were downloaded on a monthly basis. The data collected by the loggers was used to calculate daily average temperature and DO concentrations for each of the river/creek system from 1 July 2020 to 30 June 2021.

From July 2020 to June 2021 water quality parameters (temperature (°C), electrical conductivity (mS/cm), DO (%), pH, and turbidity (NTU)) were measured as spot recordings monthly at monitoring sites within each river/creek system, and from Stevens Weir on the Edward/Kolety River and the Mulwala Canal. Water samples were collected once per month from monitoring sites within each river/creek system, and from Stevens Weir on the Edward/Kolety River, and the Mulwala Canal.

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

- Dissolved organic carbon (DOC)
- Nutrients (total phosphorus (TP), filtered reactive phosphorus (FRP), total nitrogen (TN), dissolved nitrate + nitrite ($NO_x$) and ammonium ($NH_4^+$))

- Chlorophyll-*a* (Chl *a*)
- Absorbance and fluorescence spectroscopy for organic matter characterisation

Water samples for organic matter characterisation, DOC and bioavailable nutrients (FRP, $NO_x$, $NH_3$) were filtered through a 0.2 µm pore-sized membrane at the time of sampling and then stored on ice until returned to the laboratory. DOC and nutrient samples were frozen and sent to CSIRO NATA certified lab in CSU Albury campus for analysis. Carbon characterisation samples were sent to NaLSH, Wagga Wagga campus CSU and 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. 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° to the source was recorded from 200 nm to 550 nm with a 1 nm step size. Fluorescence results were corrected for sample absorption and plotted as contour plots (Howitt et al. 2008). To correct for drift in the instrument zero position, each contour plot was scaled by subtracting the average emission intensity across the range 200-210 nm for an excitation of 250 nm from all fluorescence intensities effectively setting this region of the contour plot to zero on all plots.

An example of a fluorescence contour plot is shown in Figure 5.2. The contour plots have the excitation wavelength (light shone into the sample) on the y-axis. On the x-axis is the emission wavelength (light given off by the sample). The intensity of the fluorescence (how much light is given off, corrected for absorbance by the sample) is represented by the colours of the contour plot, with more intense fluorescence represented by the blue end of the scale. The two blue diagonal lines are artefacts of the technique and will be present in all samples- key data is found between these two lines.

The monitoring results were assessed against the lowland river trigger levels for aquatic ecosystems in south-east Australia from the ANZECC (2000) water quality guidelines. If the concentration of a particular water quality parameter exceeds the trigger level or falls outside of the acceptable range, the guidelines are written with the intention that further investigation of the ecosystem is 'triggered' to establish whether the concentrations are causing ecological harm. Systems may vary in their sensitivity to various parameters and therefore exceeding a trigger level is not an absolute indicator of ecological harm. It is quite common for water quality parameters to briefly fall outside of guideline values during large overbank flows. 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.

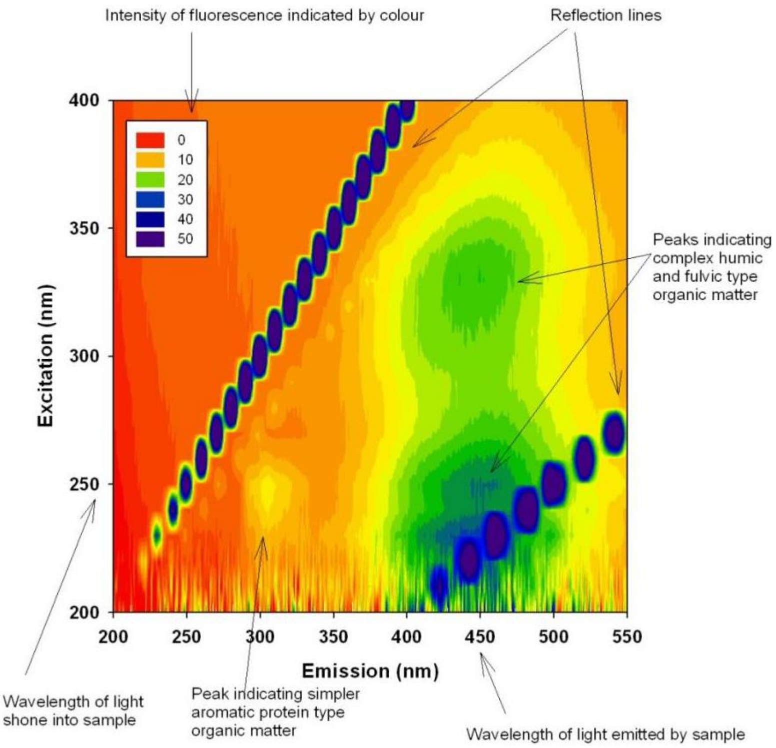



**Figure 5.2** Sample excitation emission contour plot indicating key features of the data (Watts et al. 2013).

## 5.5 Results

The collected water quality and carbon data have been grouped based on the major rivers; the Wakool-Yallakool system, the Edward/Kolety River, the Colligen-Niemur River system and Tuppal Creek. The data collected by the loggers was used to calculate daily average temperature results and DO concentrations for selected sites of each river system between 01 July 2020 and 30 June 2021. The water samples for the assessment of water quality changes and the assessment of organic matter inputs during in-stream flows were collected from each site on a monthly basis throughout the year from July 2020 to June 2021. There is a selection of sites, basically based on upper, middle and lower reaches of a river system, to provide a snapshot of results for each system and the results can be interpreted in the context of the hydrological processes at the time. In general, downstream sites affected by water actions were later and experienced longer periods than upstream sites.

### *The Wakool-Yallakool system*

#### ***Water quality parameters***

Water temperature was consistent across study sites in the Wakool-Yallakool system with water temperature exceeding 25 °C briefly during summer and staying below 10 °C for several weeks during winter. The results indicate that water temperature showed a typical season pattern. There was no discernible effect of Commonwealth environmental watering action on water temperature, with all sites displaying the same seasonal variation and influence of weather patterns. This was consistent with the trend observed in previous years.

The average daily DO concentrations in the Wakool-Yallakool system shows the expected seasonal variations with higher concentrations in the winter and lower concentrations correlating to the periods of higher water temperature. The DO values were very good compared to previous years, with no minimums below 4 mg/L at any time of the year (Table 5.3).

Spot water quality parameters (electrical conductivity (EC), turbidity and pH) remained stable (see Table 5.3) and within the normal range for the Wakool-Yallakool system throughout the study period and were very similar to results from the 2014-15, 2017-18, 2018-19 and 2019-20 sampling years in the absence of extensive overbank flows or excessive algae bloom. The EC values at all sites were well below the ANZECC (2000) trigger levels on all sampling dates. The increase in EC values sometimes observed in the upper Wakool River during autumn was not observed in the 2020-21 and the relatively variable base flows with higher discharge during this period may have reduced the impact or amount of groundwater seeping into the system which was hypothesised to be the source of this increase in some years. Most pH remained within the trigger values with the exception on two occasions at Mulwala Canal, the high pH value in December 2020 may indicate increased algal activity at that time and in June 2021 the reading was collected in a shallow and disconnected pool and is not of concern (Figure 5.3). Turbidity measurements were generally above the ANZECC (2000) trigger level but within the range commonly observed in this river system.

**Figure 5.3** Mulwala Canal in June 2021. (Photo: Xiaoying Liu)

Nutrients and DOC in most study sites of the Wakool-Yallakool system were not elevated outside the normal range and were very similar to results from the 2014-15, 2017-18, 2018-19 and 2019-20 sampling years. Downstream sites affected by water actions were later and experienced longer periods than upstream sites. Both TN and TP were increased during water actions which might have been associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column). TP generally increased downstream sites and this is consistent with the pattern in TN and trends in Chl *a*. There were generally lower concentrations in Yallakool than in the Wakool River suggesting slight increases in TP and TN as the water progresses through the system. The $NO_x$ and FRP remained below the trigger levels. Most ammonia values remained below the trigger value with the exception on one occasion at lower Wakool River (Gee Gee Bridge) in April 2021 could possibly be due to ammonia introduced from the disturbance of the sediments while sampling along with observed higher TN and $NO_x$ values.

A pulse of DOC and nutrients was detected in the Wakool-Yallakool system in November 2020 through the Southern Spring Flow watering action (action 1). The Southern Spring Flow introduced a small addition of carbon and nutrients to the Wakool-Yallakool system and the changes in DOC and nutrients concentrations did not result in any adverse water quality outcomes in the system.

**Table 5.3** Range (min-max) and mean values of water physico-chemical parameters for the Wakool-Yallakool system in 2020-21 water year. ANZECC (2000) trigger levels for available water parameters are given in bold text.

| Parameters | Mulwala canal | Stevens weir | Yallakool Creek | Upper Wakool River | Middle Wakool River (up) | Middle Wakool River (down) | Lower Wakool River (up) | Lower Wakool River (down) |
|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 12.15-26.03 (18.85) | 10.61-29.3 (19.55) | 10.37-27 (18.6) | 10.57-26.92 (18.35) | 8.1-26.94 (17.86) | 9.68-28.83 (19.04) | 9.95-27.83 (19.35) | 10.38-27.68 (20.44) |
| pH **ANZECC 6.5-8** | 7.24-8.92 (7.91) | 6.82-7.74 (7.36) | 6.84-7.36 (7.08) | 6.58-7.03 (6.79) | 6.68-7.18 (6.98) | 7.02-7.49 (7.26) | 6.98-7.47 (7.20) | 7.02-7.82 (7.38) |
| DO (mg $L^{-1}$) | 9.98-13.64 (11.58) | 9.19-13.61 (11.1) | 8.89-11.98 (10.47) | 4.84-10.47 (8.06) | 5.81-11.32 (8.45) | 8.49-13.24 (10.6) | 8.31-11.53 (9.9) | 8.28-12.31 (10.5) |
| Turbidity (NTU) **ANZECC 50** | 14.5-71.5 (45.8) | 19.5-110 (41.9) | 47.5-87.5 (60.2) | 42.8-113 (71.5) | 34.6-98.1 (57.9) | 41.2-183 (76.1) | 47.6-70.9 (59.9) | 41.2-97.2 (61.4) |
| EC (mS $cm^{-1}$) **ANZECC 0.125** | 0.037-0.063 (0.052) | 0.032-0.064 (0.051) | 0.029-0.059 (0.048) | 0.048-0.258 (0.131) | 0.031-0.077 (0.058) | 0.033-0.082 (0.063) | 0.044-0.075 (0.062) | 0.12-0.217 (0.166) |
| Chl *a* (µg $L^{-1}$) **ANZECC 5** | 5.32-26.43 (11.39) | 7.98-24.29 (13.46) | 7.47-15.79 (12.05) | 12.13-26.78 (18.83) | 6.47-21.94 (13.93) | 6.64-29.75 (16.53) | 8.64-31.1 (17.25) | 11.54-40.25 (21.61) |
| TP (mg $L^{-1}$) **ANZECC 0.05** | 0.025-0.057 (0.042) | 0.026-0.043 (0.035) | 0.032-0.05 (0.04) | 0.028-0.083 (0.052) | 0.032-0.055 (0.043) | 0.033-0.07 (0.046) | 0.031-0.071 (0.051) | 0.036-0.076 (0.058) |
| FRP (mg $L^{-1}$) **ANZECC 0.02** | 0.005-0.007 (0.005) | 0.005-0.005 (0.005) | 0.005-0.005 (0.005) | 0.005-0.006 (0.005) | 0.005-0.005 (0.005) | 0.005-0.006 (0.005) | 0.005-0.005 (0.005) | 0.005-0.005 (0.005) |
| TN (mg $L^{-1}$) **ANZECC 0.5** | 0.315-1 (0.0578) | 0.315-0.57 (0.432) | 0.34-0.68 (0.49) | 0.375-0.99 (0.587) | 0.355-0.68 (0.507) | 0.32-0.81 (0.542) | 0.36-1.35 (0.643) | 0.435-0.94 (0.64) |
| $NH_4^+$ (mg $L^{-1}$) **ANZECC 0.02** | 0.005-0.008 (0.005) | 0.005-0.006 (0.005) | 0.005-0.016 (0.005) | 0.005-0.018 (0.007) | 0.005-0.006 (0.005) | 0.005-0.006 (0.005) | 0.005-0.295 (0.031) | 0.005-0.025 (0.007) |
| $NO_x$ (mg $L^{-1}$) **ANZECC 0.04** | 0.002-0.006 (0.003) | 0.002-0.004 (0.002) | 0.002-0.012 (0.003) | 0.002-0.022 (0.007) | 0.002-0.004 (0.003) | 0.002-0.004 (0.003) | 0.002-0.037 (0.009) | 0.002-0.012 (0.003) |
| DOC (mg $L^{-1}$) | 3.5-8.1 (5.7) | 3.1-10.6 (5.6) | 3.4-10.9 (6.2) | 4.1-12.9 (7.0) | 3.3-13.2 (5.9) | 3.3-13.7 (6.1) | 3.9-11.1 (6.4) | 3.5-10.1 (5.9) |

### *Water quality parameters at selected sites*

Yallakool Creek and the middle and lower reaches of the Wakool River were similar to each other throughout most of the 2020-21 study period which were all receiving base flows and freshes of Commonwealth environmental water.

In all cases a decline in DO was observed during the hotter months, as expected with the increased water temperature (which decreases oxygen solubility and increases the rate of many microbial processes) (see Figure 5.4). The difference in DO concentration between sites does not reflect water temperature differences and likely reflects differences in input of oxygenated water from upstream and different rates of re-aeration and oxygen consumption associated with flow. In 2020-21 water year, concentrations of DO in the upper Wakool River briefly dropped into the range of concern to fish populations (below 4 mg/L) in mid-December 2020, in early January 2021 and between mid-January and mid-February 2021. No values below 2 mg/L were recorded. Dark coloured water was observed at upper Wakool River (Figure 5.5) in January 2021 with low DO concentration (2.92 mg/L) recorded, although these were within the range normally measured at that time of year. The adaptive management has been implemented to deal with the low DO issue and hence the environmental watering action 8 was commenced in the upper Wakool. The variable base flows resulted in higher discharge than other water years in upper Wakool and the increased flow made dark coloured water diluted and DO level increased. It is common the upper Wakool River had lower DO than other sites throughout the study period especially in summer when discharge is much lower at this reach, the upper Wakool watering action in summer/autumn 2021 demonstrates Typically flow is extremely low in upper Wakool over the summer/autumn, using Commonwealth environmental water in this part of the system could provide a proactive and longer term approach to improve water quality (preventing potential hypoxic water events).

In general, Chl *a* values were lower in the Wakool-Yallakool system in summer 2020-21 than observed in 2019-20, the lower Chl *a* value likely was associated with the different watering actions occurred at that time reflecting dilution as a consequence of flow events.

Yallakool-Wakool Spring fresh commenced in mid-October 2020 with environmental water delivered via the Yallakool offtake, Wakool offtake and the Wakool escape from Mulwala Canal to create a combined flow pulse with a peak of approximately 800 ML/day in the Wakool River downstream of Wakool Reserve. The peak flows in the middle reach of the Wakool River were higher in 2020 800 ML/day flow trial than during the 2018 flow trial and the duration of the peak was also longer in 2020 800 ML/day flow trial than in the 2018 flow trial. Discharge in the upper Wakool River was considerably higher during Spring fresh 2020 than in previous years. Elevated DOC and nutrients in the Wakool-Yallakool system during 2020 800 ML/day flow trial suggests carbon and nutrient pulses were introduced by Southern Spring Flow watering action and there also were local sources of DOC and nutrients at times during this period, possibly due to larger areas were wetted or commence to flow conditions where water that was in backwaters or on low lying benches started to drain back into the river system.

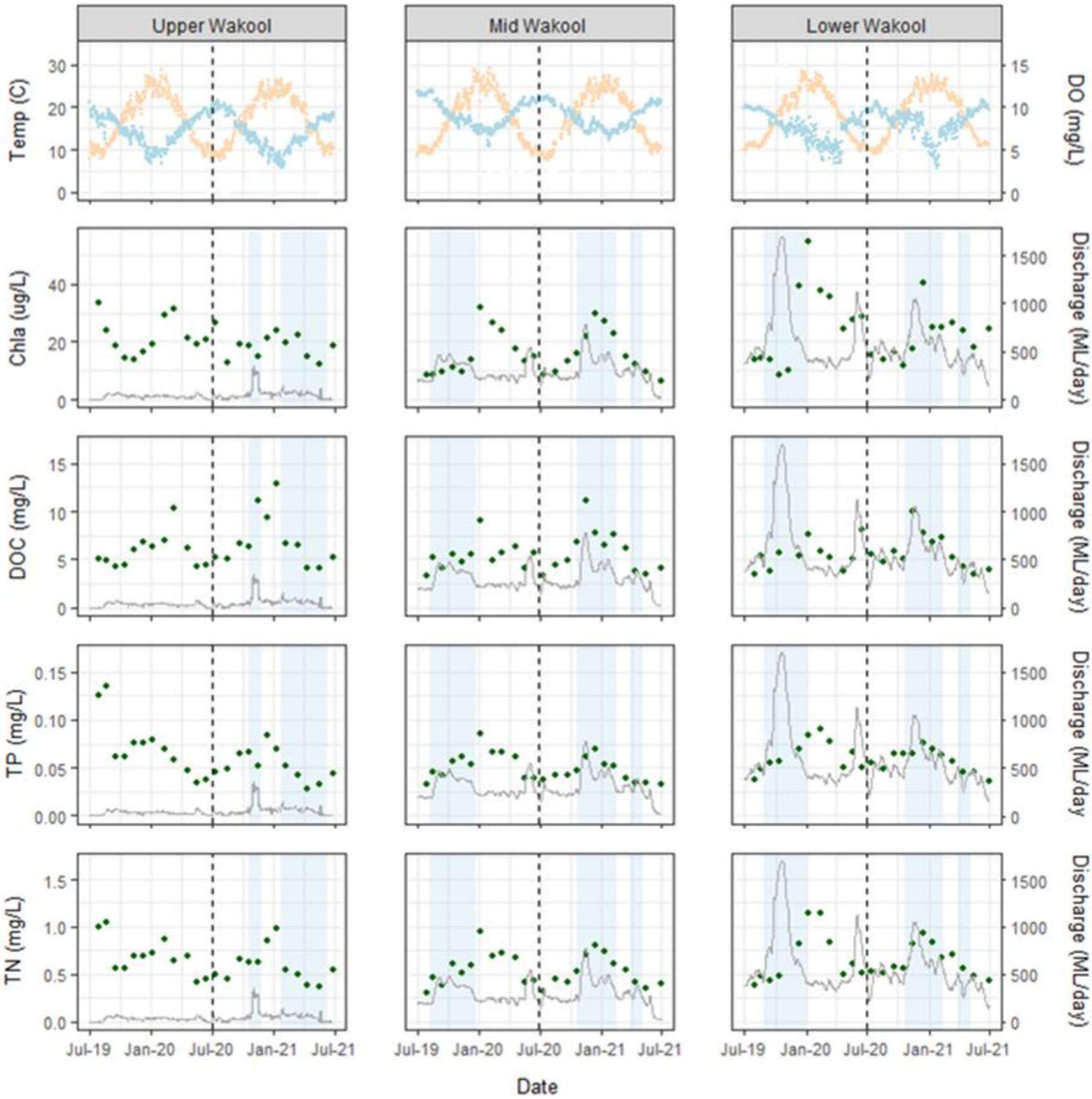



**Figure 5.4** Water temperature, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for the selected sites over the 2020-21 watering year in the Wakool-Yallakool system. Blue shaded vertical bars indicate watering actions.

A higher level of DOC was detected at middle and lower reaches of Wakool River in November 2020 through the Southern Spring Flow watering action (Figure 5.5). The contribution of DOC and nutrients to the middle and lower reaches of the Wakool River might not only be associated with the carbon pulse introduced by Southern Spring Flow watering action, but it might be related to the water flushed from Thule Creek channel following watering from the Yarraman Chabbel (see below) introducing an additional carbon and nutrients the Wakool River downstream of the confluence with Thule Creek. DOC concentration at middle Wakool was outside the normal range observed in the system which almost reached the similar level during 2016-17 flooding year.

A pulse of DOC and nutrients was detected in the upper Wakool in January 2021, this corresponds with dark coloured water and floating algae were observed in this part of the system. It is common for DOC and nutrients levels were a bit higher in upper Wakool than the other study sites during summer when discharge is much lower at this reach. Increased flow condition in the upper Wakool River action in summer/autumn 2021 resulted in this part of the system responded differently compared to other years' monitoring. The higher DOC and nutrients levels were alleviated during watering action 8 reflecting Commonwealth environmental water could improve water quality in hot months. The changes in DOC and nutrients concentrations in 2020-21 water year did not result in any adverse water quality outcomes in the Wakool-Yallakool system.

**Figure 5.5** Poor water quality was observed in the upper-Wakool River system in January 2021. (Photo: Sascha Healy and Xiaoying Liu)

### *Water quality in Thule Creek*

As mentioned above, water from Thule Creek channel may have mnade a contribution to the elevated DOC and nutrients at Wakool River downstream of Thule Creek confluence (mid reach of Wakool River). The NSW environmental water released from the Yarraman Channel through Thule Creek was implemented from 6th September to 15th November 2020, and the water started to flow into the Wakool River at the junction of Thule Creek around 6th October. Environmental watering actions in Thule Creek have been implemented by NSW DPIE in previous years and outomes of the 2019-20 watering action ewas reported in Watts and Liu (2020).

The water samples were collected weekly between 6th October and 23rd November 2020 covering the period of before and after the water from Thule Creek was mixed with Wakool River. Increases in DOC and nutrients concentrations in the Thule Creek channel were detected as water travelled downstream. As shown in Figure 5.6, a small addition of DOC and nutrients from Thule Creek introduced to Wakool River was detected between late October and end of November. A pulse of DOC leached from the Thule Creek channel combined with DOC released from upper Wakool River resulting in a higher DOC concentration was detected at middle reach of Wakool River on 17th November 2020 based on available data.

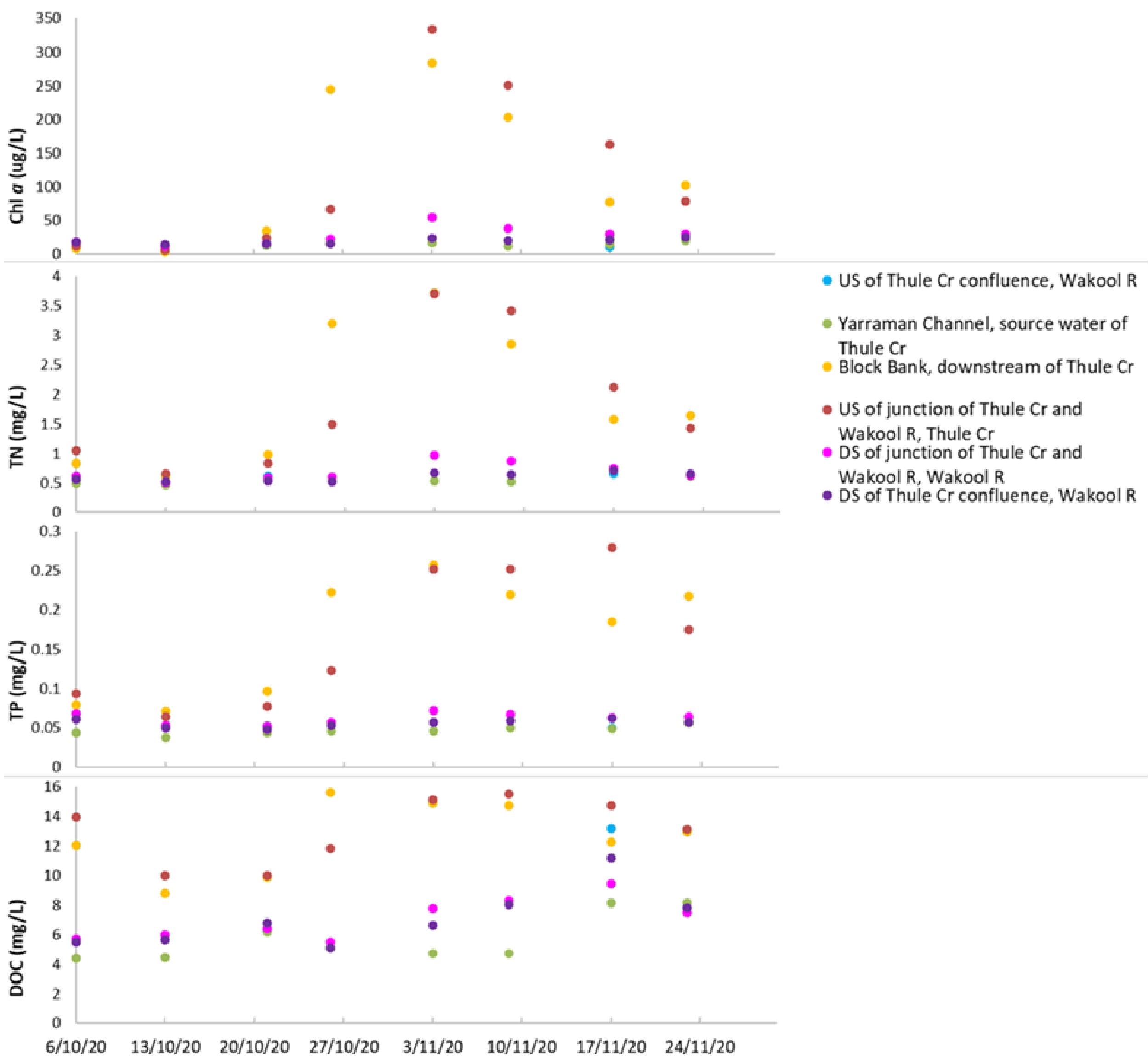



**Figure 5.6** Chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) in Thule Creek, Yarraman Channel and Wakool River from mid-October to the end of November 2020. Data of upstream of Thule Creek confluence (Wakool River) are only available on 21st October and 17th November 2020.

In early November 2020 an algal bloom was occurred in the Thule Creek channel (Figure 5.7), corresponding with higher values in Chl *a* and rapid increases in nutrients concentrations. Black colored water was observed in Thule Creek from mid-November to the end of November 2020 (Figure 5.8), which corresponds with elevated DOC concentrations. The water in Yarraman Channel (source water of Thule Creek) had DOC concentration around 4-6 mg/L which is in the normal range observed in this system (Watts et al., 2019; Watts and Liu, 2020). After the water had travelled downstream and inundated the areas of small red gum trees, grass and leaf litter and bare soil, the DOC concentration increased to 12-16 mg/L at downstream of Thule Creek (Block Bank) and upstream of junction of Thule Creek and Wakool River (Thule Creek Bridge at Barham Road). This shows that water released via Thule Creek can leach significant sources of carbon and nutrients and contribute to the instream productivity of Wakool River.


**Figure 5.7** Excessive algal growth was observed at Thule Creek during sample collection on 3rd and 9th November 2020.


**Figure 5.8** Black coloured water was observed at Thule Creek during sample collection on 17th, 23rd and 30th November 2020.

***Organic matter charcateristation - Absorbance***

The absorbance spectra for water samples collected from the Wakool-Yallakool system are shown in Figure 5.9. Absorbance scans indicate that throughout most of the 2020-21 water year the mixture of organic compounds making up the DOC was fairly consistent across sites with no clear upstream/downstream trends in variation between the scans. The amount and mixture of DOC at all sites in 2020-21 Southern Spring Flow watering action are higher than those in 2019-20 Southern Spring Flow watering action (scans are higher in both height and shape). In November 2020 during the 800 ML/day flow trial the upper Wakool River (Zone 2) more closely resembled the organic matter profile of the source water at Mulwala Canal and other sites were extremely similar to the organic matter profile of source water at Stevens Weir, although the differences were minimal. Absorbance scans in November 2020 also show the organic matter at all sites in 2020 800 ML/day flow trial was higher than it was in 2018 flow trial, particularly at middle Wakool River (Zone 4). The absorbance in upper Wakool River (Zone 2) in January 2021 was slightly steeper (more small organic molecules) than at other sites, otherwise study zones are similar in organic matter composition. By February 2021 absorbance has decrease and all sites are similar. In April 2021 there is a trend towards increasing organic matter absorbance at downstream sites while in May 2021 this trend is reversed. This covers the period of Autumn fresh at Yallakool Creek and may indicate a transfer of different organic carbon quality downstream.

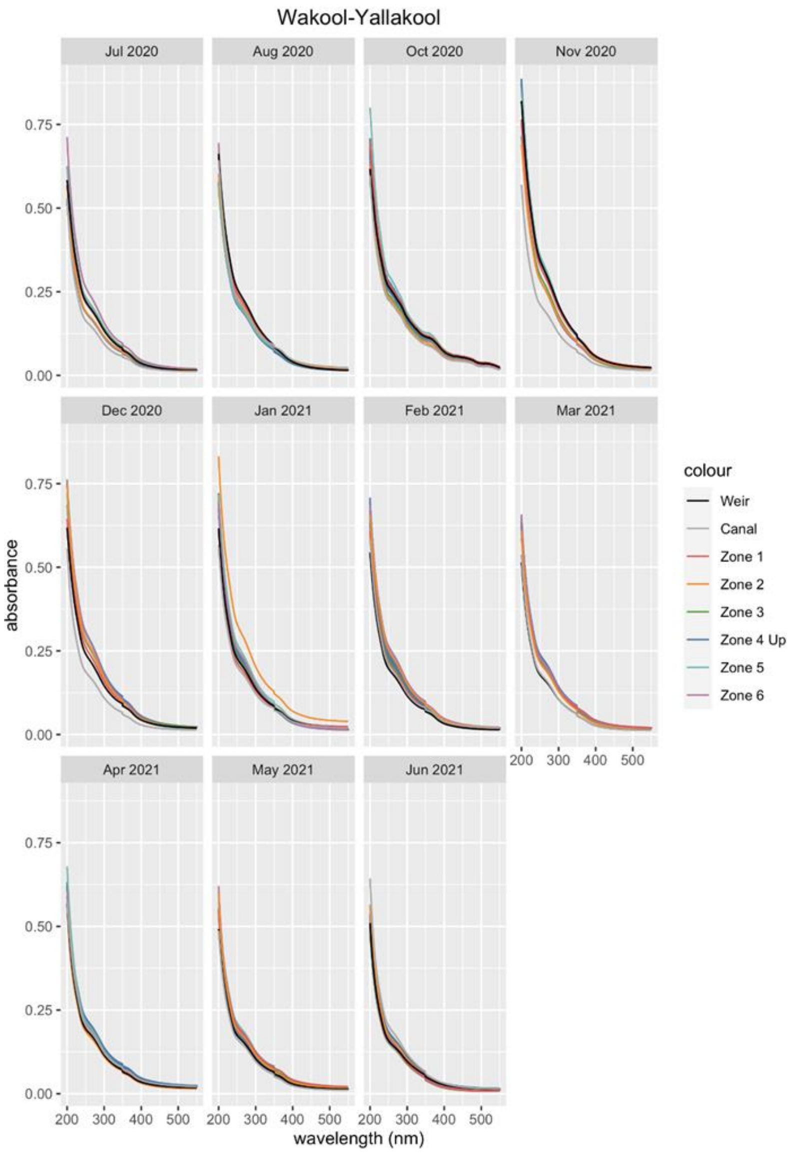



**Figure 5.9** Absorbance of water samples at the Wakool-Yallakool system in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

***Organic matter charcateristation - Fluorescence***

Fluorescence excitation-emission matrices for water samples at the Wakool-Yallakool system through the sampling period (Figure 5.10) indicate that the organic matter mix was similar across sites across most of the 2020-21 water year. In November 2020 higher fluorescence was observed at all sites with a gradual increase downstream, fluorescence of upper Wakool River (zone 2) was close to Mulwala Canal and other sites were similar to Stevens Weir, consistent with the absorbance results. Water from Stevens Weir to the Wakool-Yallakool system was showing more obvious increases in fluorescence in a mixture of humic and fulvic substances (bands of emissions around 450 nm), suggesting organic matter has a floodplain origin (fresh or possibly aged from wetlands). The results indicate the Southern Spring Flow watering action might introduce a pulse of organic matter into the system. In addition, the stronger fluorescence was detected in the mid reach of Wakool River (zones 3 and 4, Figure 3.2) supporting the conclusion that a pulse with stronger fluorescence transited through the system during the 800 ML/day flow trial where larger areas were wetted and additional carbon inputs from Thule Creek may be present. During this period hypoxia was not present in the Wakool River and the organic matter was likely to stimulate productivity.

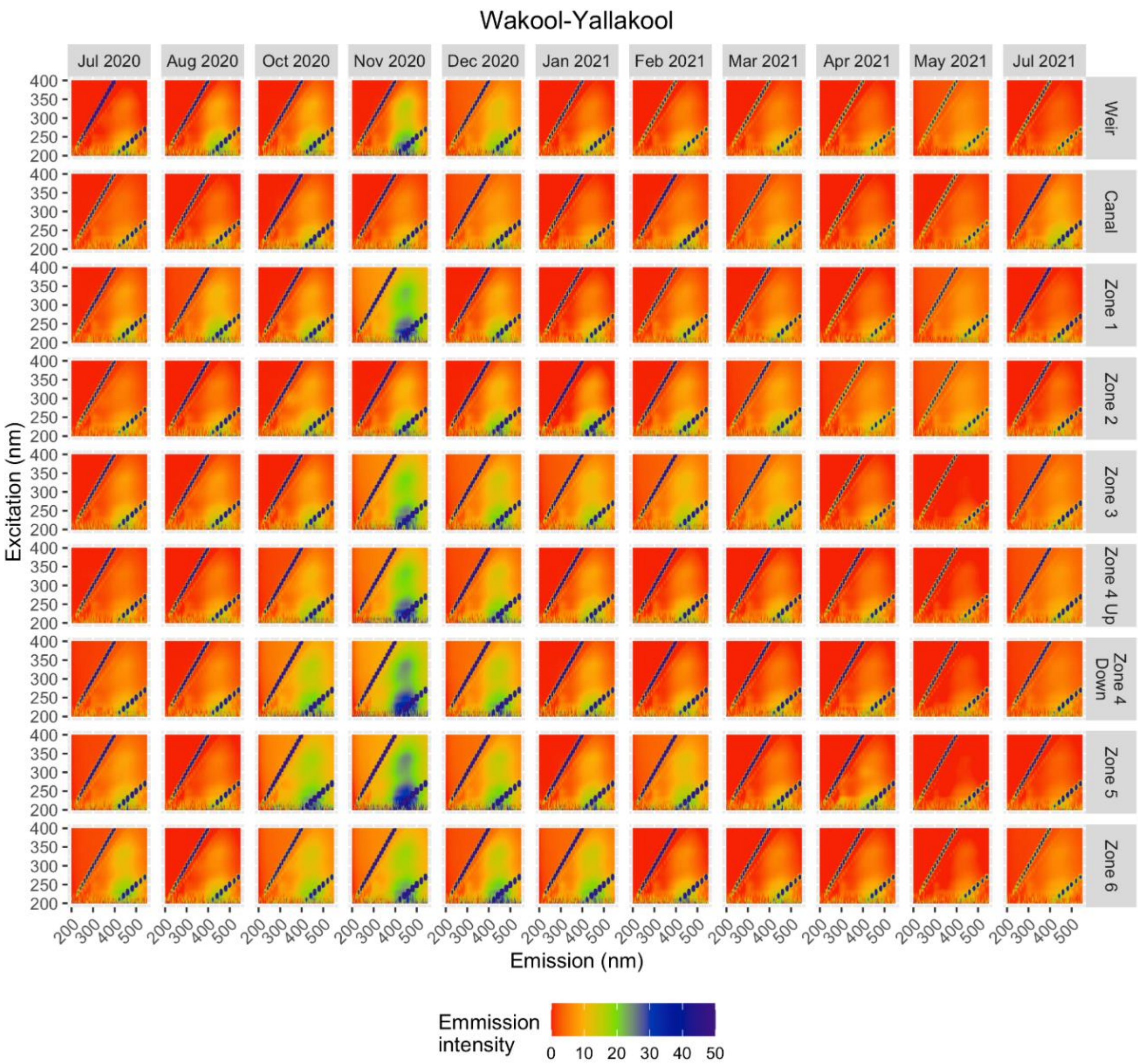



**Figure 5.10** Fluorescence scans of water samples from the Wakool-Yallakool system in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

The black coloured water and floating algae were observed in upper Wakool River (zone 2) in January 2021, broadly similar fluorescence is present as a number of broad peaks distributed across the region between the two blue scatter lines. This is suggestive of a mixture of humic and fulvic substances and smaller fluorescent molecules, possibly a combination of aged organic matter and very fresh leachates or algal organic matter. Middle and lower reaches of Wakool River have a similar distribution of peaks as upper Wakool River, this is consistent with slight increases in DOC concentrations over that period. Fluorescence generally decreased from late summer through to winter 2021.

Monitoring sites in the Edward/Kolety River, the Colligen-Niemur River and Tuppal Creek are expanded sites for Flow-MER Program 2019-22.

### *The Edward/Kolety River*

#### ***Water quality parameters***

Water temperature was similar at all sites in the Edward/Kolety River with water temperature exceeding 25 °C briefly during summer and staying below 10 °C for several weeks during winter. The results indicate that water temperature is influenced predominantly by seasonal rather than site-specific factors with all sites displaying the same seasonal variation and influence of weather patterns.

Concentrations of DO in the Edward/Kolety River were above the range of concern to fish populations (below 4 mg/L) over the study season (Table 5.4). It shows the expected seasonal variations with higher concentrations in the winter and lower concentrations correlating to the periods of higher water temperature. The difference in DO concentration between sites does not reflect water temperature differences and likely reflects differences in input of oxygenated water from upstream and different rates of re-aeration and oxygen consumption associated with flow.

EC, pH and turbidity remained stable (Table 5.4) and within the normal range for this system throughout the study period and were very similar to results from the 2019-20 sampling year. EC remained stable within the lower end of the range expected for lowland rivers indicating in ANZECC (2000). pH values were within the acceptable range (ANZECC, 2000) throughout the year. Turbidity measurements generally fluctuated above and below the ANZECC (2000) trigger level and values were very similar between sites.

In general, the range of DOC and nutrients concentrations in the Edward/Kolety River was slightly lower than the concentrations measured in the Wakool-Yallakool system in 2020-21 water year. Nutrients and DOC in most study sites of the Edward/Kolety River system were not elevated outside the normal range and were very similar to results from the 2019-20 sampling year. Downstream sites affected by water actions were later and experienced longer periods than upstream sites. TP and TN concentrations fluctuated above and below the ANZECC (2000) trigger values and values were very similar between sites. The bioavailable nutrient (FRP, $NO_x$ and ammonia) concentrations did not exceed trigger values, with the exception of ammonia on just one occasion at Liewah in June 2021 could possibly be due to ammonia introduced from the disturbance of the sediments while sampling.

**Table 5.4** Range (min-max) and mean values of water physico-chemical parameters for the Edward/Kolety River system in 2020-21 water year. ANZECC (2000) trigger levels for available water parameters are given and bolded. Loggers of temperature and DO data for selected sites are italicised.

| Parameters | Four posts | StevensWeir | Eastman Bridge | Balpool Road Bridge | Moulamein | Liewah |
|---|---|---|---|---|---|---|
| Temperature (°C) | 10.61-27.71 (18.62) | 10.61-29.3 (19.55) | 10.84-27.6 (18.65) | 10-25.89 (17.97) | 10.28-26.02 (18.2) | 10.49-26.46 (18.31) |
| pH **ANZECC 6.5-8** | 6.74-7.82 (7.32) | 6.82-7.74 (7.36) | 6.7-7.41 (7.15) | 6.54-7.23 (6.9) | 7.02-7.45 (7.23) | 6.93-7.61 (7.27) |
| DO (mg $L^{-1}$) | 8.64-13.22 (10.77) | 9.19-13.61 (11.1) | 8.64-13.9 (10.51) | 8.35-11.08 (9.79) | 8.71-12.02 (9.95) | 8.8-13.41 (10.26) |
| Turbidity (NTU) **ANZECC 50** | 22.1-64 (39.3) | 19.5-110 (41.9) | 26.8-126 (48.0) | 32.7-98.3 (66.2) | 34.5-103 (55.1) | 33.8-99.8 (56.1) |
| EC (mS $cm^{-1}$) **ANZECC 0.125** | 0.031-0.057 (0.048) | 0.032-0.064 (0.051) | 0.013-0.059 (0.047) | 0.028-0.059 (0.05) | 0.044-0.101 (0.072) | 0.048-0.105 (0.07) |
| Chl *a* (µg $L^{-1}$) **ANZECC 5** | 8.98-34.93 (15.64) | 7.98-24.29 (13.46) | 9.47-27.95 (13.76) | 10.3-25.12 (14.87) | 11.3-22.8 (16.13) | 10.64-25.78 (15.82) |
| TP (mg $L^{-1}$) **ANZECC 0.05** | 0.026-0.057 (0.041) | 0.026-0.043 (0.035) | 0.026-0.046 (0.036) | 0.029-0.051 (0.038) | 0.031-0.065 (0.046) | 0.033-0.059 (0.045) |
| FRP (mg $L^{-1}$) **ANZECC 0.02** | 0.005-0.007 (0.005) | 0.005-0.005 (0.005) | 0.005-0.005 (0.005) | 0.005-0.005 (0.005) | 0.005-0.005 (0.005) | 0.005-0.005 (0.005) |
| TN (mg $L^{-1}$) **ANZECC 0.5** | 0.31-0.69 (0.46) | 0.32-0.57 (0.43) | 0.33-0.68 (0.44) | 0.34-0.63 (0.43) | 0.37-0.73 (0.51) | 0.31-0.58 (0.47) |
| $NH_4^+$ (mg $L^{-1}$) **ANZECC 0.02** | 0.005-0.006 (0.005) | 0.005-0.006 (0.005) | 0.005-0.007 (0.005) | 0.005-0.006 (0.005) | 0.005-0.006 (0.005) | 0.005-0.025 (0.007) |
| $NO_x$ (mg $L^{-1}$) **ANZECC 0.04** | 0.002-0.004 (0.002) | 0.002-0.004 (0.002) | 0.002-0.003 (0.002) | 0.002-0.004 (0.003) | 0.002-0.004 (0.002) | 0.002-0.003 (0.002) |
| DOC (mg $L^{-1}$) | 3-9 (4.9) | 3.1-10.6 (5.6) | 2.9-9.6 (4.9) | 3.4-8.1 (5.0) | 3-9.9 (5.9) | 3.4-9.9 (5.1) |

***Water quality parameters at selected sites***

Concentrations of DO in the upper, middle and lower reaches of Edward/Kolety River show the expected seasonal variations (Figure 5.11). However, there was a discernible effect of the Southern Spring Flow watering action in the Edward/Kolety River system from mid-October through to late-December 2020 at Eastman Bridge (middle reach of Edward/Kolety River) with lower DO levels were detected in November 2020 through the watering action.

Chl *a* concentrations remained stable in the Edward/Kolety River system and values were lower during summer 2020-21 than observed in 2019-20, the lower Chl *a* value likely was associated with the timing of Southern Spring Flow watering action that occurred relatively postponed reflecting dilution as a consequence of flow events in hot months. The lower Chl *a* level along the Edward/Kolety River also might be related to slightly lower water temperatures over 2020-21 summer, that is, photosynthesis is not as active as when the water temperature is higher.

The change in DOC and nutrients concentrations was small and similar to the range observed in 2019-20 and the pulse of DOC and nutrients progressed downstream over time. A slightly increase in DOC and nutrients was detected in August 2020 at the Edward/Kolety River system possibly caused by the increased return flows from the Murray via the Millewa Forest to the system in late July 2020. Elevated DOC and nutrients in the Edward/Kolety River system in October and November 2020 indicate greater carbon inputs associated with the Spring Flow watering action, corresponding with the lower DO concentrations observed in middle Edward/Kolety River. These may be sourced from organic material in channel or from return flows from newly wetted forests, wetlands, and anabranches.

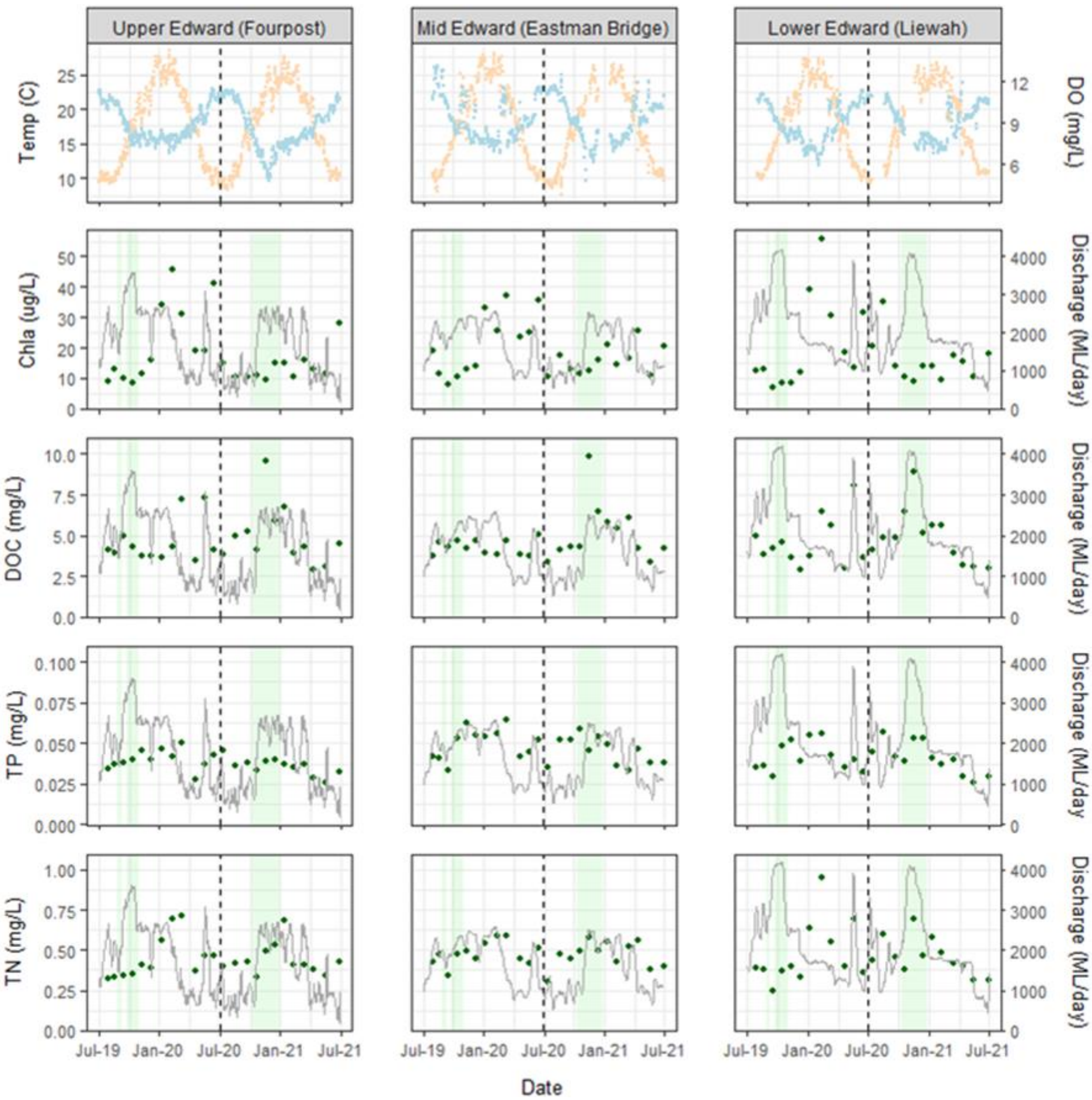



**Figure 5.11** Water temperature, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for the selected sites over the 2020-21 watering year in the Edward/Kolety River system. Green shaded vertical bars indicate watering actions.

Both TN and TP were increased in October and November 2020 corresponding with Southern Spring Flow with higher discharges which might have been associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column). The impact of the Southern Spring Flow watering action 2020-21 on the Edward/Kolety River system was slight and it is unlikely to be ecologically significant due to the change in DOC and nutrients concentrations was very small.

### *Organic matter charcateristation - Absorbance*

Absorbance scans (Figure 5.12) indicate that throughout the 2020-21 water year the mixture of organic compounds making up the DOC was fairly consistent across sites with no clear upstream/downstream trends in variation between the scans in the Edward/Kolety River. Both the amount and mixture of DOC at all sites during 2020-21 Southern Spring Flow watering action are a bit more obvious than those in 2019-20. There is a slight increase in the absorbance in August 2020 which is consistent with a small pulse of DOC detected as the increased return flows from the Murray via the Millewa Forest to the system occurred. This probably suggest different organic carbon quality was transferred to the Edward/Kolety River system. In October and November 2020 there is an obvious trend towards increasing organic matter absorbance at all sites. This covers the period of the Southern Spring Flow watering action in the Murray River pulse and may indicate an introduction of different organic carbon quality downstream. As shown in December 2020 the pulse of DOC progressed downstream over time. By January 2021 the absorbance spectra for all sites were very similar and through the later summer to winter 2021 the sites remain similar, with slightly higher absorbance at the most downstream sampling site.

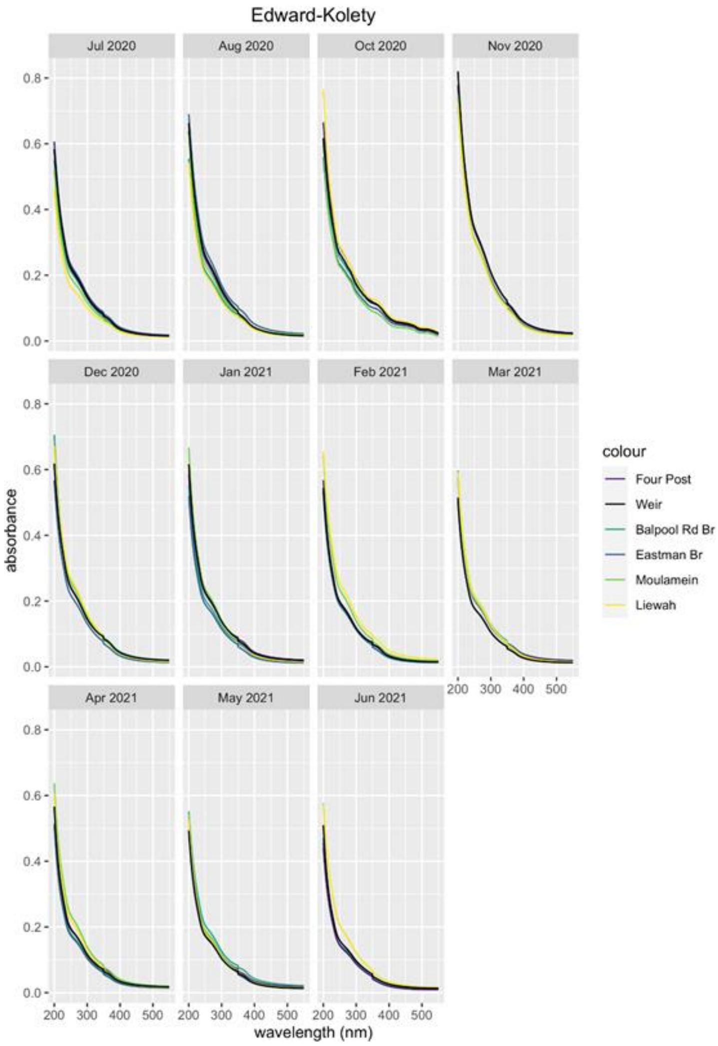



**Figure 5.12** Absorbance of water samples at the Edward/Kolety River system in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

### *Organic matter charcateristation - Fluorescence*

Fluorescence excitation-emission matrices for water samples at the Edward/Kolety River system through the 2020-21 water year are shown in Figure 5.13. In November 2020 an obviously higher fluorescence was observed at all sites which was progressed downstream over time, consistent with the absorbance results. Broadly similar fluorescence is present at all sites of Edward/Koley River showing a number of broad peaks distributed across the region between the two blue scatter lines. This is suggestive of a mixture of humic and fulvic substances and smaller fluorescent molecules, possibly a combination of aged organic matter and very fresh leachates or algal organic matter introduced by Southern Spring Flow watering action. Fluorescence generally decreased from late summer through to winter 2021 consistent with decreases in DOC and Chl *a*. The Southern Spring Flow watering action commenced relatively postponed in 2020-21 water year than occurred in 2019-20, the algal carbon was not present in the system in 2020-21 water year reflecting dilution as a consequence of flow events in hot months.

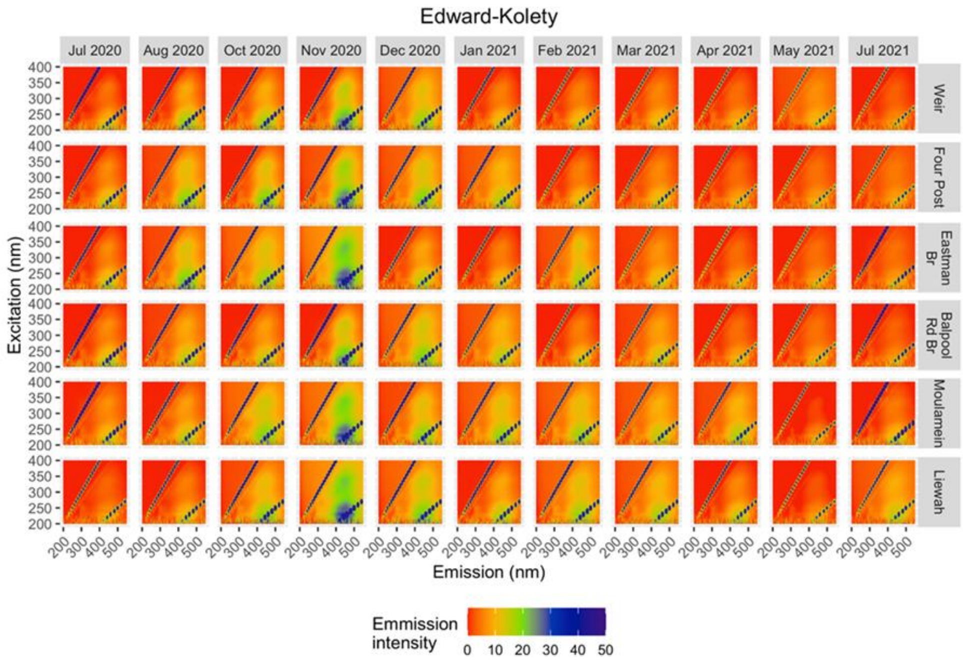



**Figure 5.13** Fluorescence scans of water samples from the Edward/Kolety River system in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

## The Colligen-Niemur system

### *Water quality parameters*

Water temperature in the Colligen-Niemur system exceeded 25 °C briefly during summer and staying below 10 °C for a couple of weeks during winter. The results indicate that water temperature was influenced predominantly by seasonal with all sites displaying the same seasonal variation and influence of weather patterns.

Concentrations of DO in Colligen-Niemur were above the range of concern to fish populations (below 4 mg/L) over the entire study season (Table 5.5) but were lower than the DO levels in the Edward/Kolety River system (Tble 5.4). Water temperature was lower and DO concentration was higher in 2020-21 summer/autumn than was observed in 2019-20 probably due to watering actions 5, 6 and 7 operated in the system over that period with stable and more discharges.

EC, pH and turbidity collected from the Colligen-Niemur system (see Table 5.5) were similar to the values of Edward/Kolety River remaining within the normal range for this system throughout the study period of 2020-21 and were similar to results from the 2019-20 sampling year. EC remained stable within the lower end of the range expected for lowland rivers and pH values were within the ANZECC (2000) trigger range. Turbidity measurements were slightly fluctuated above and below the ANZECC (2000) trigger level and values were very similar between sites with increasing turbidity in downstream sites.

Chl *a* level remained stable in the Colligen-Niemur system and was generally lower in 2020-21 summer than it was observed in 2019-20 which was likely associated with the increased flow during watering actions 5, 6 and 7. The range of DOC and nutrients concentrations in the Colligen-Niemur system was slightly higher than the concentrations measured in the Edward/Kolety River system in 2020-21 water year remaining in the acceptable range. Both TN and TP were increased corresponding with higher discharges of watering actions which might have been associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column). The bioavailable nutrient concentrations remained stable and did not exceed trigger values.

**Table 5.5** Range (min-max) and mean values of water physico-chemical parameters for the Colligen-Niemur system in 2020-21 water year. ANZECC (2000) trigger levels for available water parameters are given and bolded.

| Parameters | Stevens weir | Colligen Creek | Niemur River<br>Barham Road (up) | Niemur River Mallan School (down) |
|---|---|---|---|---|
| Temperature (°C) | 10.61-29.3 (19.55) | 10.48-27.9 (18.44) | 10.74-27.68 (19.3) | 9.47-27.4 (18.56) |
| pH<br>**ANZECC 6.5-8** | 6.82-7.74 (7.36) | 6.59-7.3 (6.9) | 6.97-7.39 (7.21) | 7.01-7.48 (7.2) |
| DO (mg $L^{-1}$) | 9.19-13.61 (11.1) | 8.86-11.67 (10.03) | 8.92-11.49 (10.44) | 7.66-11.8 (10) |
| Turbidity (NTU)<br>**ANZECC 50** | 19.5-110 (41.9) | 36.2-138 (68.6) | 28.6-65.1 (46.3) | 39.5-96 (71.4) |
| EC (mS $cm^{-1}$)<br>**ANZECC 0.125** | 0.032-0.064 (0.051) | 0.029-0.06 (0.05) | 0.03-0.064 (0.051) | 0.03-0.071 (0.055) |
| Chl *a* (µg $L^{-1}$)<br>**ANZECC 5** | 7.98-24.29 (13.46) | 7.81-38.42 (13.83) | 9.64-30.93 (16.21) | 11.13-33.44 (17.49) |
| TP (mg $L^{-1}$)<br>**ANZECC 0.05** | 0.026-0.043 (0.035) | 0.026-0.056 (0.04) | 0.03-0.062 (0.044) | 0.042-0.079 (0.058) |
| FRP (mg $L^{-1}$)<br>**ANZECC 0.02** | 0.005-0.005 (0.005) | 0.005-0.006 (0.005) | 0.005-0.006 (0.005) | 0.005-0.006 (0.005) |
| TN (mg $L^{-1}$)<br>**ANZECC 0.5** | 0.32-0.57 (0.43) | 0.35-0.85 (0.51) | 0.34-0.8 (0.52) | 0.41-1.1 (0.66) |
| $NH_4^+$ (mg $L^{-1}$)<br>**ANZECC 0.02** | 0.005-0.006 (0.005) | 0.005-0.007 (0.005) | 0.005-0.006 (0.005) | 0.005-0.009 (0.006) |
| $NO_x$ (mg $L^{-1}$)<br>**ANZECC 0.04** | 0.002-0.004 (0.002) | 0.002-0.032 (0.005) | 0.002-0.003 (0.002) | 0.002-0.007 (0.003) |
| DOC (mg $L^{-1}$) | 3.1-10.6 (5.6) | 3.15-10.7 (6.0) | 3.25-7.6 (5.48) | 3.8-12.9 (6.94) |

***Water quality parameters at selected sites***

Water temperature was lower and DO level was higher at sampling sites in the Colligen-Niemur system in 2020-21 summer than it was observed in 2019-20 sampling year which might be associated with watering actions 5, 6 and 7 operated during that time (Figure 5.14).

Increases in Chl *a* level at sampling sites in the Colligen-Niemur system since December 2020, suggesting increases in photosynthesis which is quite common during the summer months with high water temperatures and light levels. However Chl *a* level was much lower in 2020-21 summer than it was observed in 2019-20, particularly at lower reach of Niemur River, which was likely associated with the increased discharge during watering actions in hot months reflecting dilution as a consequence of flow events. The lower Chl a level along the Colligen-Niemur system also might be related to slightly lower water temperatures over 2020-21 summer, that is, photosynthesis could not be as active as when the water temperature is higher.

Elevated DOC in October and November 2020 in the Colligen-Niemur system indicates carbon inputs associated with the Southern Spring Flow watering action (action 1). A slightly bigger pulse of DOC also occurred in December 2020 indicates greater carbon inputs associated with the watering action 6 where larger low-lying areas might be wetted. There were generally higher concentrations in downstream site (lower reach of Niemur River) than upstream site (Colligen Creek) suggesting slight increases in DOC and nutrients as the water progresses through the system. Concentration of DOC and nutrients at lower reach of Niemur River (Niemur Mallan School) did not keep increasing during summer period as it was in 2019-20 probably resulted from receiving more amount of discharge during hot months.

Overall, the change in DOC and nutrients concentrations in the Colligen-Niemur system in 2020-21 was small and similar to the range observed in 2019-20 and the pulse of DOC and nutrients progressed downstream over time. The impact of 2020-21 watering actions on the Colligen-Niemur system was small and it is unlikely to be ecologically significant due to the change in DOC and nutrients concentrations was too insignificant.

***Organic matter characterisation - Absorbance***

Absorbance scans (Figure 5.15) indicate that throughout most of the 2019-20 water year the mixture of organic compounds making up the DOC was fairly consistent across sites with no clear upstream/downstream trends in variation between the scans in the Colligen-Niemur River system. Both the amount and mixture of DOC at all sites in 2020-21 water year are quite similar to those in 2019-20 (scans are similar in both height and shape). In November and December 2020 there is an obvious trend towards increasing organic matter absorbance at sampling sites in the system. This covers the periods of the Southern Spring Flow watering action in the Murray River and elevated base flow in the Colligen-Niemur system indicating different organic carbon quality might be introduced into the system from Edward/Kolety River (source water). As shown in January 2021 downstream sites experienced longer periods of DOC pulse than upstream sites. By February 2021 the absorbance spectra for all sites were very similar and through the later summer to winter 2021 the sites remain similar, with slightly higher absorbance at the most downstream sampling site. In

April 2021 there is a slight increase in absorbance in lower Niemur River but the pattern between sites is maintained.

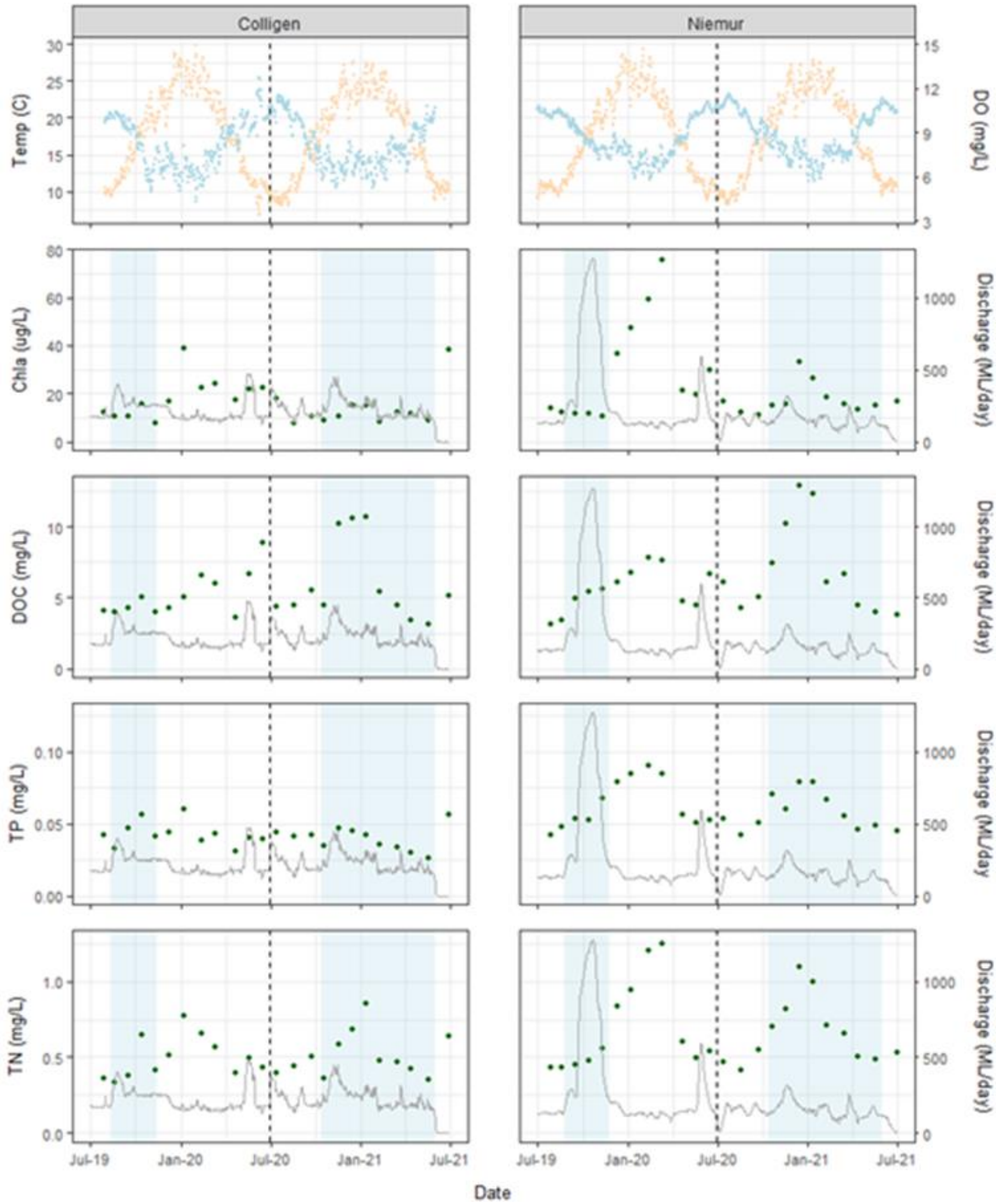



**Figure 5.14** Water temperature, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for the selected sites over the 2020-21 watering year in the Colligen-Niemur system. Blue shaded vertical bars indicate watering actions.

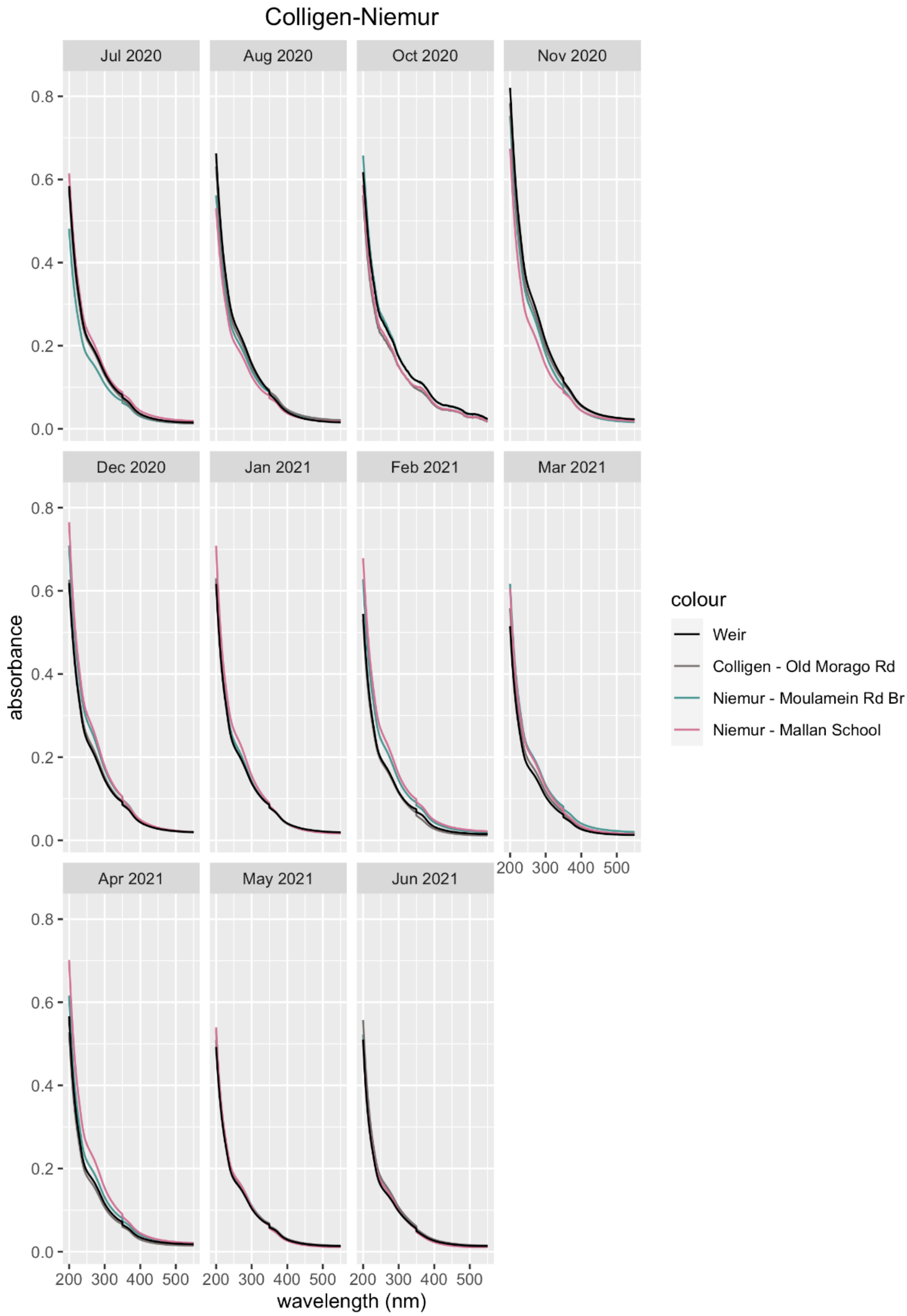



**Figure 5.15** Absorbance of water samples at the Colligen-Niemur River system in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

### *Organic matter charcateristation - Fluorescence*

Fluorescence excitation-emission matrices at all sites through the sampling period (Figure 5.16) indicate that the organic matter mixture was similar across sites at the Colligen-Niemur River system in the 2020-21 water year. In November and December 2020 an obvious fluorescence was observed at all sites progressed downstream over time with a very gradual increase at downstream sites, consistent with the absorbance results. Similar fluorescence is present at all sites of the Colligen-Niemur River during that period showing a number of broad peaks distributed across the region between the two blue scatter lines clearly has a stronger humic and fulvic signature. This is indicative that the humic and fulvic component of dissolved organic matter might be terrestrially derived on lowland rivers by Southern Spring Flow watering action. Fluorescence generally decreased from late summer through to winter 2021 consistent with decreases in DOC and Chl *a*. The algal carbon did not occur in 2020-21 water year at the Colligen-Niemur system might be associated with the watering actions 5, 6 and 7 implemented between middle of October 2020 and the end of May 2021 reflecting dilution as a consequence of flow events in hot months.

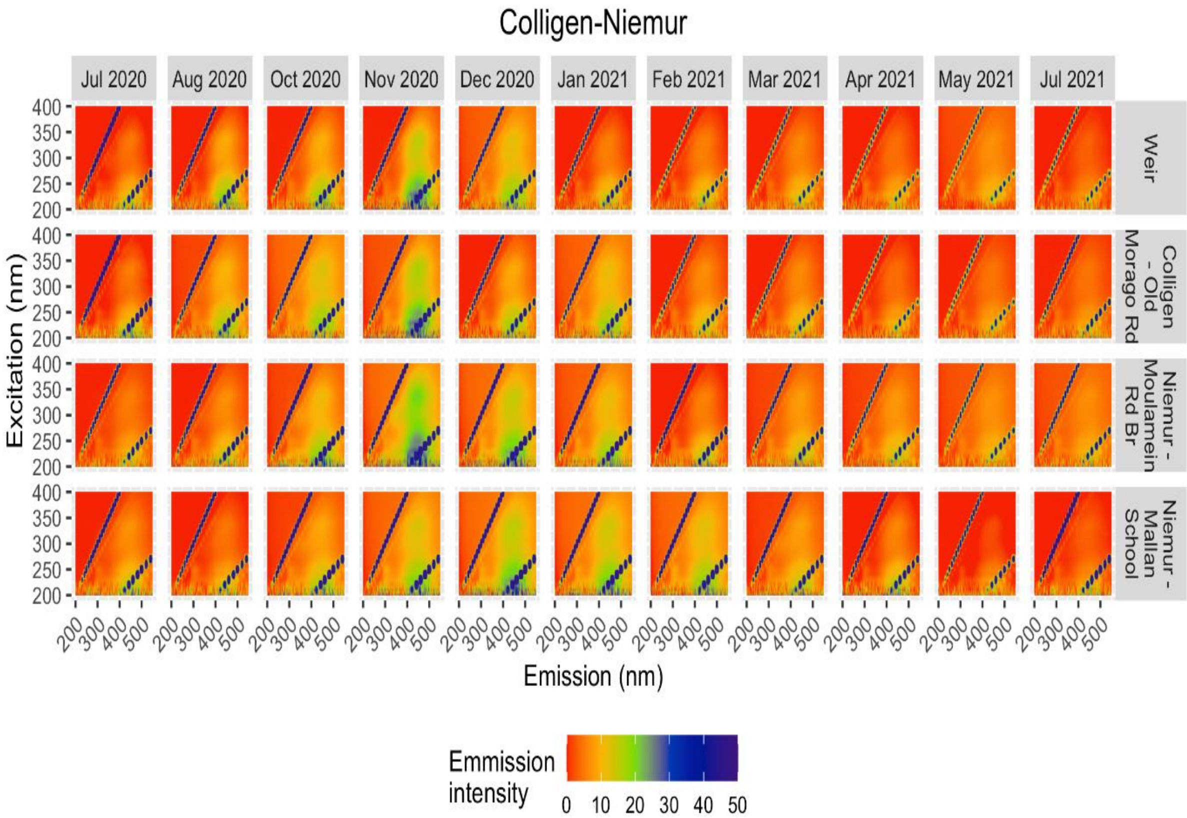



**Figure 5.16** Fluorescence scans of water samples from the Colligen-Niemur River system in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

### *Tuppal Creek*

#### *Water quality parameters*

During the 2020-21 water year there were several interruptions to flows due to constraints works in the channel. Flows were limited to low flows due to third party constraints.

The water temperature in Tuppal Creek exceeded 25 °C briefly during summer and staying below 10 °C for a couple of months during winter. The results indicate that water temperature was influenced predominantly by seasonal with all sites displaying the same seasonal variation and influence of weather patterns.

Most spot readings in Tuppal Creek remained within the acceptable range (see Table 5.6) throughout the study period of 2020-21 and were very similar to the 2019-20 sampling year. EC remained stable within the lower end of the range expected for lowland rivers indicating in ANZECC (2000). Turbidity measurements fluctuated above and below the ANZECC (2000) trigger level. Most pH values were within the acceptable range throughout the year.

**Table 5.6** Range (min-max) and mean values of water physico-chemical parameters for Tuppal Creek in 2020-21 water year. ANZECC (2000) trigger levels for available water parameters are given and bolded.

| | Temp °C | pH | DO mg $L^{-1}$ | Turbidity NTU | EC mS $cm^{-1}$ | Chl *a* µg $L^{-1}$ | TP mg $L^{-1}$ | FRP mg $L^{-1}$ | TN mg $L^{-1}$ | $NH_4^+$ mg $L^{-1}$ | $NO_x$ mg $L^{-1}$ | DOC mg $L^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **6.5-8** | | **50** | **0.125** | **5** | **0.05** | **0.02** | **0.5** | **0.02** | **0.04** | |
| Tuppal Creek | 9.3-25.5 (16.5) | 9.0-6.7 (6.4) | 3.52-7.26 (5.75) | 35.5-176 (86) | 0.052-0.163 (0.085) | 18.77-35.61 (29.45) | 0.085-0.115 (0.1) | 0.005-0.008 (0.006) | 0.77-1.15 (0.92) | 0.005-0.028 (0.009) | 0.002-0.04 (0.003) | 6.3-14.7 (9.1) |

Tuppal Creek received smaller magnitude of discharge in 2020-21 than it had in 2019-20 (Figure 5.17) due to the third-party constraints. Concentrations of DO in the Tuppal Creek dropped into the range of concern to fish populations (below 4 mg/L) between January and February 2021 and in early March 2021 and briefly dropped into the range of lethal to fish populations (below 2 mg/L) in mid-December 2020 and late-January 2021, this corresponds with dark coloured water was observed in the system. During the period of low base flows DO in Tuppal Creek remained low.

Chl *a* level remained stable in Tuppal Creek over 2020-21 sampling year which might be associated with several small and steady water pulses occurred in the channel. The stable Chl *a* level in Tuppal Creek also might be related to slightly lower water temperatures over 2020-21 summer, that is, photosynthesis could not be as active as when the water temperature is higher.

Elevated nutrients and DOC in Tuppal Creek detected in November 2020 suggest there may be local sources of nutrients and DOC at times during this study period, possibly due to water that was in backwaters or on low lying benches started to flow down the system. High DOC was measured in December 2020 which corresponds with dark coloured water was observed and DO level remained quite low in the system, probably due to Tuppal Creek received very low base flows at that time.

Both TN and TP were increased in Tuppal Creek during several low and steady water pulses, which might have been associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column). Similar as 2019-20, TP and TN concentrations consistently exceeded the ANZECC (2000) trigger values of 0.05 mg/L and 0.5 mg/L respectively. The FRP and $NO_x$ remained below the trigger levels (ANZECC, 2000). One outlier ammonia value in the Tuppal Creek system occurred on one occasion in June 2021 could possibly be due to ammonia introduced from a disturbance upstream or disturbance of the sediments while sampling.

The nutrients and DOC concentrations in Tuppal Creek was generally higher than the concentrations recorded in the Edward/Kolety-Wakool system in 2020-21 water year. Tuppal Creek is an ephemeral creek and received low base flows interspersed by a few larger pulsed flows that can be the source of carbon and nutrients to the Edward/Kolety-Wakool River system if it's connected to the main river channel.

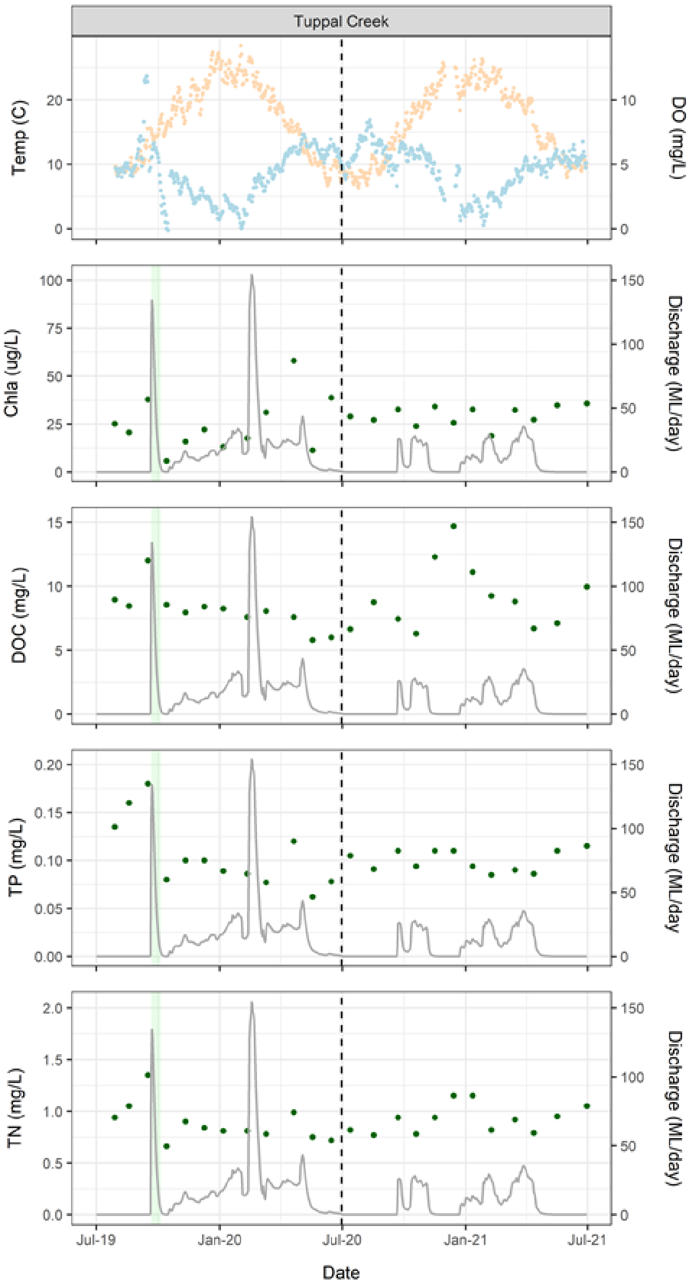



**Figure 5.17** Water temperature, dissolved oxygen (DO), chlorophyll a (Chl a), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for the selected sites over the 2020-21 watering year in Tuppal Creek. Green shaded vertical bars indicate watering actions.

### *Organic matter characterisation - Absorbance*

Absorbance scans (Figure 5.18) indicate that the mixture of organic compounds making up the DOC was consistent in Tuppal Creek throughout most of the 2020-21 water year. The height of absorbance scans in 2020-21 is similar to the range in 2019-20. In October 2020 and summer months in 2020/21, there is a slight increase in absorbance, but the pattern is maintained.

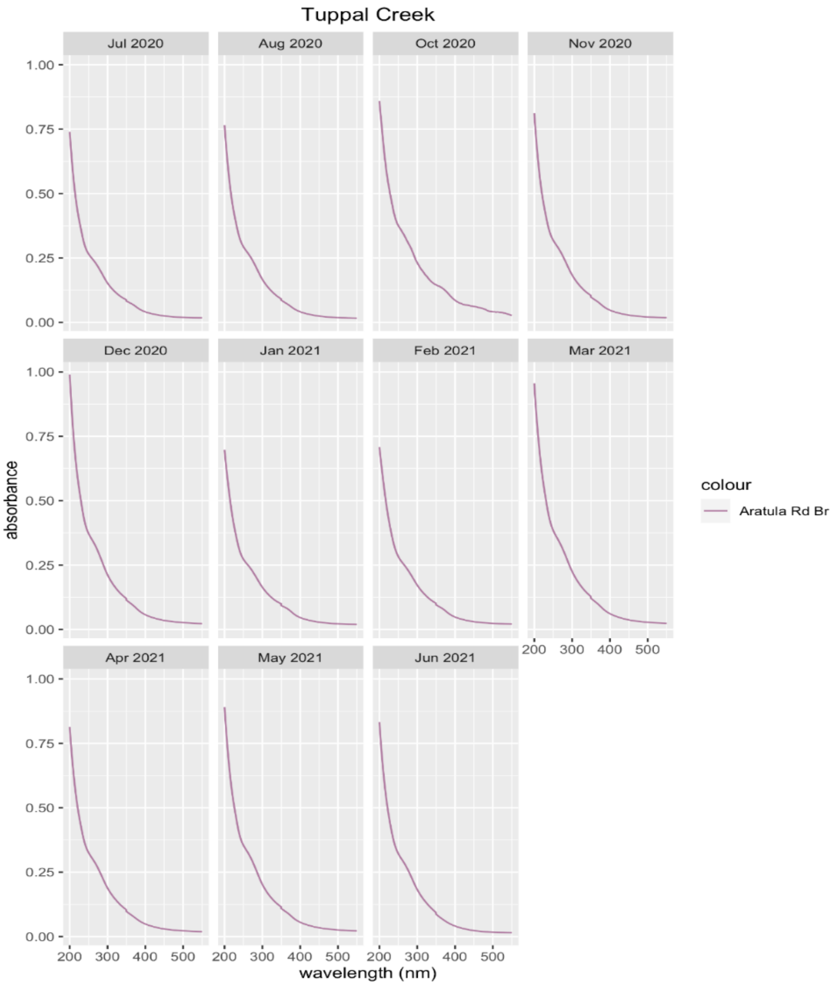



**Figure 5.18** Absorbance of water samples at Tuppal Creek in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

### *Organic matter charcateristation - Fluorescence*

At Tuppal Creek fluorescence excitation-emission matrices for water samples through the sampling period (Figure 5.19) indicate that the organic matter mix was similar at the system with stronger humic and fulvic signatures. In October 2020 and hot months in 2020/21, stronger humic and fulvic signature was identified which is consistent with observed bad water quality and an increase in DOC concentration in Tuppal Creek. It is possibly a combination of aged organic matter and very fresh leachates or algal organic matter which is consistent with receiving very low base flows during that period.

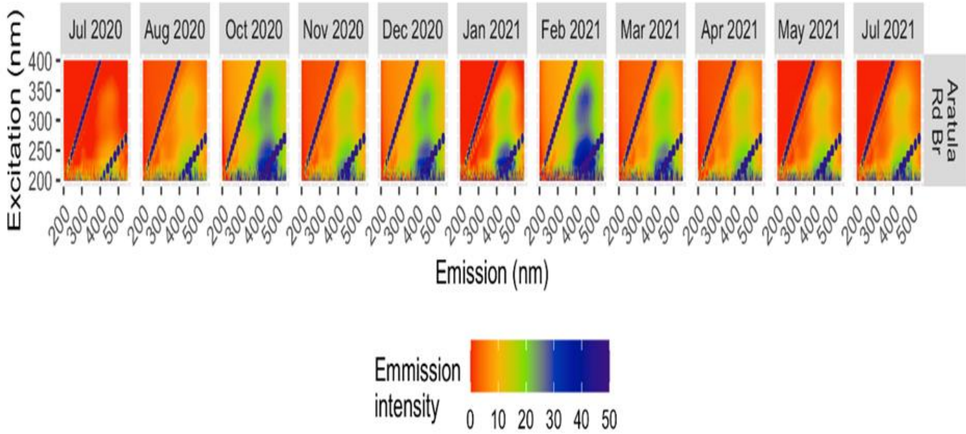



**Figure 5.19** Fluorescence scans of water samples from Tuppal Creek in 2020-21. The water samples for the assessment of organic matter inputs were collected from July 2020 to June 2021 and the data are not available for September 2020 due to instrument failure.

## 5.6 Discussion

### *Short and long-term evaluation questions for core monitoring*

Overall the water quality in the Edward/Kolety-Wakool Selected Area during the 2020-21 water year was characterised by normal conditions (similar to 2019-20). In 2020-21 the key questions relating to the CEW actions were as follows:

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

For Wakool-Yallakool system, Yallakool Creek and middle and lower reaches of Wakool River normally received more environmental water than upper reach of Wakool River in previous years. In 2020-21 water year, the first Commonwealth environmental watering action (referred to as a Spring fresh watering action 1) commenced in mid-October 2020 in Yallakool Creek and progressed down the Wakool River (middle and lower reaches of Wakool River) until the end of November 2020 to support the recovery of the river system following the low-oxygen event in 2016 and to contribute to connectivity and water quality and to maintain dissolved oxygen concentrations in the system. Although Commonwealth environmental watering actions 2, 3 and 4 commenced in Yallakool Creek from the end of November 2020 to early of May 2021 did not aim to contribute to water quality, these environmental watering actions assisted in the maintenance of dissolved oxygen concentrations over the summer period in Yallakool Creek and middle and lower reaches of Wakool River receiving the additional flows.

It is common for dissolved oxygen to be lower in the upper reach of Wakool River than other sites in the system during hot months when discharge is much lower in the reach and the risk of temperature induced hypoxia during heatwaves is greater in this part of the system. The difference in DO between the upper Wakool and the other sites within the Wakool-Yallakool system was less in 2018-19 water year than was commonly observed in other years and the period where DO was close to 4 mg/L was shorter, likely due to the higher than usual flow conditions in the upper Wakoo (Watts et al., 2019). While Commonwealth environmental water was not the source of the additional flow in the 2018-19 summer, the higher discharge demonstrated that there is potential to use environmental water to improve water quality in this part of the system in the future.

In 2020-21 water year, black colored water was observed with low dissolved oxygen level measured in the upper reach of Wakool River in January 2021, adaptive management has been implemented to improve water quality and maintain dissolved oxygen concentrations. Commonwealth environmental water (referred to as variable base flows watering action 8) commenced from January to June 2021 in upper Wakool River resulted in higher discharge than other years in this part of the system. The variable base flows made dark coloured water diluted and minimised the period where dissolved oxygen concentration falling below 4 mg/L (concern to fish populations) and prevented dissolved oxygen concentration falling below 2 mg/L (sublethal to fish populations). The upper Wakool watering action in summer/autumn 2021 demonstrates that using Commonwealth environmental water (more variable flows) in upper Wakool with extremely low flow in hot months could provide a proactive, longer term approach to improve water quality (preventing potential hypoxic water events), and enable a comparison to previous monitoring data to determine if a longer, higher flow rate is better at maintaining fish, plants, invertebrates and aquatic species, and improve our ability to provide longitudinal connectivity, flow variability and potential refuge.

- *What did Commonwealth environmental water contribute to nutrient concentrations?*

Nutrient concentrations remained within the expected range throughout the Edward/Kolety-Wakool River system during the 2020-21 water year. The absence of overbank flows meant that substantial nutrient inputs were not expected in the system, although a general downstream increase in TN and TP were observed in sampling sites which received the majority of flow. TP and TN were slightly elevated over Commonwealth environmental watering actions at Yallakool Creek and middle and lower reaches of Wakool River, possibly caused by higher turbidity and in-stream processes during the watering actions.

It is noted that a higher concentration of nutrients was detected at middle and lower reaches of Wakool River in November 2020 through the Southern Spring Flow watering action from Murray River (referred to as environmental watering action 1). The contribution of nutrients to middle and lower reaches of Wakool River might not only be associated with the pulse introduced by Southern Spring Flow watering action. They might also be related to the water flushed from Thule Creek channel introducing an addition of nutrients to its downstream of Wakool River. In general, TN and TP were higher in the upper reach of Wakool River receiving minor to no amount environmental water. However nutrient concentrations at upper Wakool were decreased during the upper Wakool watering action 8 in summer/autumn 2021, suggesting dilution of these nutrients by Commonwealth environmental water at the study site. Bioavailable nutrient remained low and were similar across study sites and do not appear to have been influenced by Commonwealth environmental water.

Chl *a* content is closely associated with nutrient concentrations and acts as an indicator of trophic status in freshwater systems. Chl *a* levels fluctuate naturally over time and higher concentrations are common during the summer months when water temperature and light level are higher. Chl *a* values generally were in the Wakool-Yallakool system in summer 2020-21 than observed in summer 2019-20, the lower Chl *a* value likely was associated with the different Commonwealth environmental watering actions occurred at hot months reflecting dilution as a consequence of flow events. Overall, the changes in nutrient concentrations in 2020-21 water year did not result in any adverse water quality outcomes in the Wakool-Yallakool system.

- *What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnect in-channel habitat?*

There was no detectable effect of Commonwealth environmental watering actions on this indicator in 2020-21 water year. Poor water quality was observed in the upper reach of Wakool River in January 2021, corresponding with a slight increase in DOC concentration but these remained within the normal range. It is common for DOC concentration to be higher during summer and early autumn in upper reach of Wakool River receiving minor to no amount of environmental water. As shown in Watts et al. (2019), the DOC concentration in upper reach of Wakool River was lower than other sites in the system in February 2019, likely due to the higher discharge in this reach than in other years suggesting that there is potential to use Commonwealth environmental water to improve water quality in this part of the system in the future. In 2020-21 water year, Commonwealth environmental water (referred to as variable base flows watering action 8) commenced from January to June 2021 in upper Wakool River resulted in higher discharge than other years in this part of the system. The variable base flows made dark coloured water diluted and DOC concentration decreased. The result demonstrates that using Commonwealth environmental water (the higher than usual flow conditions) could improve water quality and prevent potential hypoxic water events in this part of the system.

Hypoxic blackwater event occurs when large quantities of organic matter dissolve into water resulting in a dark tea color in the water. This dissolved organic material in the water is then consumed by microbes which can rapidly multiply and consume a lot of oxygen, leading to a sudden depletion of dissolved oxygen in the water. The severity of hypoxic blackwater events is determined by the amount, age and type of organic matter in the path of the flow and whether it has been previously submerged in water. The impact of hypoxic blackwater event on the river is also affected by temperature (Howitt et al., 2007). When the weather is hot there is naturally less oxygen in the water and the consumption of carbon occurs more quickly, so hypoxia is more likely to occur and is more likely to result in fish kills. In cooler weather organic carbon can stimulate productivity in the food chain but the dissolved oxygen is not consumed so quickly that the water becomes hypoxic.

Large quantities of organic matter and nutrients were introduced to the Edward/Kolety-Wakool system during the 2016-17 flooding year accompanying hypoxic blackwater event (Watts et al., 2017). The larger peak combined warmer water temperatures with high concentrations of DOC and this caused very high rates of microbial respiration and oxygen consumption from the water column. Organic matter characterisation showed a series of changes in organic matter mix over the course of the flooding as sources of carbon changed and material was subject to in-stream processing.

It is noted that a higher concentration of DOC was detected at middle and lower reaches of Wakool River in November 2020 through the 2020 800 ML/day flow trial coordinated with wider Murray River actions (Southern Spring Flow watering action) and DOC concentration at middle Wakool River was outside the normal range observed in the system which almost reached the similar level during 2016-17 flooding year. The contribution of DOC to middle and lower reaches of Wakool River might not only be associated with the carbon pulse introduced by the 2020 800 ML/day flow trial, also might be related to the water flushed from Thule Creek channel introducing an addition of carbon to its downstream of Wakool River. Although DOC concentrations at middle Wakool River in November 2020 were similar to that in 2016-17 flooding year, the organic matter profiles at all sites were having weaker and less intense humic and fulvic signals than was observed in 2016-17, no aromatic protein type organic matter was detected. During 2020-21 water year hypoxia was not present in the Wakool River, probably due to the wetted area that was previously inundated and/or water temperature was cooler.

The changes in DOC concentrations in 2020-21 water year did not result in any adverse water quality outcomes in the Wakool-Yallakool system. Small pulses of DOC to the Wakool-Yallakool system could support microbial productivity which become available as food for aquatic organisms such as fish.

### *Broader system monitoring*

Water quality monitoring across the broader Edward/Kolety-Wakool system in 2020-21 water year expanded the monitoring further downstream in the Wakool River and to Tuppal Creek, the Edward/Kolety River, and the Colligen-Niemur River system to better capture the impact of environmental water in the broader system. In general, the impact of watering actions in 2020-21 water year on the Edward/Kolety-Wakool River system was slight and the change in DOC and nutrients concentrations was small.

Concentrations of DO in the Edward/Kolety River system and the Colligen-Niemur River system were above the range of concern to fish populations (below 4 mg/L) over the study season in 2020-21. It shows the expected seasonal variations with higher concentrations in the winter and lower concentrations correlating to the periods of higher water temperature. For Colligen-Niemur system, Commonwealth environmental watering actions 2020-21 operated in the system assisted in the maintenance of dissolved oxygen concentrations over the summer period in the system receiving the additional flows, particularly in the lower reach of Niemur River, despite that the objectives of most of those watering actions were not to maintain of dissolved oxygen concentration.

Chl *a* concentrations remained stable in the Edward/Kolety River system and values were lower during summer 2020-21 than observed in 2019-20, the lower Chl *a* value likely was associated with the timing of Southern Spring Flow watering action that occurred relatively postponed reflecting dilution as a consequence of flow events in hot months. Commonwealth environmental watering actions operated in the Colligen-Niemur system also assisted in the maintenance of stable Chl *a* level over the summer period in the system receiving the additional flows. The lower Chl *a* level along the Edward/Kolety River and the Colligen-Niemur system also might be related to slightly lower water temperatures over summer 2020-21, that is, photosynthesis is not as active as when the water temperature is higher.

In 2020-21 water year the range of DOC concentrations in the Edward/Kolety River system and Colligen-Niemur system was quite similar remaining in the acceptable range. A slight increase in DOC concentrations during the periods of environmental watering actions might be local sources of DOC, possibly due to larger areas were wetted or commence to flow conditions where water that was in backwaters or on low lying benches started to drain back into the river system.

The nutrients and DOC concentrations in Tuppal Creek was slightly higher in 2020-21 water year remaining in the acceptable range which is consistent with receiving very low base flows during that period. However, DO dropped below critical levels for a period over summer, as there were several interruptons to flows in 2020-21 due to constraints work being undertaken I the channel.

The River Murray Spring Pulse had an impact on the water quality and stream metabolism of Edward/Kolety River (Rees et al. 2021). The return flows from MIllewa Forest to The Edward/Kolety River were large enough to have a system wide impact on water quality, with the section of the mid and lower Wakool getting a further boost in response to carbon inflows from Thule Creek NSW DPIE watering action.

### *Evaluation questions for targeted contingency monitoring*

The remaining question was not addressed as these conditions required to generate blackwater were not present in the Edward/Kolety-Wakool River system during this 2020-21 water year.

- *What did Commonwealth environmental water contribute to reducing the impact of hypoxic blackwater or other adverse water quality events in the system?*

### *Links to other indicators*

Water quality and river flows are fundamentally linked. Water quality can be positively and negatively influenced by river flows and this can directly or indirectly influence productivity, aquatic vegetation and aquatic organisms including fish. Under certain temperature and flow conditions the input of DOC from large scale events can have the positive outcome of increasing productivity in the river ecosystem. However, it should be noted that large scale events also have the potential to result in negative outcomes. For example, an extensive unregulated overbank flooding event in 2016 inundated the Edward/Kolety-Wakool floodplain (including forested areas, cropping and grazing land and urban areas) and introduced considerable quantities of DOC into the river system, causing a widespread hypoxic blackwater event that resulted in the death of native fish.

Small inputs of DOC to the river can support microbial productivity which become available as food for aquatic organisms such as fish. As shown in this section, pulses of DOC and nutrients were introduced to the Edward/Kolety-Wakool River system by Commonwealth environmental watering actions in 2020-2021 water year. For example in 2020 800 ML/day flow trial, the discharge in the upper Wakool River was considerably higher than in previous years and peak flows in middle reach of Wakool River were higher and duration of the peak was longer than in the 2018 flow trial. Watts et al. (2009) indicated that in 2018 flow trial the discharge did not result in a change in water quality. However a pulse with stronger fluorescence transited through the Wakool-Yallakool system during 2020 800 ML/day flow trial suggesting where larger areas were wetted and additional carbon inputs from Thule Creek may be present. During this period hypoxia was not present in the Wakool River and the organic matter was likely to stimulate productivity. As stated in Section 6, watering actions in 2020-21 had a beneficial outcome on stream metabolism in the riverine ecosystem. Commonwealth environmental water significantly contributed to total carbon production and consumption where water was delivered. Creating more 'food' at the base of food web through primary productivity and more nutrients from ecosystem respiration is a positive outcome of these watering actions, even though water remained within the defined stream channel.

# 6 STREAM METABOLISM

Authors: Andre Siebers and Nick Bond

| **Key Findings** | |
|---|---|
| **Gross Primary Production (GPP)** | The environmental watering actions did not substantially affect areal rates of gross primary productivity (mg $O_2/m^2$/day), which largely followed seasonal trends. However, when GPP was calculated as the amount of organic carbon ('fish food') produced per day (kg C/day) then watering actions had a beneficial effect (more 'food' is better). The size of the beneficial impact was largely related to the proportion of total flow that came from the watering action, with greater proportional effects of environmental water in lower-flow periods. Carbon production was enhanced by between 18% and 285% during the watering actions, with a median across all sites and watering actions of 117% more carbon produced during Commonwealth environmental watering actions compared to no Commonwealth environmental water. |
| **Ecosystem Respiration (ER)** | As with GPP, areal rates of ecosystem respiration (mg $O_2/m^2$/day) were largely driven by seasonal trends. However, when ER was calculated as the amount of organic carbon consumed per day (kg C/day), then watering actions had a beneficial effect. A higher amount of organic carbon consumed means more nutrient recycling and hence greater nutrient supply to fuel GPP. Carbon consumption was enhanced by between 18% and 257% during the watering actions, with a median across all sites and watering actions of 113% more carbon consumed during Commonwealth environmental watering actions compared to no Commonwealth environmental water. |

## 6.1 Background

Whole stream metabolism measures the production and consumption of DO gas, which occurs as a result of 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 and to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic food webs. The relationships between these processes are shown in Figure 6.1.

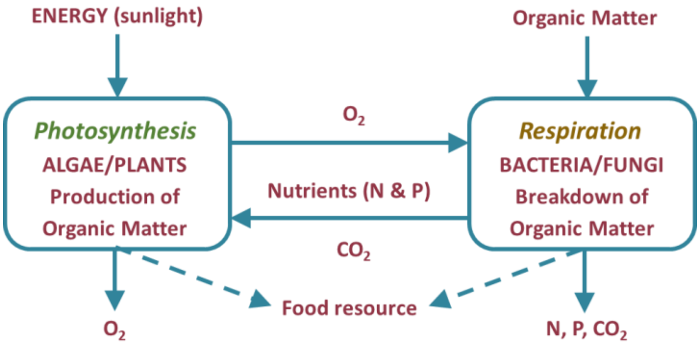


**Figure 6.1** Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

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

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

In general, there is concern when process rates are too high. Greatly elevated primary production rates usually equate to algal bloom conditions or excessive growth of plants, which may block sunlight penetration, killing other submerged plants, produce algal toxins and large diel DO swings - overnight elevated respiration rates can decrease DO to the point of anoxia (no DO in the water). When an algal bloom collapses, the large biomass of labile organic material is respired, often resulting in extended anoxia. Very low or no DO in the water can result in fish kills and unpleasant odours.

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

This chapter reports on stream metabolism in response to flows in the 2020-21 water year and will consider changes in GPP and ER in the system.

## 6.2 Environmental watering actions in 2020-21

Eight Commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2020-21 (Section 4). The response of stream metabolism to seven of these watering actions was evaluated (Table 6.1).

**Table 6.1** Environmental watering actions assessed for ecosystem metabolism in the Edward/Kolety-Wakool system in 2020-21

| | Type of action | Rivers | Dates |
|---|---|---|---|
| 1 | Spring fresh | Yallakool /Wakool system | 20/10/20 – 30/11/20 (Yallakool)<br>23/10/20 – 27/11/20 (Wakool) |
| 2 | Elevated base flow | Yallakool | 30/11/20 – 15/12/20 |
| 3 | Summer freshes | Yallakool | 15.12.20 – 15.2.21 |
| 4 | Autumn fresh | Yallakool | 30/3/21 – 6/5/21 |
| 5 | Spring fresh | Colligen–Niemur | 21/10/20 – 6/12/20 |
| 6 | Elevated base flow | Colligen–Niemur | 6/12/20 – 8/1/21 |
| 7 | Summer fresh | Colligen–Niemur | 26/1/21 – 31/5/21 |
| 8 | Variable base flows | Upper Wakool | 23/1/21 – 9/6/21 |

## 6.3 Selected area questions

This Edward/Kolety-Wakool Flow-MER report follows the previous Selected Area evaluations of stream metabolism responses to Commonwealth environmental water delivery. The questions addressed arises from the importance of new organic (plant) matter, created through photosynthesis, supplying essential energy to the food web and the critical role of respiration in breaking down organic detritus and therefore resupplying nutrients to enable such growth to occur (Table 6.2).

**Table 6.2** Selected Area evaluation questions relating to the effect of Commonwealth environmental water on stream metabolism.

| Selected Area questions |
|---|
| • What was the effect of Commonwealth environmental watering actions on rates of GPP, ER, and NPP?<br>• What did Commonwealth environmental water contribute to total GPP, ER, and NPP?<br>• Which aspect of Commonwealth environmental water delivery contributed most to productivity outcomes? |

## 6.4 Methods

### *Data collection*

Stream metabolism measurements were performed in accordance with the LTIM Standard Operating Procedure (Hale et al. 2014). As in 2019-2020, water temperature and dissolved oxygen were logged every ten minutes with at least one logger placed in each of five study zones (zones 1-4 and Colligen Creek); in zones 3 and 4, loggers were placed at the upstream and downstream end of these zones. For 2020-21, water temperature and dissolved oxygen were also logged at Liewah on the lower Edward/Kolety River. Data were downloaded and loggers calibrated approximately once per month if sites were accessible, and more frequently (often fortnightly) during summer to avoid problems with probe biofouling. Light and depth loggers were deployed alongside oxygen loggers and data were downloaded on an approximately monthly basis. The data collected by the loggers was also used to calculate daily average temperature and dissolved oxygen concentrations (see Section 5) for each of the zones.

In accord with the LTIM Standard Protocol, temperature (°C), electrical conductivity (µS/cm), dissolved oxygen (%), pH and turbidity (NTU) were also measured as spot recordings fortnightly within each zone. As in 2019-20, average water depth was also estimated from hydraulic flow modelling (undertaken by Marine Solutions on behalf of CSU) which derived 5 cross-sectional wetted areas of each zone at varying discharge (approximately 25 to 1900 ML/day). A 2$^{nd}$-order polynomial trendline was derived from the 5 discharge-depth relationships and used to predict average depth from daily discharge data.

### *Data analysis*

Acceptance criteria for inclusion of daily results from the BASEv2 model (updated from Grace et al., 2015 according to Song et al., 2016) followed Watts et al. (2019) as established at the July 2015 LTIM Workshop and then refined at the equivalent meeting in July 2016. These criteria were that the fitted model for a day must have (i) an $R^2$ value of at least 0.90 *and* a coefficient of variation for the GPP, ER, and K parameters of < 50%, (ii) a reaeration coefficient (K) within the range 0.1 to 15, and (iii) model fit parameter PPfit within the range 0.1 to 0.9. Values outside these parameters indicate that the 'best fit' to the data was still an implausible model.

The original units of GPP and ER estimation from BASE are volumetric (mg $O_2$/L/day) and can be affected by concentration and dilution effects from varying discharge (Watts et al., 2019). We therefore converted all GPP and ER estimates to areal rates (g $O_2/m^2$/day) by multiplication with estimated average depth. This approach addresses issues associated with the fact that higher flows are often associated with lower rates of production per litre.

For the environmental watering actions, the estimation of the additional daily carbon production (kg) attributable to Commonwealth environmental watering actions entailed the following steps.

1. Rates of carbon produced and consumed each day were calculated by multiplying GPP or ER in mg $O_2$/L/Day by the number of litres discharged that day. Conversion to organic carbon involves a factor of 12/32 (ratio of atomic mass of C to molecular mass of $O_2$). This factor does not include any physiological efficiency factor for converting oxygen to organic carbon which typically is in the range 0.8 to 1. Given the exploratory use of this metric, concern over conversion efficiency at this stage is unwarranted.
2. Total production for each day was estimated by multiplying the rate of production derived for that day (in kg C/L/day) by the observed discharge on that day (L).
3. To calculate the discharge predicted to have occurred in the absence of Commonwealth Environmental Water (CEW), we subtracted the volume of CEW from the total discharge (observed discharge – CEW).
4. To calculate the average depth of the water column in the absence of CEW, we applied the estimation equations for average depth to the discharge predicted to have occurred in the absence of CEW.

5. To estimate volumetric rates of GPP and ER in the absence of CEW, we divided areal rates of production and consumption (in g $O_2/m^2$/day) for each day by the estimated average depth of the water column in the absence of CEW. Rates were then converted to units of organic carbon as above.
6. These alternative rates of production and consumption were then multiplied by the non-CEW discharge volume to determine the total production predicted to have occurred on that day in the absence of CEW.
7. The above steps produced two time-series of estimated total daily production with and without CEW.
8. The daily estimates of CEW/non-CEW derived production were averaged to determine the mean daily additional production during watering actions and total additional production over the entire watering action.

## 6.5 Results

### *Rates of stream metabolism*

Using the acceptance criteria for each day's diel DO curve, the acceptance rate ranged from a low of 8% of all days with data available for Zone 3 to a high of 73% at Zone 2 (Table 6.3). These values are slightly higher than those for 2019-2020 (3 to 63%) (Watts et al., 2020).

**Table 6.3** Summary of data availability for the seven data logger sites, July 2020 – April 2021.

| Hydrological zone | Site | Total days | Days with acceptable data | % Acceptable data days |
|---|---|---|---|---|
| Zone 1: Yallakool Creek | | 294 | 168 | 57.1 |
| Zone 2: Wakool River | | 307 | 224 | 73.0 |
| Zone 3: Wakool River upstream Thule Creek | | 295 | 24 | 8.1 |
| Zone 4: Wakool River downstream Thule Creek | Upstream | 309 | 169 | 54.7 |
| | Downstream | 295 | 172 | 58.3 |
| Colligen Creek | | 280 | 35 | 12.5 |
| Liewah: lower Edward/Kolety River | | 247 | 67 | 27.1 |

Median GPP values for all seven sites fell within a narrow range of 0.8 to 1.9 mg $O_2$/L/day, with a similar minimum but lower maximum than the range in 2019-20 (0.9 to 4.2 mg $O_2$/L/day) (Watts et al., 2020). When converted to areal rates, the median GPP values had a similarly narrow range (from 1.1 to 1.8 $O_2/m^2$/day) (Table 6.4) comparable with that from 2019-20 (0.9 to 2.9 g $O_2/m^2$/day) (Watts et al., 2020). Major events such as large flows and anoxia can often preclude data meeting acceptance criteria. These comparisons are therefore made using metabolic rates obtained primarily during in-channel flow conditions.

**Table 6.4** Summary of gross primary production (GPP) and ecosystem respiration (ER) rates and GPP/ER ratios for the seven sites in six hydrological zones, July 2020 – June 2021. Each metabolic parameter is expressed as a median and mean with minimum and maximum values also included. 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

| | Yallakool Creek Zone 1 | | | |
|---|---|---|---|---|
| | Median | Mean | Min | Max |
| GPP (g $O_2/m^2$/day) | 1.46 | 1.53 | 0.31 | 4.68 |
| ER (g $O_2/m^2$/day) | 2.75 | 2.97 | 0.05 | 13.62 |
| GPP / ER | 0.56 | 0.74 | 0.15 | 15.82 |

| | Upper Wakool River Zone 2 | | | |
|---|---|---|---|---|
| | Median | Mean | Min | Max |
| GPP (g $O_2/m^2$/day) | 1.59 | 1.77 | 0.38 | 8.93 |
| ER (g $O_2/m^2$/day) | 4.14 | 5.48 | 0.86 | 32.27 |
| GPP / ER | 0.36 | 0.40 | 0.06 | 1.21 |

| | Mid Wakool River upstream Thule Creek Zone 3 | | | |
|---|---|---|---|---|
| | Median | Mean | Min | Max |
| GPP (g $O_2/m^2$/day) | 1.62 | 1.83 | 0.40 | 3.52 |
| ER (g $O_2/m^2$/day) | 2.71 | 2.90 | 0.46 | 6.95 |
| GPP / ER | 0.69 | 0.68 | 0.28 | 1.14 |

| | Mid Wakool River downstream Thule reek Zone 4 (upstream logger) | | | | Mid Wakool River downstream Thule Creek Zone 4 (downstream logger) | | | |
|---|---|---|---|---|---|---|---|---|
| | Median | Mean | Min | Max | Median | Mean | Min | Max |
| GPP (g $O_2/m^2$/day) | 1.62 | 2.55 | 0.40 | 16.56 | 1.70 | 1.99 | 0.33 | 9.40 |
| ER (g $O_2/m^2$/day) | 3.02 | 4.26 | 0.61 | 23.26 | 3.39 | 3.63 | 0.70 | 16.47 |
| GPP / ER | 0.57 | 0.59 | 0.20 | 1.16 | 0.54 | 0.56 | 0.18 | 1.51 |

| | Colligen Creek | | | |
|---|---|---|---|---|
| | Median | Mean | Min | Max |
| GPP (g $O_2/m^2$/day) | 1.09 | 1.23 | 0.42 | 3.85 |
| ER (g $O_2/m^2$/day) | 3.45 | 4.37 | 1.68 | 16.21 |
| GPP / ER | 0.33 | 0.33 | 0.09 | 0.81 |

| | Liewah | | | |
|---|---|---|---|---|
| | Median | Mean | Min | Max |
| GPP (g $O_2/m^2$/day) | 1.12 | 1.56 | 0.30 | 11.25 |
| ER (g $O_2/m^2$/day) | 1.91 | 3.11 | 0.46 | 23.52 |
| GPP / ER | 0.54 | 0.64 | 0.17 | 3.82 |

There was a seasonal increase in GPP from spring into summer in zones 1, 2, and 4, and a subsequent decrease from the end of summer into autumn. Useable data at Zone 3 was too scarce to assign seasonal patterns in 2020/21 as data did not meet the model acceptance criteria (see methods section). Despite the constrained range of median values, Zones 1, 2, and 4 also exhibited short pulses of very high GPP (> 5 mg $O_2/m^2/d$) in late December 2020/early January 2021. As with the 2019/20 data, warmer days and more hours and higher intensity of sunshine during summer are the most likely driver of these patterns (Watts et al., 2019). ER also showed a seasonal trend at zones 1, 2, and 4, and pulses of respiration were largely correlated with those of GPP. These pulses did not appear to be correlated with any consistent hydrological driver (e.g., drawdown periods following flow pulses) across sites, and may thus be driven by similar climatic conditions (Figure 6.2).

GPP at Liewah followed a similar seasonal pattern to that at zones 1, 2, and 4, although a pulse of GPP was also recorded in late March 2021. GPP data at Colligen Creek was too scarce to assign seasonal patterns in 2020/21. There was little seasonal trend in ER at Liewah, however, and ER did not appear to peak in response to increased GPP as at zones 1, 2, and 4 (Figure 6.3).

For most of the time each system was strongly heterotrophic (GPP < ER), even during early-summer GPP peaks (Figure 6.1, Figure 6.2). The exceptions were early autumn peaks in GPP at zone 4 and Liewah. This indicates that at most times, much more carbon is being consumed by respiration within the river than is being produced by photosynthesis. Much of the organic carbon being respired must therefore have been transported into the systems from upstream or from the surrounding catchment. For example, as discussed in section 4 (Hydrology) and section 5 (Water quality and carbon) the Southern Spring Flow in the Murray River resulted in return flows from Millewa Forest that introdued pulses of carbon into the Edward/Kolety-Wakool system. A small amount of production would also be occurring within the system due to connection of anabranches or low-lying floodplains during th 800 ML/day flow trial, i.e., shallow wetted habitat where primary productivity can often reach very high areal rates. However, for much of the 2020-21 water year flows were low, so the most likely source of most of the additional carbon in the system is transport from upstream reaches.

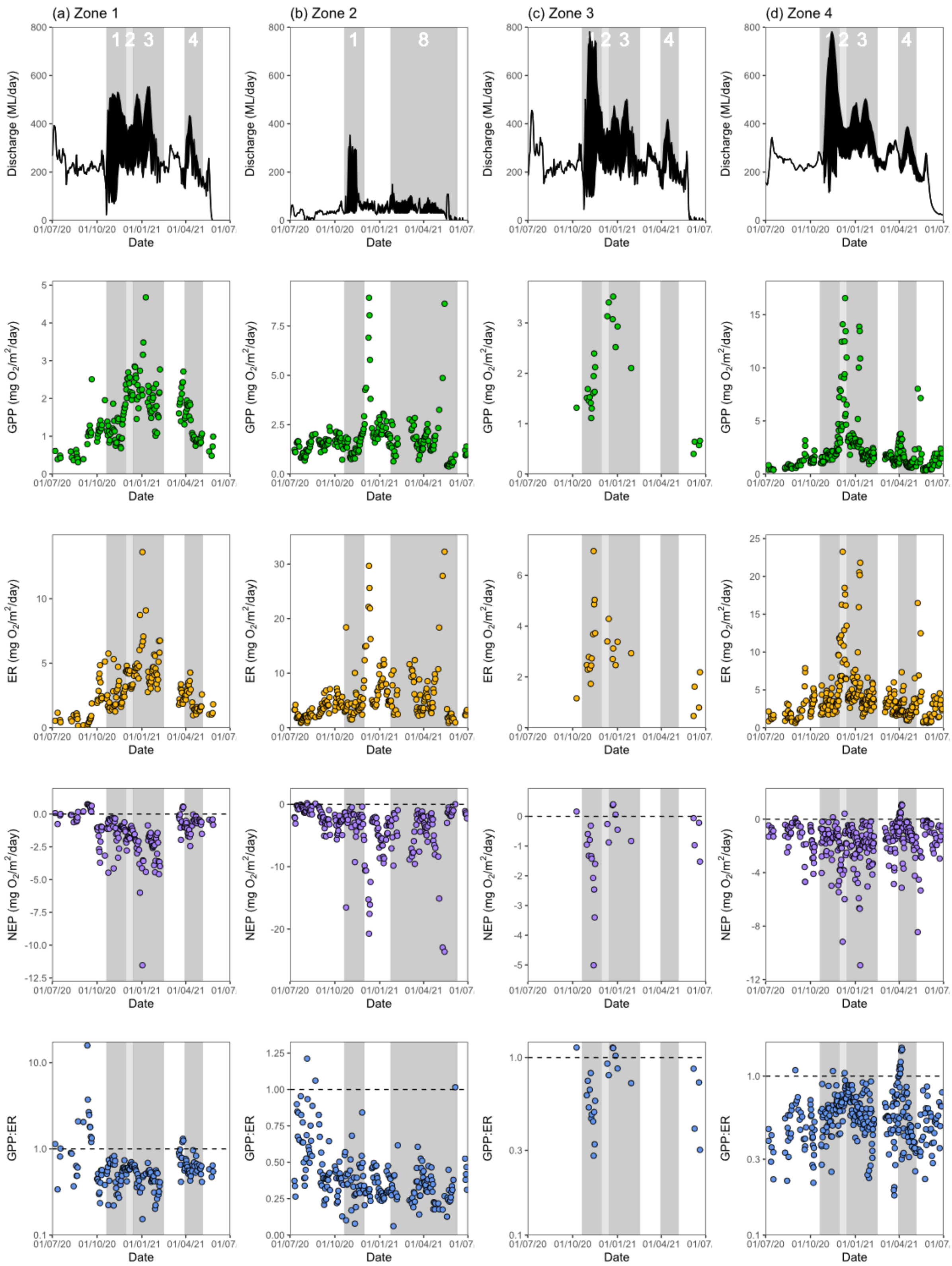



**Figure 6.2** Plots of discharge, oxygen production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GPP:ER) over all sites in the four hydrological zones from Yalllakool Creek and the Wakool River in 2020-21. Watering actions are indicated by shaded bars. Shaded bars are adjusted for travel time for zones 3 (4 days) and 4 (9 days). Note log scale for GPP:ER in Zone 1.

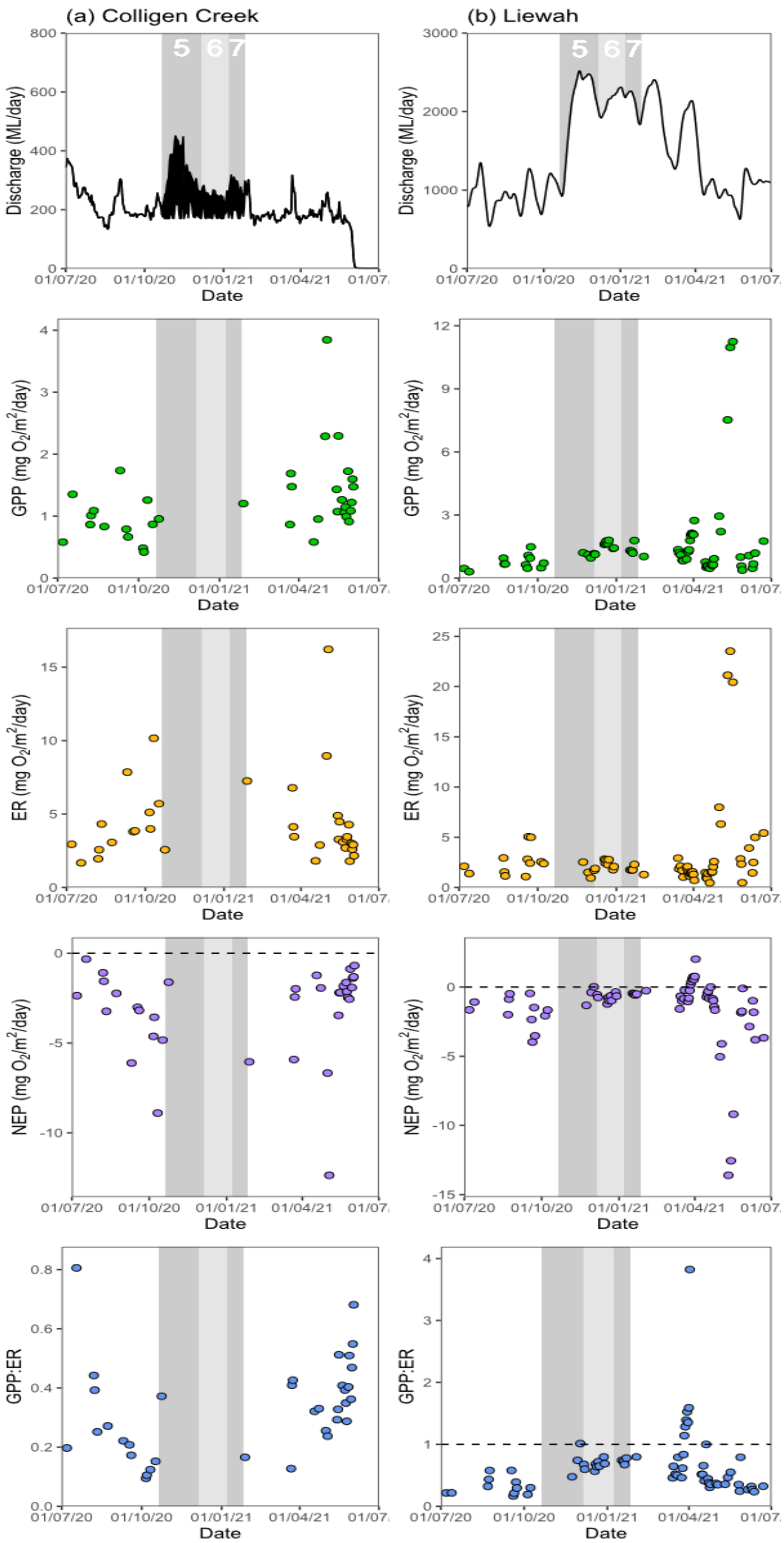



**Figure 6.3** Plots of discharge, oxygen production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GPP: ER) in the Colligen Creek and Liewah sites in 2020-21. Watering actions in Colligen Creek are indicated by shaded bar.

### *Response of stream metabolism to Commonwealth environmental watering actions*

**Action 1: Spring fresh, Yallakool-Wakool (20/10/20 – 30/11/20):** GPP rates mostly fell within a narrow range (1 to 5 g $O_2/m^2$/day) across all sites during the first watering action, although Zone 4 had higher mean GPP and a number of days with notably higher rates of GPP. ER rates varied largely between 1 and 6 g $O_2/m^2$/day, with Zones 2 and 4 exhibiting a number of days with higher values. All zones were largely heterotrophic during the watering action (Figure 6.4). Delivery of environmental water resulted in noticeably increased production and consumption of carbon at Zones 1, 2, and 4 (Figure 6.5). The effect of CEW was more difficult to predict at Zone 3 due to lower amounts of useable data, but the data available suggests that there were still substantial increases in carbon produced and consumed with delivery of environmental water.

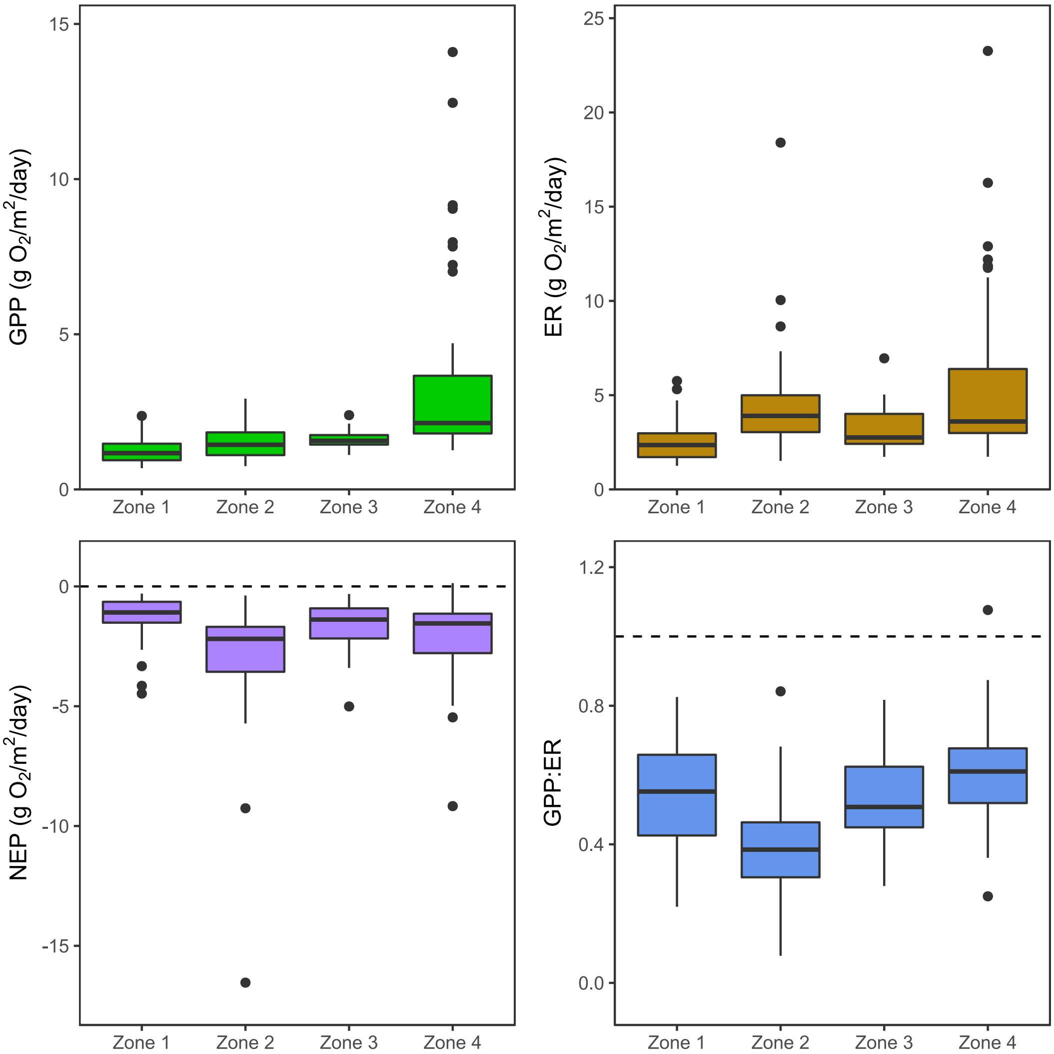



**Figure 6.4** Watering action 1, zones 1-4. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

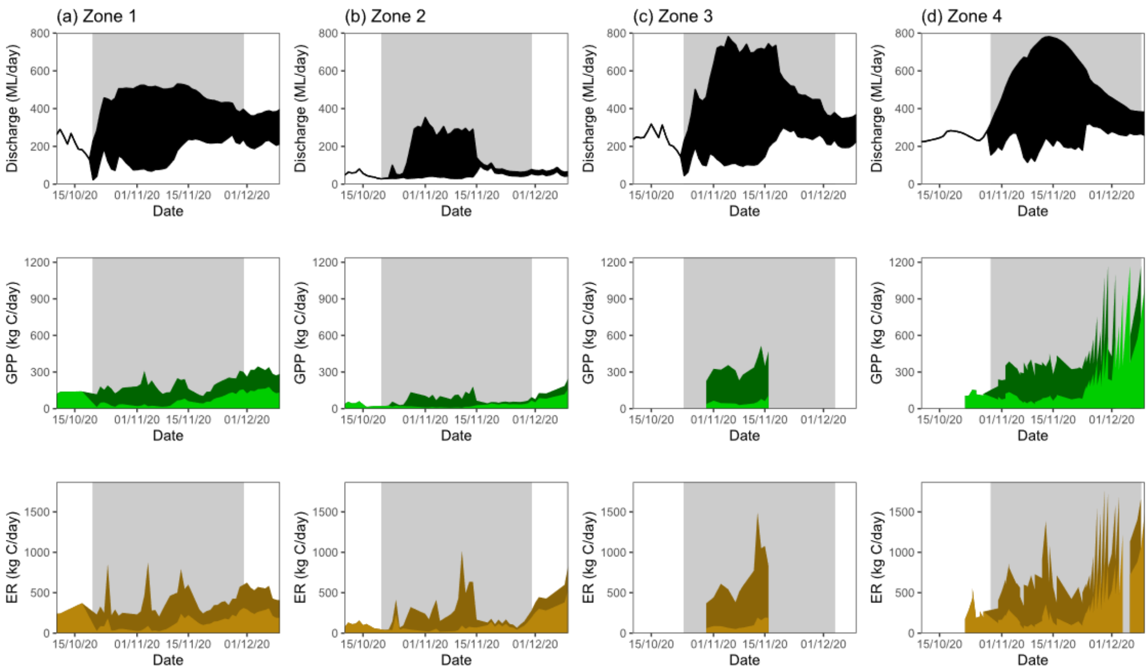



**Figure 6.5** Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during watering action 1, zones 1-4, showing the component attributed to Commonwealth environmental water. Duration of action is shown by grey shaded area. Shaded bars are adjusted for travel time for zones 3 (4 days) and 4 (9 days).

**Action 2: Elevated base flow, Yallakool (31/11/20 – 15/12/20):** Zone 4 had a wider range of GPP and ER (3 to 7 g $O_2/m^2$/day than Zones 1 and 3 during the elevated base flows action. This reflects the early summer pulse of GPP and ER that occurred in Zone 4 but not Zones 1 and 3 during the action (Figure 6.2). All zones were still largely net heterotrophic during the action, however (Figure 6.6). During the elevated base flows, delivery of environmental water resulted in increased production and consumption of carbon at all zones, although predictions at Zone 3 were again restricted by lower amounts of useable data (Figure 6.7).

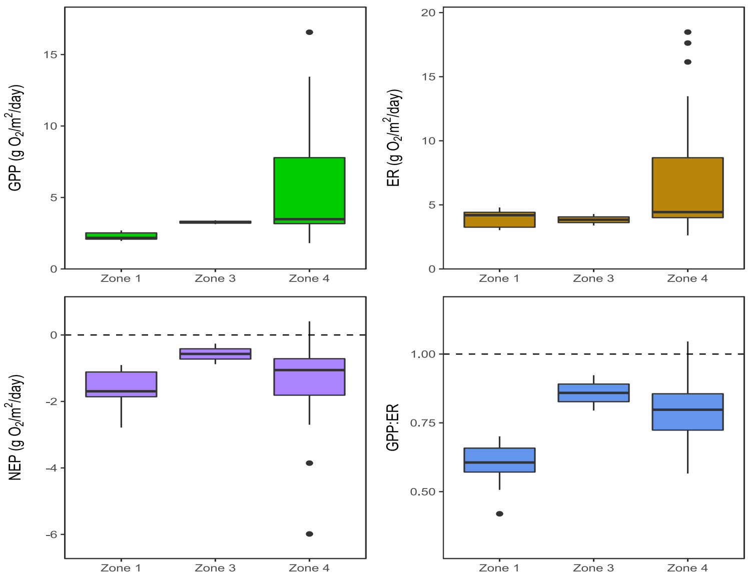



**Figure 6.6** Watering action 2, zones 1, 3, and 4. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

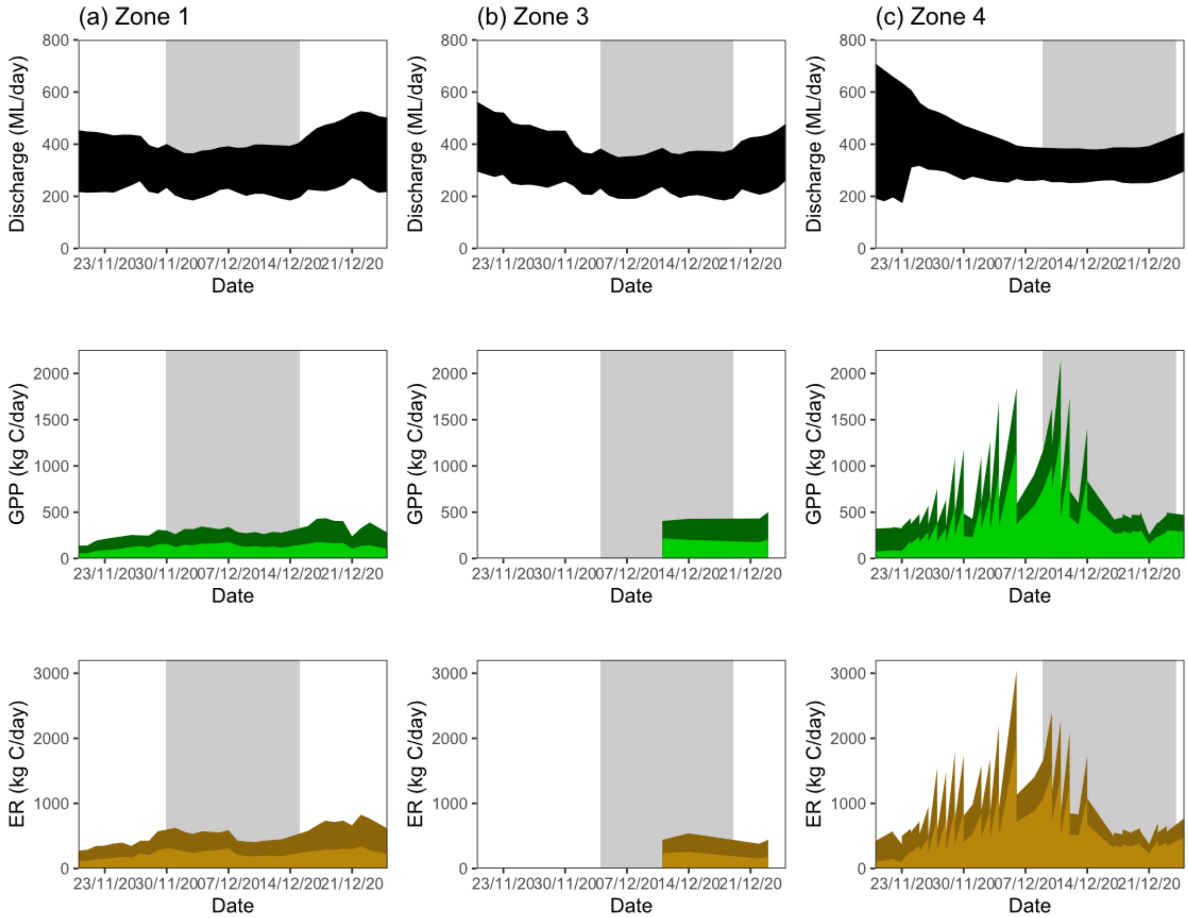



**Figure 6.7** Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during watering action 2, zones 1, 3, and 4, showing the component attributed to Commonwealth environmental water. Duration of action is shown by grey shaded area. Shaded bars are adjusted for travel time for zones 3 (4 days) and 4 (9 days).

**Action 3: summer freshes, Yallakool (15/12/20 – 15/2/21):** During the summer freshes, rates of both GPP (2 to 3 g $O_2$/m$^2$/day) and ER (3 to 6 g $O_2$/m$^2$/day) were largely consistent through time, although Zone 4 had several days with higher rates. Both Zone 1 and Zone 4 were heterotrophic during the watering action, but Zone 3 alternated between net heterotrophy and net autotrophy (Figure 6.8). The summer freshes resulted in increased production and consumption of carbon at all zones, particularly when CEW contributed a larger proportion of total flows (Figure 6.9).

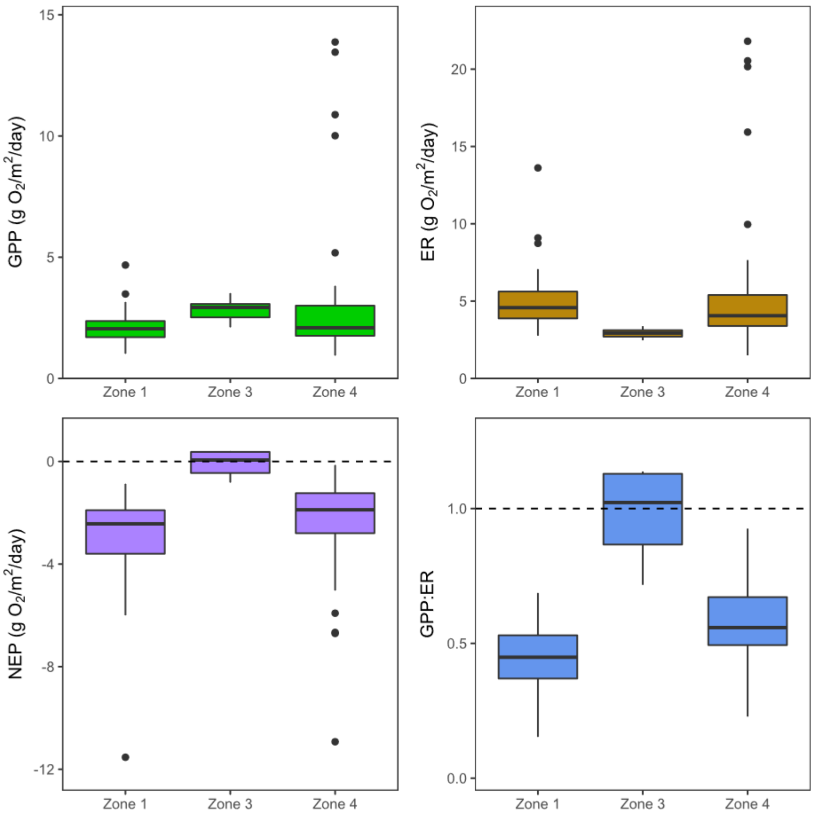



**Figure 6.8** Watering action 3, zones 1, 3, and 4. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

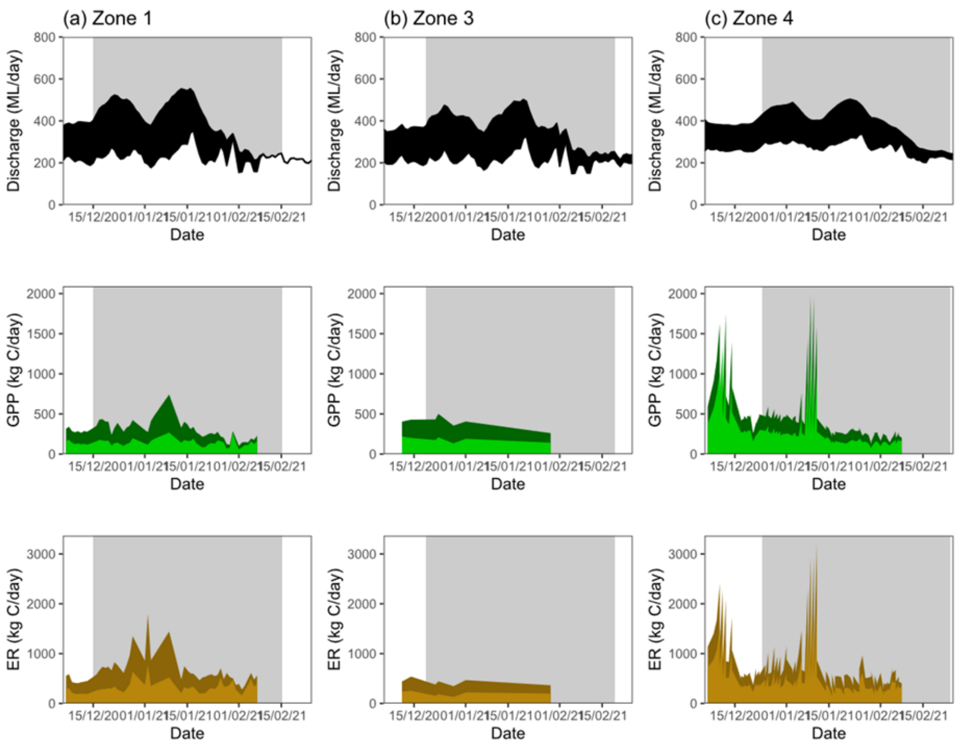



**Figure 6.9** Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during watering action 3, zones 1, 3, and 4, showing the component attributed to Commonwealth environmental water. Duration of action is shown by grey shaded area. Shaded bars are adjusted for travel time for zones 3 (4 days) and 4 (9 days).

**Action 4: Autumn fresh, Yallakool (30/3/21 – 6/5/21):** Rates of GPP (1 to 2 g $O_2/m^2$/day) and ER (2 to 3 g $O_2/m^2$/day) were similar between Zone 1 and 4. Both zones were net heterotrophic during this watering action (Figure 6.10). There was no useable data at Zone 3 during this time, however, and mean rates of GPP and ER were thus unable to be determined. The effect of environmental water delivery was to increase production and consumption of carbon at Zones 1 and 4, with a particularly noticeable effect when CEW provided the majority of flows during April (Figure 6.11). As with mean rates, the effect of CEW was unable to be predicted at Zone 3 due to no useable data.

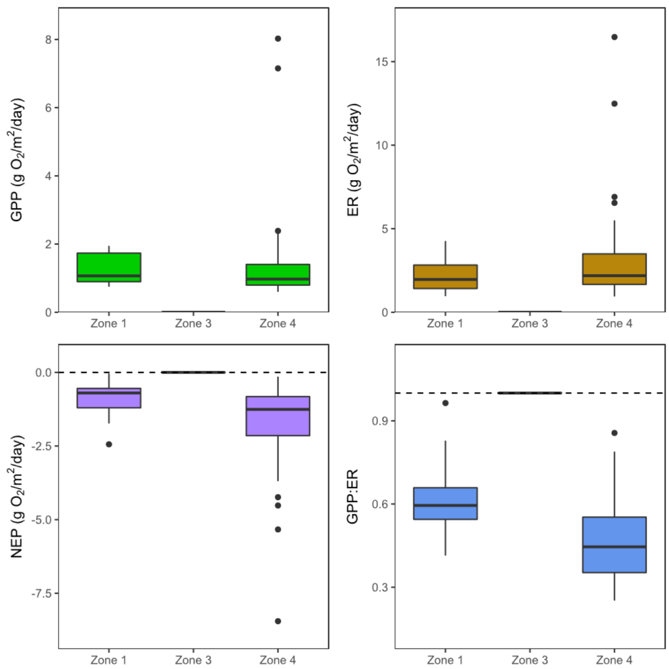



**Figure 6.10** Watering action 4, zones 1, 3, and 4. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

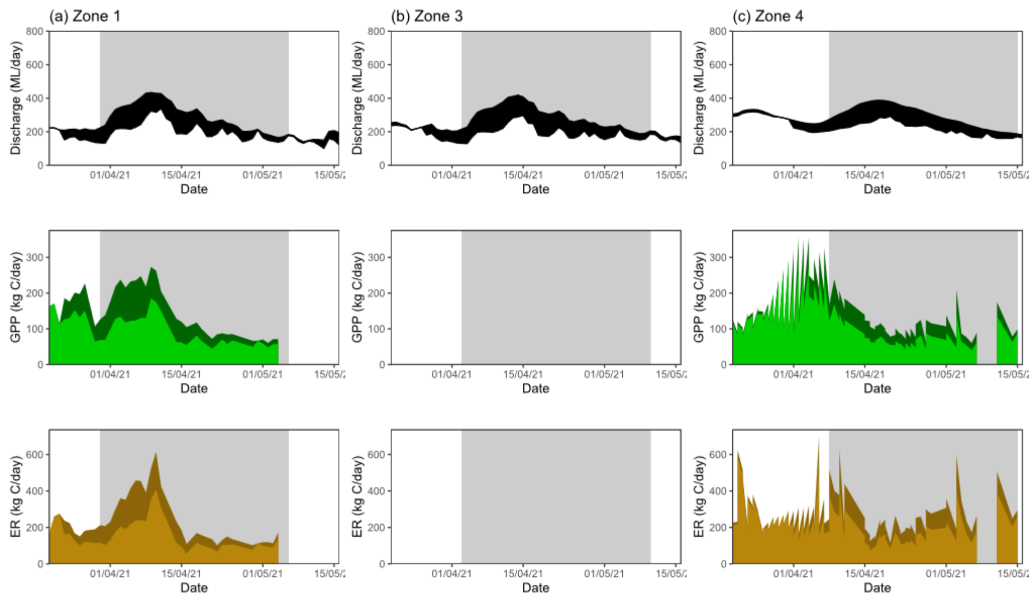



**Figure 6.11** Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during watering action 4, zones 1, 3, and 4, showing the component attributed to Commonwealth environmental water. Duration of action is shown by grey shaded area. Shaded bars are adjusted for travel time for zones 3 (4 days) and 4 (9 days).

**Action 8: Variable base flows, Upper Wakool (23/1/21 – 9/6/21):** GPP rates (1 to 2 g $O_2/m^2$/day) were noticeably lower than ER (4 to 7 g $O_2/m^2$/day) in Zone 2 during variable base flows. This resulted in Zone 2 being strongly heterotrophic during the watering action (Figure 6.12). The variable base flows therefore resulted in higher consumption than production of carbon at Zone 2, although both processes were still enhanced by delivery of environmental water (Figure 6.13).

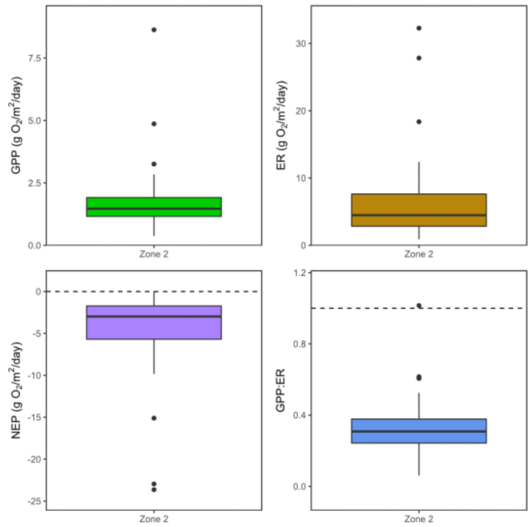



**Figure 6.12** Watering action 8, zone 2. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

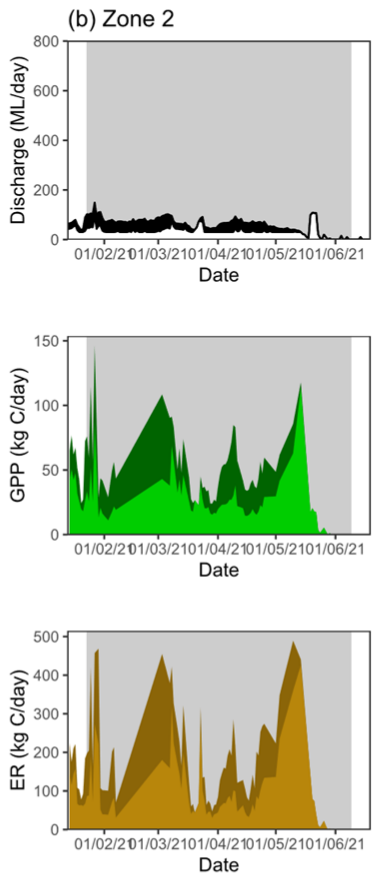



**Figure 6.13** Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during watering action 8, zone 2, showing the component attributed to Commonwealth environmental water. Duration of action is shown by grey shaded area.

**Actions 5, 6, and 7: Spring and summer freshes, Colligen-Niemur (21/10/20 – 8/01/21, 26/1/21 – 31/5/21):** There was too little useable data during watering actions 5 and 7 at either Colligen Creek or Liewah to assess the effects of environmental water on stream metabolism (Figure 6.3). Useable data at these sites was too scarce because the data did not meet the model acceptance criteria (see methods section. Consequently, these actions are not discussed further here.

### *Estimated contribution of Commonwealth environmental water to carbon production across all watering actions*

The daily estimates of CEW/non-CEW derived production were averaged across the number of days for each watering action to determine the average daily additional production and consumption for each watering action, and the total additional carbon production and consumption over each watering action.

Both watering actions resulted in increased production (Figure 6.14) and consumption of carbon (Figure 6.15). The largest gross contribution of CEW to both mean and overall C production and consumption occurred during watering actions 2 and 3 (summer elevated base flows and freshes, Yallakool) at the time when there were return flows from Millewa Forest due to the Southern Spring Flow. This also reflects (i) the seasonal trend in GPP and ER rates, where summer is the period of highest rates overall, and (ii) the pulsed events (i.e., days with very high GPP and ER) that occurred in summer in Zones 1, 3, and 4. It is worth noting in this context that pulsed events also occurred in Zone 2 in summer, but not during a watering action (Figure 6.2). However, although C production and consumption were lower in general for watering actions 4 and 8 (autumn fresh and variable base flows, Yallakool-Wakool), the proportional contribution of CEW to overall stream metabolism was still substantial at these times. This parallels the greater proportional contribution of CEW to total discharge during low-flow periods.

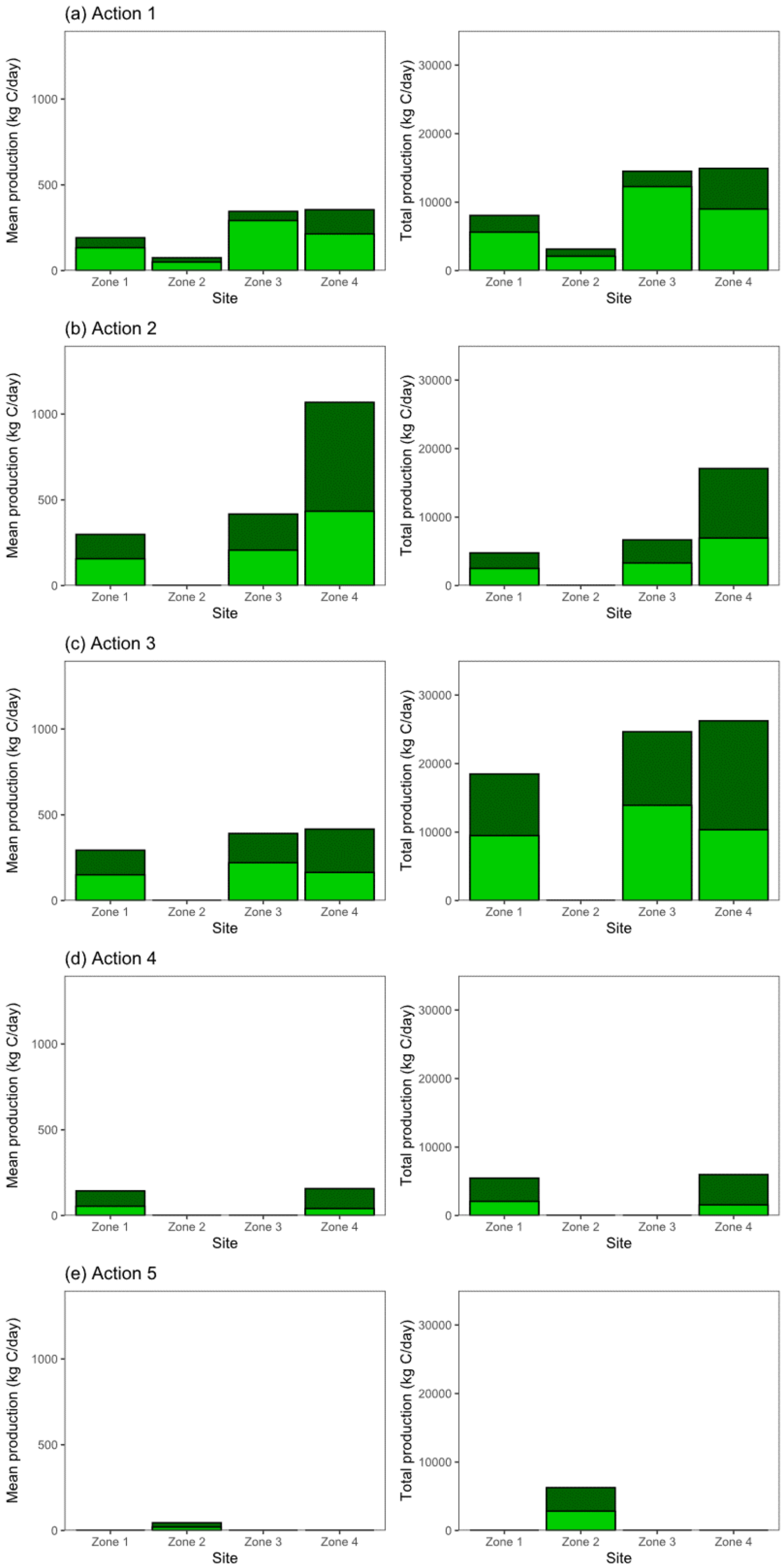



**Figure 6.14** Left: The average daily additional production of carbon (kg C/day) during the two environmental watering actions. Right: The total additional production of carbon (kg) during the two watering actions. Light green is the production attributed to operational water (non CEW), and dark green indicates the production attributed to Commonwealth environmental water. Zone 3 estimates are missing from action 4 due to a lack of useable data.

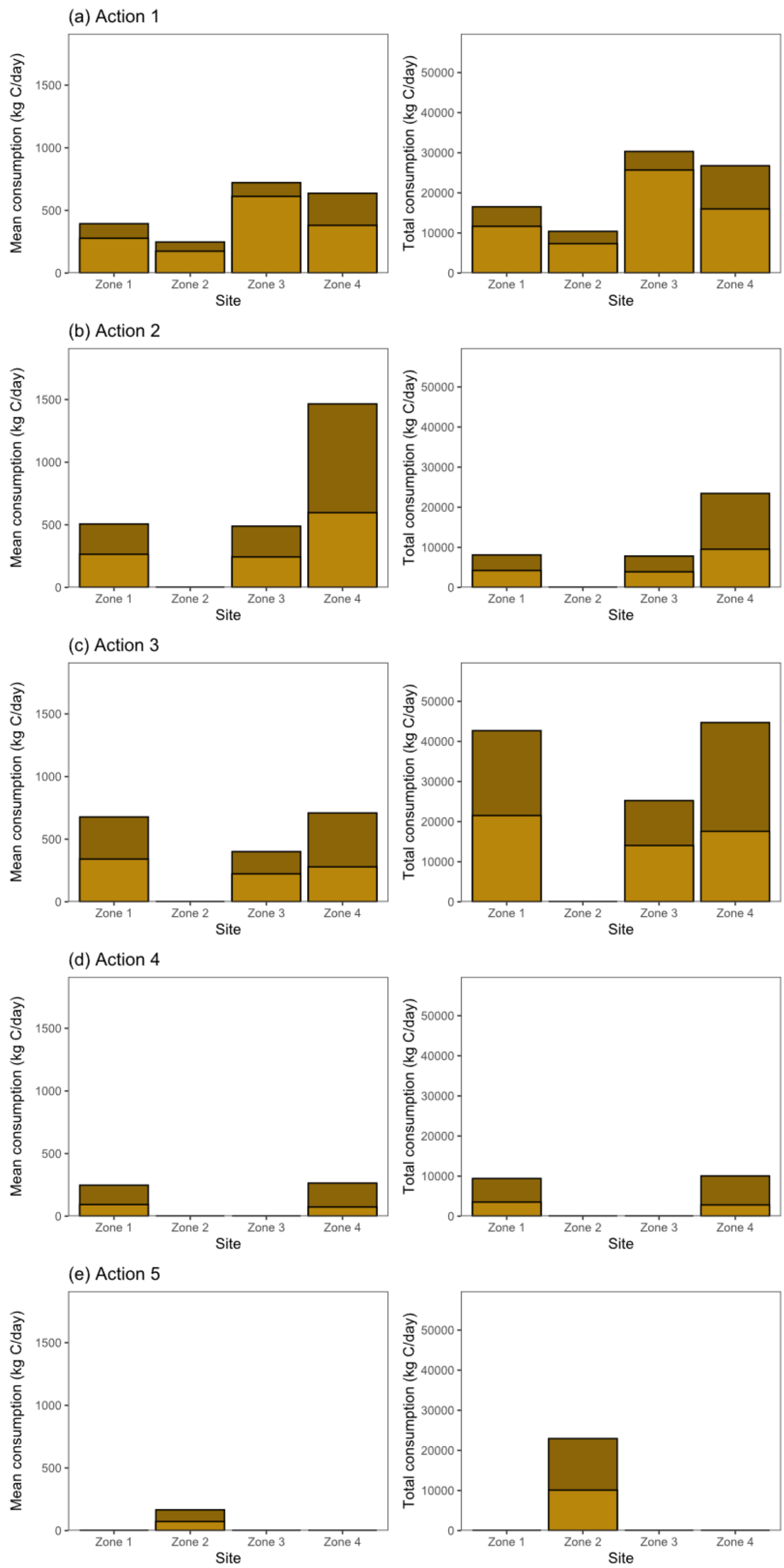



**Figure 6.15** Left: The average daily additional consumption of carbon (kg C/day) during the two environmental watering actions. Right: The total additional consumption of carbon (kg) during the two watering actions. Light orange is the production attributed to operational water (non CEW), and dark orange indicates the production attributed to Commonwealth environmental water. Zone 3 estimates are missing from action 4 due to a lack of useable data.

## 6.6 Discussion

### *What was the effect of Commonwealth environmental watering actions on rates of GPP, ER, and NPP?*

In 2020-21 for most of the time the system was strongly heterotrophic (GPP < ER), even during early-summer GPP peaks. The exceptions were early autumn peaks in GPP at zone 4 and Liewah, at the downstream end of the Edward/Kolety River. This indicates that at most times, much more carbon is being consumed by respiration within the river than is being produced by photosynthesis. This pattern is consistent with the heterotrophy that has been reported for the Edward/Wakool system during most years of LTIM/Flow-MER program (e.g., Watts et al. 2019, 2020). This pattern in the Edward/Kolety-Wakool system has been summarized as part of the Whole of Basin analysis as a heterotrophic 'fingerprint' (Ryder et al. 2021). The fingerprint visualisation shows that the data collected by Watts et al (2020) for the Edward/Kolety-Wakool system reside above the 1:1 line, indicating that most of the time river ecosystems were heterotrophic and consuming more carbon than they were producing (Ryder et al. 2021).

It is highly likely that much of the organic carbon being respired must have been transported into the systems from upstream., For example, as discussed in section 4 (Hydrology) and section 5 (Water Quality and Carbon) the Southern Spring Flow in the Murray River resulted in return flows from Millewa Forest that introduced pulses of carbon into the Edward/Kolety-Wakool system. Although a small amount of production would also be occurring within the system due to connection of anabranches or low-lying floodplains during th 800 ML/day flow trial, for much of the 2020-21 water year flows were low, so the most likely source of most of the additional carbon in the system is transport from upstream reaches.

In 2019-20, conversion of volumetric rates (mg $O_2$/L/day) to areal rates (g $O_2$/m$^2$/day) was introduced in the Edward/Kolety-Wakool Flow-MER Program to account for the diluting effects of flows on estimates of GPP and ER (Watts et al., 2020) i.e., the immediate effect of a significant flow increase was previously a substantial decrease in estimated rates of both GPP and ER (Watts et al. 2016, Watts et al. 2017). As in 2019-20, after this conversion was applied areal rates of GPP and ER, as well as the ratio between them, showed little change during Commonwealth environmental watering actions and a strong seasonal trend in rates of GPP and ER became apparent. In particular, areal rates of GPP are higher and pulses appear more frequently during warmer summer months, indicating that temperature and light are major drivers of GPP rates within the Edward/Kolety-Wakool system.

Except in conditions of major phytoplankton growth (e.g., an algal bloom), much of the metabolism in the Edward/Kolety-Wakool system appears to be from biofilms and microbial communities growing on (and in the surface layers) of the sediment and also on hard substrates within the channel, such as logs and plant stems. Substantial increases in areal rates of GPP with increased flows would thus likely only occur when discharge is high enough for low-lying anabranches, backwaters and floodplain to become inundated and connected to the river channel. Increases and in flow in 2020-21 during the 800 ML/d flow trial likely had a small effect on where production and consumption of carbon is occurring within the Edward/Kolety-Wakool system, with low lying areas connected during the flow trial. Higher flow events can provide a substantial increase in the proportion of shallow wetted habitat where light can penetrate to substrates and stimulate primary production, particularly where inundated macrophytes (plants such as rushes and reeds) provide attachment points for the growth of attached algae.

### *What did Commonwealth environmental water contribute to total GPP, ER, and NPP?*

Overall, Commonwealth environmental water contributed significantly to total carbon production and consumption where water was delivered. Creating more 'food' at the base of the food web through primary productivity and more nutrients from ecosystem respiration (to generate this 'food') is a positive outcome of these watering actions, even though water remained within the defined stream channel.

Beyond the effect of duration on the total additional production and consumption of C (i.e., watering actions with longer durations logically produce and consume more C in total than those with shorter durations), total production and consumption varied with (i) time of year (i.e., with season), (ii) the background flow (i.e., without CEW), and (iii) the volume of CEW being delivered. As with previous years (Watts et al., 2020), total production and consumption was enhanced most in the summer months when both mean GPP and ER rates and the potential for pulsed events (i.e., days with very high rates) are highest. Season appears to be the strongest driver of GPP and ER rates in the Wakool and Yallakool systems and is thus also a strong influence on total carbon production and consumption.

Although the proportional contribution of CEW to total production and consumption is higher when discharge is lower, thetotal amount of carbon produced and consumed is greater when there is more environmental water delivered. If CEW delivery resulted in flows that connected shallow anabranches and low-lying floodplains, this would greatly increase the total wetted surface area where high rates of GPP could occur.

### *Which aspect of Commonwealth environmental water delivery contributed most to productivity outcomes?*

The median total contribution of Commonwealth environmental water to carbon production was higher during watering actions 1 (11286 kg) and 3 (24649 kg) than watering actions 2 (6676 kg) and 4 (5726 kg). As above, these results reflect the higher overall rates of GPP during summer and the greater probability that pulsed events (i.e., days with very high rates) will occur, as well as the longer durations of watering actions 1 and 3 (41 and 62 days) compared with actions 2 and 4 (15 and 37 days). These actions occurred at the time when there were return flows from Millewa Forest due to the Southern Spring Flow. However, the percentage contribution of CEW to total production was higher during watering action 4 (68 % of total) than in watering actions 1 (32 % of total) and 3 (49 % of total). As in previous years (Watts et al., 2020) delivery of Commonwealth environmental water thus had a substantial proportional effect during low-flow periods (i.e., GPP and ER were increased by a greater percentage over what could be expected without CEW). Maintaining discharge and wetted area during these periods likely helps maintain zooplankton and other invertebrates that feed on phytoplankton and periphyton, and in turn this increases food availability for fish and other higher order consumers during periods in which food availability might otherwise be low.

It is still very important to note that although these watering actions provided a beneficial outcome for the riverine ecosystem, it is highly probable that reconnecting backwaters and the floodplain to the river channel would result in much larger positive outcomes. At this stage there is too much uncertainty in the nominal flow category discharges to extend the analysis done here to the relatively small number of days with higher flows, but this may be achievable for future analyses. It is recommended that, when possible, consideration be given to providing larger within channel flows in the Edward/Kolety-Wakool system in future years.

# 7 RIVERBANK AND AQUATIC VEGETATION

Authors: Robyn Watts, Sascha Healy, Nicole McCasker

| Key findings | |
|---|---|
| **Total species richness** | In general, the watering actions in 2020-21 maintained total species richness of riverbank and aquatic plants. There has been an increase in the mean total richness in each of the five monitored zones since the flood in 2016, especially in zones 1 and 4, however the mean total species richness has not yet recovered to the same as prior to the 2016 flood. The mean total number of taxa was higher in zones 1,3,4 and 8, that have consistently received environmental watering actions compared to zone 2. |
| **Richness and percent cover of functional groups** | Since the 2016 flood there has been a reduction in the % cover of riverbank and aquatic plants. The patterns varied within functional groups. In 2020-21 taxa were classified into 6 groups) previously 3 groups): submerged, amphibious responder, amphibious tolerator, terrestrial damp, terrestrial dry, and terrestrial woody taxa.<br>After the 2016 flood all submerged taxa were absent from monitored river zones. Since the flood submerged taxa have receovered in all zones, but the total richness has not yet reached levels observed prior to 2016. In 2020-21 the maximum mean % cover of submerged *Chara* sp decreased, but presence was maintained in zones 1,3,4,8 that regularly receive environmental water. *Chara* continues to be absent from Wakool River zone 2 that has not received as many watering actions as other zones.<br>Since the flood the number of amphibious taxa has increased in all zones, but total richness has not recovered to that observed prior to the flood. Amphibious responder taxa have responded variably to flows.<br>• The 2016 flood had minimal impact on the percent cover of spiny mudgrass (amphibious responder). In 2020-21 this species had higher % cover in all zones compared to prior to the flood, regardless of environmental watering history.<br>• Amphibious responders floating pondweed, azolla, milfoil and water primrose were negatively impacted by the 2016 flood, with most of these taxa absent from most zones after the flood. There has been a small increase of % cover of these taxa since the flood. More amphibious responder taxa have re-established in zones 1, 3, 4, and 8, that have received more environmental water than zone 2.<br>• The number of amphibious tolerator taxa in zones 1, 3 and 8 in 2020-21 continued to be lower than the number of taxa prior to the 2016 flood. Common spikerush (*Eleocharis sp.)* tolerated the 2016 floods and maintained % cover across all years with no strong relationship to watering regime. The patterns of rush (*Juncus*) % cover do not appear to be related to environmental watering.<br>• Following the flood in 2016 there was a reduction in the mean total richness of terrestrial taxa in all zones, but the patterns were variable. For example, the terrestrial damp common sneezeweed increased in cover after the flood, especially at transects higher up on the bank that are not usually inundated. Most other terrestrial damp taxa have shown very little change over time. |
| **Other responses** | Watering actions 1 and 5 (spring fresh) in Yallakool-Wakool and Colligen-Niemur systems stimulated germination and early growth of riverbank and aquatic vegetation. Germination was evident on the part of the riverbank that had been wetted from the watering actions. Watering action 3 (summer fresh to follow-up spring fresh) supported the persistence and growth of seedlings on the riverbank in 2020-21. |

## 7.1 Background

Riverbank and aquatic plants play an important role in the functioning of aquatic ecosystems, supporting riverine productivity and food webs and providing habitat for fish, frogs, birds and invertebrates (Roberts and Marston 2011). Flow management and the water regime in a river system can affect the survival, growth and maintenance of adult plants and influence reproductive cycles, including flowering, dispersal, germination and recruitment. Riverbank plant survival and growth is affected by the frequency and duration of inundation (Toner and Keddy 1997; Johansson and Nilsson 2002; Lowe et al. 2010). Frequent inundation can delay reproduction (Blom and Voesenek 1996), whilst long duration of inundation, such as during floods or long periods of regulated flows, can reduce growth or survival of riverbank plants (Blom et al. 1994; Johansson and Nilsson 2002; Lowe et al. 2010). Favourable soil moisture and nutrient conditions created by a receding flood can encourage rapid recovery and root and shoot development. Many plants, including emergent macrophytes and riparian understorey plants, germinate on flood recessions (Nicol 2004; Roberts and Marston 2011). However, a high level of sediment deposition during periods of inundation can reduce the survival of some small herbaceous riverbank species (Lowe et al. 2010). Riverbank and aquatic plants can be broadly classified into three functional groups that are defined by wetting and drying patterns. Submerged taxa occupy the wetted river channel, terrestrial taxa typically occupy the upper section of the riverbank, and amphibious taxa occupy both wet and dry parts of the riverbank and respond to, or tolerate, fluctuations in wetting and drying.

The Edward/Kolety-Wakool system has had a history of river regulation. This, combined with the prolonged millennium drought (van Dijk 2013; Chiew et al. 2014), has had negative impacts on riverbank and aquatic plants in the Edward/Kolety-Wakool system. Community members and landholders report there were historically beds of ribbon weed (*Valisineria australis*) within the channels and diversity of other plants occurring on the riverbanks prior to the Millenium drought. However, after the break of the drought, submerged and amphibious plant taxa were largely absent throughout the system, with the exception of the longer-lived rush *Juncus* sp.

One of the aims of environmental water delivery in the Edward/Kolety-Wakool system is to maintain riparian and in channel vegetation condition and increase periods of growth for nonwoody vegetation communities that closely fringe or occur within river corridors (CEWO 2020b). Environmental flows can increase lateral connectivity by increasing the area of riverbank receiving periods of wetting and drying than under operational flows. This is expected to maintain the health of riparian and in-channel aquatic native vegetation and support ongoing recovery and re-establishment of native aquatic vegetation in this system.

The response of vegetation to environmental watering actions in 2020-21 will be influenced by the condition and diversity of plants at the start of the watering year. The 2016 flood reduced the cover and richness of riverbank and aquatic vegetation in all zones (Watts et al. 2017b). Between 2017 and 2020 there was evidence of recovery, with some tolerant taxa responding relatively quickly after the flood, while other less tolerant taxa were taking a longer-time to recover. However, the total species richness and the percent cover of plant taxa continued to be lower than prior to the 2016 flood (Watts et al. 2019, 2020). This chapter reports on the recovery of riverbank and aquatic vegetation in the Edward/Kolety-Wakool system in 2020-21 since the 2016 flood.

## 7.2 Environmental watering actions for vegetation outcomes

Eight Commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2020-21 (Table 2.7). Those actions that specifically included objectives relating to vegetation are shaded in Table 7.1. Responses to these watering actions and antecedent actions over previous watering years is evaluated in this section.

**Table 7.1** Commonwealth environmental watering actions in 2020-21 in the Edward/Kolety-Wakool River system and list of objectives from Table 2.7, with those targeting vegetation outcomes marked in blue.

| Watering Action | System | Name | Objectives (from CEWO) | Dates |
|---|---|---|---|---|
| 1 | Yallakool-Wakool system | Spring fresh | 800 ML/day flow trial to test inundation extent, coordinated with wider Murray River actions to maximise benefit. Slow recession for instream water plants to elevated base flow of 380 ML/d<br>To provide early season rise in river level to contribute to connectivity, water quality, **stimulate early growth of in-stream aquatic vegetation**, pre-spawning condition of native fish and/or spawning in early spawning native fish. | 20/10/20-30/11/20 *(Yallakool)*<br>23/10/20-27/11/20 *(Wakool)* |
| 2 | Yallakool | Elevated base flow | To maintain nesting habitat for Murray Cod, **and inundation for aquatic vegetation growth** | 30/11/20 - 15/12/20 |
| 3 | Yallakool | Summer freshes | To influence and encourage silver perch breeding and fish movement, may also assist with dispersal of larvae and juveniles of a number of fish species. **Slow recession to support instream water plants.**<br>Two freshes: 15/12/20 start peak 1/4.01/21 finish peak 1 start peak 2. 15/2/21 finish peak 2 and recession down to operational base levels of 170 ML/d | 15/12/20–15/2/21 |
| 4 | Yallakool | Autumn fresh | To influence/encourage fish movement. May also assist with dispersal of juveniles of a number of fish species. | 30/3/21-6/5/21 |
| 5 | Colligen-Niemur | Spring fresh | To provide early season rise in river level to contribute to connectivity, water quality, **stimulating early growth of in-stream aquatic vegetation**, pre-spawning condition of native fish and/or spawning in early spawning native fish | 21/10/20 - 6/12/20 |
| 6 | Colligen-Niemur | Elevated base flow | To maintain nesting habitat for Murray Cod, **and inundation for aquatic vegetation growth.** | 6/12/20-8/1/21 |
| 7 | Colligen-Niemur | Summer fresh | Summer fresh to influence and encourage fish movement, may be coordinated with wider Murray River actions to maximise benefit. May also assist with dispersal of larvae and juveniles of a number of fish species. | 8/1/21-26/1/21 |
| 8 | Upper Wakool | Variable base flows | To provide a proactive, longer-term approach to preventing a potential hypoxic water event. **Enable a comparison to previous monitoring data to determine if a longer, higher flow rate is better at maintaining fish, plants**, invertebrates and aquatic species. Improve ability to provide longitudinal connectivity, flow variability and potential refuge. Continue to build good social license among landholders and other stakeholders. Variable cycling for WQ Ranging from 50 ML/d to 120 ML/d | 23/1/21-9/6/21 |

## 7.3 Selected Area evaluation questions

### *Long-term evaluation questions*

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

### *Short-term evaluation questions*

- *What did Commonwealth environmental water contribute to the percent cover of riverbank and aquatic vegetation?*
- *What did Commonwealth environmental water contribute to the diversity of riverbank and aquatic vegetation taxa?*

## 7.4 Methods

### *Monitoring design and field sampling*

Four sites in each of five hydrological zones (Yallakool Creek, Wakool River zone 2, Wakool River zone 3, Wakool River zone 4 and Colligen Creek zone 8) were surveyed (Figure 7.1). Sites were initially established in late 2014 in areas where grazing impacts were minimal or absent, and were located a minimum of two kilometres apart. Monitoring was undertaken once per month from September 2020 to June 2021. At each site six permanent 20 m long transects were established in 2014 parallel with the river channel. Star pickets were installed at each end of the permanent transect. The lowest transect on the riverbank was labelled as transect 0 and the other five transects labelled consecutively up to transect 5 highest on the riverbank. The transects were surveyed so they were 25 cm apart in vertical height, with the five transects thus covering 1.25 m of vertical height of the bank. Transects zero and one were generally in the water at base operational flows, and the other four transects further up the riverbank have the potential to be inundated during environmental watering or during unregulated flows.

Vegetation was assessed using the line point intercept method along transects. At each of the transects on each sampling date a 20 m tape measure was laid out running horizontally along the riverbank between two star pickets that had been installed at a known height of riverbank. The taxa at each 50 cm point quadrat along the 20 m transect (40 points on each transect) were recorded. Plants and macroscopic algae (e.g., Charophytes) were identified to species where possible, but if the plants were very small and without seeds or flowers to enable correct identification they were identified as far as possible. Plants were identified using the Flora of New South Wales Volumes 1–4 (Harden 1992, 1993, 2000, 2002) and keys and descriptions from PlantNet (RBGDT, 2019) and information from field guides (Sainty and Jacobs 2003, Cunningham et al. 1992). If no vegetation was present at a point, then that point was recorded as bare ground, leaf litter or log/tree trunk. When the transects were in the water the tape measure was laid at the water's edge and a flexible fibreglass pole held from the tape out to the water surface to locate the point on the transect for recording data. Photo-points were established in 2014 at each site and photos were taken on every sampling event.

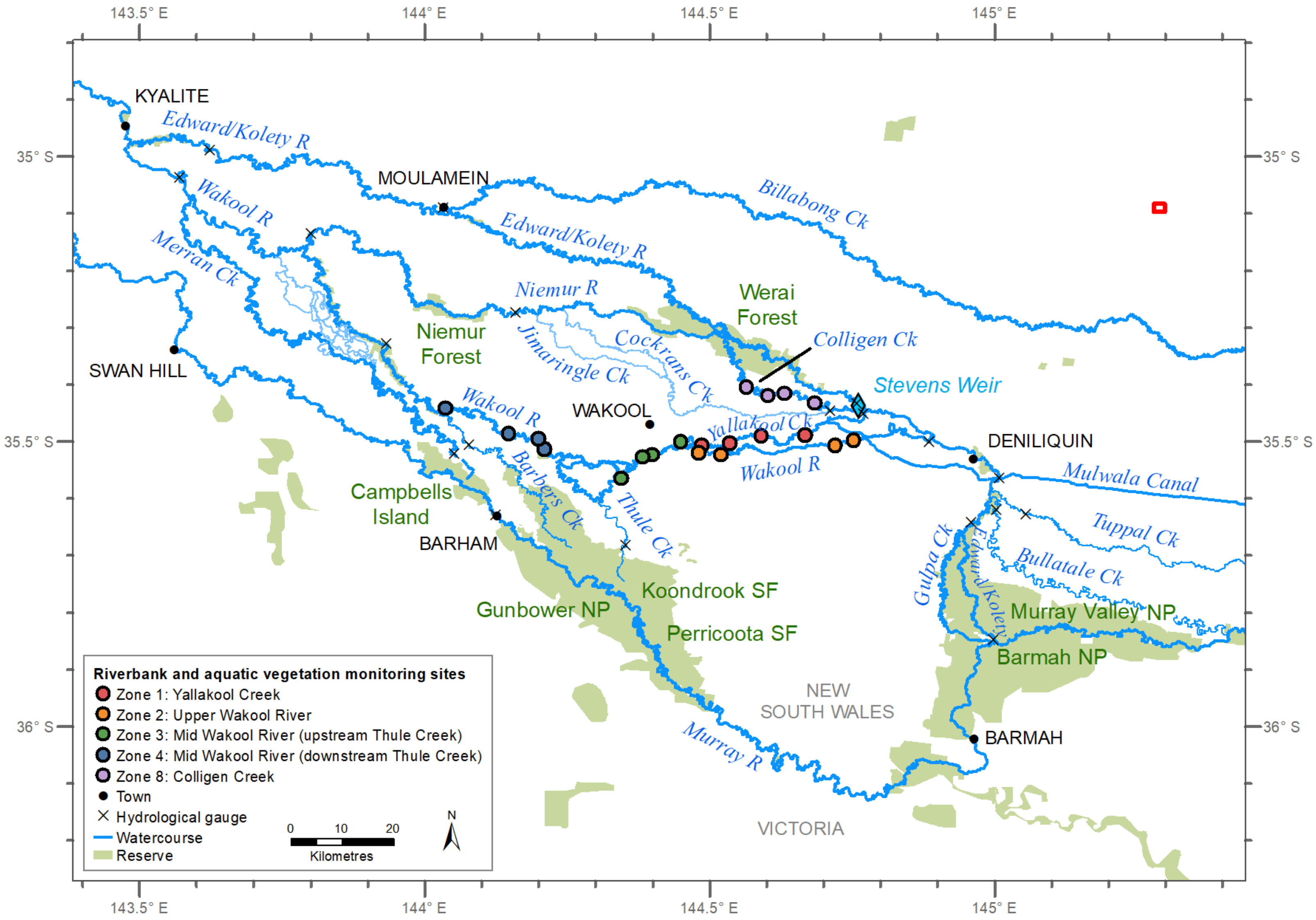



**Figure 7.1** Map of the Edward/Kolety-Wakool Selected Area showing existing LTIM/Flow-MER sites where riverbank and aquatic vegetation are surveyed.

### *Data analysis*

Each plant taxa was classified into one of three broad functional categories using a range of sources including Brock and Casanova (1997), Casanova (2011) and Roberts and Marston (2011). Although there are some limitations of using water plant functional groups to classify taxa, the approach of using three functional categories is sound for common taxa that can be related to hydrological information on wetting and drying regimes. For the 2020-21 reporting the three functional categories were submerged, amphibious and terrestrial, with 6 categories:

**Submerged** - taxa that have adaptations for living submerged in water.

**Amphibious** - taxa that tolerate wetting and drying and taxa that respond to water level fluctuations. Taxa in this grouped were classified as responder taxa and tolerator taxa

**Terrestrial** - taxa that typically occur in damp or dry habitats. This group is subdivided into Terrestrial damp (Tda), terrestrial dry (Tdr), and woody taxa (W).

Total species richness was calculated for each site in each zone for each month. The percent cover was calculated for each transect for each month. To compare cover of vegetation across the six years of the LTIM/Flow-MER Program (2014-2020), the month when the maximum cover occurred across the months of October to May was identified for each taxa. The period from October to May was selected because it is the main growing season for these plants.

## 7.5 Results

### *Total species richness and cover*

The 2016 flood resulted in a decrease in total species richness in all study zones in 2016-17 (Figure 7.2). The mean species richness has not yet recovered to the same levels as prior to the flood. The mean total number of taxa continues to be consistently lower in zone 2, which in some years received no environmental water, and has received fewer environmental watering actions over the seven years of monitoring compared to the other zones. In general, the environmental watering actions in 2020-21 maintained total species richness of riverbank and aquatic plants.

A large percentage of taxa across the five hydrological zones were native taxa (Figure 7.3). A greater proportion of native taxa were negatively impacted by the 2016 flood. There was a significant reduction in percent cover of native taxa following the 2016 flood (Figure 7.4). The maximum mean percent cover is still considerably lower than that observed in 2015-16 prior to the flood (Figure 7.4), particularly in zone 3.

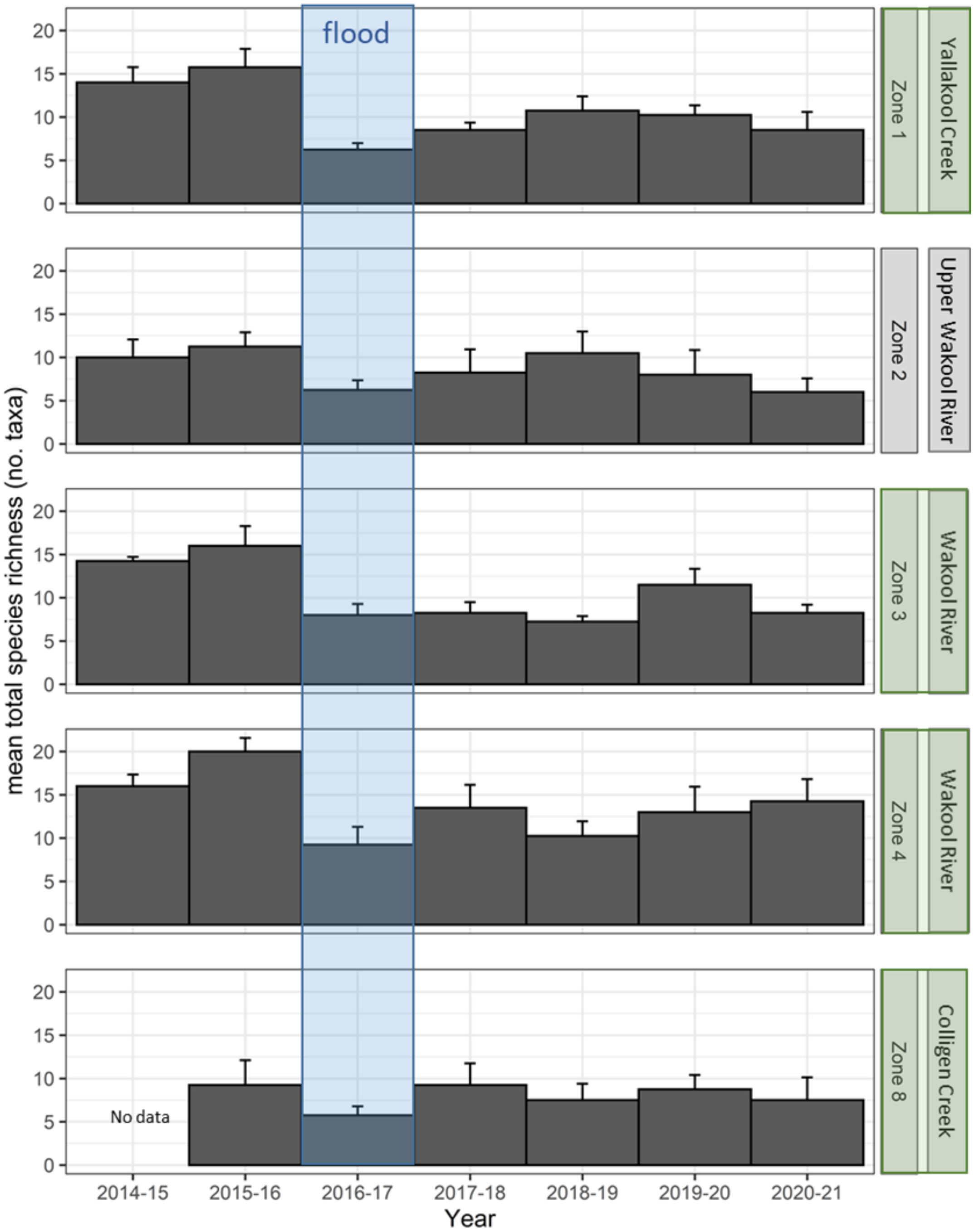



**Figure 7.2** Mean total richness of vegetation taxa monitored monthly in five zones in the Edward/Kolety-Wakool system between 2014 and 2021. Blue shading indicates the unregulated flood in 2016-17 water year. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

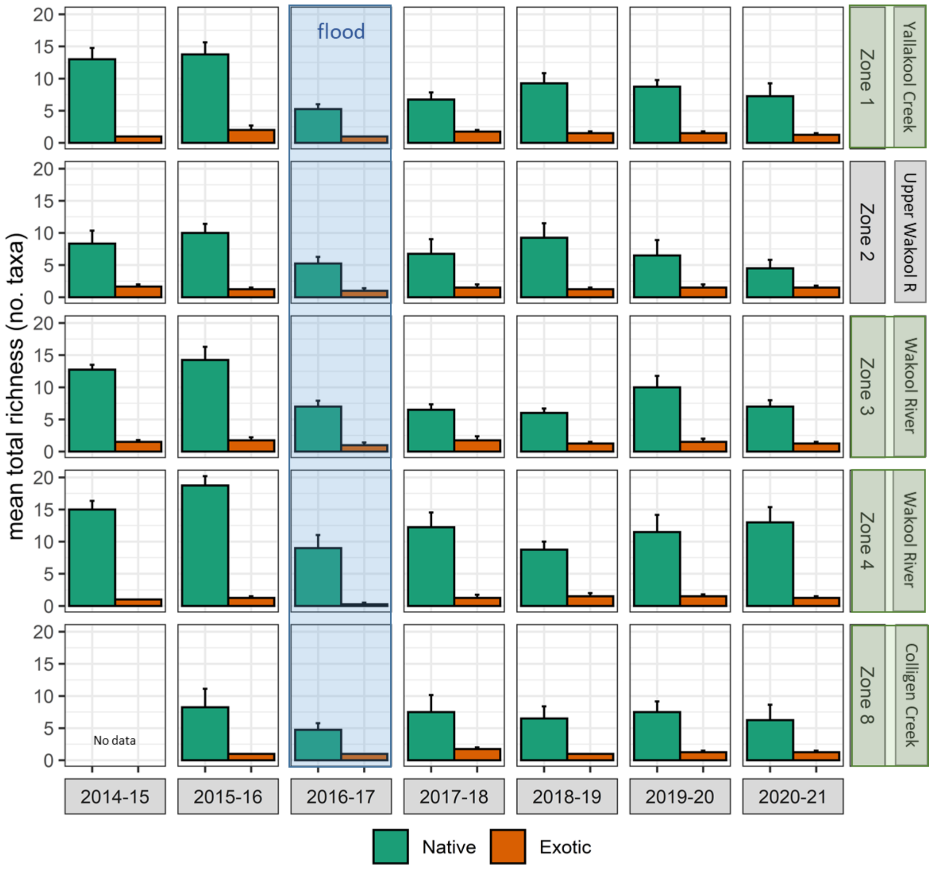



**Figure 7.3** Mean richness of native and exotic vegetation taxa monitored monthly in five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Blue shading indicates the unregulated flood in 2016-17 water year. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

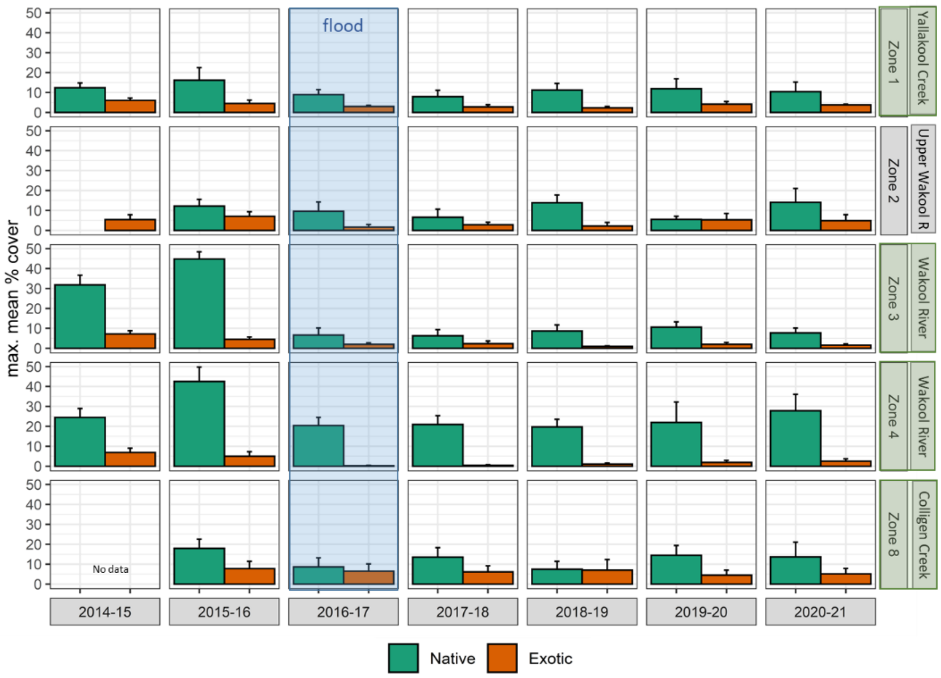



**Figure 7.4** Mean percent cover of native and exotic vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

### Richness and cover of functional groups

Following the flood in 2016 there was a reduction in mean total richness of most functional groups in all hydrological zones, with the least change observed in terrestrial dry taxa (Figure 7.5). Similarly, since the flood there has been a reduction in the percentage cover of functional groups (Figure 7.6). However, the patterns are varied within functional groups.

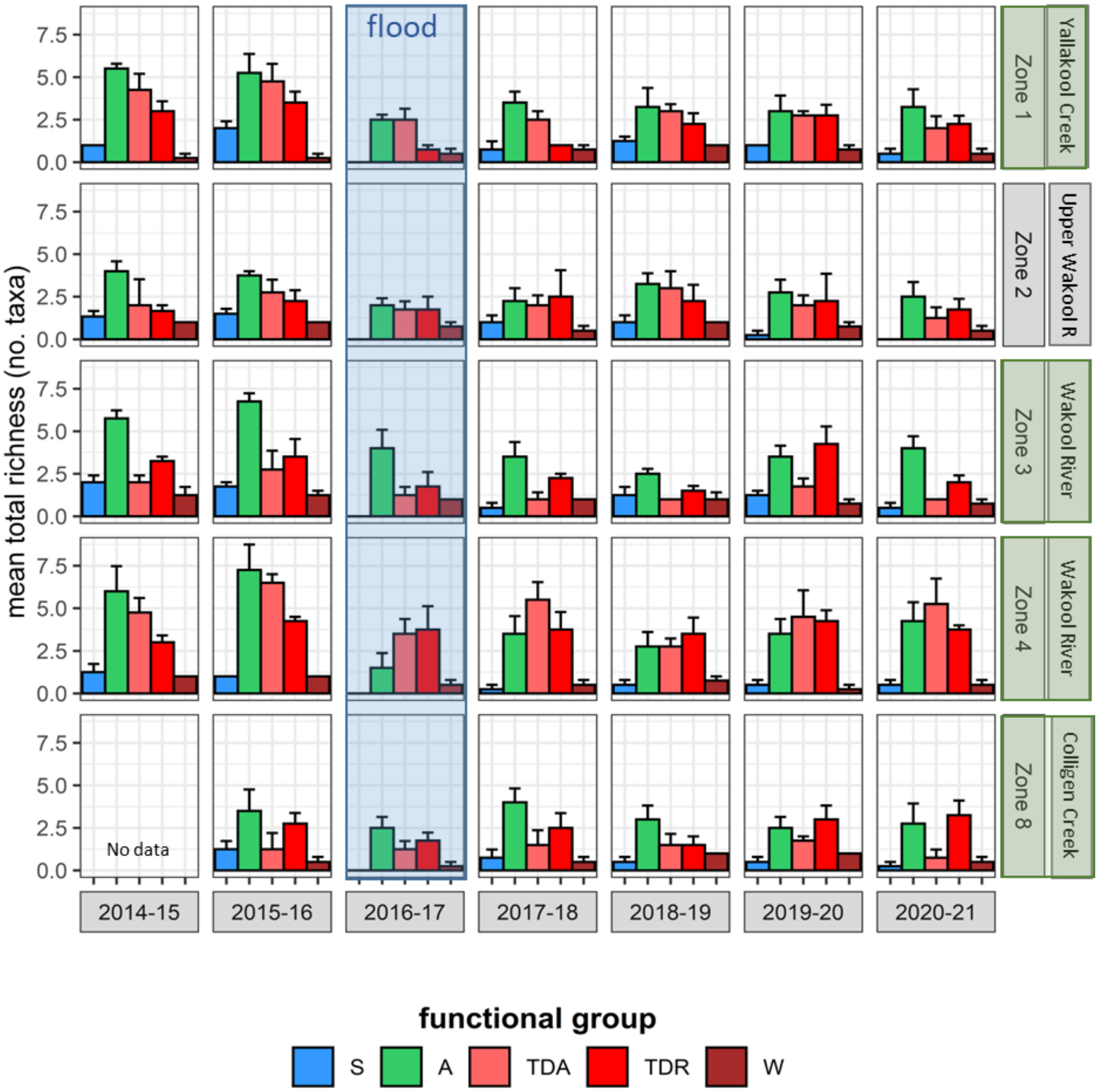



**Figure 7.5** Mean total richness of vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2020. Taxa were classified as submerged, amphibious, terrestrial damp, terrestrial dry, and woody. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

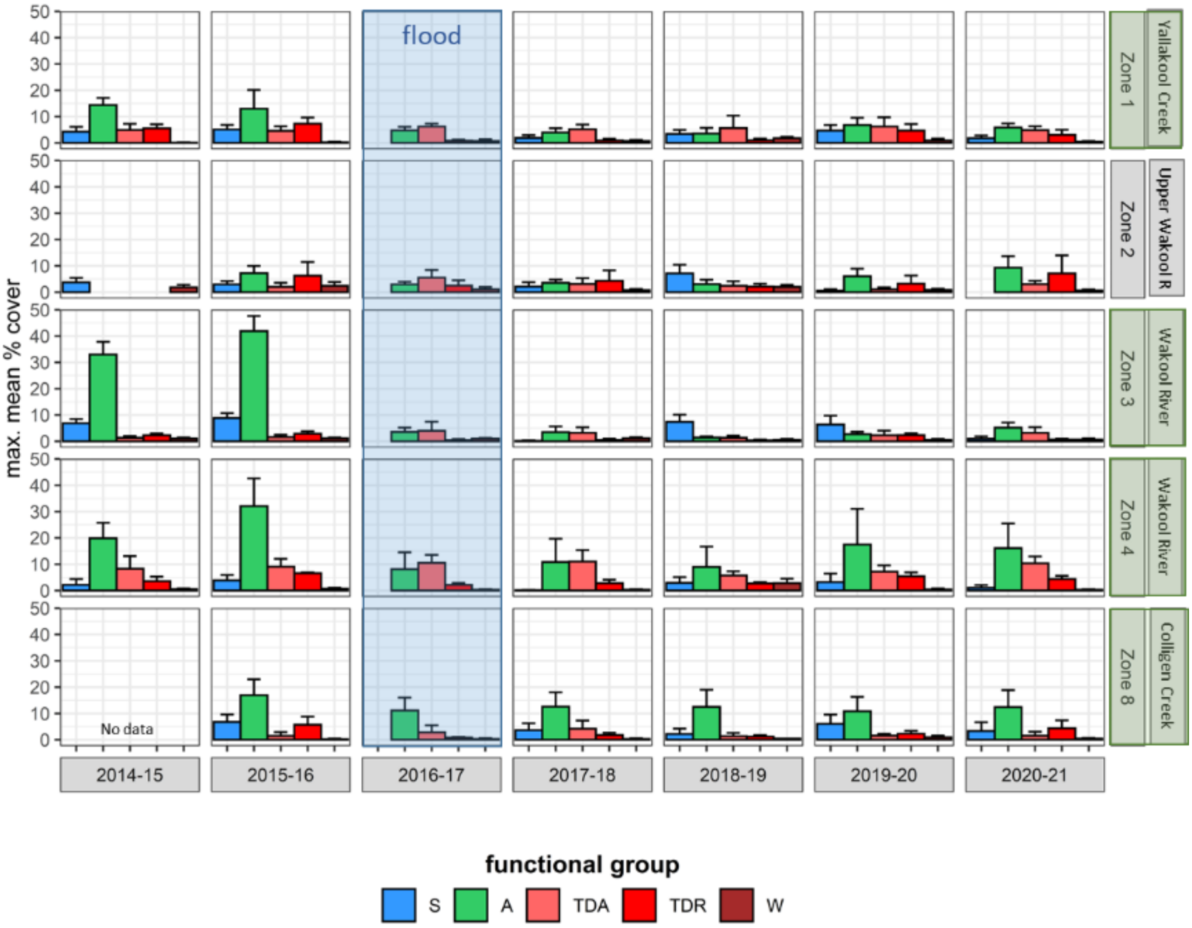



**Figure 7.6** Mean percent cover of vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Taxa were classified as submerged, amphibious, terrestrial damp, terrestrial dry, and woody. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

### *Richness and cover of submerged taxa*

Following the flood in 2016 there was a reduction in mean total richness of submerged taxa in all zones, with no submerged taxa surviving after the flood. Since 2017-18 there has been a recovery of submerged taxa in all zones (Figure 7.7), but the total richness has not yet reached levels observed prior to the flood. In 2019-20 the maximum mean percent cover of submerged taxa increased (zones 1 and 8) or was maintained (zones 3 and 4) in zones that received environmental water, but reduced in zone 2 (Upper Wakool River) that did not receive environmental water in 2019-20. However, in 2020-21 there was reduction in the cover of submerged taxa in all zones.

The dominant submerged taxa is Chara, a macroalgae. There is a seasonal pattern in the presence of Chara, with highest cover observed between September and December in most years.

In 2018-19 Chara was present in all five study zones following environmental watering actions, but the percent cover of this taxa was low. In 2019-20 and 2020-21 there was a significant increase in the cover of *Chara* in the zones 1, 3, 4 and 8 that received spring freshes (Figures 7.7, 7.8). This increase was substantial, such that the percent cover of Chara in these four zones had returned to levels observed prior to the flood. In 2019-20 there was no environmental water delivered to zone 2 and Chara was absent (Figures 7.7, 7.8).

In 2020-21 *Chara* in the zones 1, 3, 4 and 8 that received spring freshes, albeit at a slightly lower cover than in 2019-20. Chara was absent in zone 2 upper Wakool River that received variable base environmental flows, but did not receive a fresh.

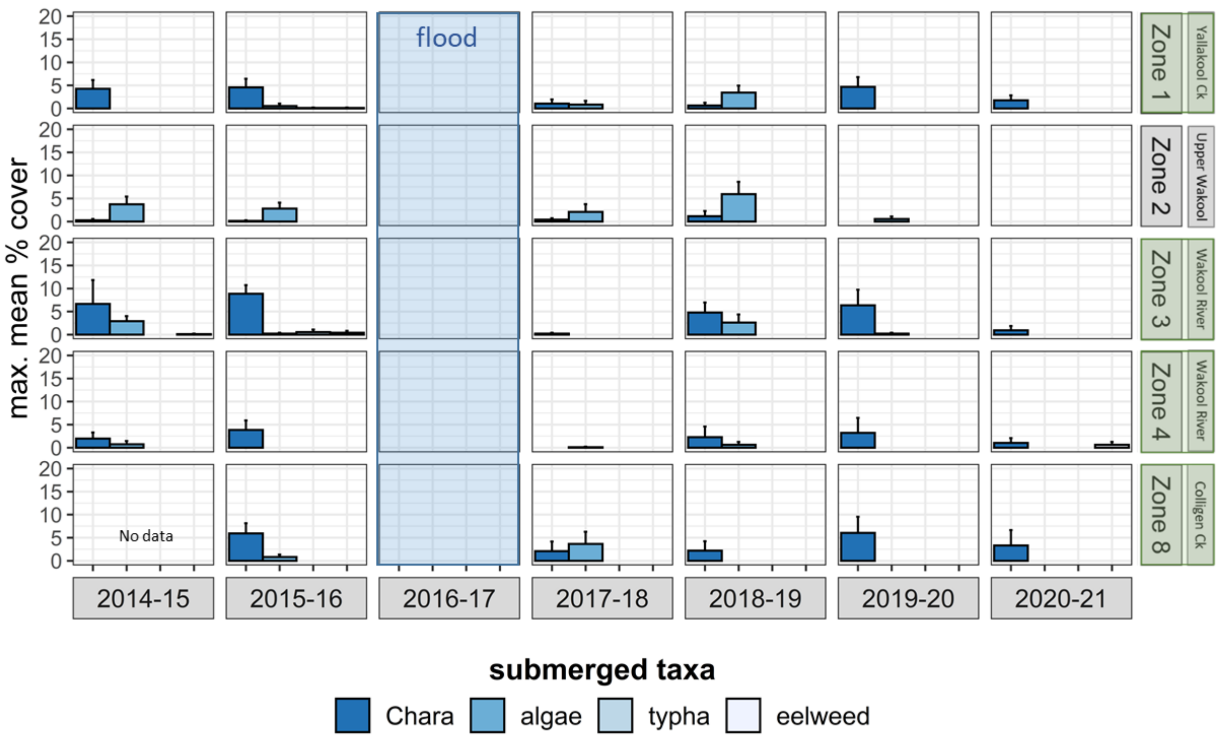



**Figure 7.7** Mean percent cover of four submerged vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

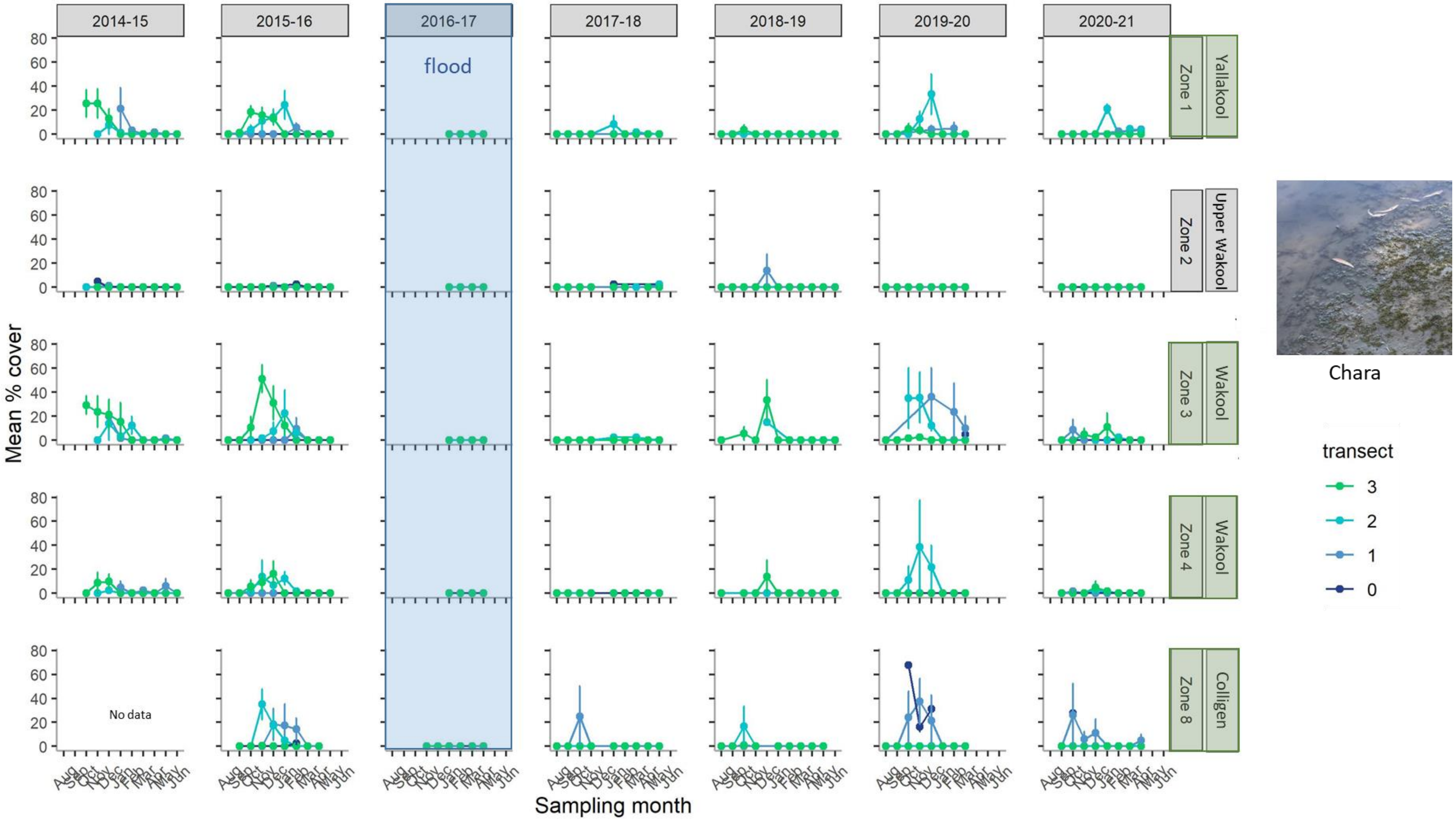



**Figure 7.8** Mean percent cover of *Chara* monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

### *Richness and cover of amphibious taxa*

Following the flood in 2016 there was a reduction in mean total richness and percent cover of amphibious taxa in all zones (Figures 7.5, 7.6). The reduction in percent cover was considerable in zones 3 and 4. Since the flood the number of amphibious taxa has increased in all zones (Figure 7.5). However, total richness has not recovered to that observed prior to the flood.

In 2020-21 we classified amphibious taxa as responder and tolerator taxa, which is a different approach to that taken in prrevious years.

**Amphibious responders**

Amphibious responder taxa have responded variably to the flood disturbance in 2016 (Figure 7.9).

The flood in 2016 had minimal impact on the percent cover of amphibious responder spiny mudgrass (*Pseudoraphis spinescens)* (Figures 7.9 and 7.10). Spiny mudgrass persisted in all zones after the 2016 and has increased in percent cover every year, particularly in zone 4 where it was prevalent prior to the flood. In zones 2, 4 and 8 it is currently at higher percent cover than prior to the flood. This species has recovered well since the flood and increased in percent cover in zone 4 such that it currently has a higher percent cover in all zones than was recorded prior to the flood (Figures 7.9, 7.10), regardless of environmental watering history.

In contrast, amphibious responders floating pondweed (*Potamogeton tricarinatus)*, azolla, milfoil and water primrose were all negatively impacted by the flood in 2016 (Figure 7.9), with most of these taxa absent in most zones after the flood. There has only been a very small increase of percent cover of these taxa since the 2016 flood. None of these four responder taxa has re-established in Zone 2 that has received fewer environmental watering actions than the other four zones. More of the responder taxa have re-established in zones 1, 3, 4, and 8 that have received more environmental watering actions than zone 2 (Figure 7.9).

Floating pondweed was previously the dominant amphibious taxa in zone 3 prior to the flood (Figure 7.9) but significantly reduced in cover or was killed by the flood in 2016 (Figure 7.11). It was absent from all zones after the flood and was not recorded in 2017-18 or 2018-19. It was recorded again for the first time in 2019-20 in zone 3 at low percent cover (Figure 7.9) and in 2020-21 showed a large imcrease in percent cover in zones 3 and 4 (Figure 7.11), but has not yet reached the same cover as prior to the 2016 flood.

Similarly, the amphibious responder milfoil (*Myriophyllum spp)* was abundant in zones 1, 3 and 4 prior to the flood and was absent in 2017-19 but was recorded at low percent cover in zones 1 and 3 in 2019-20 (Figure 7.12) and was recorded at slightly increased percnt cover in zones 1, 3 and 8 in 2020-21, suggesting there is a gradual recovery of these species following environmental watering actions.

Water primrose has recovered in zone 4 at low percent cover but has not yet been detected in the survey transects in the other zones (Figure 7.9).

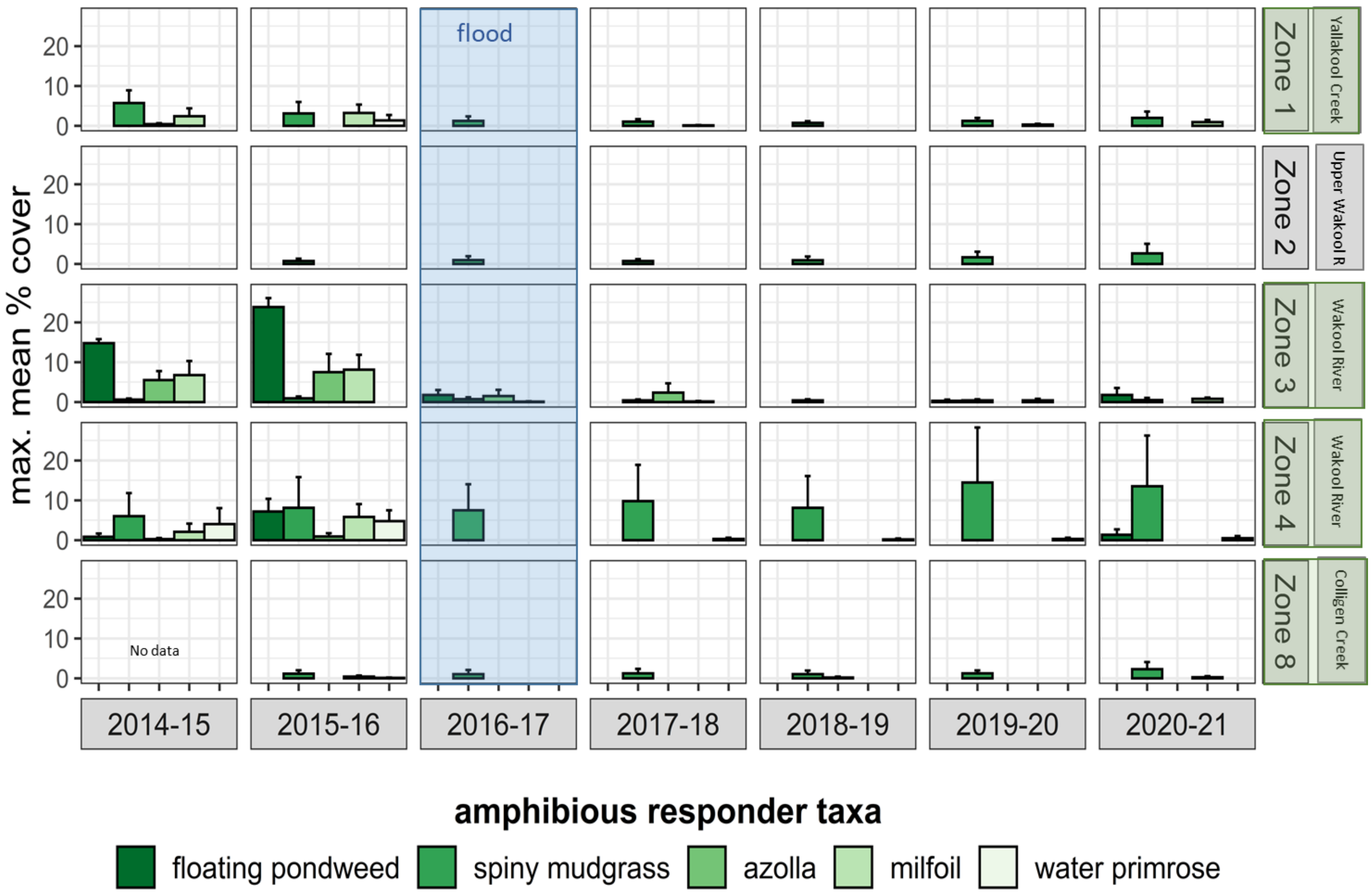



**Figure 7.9** Mean percent cover of the five most abundant amphibious responder vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

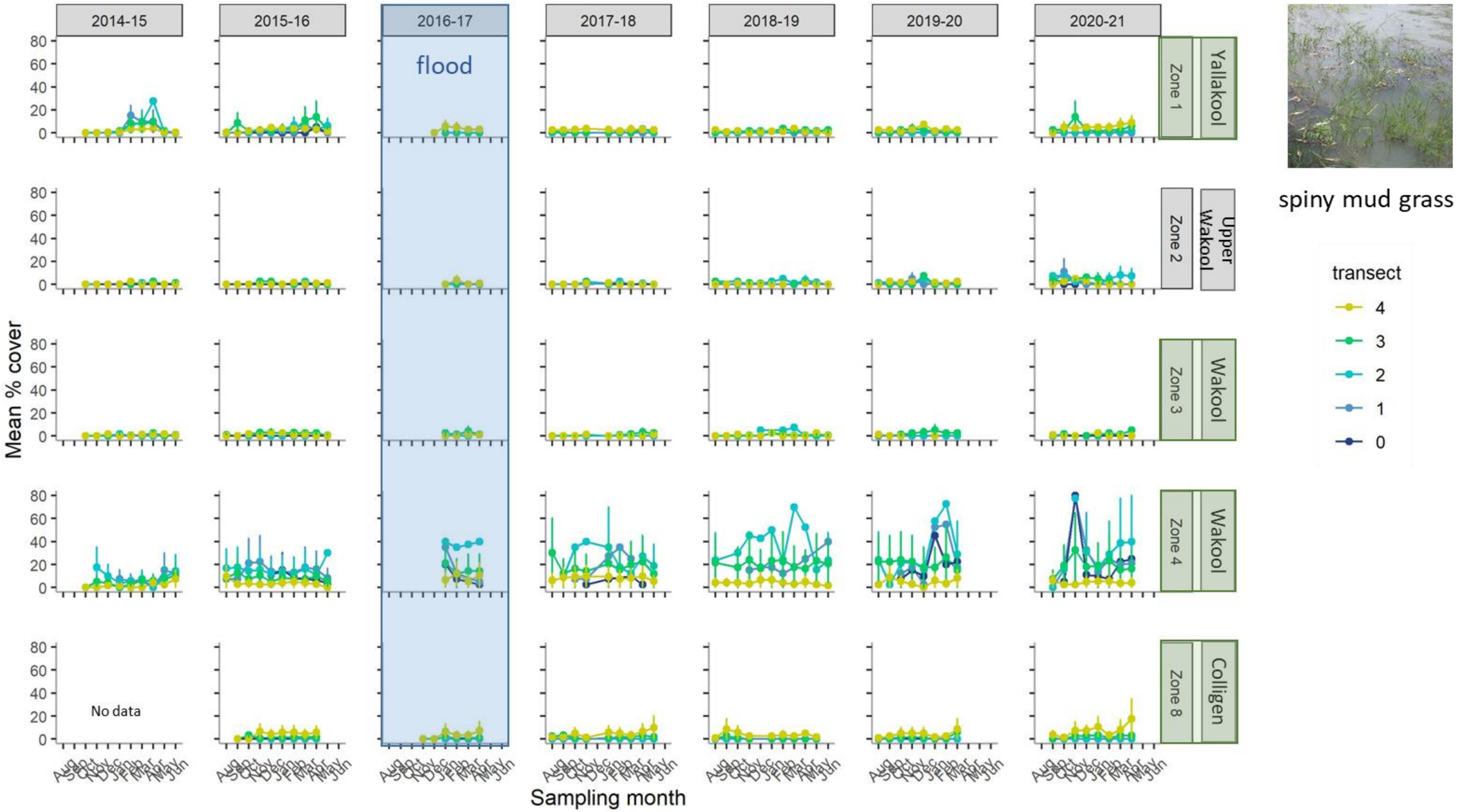



**Figure 7.10** Mean percent cover of spiny mud grass (*Pseudoraphis spinescens*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

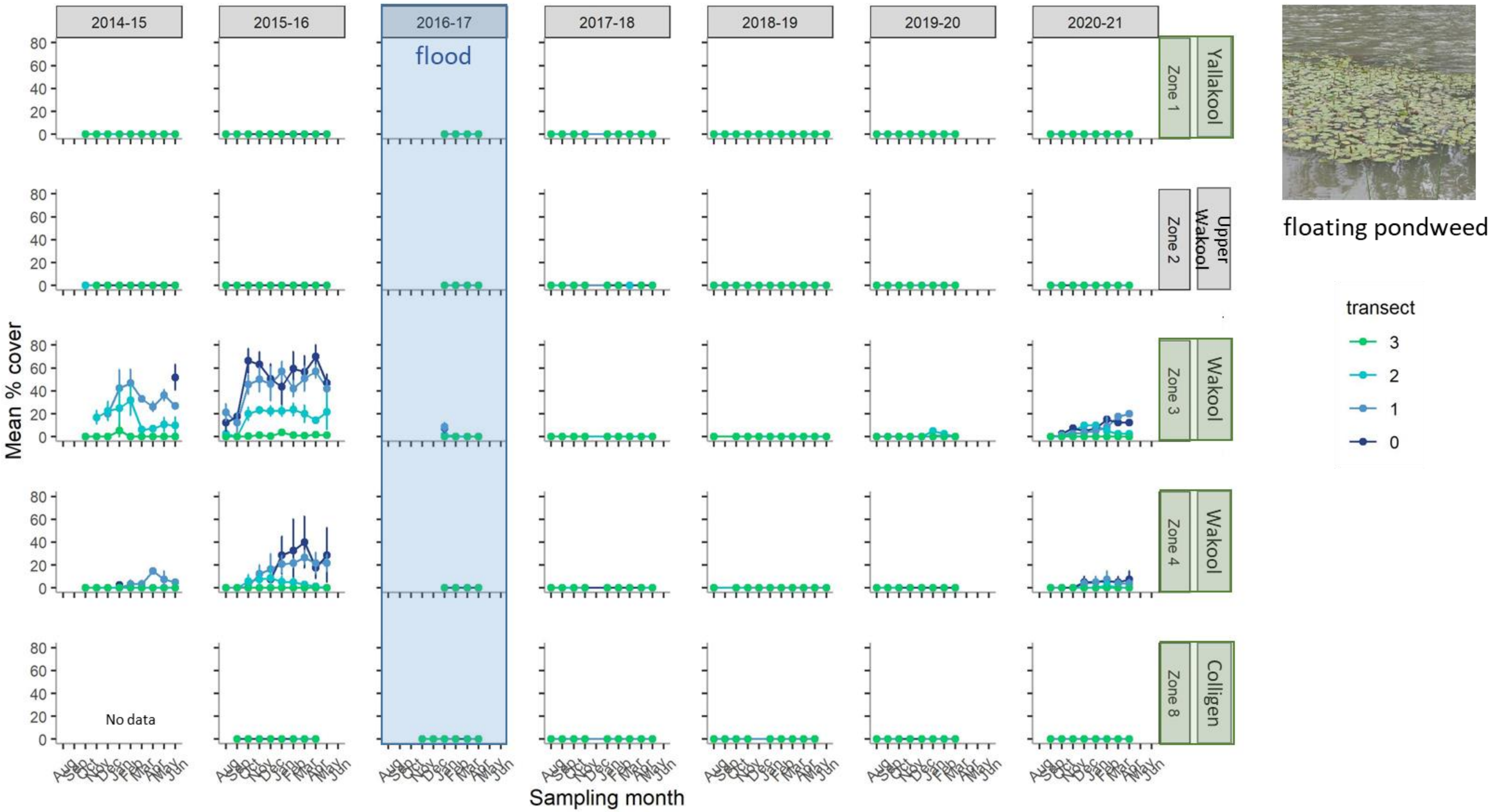



**Figure 7.11** Mean percent cover of floating pondweed (*Potamogeton tricarinatus*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

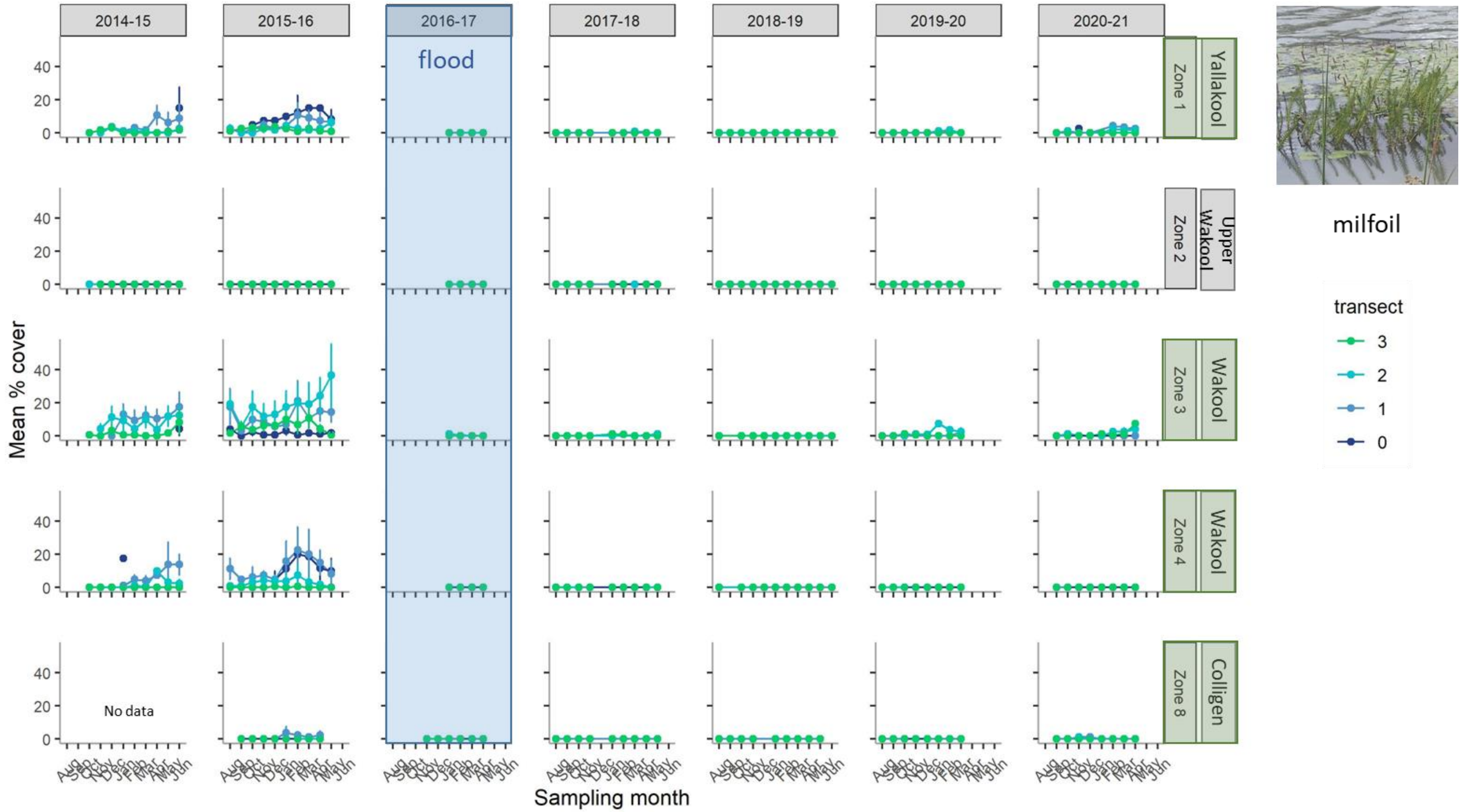



**Figure 7.12** Mean percent cover of milfoil (*Myriophyllum spp*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

**Amphibious tolerators**

Amphibious tolerator taxa responded differently to the flood disturbance in 2016 (Figure 7.13). The number of amphibious tolerator taxa in zones1, 3, and 8 in 2020-21 continues to be lower than the number of taxa in this group prior to the flood.

Common spikerush (*Eleocharis sp.)* was the dominant taxa in zone 8 (Colligen Creek) prior to the flood, and tolerated the flooding and has maintained similar mean percent cover across all years (Figures 7.13) with no strong relationship to watering regime. Spikerush was also present in zones 3 and 4 prior to the 2016 flood as while there was s light reduction in percent cover in zone 3 after the flood, it was present in these zones in all years and has slightly increased cover in zone 4 over time. In 2020-21 it was absent in zones 1 and 2.

The rush (*Juncus sp*.) was also an abundant species and had high percent cover in all zones prior to the flood (Figure 7.13). This rush reduced in percent cover during the flood (with the exception of zone 8), but tolerated the flood and persisted in all zones. Juncus has not yet recovered to the same percent cover in zone 3 and 4 as observed prior to the flood. The percent cover does not appear to be related to patterns of environmental watering.

## *Richness and cover of terrestrial taxa*

In 2020-21 we classified terrestrial taxa as i) terrestrial damp, ii) terrestrial dry, and iii) woody taxa, which is a different approach to that taken in prrevious years.

Following the flood in 2016 there was a reduction in the mean total richness of terrestrial taxa in all zones (Figures 7.5), but the change in cover was variable. Indeed, in some zones there was an increase in percent cover of terrestrial damp taxa (Figure 7.6).

**Terrestrial damp taxa**

The number of taxa of terrestrial damp species did not change following the 2016 flood (Figure 7.14). The terrestrial damp common sneezeweed (*Centipeda cunninghamii)* (Figure 7.15) increased in cover after the flood, especially at transects higher up on the bank (Figure 7.15) that are not usually inundated during operational flows or environmental actions. Most other terrestrial damp taxa have shown very little change over time.

**Terrestrial dry taxa**

The number and cover of taxa of terrestrial dry species reduced following the 2016 flood (Figure 7.16). However, the year following the flood most taxa had returned.

**Terrestrial woody taxa**

Terrestrial woody taxa respond to large floods, with increase in the cover of eucalyptus seedlings particularly evident 2 years after the flood (Figure 7.17). Tangled lignum is more prevalent on the floodplain than on the riverbanks within the channel, so is not impacted by environmental wateing actions.

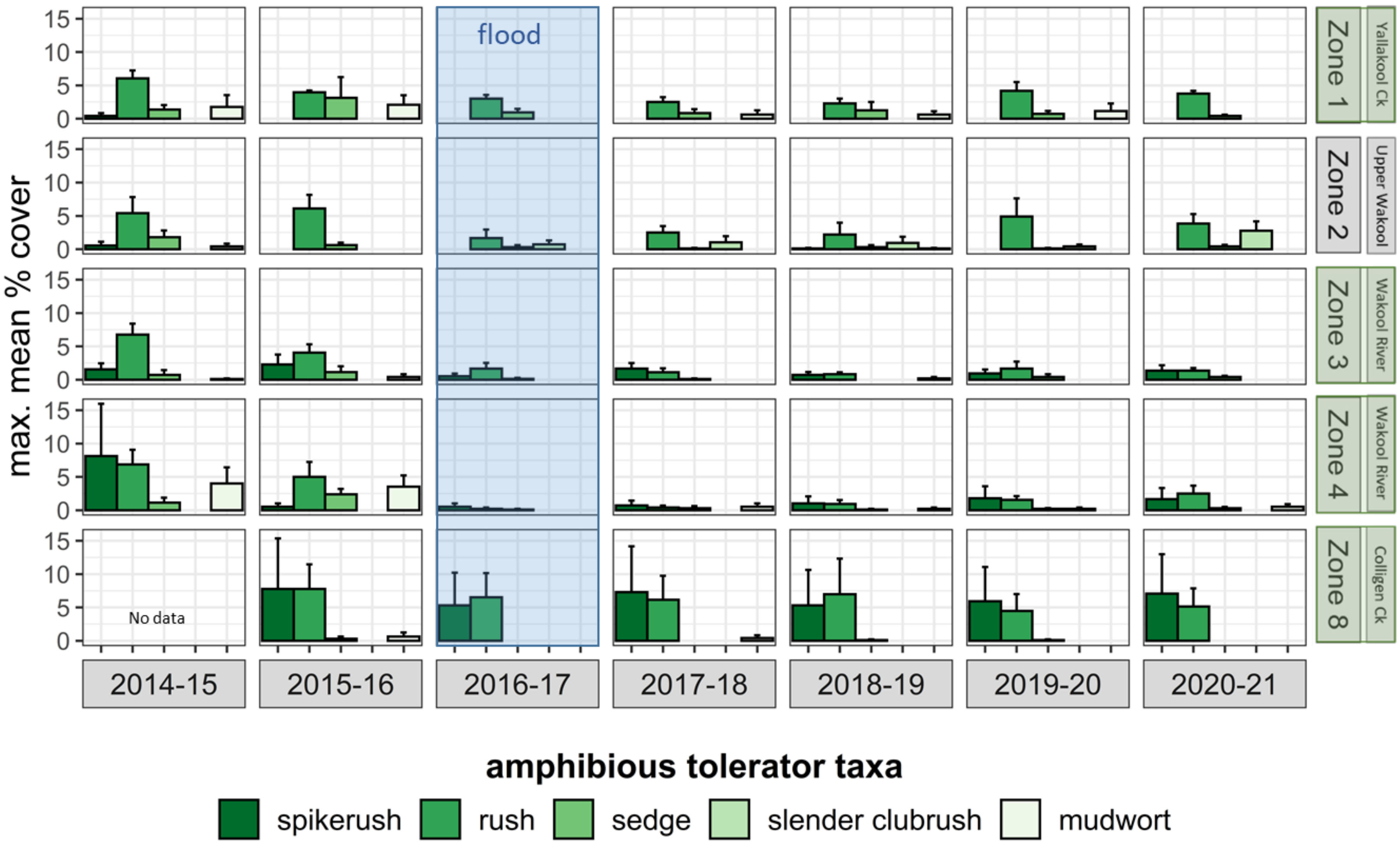



**Figure 7.13** Mean percent cover of the five most abundant amphibious tolerator vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Zones 1, 3, 4 and 8 received environmental water each year. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

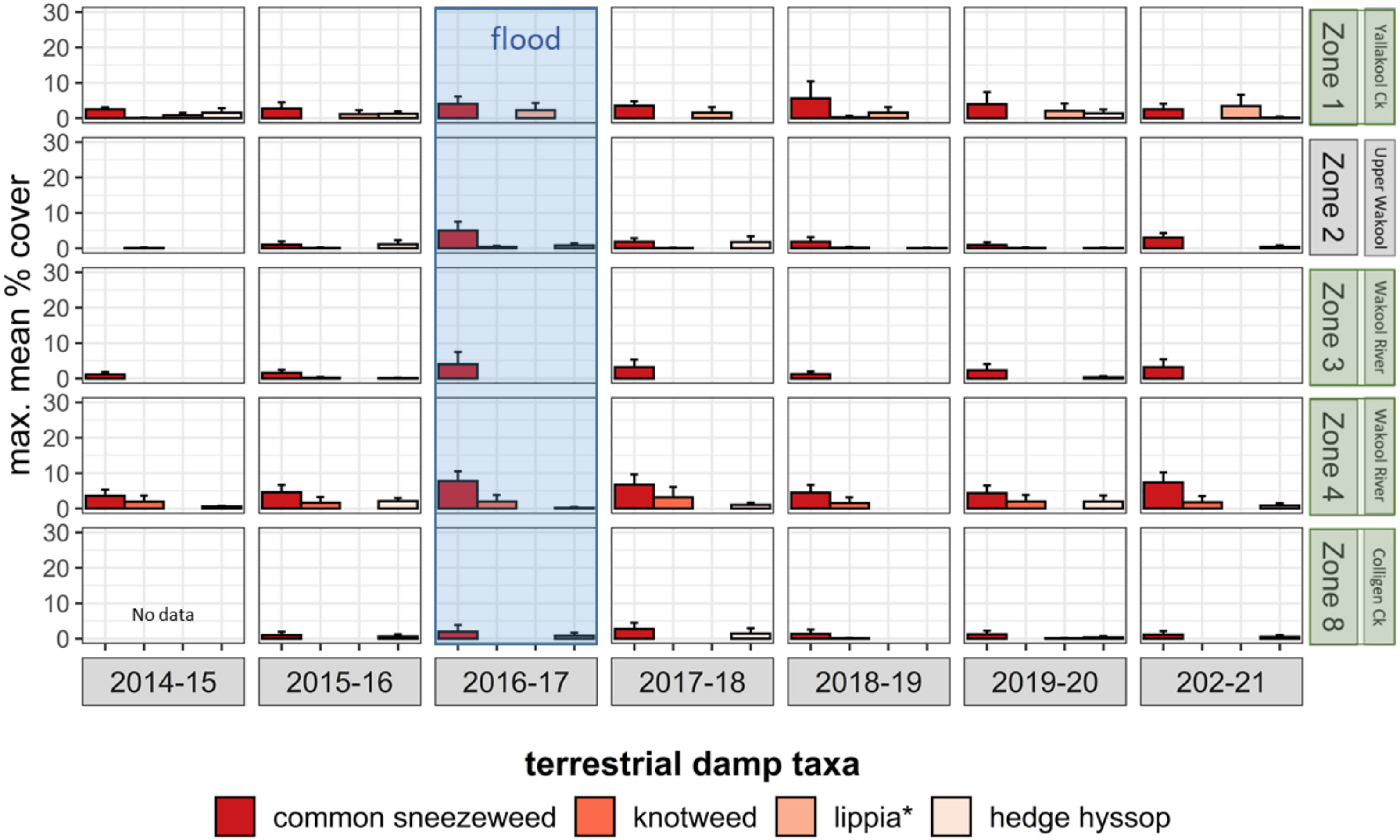



**Figure 7.14** Mean percent cover of the four most abundant terrestrial damp vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

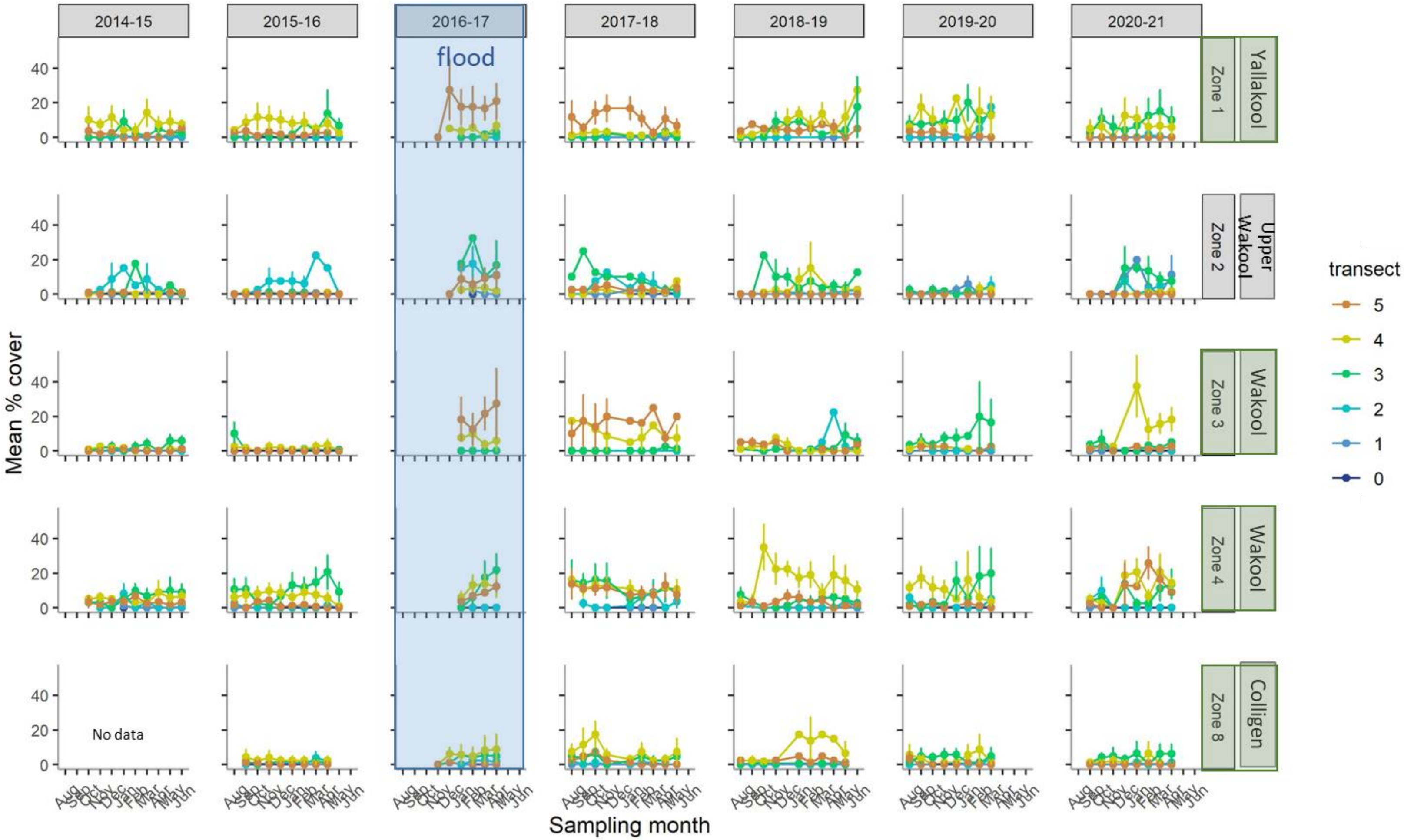



**Figure 7.15** Mean percent cover of common sneeze weed (*Centipeda cunninghamii*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

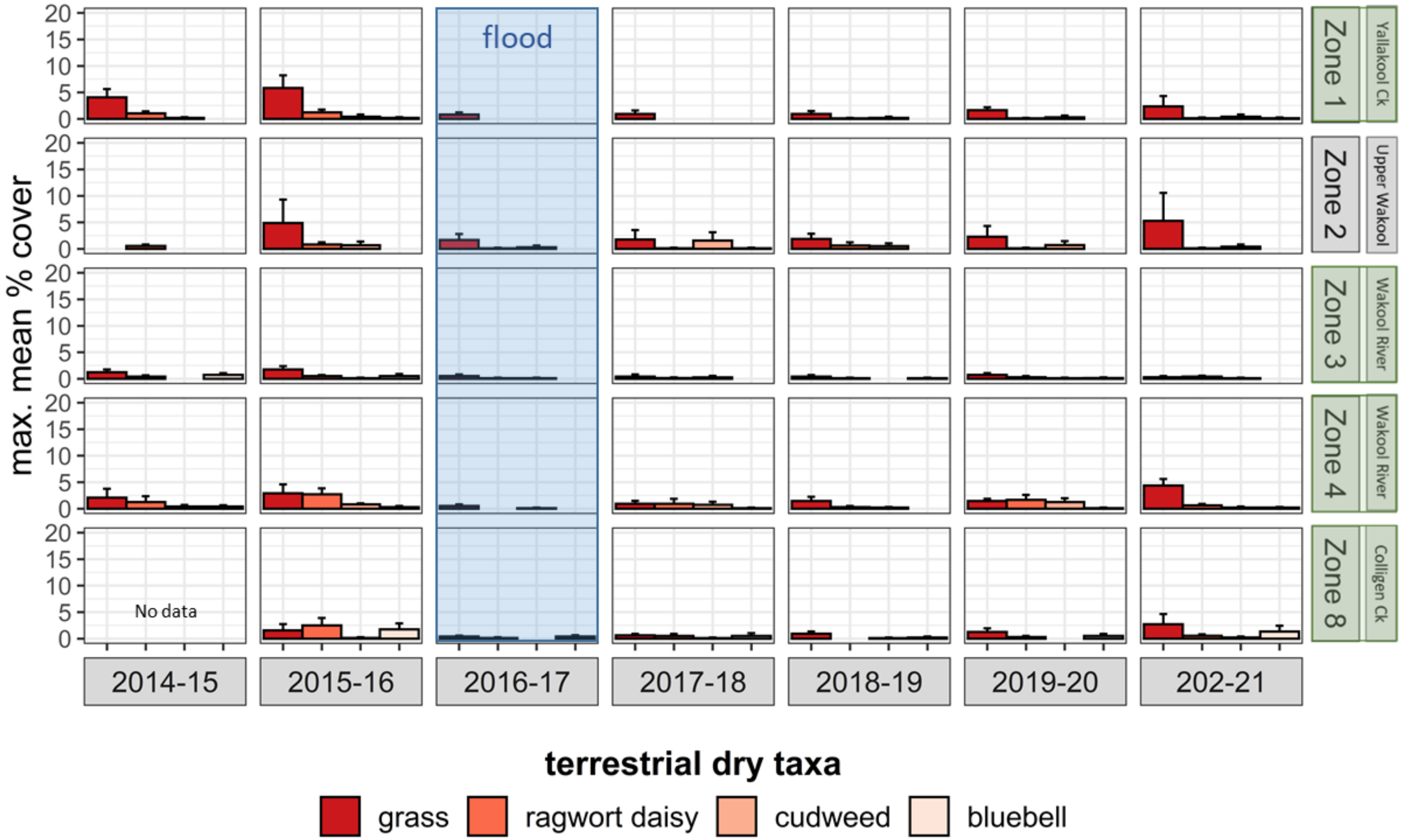



**Figure 7.16** Mean percent cover of the four most abundant terrestrial dry vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

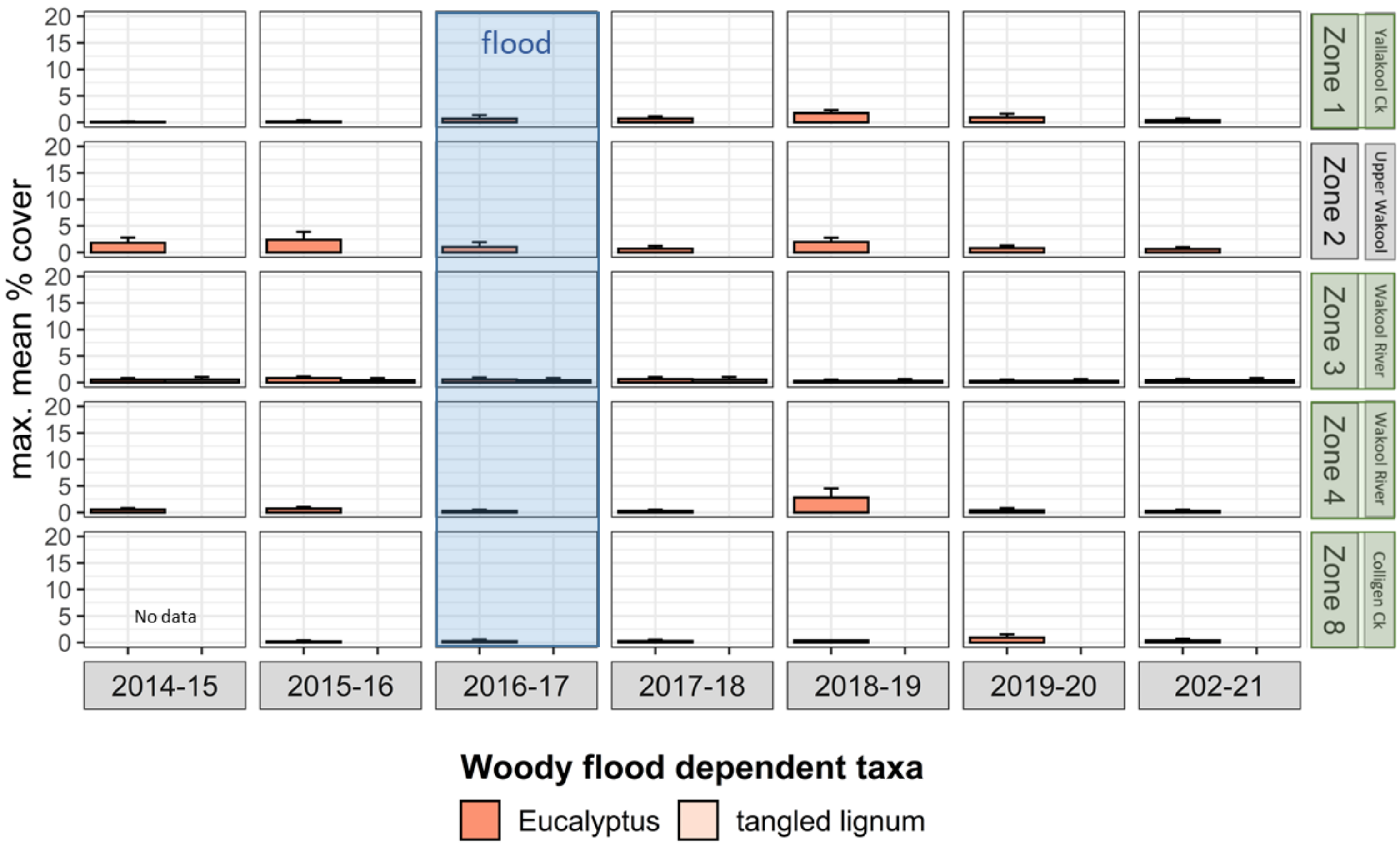



**Figure 7.17** Mean percent cover of the two most abundant terrestrial woody vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Blue shading indicates the unregulated flood in 2016-17. Green shading on zone names indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21.

## 7.6 Discussion

Riverbank and aquatic plants in the Edward/Kolety-Wakool system continue to recover following the reduction in mean species richness and mean cover that occurred following the unregulated flood in 2016.

Since the flood in 2016 there has been evidence of recovery of submerged and amphibious taxa. In 2020-21 there was further evidence signs of recovery such as an increase in the number of amphibious taxa. However, there was considerable variability in the recovery of different taxa and the response to environmental watering actions has not been consistent among zones. The reason for this is because the dominant taxa in different zones have characteristics that enable them to respond differently to inundation. Amphibious responder taxa such as floating pondweed and milfoil that were more common in zone 3 are slowly recovering. In contrast, early responder submerged taxa Chara, and the tolerator amphibious species rush (*Juncus sp.)* and common spike rush have recovered more quickly following the 2016 flood. Other taxa, such as spiny mudgrass were minimally affected by the flood and have continued to thrive in the system. This variability in responses can make it difficult to assess the contribution of environmental water in the recovery of vegetation.

The potential for environmental water to promote recovery of vegetation is evident by comparing the response of taxa in zone 2. In most years zone 2 receives none or very minimal environmental water and this zone has consistently had lower taxa richness than other zones. However, in 2018-19 zone 2 received environmental water released from the Wakool escape from Mulwala canal. This resulted in an increase in mean total species richness of amphibious taxa in the upper Wakool River zone 2 and increased cover of terrestrial taxa. Watts et al (2019) suggested this was likely to be in response to the higher flows and increased variability in this river, and particularly increased wetted area of riverbank that is not usually experienced in this system during operational flows. In 2019-20 zone 2 did not receive any environmental water and the richness and cover of submerged and amphibious taxa reduced relative to the previous year. These observations suggest that environmental water is contributing to the recovery of submerged and amphibious vegetation in this system. The results also support the hypothesis that future delivery of environmental water to zone 2 would result in better environmental outcomes. In 2020-21 zone 2 received variable base flows, but not a large spring fresh as did the other zones. The outcomes of this autumn action maybe more evident in 2021-22 than in the results this year.

These observations of responses of riverbank plants to environmental watering actions over many years suggest that late winter/early spring freshes that inundate slackwater, in-channel benches or low lying areas of riverbank within the channel can trigger emergence of river bank vegetation. Following the recession of flows, these damp banks provide ideal conditions for plant growth prior to the onset of hotter weather in summer that can quickly dry out the riverbanks. Further freshes delivered after the initial event that re-wet these areas can provide suitable conditions for amphibious plants to grow and survive the warmer conditions over the summer.

The floods in 2016 decreased the richness and cover of submerged and amphibious taxa throughout the Edward/Kolety-Wakool system. The reduction in the cover of submerged taxa and amphibious taxa may have been due to extreme physical disturbance experienced during the flood which can restrict access to atmospheric carbon dioxide and oxygen, causing anoxic soil conditions and depleted soil biota (Campbell et al. 2019). Some of the sites had overbank flows for over 1 month during late 2016 and most riverbank transects were underwater for 4 to 5 months and higher turbidity levels with values ranging from ~50 to 300 NTU were observed during this period (Figure 5.4). A reduced light climate during the 2016 flood would have potentially prevented submerged and amphibious plants from photosynthesising. Likewise, in a controlled experiment Doyle and Smart (2001) found that higher turbidity levels significantly affected *Vallisneria americana* in terms of producing less leaf production and biomass and causing a higher mortality rate of plants. In the years since the flood the turbidity in this Edward/Kolety-Wakool study sites were generally above the ANZECC (2000) trigger level and in the range ~40 to150 NTU (section 5). This limitation on light penetration may offer, at least in part, a hypothesis as to why the recovery of submerged and amphibious taxa is slow.

On the recession of the flood, some plants were observed to have died and rotted during the long period of inundation. These observations are consistent with findings of previous studies that long duration of inundation, such as can occur during floods or long periods of regulated flows, can reduce growth or survival of riverbank plants (Blom et al. 1994; Johansson and Nilsson 2002; Lowe et al. 2010). The recovery of several taxa such as floating pond weed, milfoil and water primrose has been slow, as it will take while for the root stocks to increase in the system. The risks to recovery of the submerged and amphibious riverbank plants include disturbance by carp, disturbance by pigs when rhizomes become exposed, damage to riverbanks and reduction of establishing vegetation by stock, and damage from frost if the regulators and system is shut down during the winter.

### *Plant responses to watering actions in 2020-21*

**Watering actions 1 and 5 spring fresh** in Yallakool-Wakool and Colligen-Niemur systems had an objective to stimulate early growth of in-stream aquatic vegetation (Table 7.1). Field observations confirmed that germination did occur in response to this inundation. Photos of seedling emerging on the riverbanks (Figure 7.18) and photos of the riverbank from zone 4 site 2 (Figure 7.19) show extensive germination of riverbank plants in December 2020 in the part of the riverbank that has been wetted from the spring watering action earlier in the year.

**Figure 7.18** Riverbank plant seedlings emerging after the recession of the spring flow.


**Figure 7.19** Photo evidence of extent of germination of riverbank plants following th spring flow. The plants evident in December 2020 at zone 4 site 2 have germinated in the location where there were visibly damp banks in November 2020 following the recession of the environmental watering action.

**Watering action 2 in the Yallakool-Wakool system and action 6 delivery of an elevated base flow** in December 2020 the Colligen-Niemur had an objective to support inundation for aquatic vegetation growth (Table 7.1). There is no strong evidence that this action achieved the outcomes. However, the observed persistence and growth seedlings on the riverbank in December 2020, when in previous years the banks would usually have low cover at this time, suggests this elevated base flow in December may have supported the riverbank plant outcomes.

**Watering action 3 Yallakool fresh (mid December 2020 to mid February 2021) including slow recession** had a general objective to support instream water plants (Table 7.1). There is no definitive evidence that this action achieved the outcomes. However, the observed persistence and growth seedlings on the riverbank in 2020-21 suggests this may have supported the riverbank plant outcomes. For example, Chara showed two peaks of cover including a peak in early 2021, that may have been in reposne to this action (Figure 7.8). Furthermore, in 2020-21 Potamogeton in zone 3 and 4 showed a gradual increase in cover over the course of 2020-21 water year (Figure 7.11, Figure 7.20), which is consistent with what we have previously predicted would happen when there is a summer fresh to follow-up fresh in spring. One of the recommendations in 2019-20 report was to *"Deliver a series of freshes to all rivers in all major tributaries of the Edward/Kolety-Wakool system to increase the wetted area of the bank."* Watering action 3 is an example of the type of water actions that was recommended.

**Figure 7.20** Photo showing the extent of potamogeton in zone 3 in 2020-21. This is the the most extensive cover of this species observed in the system sic=nce the flood in 2016.

**Watering action 8, variable base flows in Upper Wakool river in autumn** 2021, had an objective to enable a comparison to previous monitoring data to determine if a longer, higher flow rate is better at maintaining fish, and plants (Table 7.1). The outcome of this action is unlikely to be evident in autumn when the plants are senscing. However, the benefits of this action may be evident over a longer time frame and could result in a stronger response in spring 2021 which could be evaluated in the 2021-22 report.

### Long-term evaluation questions

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

*How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones*?

Riverbank and aquatic vegetation in the EKW system was considerably impacted by the 2016 flood. Since 2017 there is evidence that riverbank and aquatic vegetation is recovering and that environmental watering actions have contributed to this recovery. Spring freshes have increased opportunities for germination and follow-up freshes contribute to growth and survival. The winter watering action in 2017 would have prevented loss from frost and aided the recovery of vegetation.

In previous years the species richness and cover of vegetation was lower in the upper Wakool River zone 2 (received minimal or no environmental water) than in zones 1, 3 and 4 that had received environmental water. In 2018-19 a pulse of environmental water was delivered to zone 2 in September 2018 during the 800 ML/d flow trial and this was followed by a period of operational flows from the MIL Wakool escape between October 2018 and February 2019. These actions resulted in an increase in total and mean richness of vegetation taxa in zone 2, demonstrating a clear response to environmental watering.

Despite the increase in the total species richness, the mean species richness in zones 1, 3 and 4 has not yet recovered to the same levels as prior to the 2016 flood. Some amphibious taxa such as floating pondweed and milfoil that had high percent cover prior to the flood were neatively impacted during flood in 2016 and were reduced in cover or were killed. In 2020-21, four years after the flood, there are signs that these taxa are beginning to recover. Plants of these species were observed in 2020-21 and percent cover has increased. This suggests there is the possibility of the recovery of these species over the next years that can be supported by environmental watering.

### Short-term evaluation questions

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

Evidence of responses to individual watering actions include observations of germinating plants on riverbanks following recession of flows. Winter or early spring freshes that inundate slackwater, in-channel benches or low-lying areas of riverbank within the channel can have positive outcomes on the germination of riverbank vegetation. Following the recession of flows, the damp banks provided ideal conditions for seedling to establish and grow prior to the onset of hotter weather in summer that can quickly dry out the riverbanks. The best outcomes for the diversity and percent cover of riverbank and aquatic vegetation taxa are achieved when there are subsequent freshes (environmental actions or operational flows) that re-wet these areas. These floow-up flows provide ongoing conditions that are suitable for amphibious plants to grow and survive the warmer conditions over the summer. Delivery of a follow up fresh in summer, such a in 2020-21, supports the growth of seedlings.

# 8 Fish

Authors: Nicole McCasker, Jason Thiem, John Trethewie, Daniel Wright

| 2020-21 Key Findings | | |
|---|---|---|
| spawning | Periodic species | • There was no evidence of local golden or silver perch spawning in the Wakool River or Yallakool Creek.<br>• Carp benefited from the higher in-channel flows, which resulted in inundation and commence to flows in local distributary creeks such as Black Dog Creek and other low-lying areas. This was evidenced by an increase in carp larvae during the Spring pulse (watering action 1), and subsequent recruitment (as evidenced by Category 1 adult fish survey data). |
| | Opportunistic species | • Strong spawning and recruitment in flathead gudgeon were recorded in 2020-21, with higher catches of both larval and juvenile stages (Category 1 adult surveys) recorded compared to all previous years of monitoring. |
| recruitment | Murray cod, silver perch and golden perch recruitment | • Despite low catch rates of Murray cod larvae in 2020-21, follow up recruitment surveys in summer 2021 captured 0+ (YOY) and 1+ recruits at a similar abundance to 2019-20, and across all study zones.<br>• Juvenile trout cod (1+) were captured in Yallakool Creek in February 2021.<br>• A higher abundance of silver perch, of all sizes except for YOY, were present in 2021 compared with previous years.<br>• No golden perch 0+ or 1+ fish were captured during recruitment surveys (but see below). |
| adults | Adult fish populations | • All nine native fish species and three alien fish species caught in previous Category 1 adult surveys of the Edward/Kolety-Wakool Selected Area from 2014-2020 were detected in 2021.<br>• Murray cod, silver perch and golden perch increased in abundance and biomass in 2021 compared to the previous year. Although, excluding silver perch, levels remained below those prior to the flooding/hypoxic event in 2016/2017.<br>• Golden perch sub-adults (100-300 mm), including one 0+ individual, were detected in 2021. This may have been due to fish immigrating into the Edward/Kolety-Wakool River system from the Murray River or fish stocked into the river from a hatchery. |

## 8.1 Background

The Edward/Kolety-Wakool River system is recognized as a priority area for fish diversity in the Murray-Darling Basin and is part of the threatened 'aquatic ecological community in the natural drainage system of the lower Murray River catchment' in New South Wales (*NSW Fisheries Management Act 1994*). Outcomes for fish have been a target for the delivery of environmental water in the Edward/Kolety-Wakool system. Historically, the Edward/Kolety-Wakool system had diverse fish communities and supported extensive commercial and recreational fisheries (Rowland 1998). Twenty-two native freshwater fish species are thought to have historically occupied the lowland region of the central Murray valley (Table 8.1), including the recently described obscure galaxias (*Galaxias oliros*). Fourteen of these native species still occur within the system based on recent evidence. Fish remain a key environmental asset valued by the broader Edward/Kolety-Wakool community.

A suite of questions and indicators that all have clear linkages to other components of the Monitoring, Evaluation and Research Plan were selected to monitor fish responses to environmental watering actions (Figure 8.1). The Edward/Kolety-Wakool Monitoring, Evaluation and Research Plan (Watts et al. 2019a) has a strong emphasis on the response of fish populations to Commonwealth environmental watering, and includes components directly assessing fish movement (component completed), reproduction, recruitment and adult populations. In addition, many of the other indicators evaluated in this report (such as hydrology, water quality, stream metabolism and aquatic vegetation) are likely to have indirect influence on fish population dynamics, and thus a key goal of the long-term intervention monitoring in the Edward/Kolety-Wakool Selected Area is to improve our understanding and interpretation of these interdependences.

Key processes that ultimately shape adult fish populations (spawning, recruitment and growth) have been monitored and evaluated in response to the contribution of Commonwealth environmental water. Monitoring of these key elements are complementary, allowing us to assess contributions of environmental water to the key population processes that structure fish assemblages in the Edward/Kolety-Wakool (Figure 8.1). The responses measured across these key fish indicators will be used in a multiple lines of evidence approach to evaluate competing hypotheses about underlying mechanisms driving or limiting the outcomes from environmental water delivery. For example, if watering achieves increases in production and fish spawning, but not recruitment, it may be possible to identify potential bottlenecks and strategies for overcoming those limitations as part of an adaptive management cycle. Each of the fish indicators being monitored in the Edward/Kolety-Wakool system is described below.

In section 8.6 we bring together our results across the spawning, recruitment and adult sampling to provide an overview of how the fish community in the Edward/Kolety-Wakool responded to watering events and Edward/Kolety-Wakool hydrological conditions in general.

**Table 8.1** Fish species of Edward/Kolety-Wakool River system (recorded and expected). Recorded and alien species are those that have been sampled in the region since 2010, and expected native species are species that were historically likely to have been in the lowland central Murray region. Asterisks highlight if local spawning has been detected since LTIM and Flow-MER monitoring commenced in 2014. [1]Indicates species have been recorded in the Edward/Kolety-Wakool system, but outside the focal study zones.

| Common name | species name | spawning detected 2014-20 |
|---|---|---|
| ***Native species – recorded*** | | |
| Australian smelt | *Retropinna semoni* | * |
| carp gudgeon | *Hypseleotris* spp. | * |
| flathead gudgeon | *Philypnodon grandiceps* | * |
| Murray cod | *Maccullochella peelii* | * |
| Murray River rainbowfish | *Melanotaenia fluviatilis* | * |
| unspecked hardyhead | *Craterocephalus stercusmascarum fulvus* | * |
| obscure galaxias | *Galaxias oliros* | * |
| river blackfish | *Gadopsis marmoratus* | * |
| silver perch | *Bidyanus bidyanus* | * |
| bony herring | *Nematolosa erebi* | * |
| golden perch | *Macquaria ambigua* | |
| trout cod[1] | *Maccullochella macquariensis* | |
| dwarf flathead gudgeon | *Philypnodon macrostomus* | |
| freshwater catfish[1] | *Tandanus tandanus* | * |
| ***Native species – expected*** | | |
| Agassiz's glassfish (olive perchlet) | *Ambassis agassizii* | |
| flathead galaxias | *Galaxias rostratus* | |
| Macquarie perch | *Macquaria australasica* | |
| mountain galaxias | *Galaxias olidus* | |
| Murray hardyhead | *Craterocephalus fluviatilis* | |
| shorthead lamprey | *Mordacia mordax* | |
| southern purple spotted gudgeon | *Mogurnda adspersa* | |
| southern pygmy perch | *Nannoperca australis* | |
| ***Alien species – recorded*** | | |
| common carp | *Cyrpinus carpio* | * |
| eastern gambusia | *Gambusia holbrooki* | * |
| oriental weatherloach | *Misgurnus anguillicaudatus* | * |
| redfin perch | *Perca fluviatilis* | * |
| goldfish | *Carrassius auratus* | |

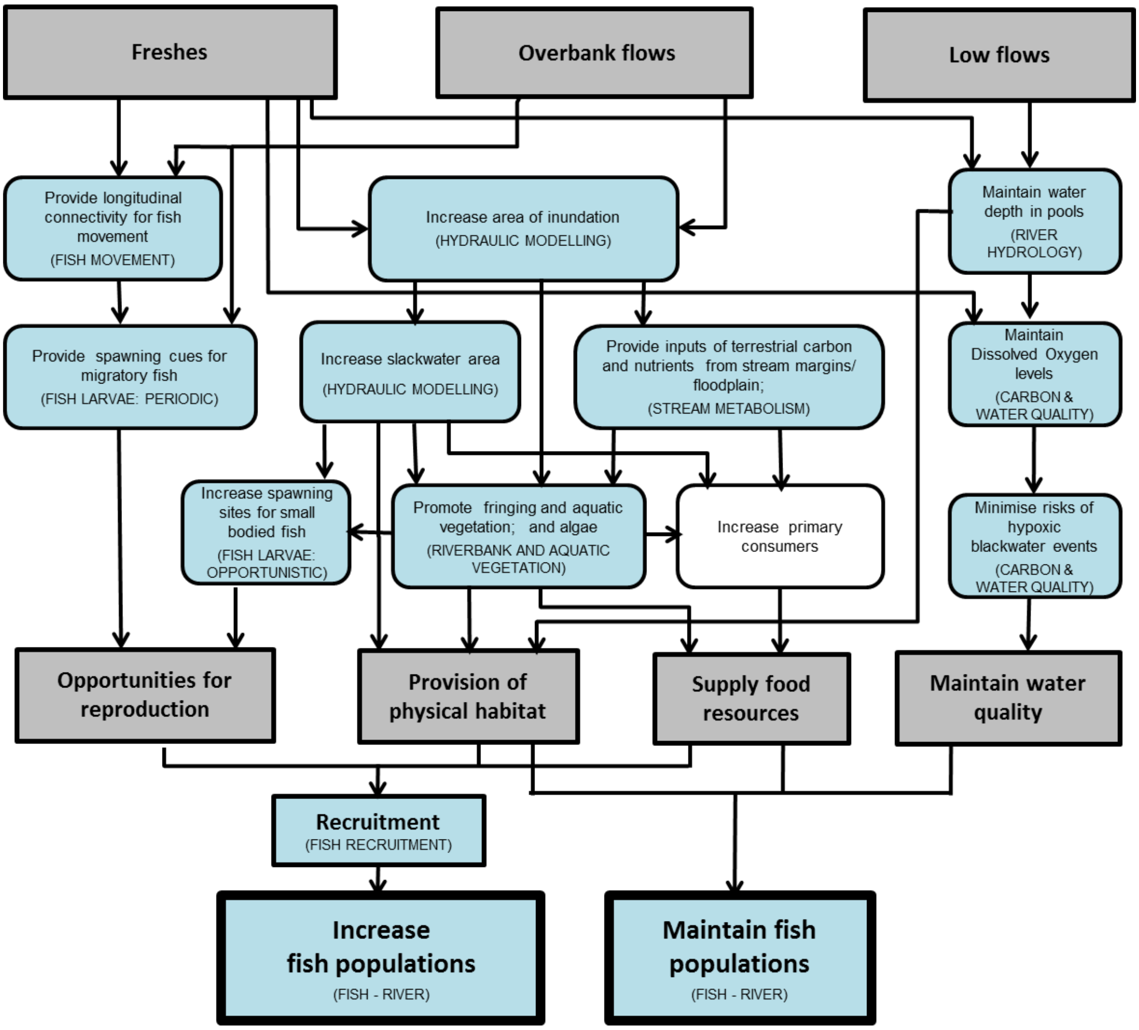



**Figure 8.1** Conceptual diagram illustrating the linkages between different types of environmental watering (freshes, overbank flows, low flows) to fish populations via key ecological processes. Key ecological processes that are being monitored as part of the Edward/Kolety-Wakool Monitoring, Evaluation and Research Plan are highlighted in blue.

### *Fish spawning and reproduction*

Monitoring the diversity and abundance of fish eggs and larvae across the spring-summer spawning period is used to identify which fish species have successfully spawned and identify the abiotic (hydraulic and temperature) conditions that contributed to this. This information enables development and refinement of ecologically meaningful flow-spawning relationships for the Edward/Kolety-Wakool fish assemblage and will assist in future planning of environmental water delivery for fish population outcomes.

### *Recruitment of Murray cod, silver perch and golden perch*

Relationships among early life-history growth and recruitment ultimately determine the abundance of many marine fish populations (Pepin et al. 2015), but much less is known about how these factors contribute to populations of freshwater species. It is well established that many species of fish in the Murray-Darling Basin do not require over-bank flows, or changes in water level to initiate spawning

(Humphries et al. 1999), but nonetheless *recruitment* of all species may be affected by disruption to the natural flow regime, and environmental flows provide a possible mechanism to address this. Fish recruitment monitoring was developed specifically for the Edward/Kolety-Wakool system in order to quantify juvenile Murray cod, silver perch and golden perch relative abundance. This monitoring enables comparison of juvenile growth rates among study zones of the Edward/Kolety-Wakool and is used to determine recruitment variation of these species among years, in response to environmental watering.

### *Adult fish community*

Evaluation of the adult fish community to Commonwealth environmental watering is being undertaken in the Edward/Kolety-Wakool river system. This work will allow us to determine long-term trajectories in the fish community assemblage in response to Commonwealth environmental watering, and to assess if movement, spawning and recruitment ultimately lead to positive responses (condition, biomass, abundance, diversity) in the adult fish community both within and outside of the Flow-MER focal area. It is anticipated that changes to the fish community will occur over longer time scales, and as such a broad-scale monitoring program of the fish community will be undertaken in year three of the Flow-MER Program (2021-2022). Additionally, annual fish community censuses are undertaken within a single focal zone (Mid Wakool River, Zone 3) to provide data for Basin-scale Evaluation of fish communities (see http://www.environment.gov.au/water/cewo/publications/cewo-basin-scale-evaluation-and-research-plan) and these data are incorporated into our Selected Area evaluation, where relevant.

## 8.2 Environmental watering actions

The CEWO's overarching objective for environmental watering for fish populations in the Edward/Kolety-Wakool River system was to provide flows to "support habitat (including longitudinal connectivity and bench inundation), food sources and promote increase movement/dispersal, recruitment and survival/condition of native fish" (CEWO 2019). There were four Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2020-21 that were evaluated by the fish monitoring program of Flow-MER (Table 8.2, for details see Chapter 2).

**Table 8.2** Commonwealth environmental watering actions in 2020-21 in the Edward/Kolety -Wakool River system that had objectives targeting native fish outcomes. Watering actions assessed by the Flow-MER Program are highlighted in blue.

| | Watering action | Dates | System | Objectives |
|---|---|---|---|---|
| 1 | Spring fresh | 20 Oct - 30 Nov | Yallakool Creek, Wakool River | To contribute to pre-spawning condition of native fish<br>To contribute to spawning in early spawning native fish |
| 2 | Elevated base flow | 30 Nov – 15 Dec | Yallakool Creek | To maintain nesting habitat for Murray Cod |
| 3 | Summer freshes | 15 Dec – 15 Feb | Yallakool Creek | To influence and encourage silver perch breeding and movement<br>To assist with dispersal of larvae and juveniles of a number of fish species |
| 4 | Autumn fresh | 30 Mar – 6 May | Yallakool Creek | To influence and encourage fish movement.<br>To assist with dispersal of larvae and juveniles of a number of fish species |
| 5 | Spring fresh | 21 Oct – 6 Dec | Colligen-Niemur | To contribute to pre-spawning condition of native fish<br>To contribute to spawning in early spawning native fish |
| 6 | Elevated base flow | 6 Dec – 8 Jan | Colligen-Niemur | To maintain nesting habitat for Murray Cod |
| 7 | Summer fresh | 8 – 26 Jan | Colligen-Niemur | To influence and encourage fish movement, may be coordinated with wider Murray River actions to maximise benefit<br>To assist with dispersal of a larvae and juveniles of a number of fish species |
| 8 | Variable base flows | 23 Jan – 9 Jun | Upper Wakool | To determine if a longer higher flow rate is better at maintaining fish |

## 8.3 Selected Area evaluation questions

Data from the Edward/Kolety-Wakool system is being evaluated at the Selected Area scale and will further contribute to Basin-scale evaluation. Basin-scale evaluation involves the integration of multiple datasets from several different catchments (Hale et al. 2014), and this will be undertaken by CSIRO/University of Canberra and evaluated in a separate report.

This is the second year of reporting for the Flow-MER Program. Much of the work reported here is a continuation of the monitoring undertaken during LTIM program (2014-19). The short and long-term Selected Area evaluation questions, as outlined in the Monitoring, Evaluation and Research Plan for the Edward/Kolety-Wakool system (Watts et al. 2019) are outlined in Table 8.3. This report will evaluate environmental water against the short-term questions, with long-term evaluation questions being further assessed in 2022.

**Table 8.3** Selected Area evaluation questions relating to the effect of Commonwealth environmental water on Edward/Kolety-Wakool fish populations relevant to this report.

| Monitoring component | Selected Area-scale short term evaluation questions |
|---|---|
| Fish spawning and reproduction | • What did CEW water contribute to the spawning of 'opportunistic' species?<br>• What did CEW contribute to spawning in 'flow-dependent' spawning species? |
| Recruitment and growth of young of year | • What did CEW contribute to native fish recruitment to the first year of life?<br>• What did CEW contribute to native fish growth rates during the first year of life? |
| Adult fish population demographics | • Does CEW contribute to the maintenance or enhancement of fish condition in the Edward/Kolety-Wakool river system?<br>• Does CEW contribute to the recovery of fish communities following negative conditions within the Edward/Kolety-Wakool river system |

## 8.4 Methods

### *8.4.1 Monitoring sites*

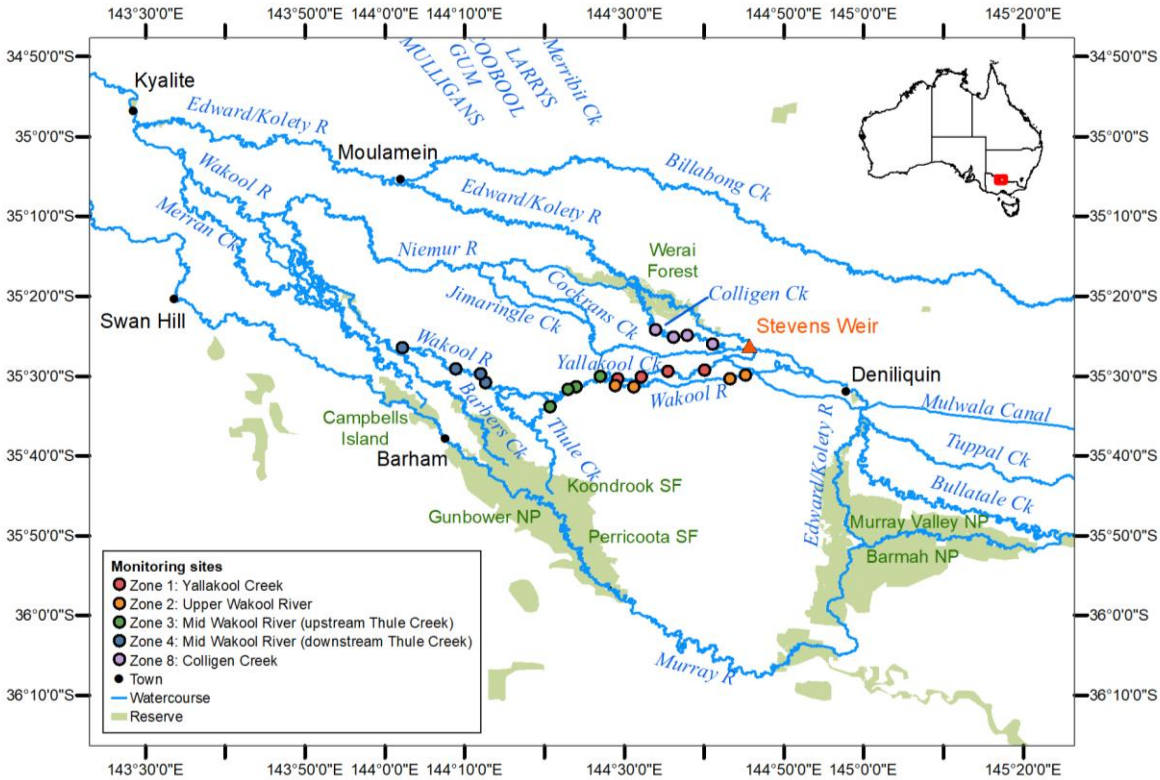



**Figure 8.2** Location of Flow-MER monitoring sites used to survey fish eggs/larvae, recruits, and adult fish. Adult fish are assessed both annually, using Cat 1 methods for Basin-scale evaluation, and in the final year of Flow-MER (2021-2022 using Cat 3 methods for Selected-area evaluation).

### 8.4.2 *Fish spawning*

Fish larvae and eggs were sampled within the Edward/Kolety-Wakool Selected Area from 14 September 2020 – 5 March 2021. A combination of modified quatrefoil light traps and drift nets were used in in four hydrological zones: Yallakool Creek (Zone 1), Upper Wakool River (Zone 2), Mid Wakool River upstream of Thule Creek (Zone 3), and Mid Wakool River downstream of Thule Creek (Zone 4).

As part of Category 3 Selected Area scale monitoring, three modified quatrefoil light traps were deployed overnight, fortnightly, at five sites in each of the four hydrological zones. Light trap sampling commenced on 14 September 2020 and finished 5 March 2021 (n=13 sampling events). The occurrence of fish larvae throughout a given river reach is patchy, and so to account for this, the three light traps deployed at each site were pooled to create one composite light trap sample per site, per sampling night.

Drift nets were also used for sampling larvae for both Selected Area scale (Category 3) and Basin-scale (Category 1) analyses. Drift nets are used in addition to the light traps as they are more effective in detecting eggs and early-stage larvae of flow-dependent spawning species, such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). For Selected

Area monitoring, drift nets were deployed fortnightly from 28 September – 23 December 2020. Drift nets sampling took place at one of the five sites used for light trap sampling across each of the four hydrological zones (Figure 8.2). At each of the sites, three drift nets were deployed overnight. The volume of water filtered by the nets was calculated using Oceanic® flow meters positioned at the mouth of each net. Volume sampled by the net was estimated as:

$$\pi r^2 \cdot v \ \cdot t,$$

where *r* is radius in metres, *v* is mean velocity in m/s, and *t* is time set in seconds. In addition to the Selected Area (Cat 3) methods, drift net samples were also collected for Category 1 Basin-scale evaluation, however this data is not reported on here. This involved setting three drift nets at three sites in Wakool River upstream of Thule (Zone 3), fortnightly, from the 28 September – 23 December 2020 (n=7 sampling trips). For all drift net sampling, drift nets were deployed in the late afternoon, and retrieved the following morning. Up on retrieval, drift nets were rinsed, entire samples preserved in 70% ethanol, and returned to the laboratory for processing.

All eggs and fish larvae collected in light trap and drift net samples were enumerated and identified to species using Serafini and Humphries (2004). Carp gudgeon larvae were identified to genus level (*Hypseleotris* spp.) only. Genetic analyses were used to identify any eggs collected, as well used to identify a sample of early-caught cod larvae, since Murray cod and trout cod larvae have similar morphological features and cannot be easily distinguished visually. A subsample of larvae comprising of possible Murray cod or trout cod were submitted to the Australian Genome Research Facility (AGRF). Nucleic acid extraction and subsequent verification of species assignment was based on dual direction sequencing following PCR amplification. Results of the PCR amplification revealed all larvae to be Murray cod, and thus, from here on, we consider all cod larvae collected to be Murray cod. The developmental stage of each individual was recorded as egg, larvae, or juvenile/adult, according to classifications of Serafini and Humphries (2004). Only the trends in abundances of eggs and larvae are reported from here on in.

To aid in visualisation associations between the timing of appearance of larvae, water temperature and discharge, time series plots for year and zone were created. Light trap data was for all species with the one exception of silver perch trends. Here, egg abundance from drift net data was used.

To address the short-term Selected Area evaluation questions relevant to spawning and reproduction, we tested to see if the total abundance of larvae (as an indication of magnitude of spawning across a season) varied in 2020-21 (only non-flood year with a large in-channel spring fresh) with other non-flood years. We used generalised linear models to test differences in larval abundance in Light traps across years for individual species where both Year (2014-15, 2015-16, 2017-18, 2018-19, 2019-20, 2020-21 ) and Zone (Zone 1, Zone 2, Zone 3 and Zone 4) were treated as a categorical, fixed effects. The sampling year 2016-17 was not included in the analysis or plotted for the figures, as access to field sites from October-December 2016 was limited due to flooding. Larvae collected from light traps was used for the analysis and restricted to the species were more than 50 individuals were collected. Numbers of obscure galaxias, Murray River Rainbowfish and unspecked hardyhead larvae were too low for any statistical comparisons across zones and years. The distribution of larval counts were non-Gaussian and highly skewed, so a Gamma distribution with a log-link function was used for all statistical models. To deal with zero data, a count of one was added to each total catch data entry in order to meet the assumptions of a gamma distribution (positive values). Statistical analyses were carried out using the freeware R (version 3.3.2, R core team 2020). F-tests were used to test the significance of Zone and Year. P-values of <0.05 were used to determine the significance of each test. When significant differences were indicated, pairwise comparisons were undertaken to determine differences in estimated marginal means between the zones using the package 'emmeans' (Length 2020, v.1.5.0).

As the presence of a late spring fresh delivered in 2020-21 was a major change to the annual flow hydrograph for each of the four zones, we hypothesised that the if spring fresh watering action did contribute to spawning in early native fish, that the number of larvae from spring spawning species such as Australian smelt, Murray cod, obscure galaxias would be greater in 2020-21 than previous years that were characterised by sustained elevated base flows (2014-15,2015-16, 2017-18) or years where a spring freshwater delivered, but much earlier on in the season when temperatures were cooler (2018-19, 2019-20).

### 8.4.3 *Fish recruitment*

Four sites were sampled in each of four river zones within the Edward/Kolety-Wakool system: Yallakool Creek Zone 1, Wakool River Zone 2, Wakool River Zone 3 and Wakool River Zone 4. Each of the 16 sites were sampled once in a randomly selected order between February and March for six years: 2014-15; 2015-16; 2016-17; 2017-18, 2018-19, 2019-20 and 2020-21.

Three sampling methods were undertaken: electrofishing (boat or backpack depending on site depth), standardised angling and baited set-lines to sample recruits of Murray cod, golden perch and silver perch at each of the 16 sites. A sub-sample of < 25 Murray cod per zone were euthanized and frozen to determine the age and growth rate of recruits, while all other fish were released alive excluding carp which were euthanized prior to disposal.

Backpack electrofishing, using a 12 V DC battery with a Smith-Root LR-20 unit was undertaken at three of the four sites in Zone 2 by an operator and one person equipped with a 5 mm mesh dip-net. Each of these sites was sampled for a minimum of 3000 seconds of backpack-on electrofishing time. All other sites were sampled using a Smith-Root 2.5 GPP boat-mounted electrofishing unit for a minimum of 1400 seconds of electrofishing time. Presence of non-target species was recorded at each site, while total length measurements and counts were made for all individuals of the three target species. Standardised angling was carried out by two anglers with the specific aim of targeting young silver perch and golden perch. Standardised angling at each site consisted of two anglers fishing on the bank for two hours. Angling gear used was light spin fishing outfits with 6 lb line baited with worms or cheese on size 10 circle hooks. Species and were recorded for all individuals caught, and weight was recorded for smaller fish under 2 kg.

Ten set-lines, each with a 3-10 m (100 lb) monofilament main-line and two 0.5-1.5 m (4 lb) leaders with a size 10 circle hook on each leader were set at each site. Lines were set, with alternating bait of worms or cheese and hauled hourly during day-light hours for 5-7 hours at each site. Species and length were recorded for all individuals caught, and weight was recorded for smaller fish under 2 kg.

To determine the annual age of fish older than 1 year of age (1+) or daily age of fish younger than 1 year of age (0+), sagittal otoliths were extracted, embedded in a polyester resin and sectioned in the transverse plane to approximately 100 $\mu$m thick and mounted on a microscope slide. Final age estimates were based on samples with matching age readings from three reads. Recruitment catch per unit effort (CPUE; number of recruits per 10 000 s of sampling) of YOY and 1+ Murray cod and 1+ silver perch were calculated from catch and effort data from backpack electrofishing, set-lines and angling. For comparisons in growth between years and zones, length at age was used for 1+ recruits and average growth rate of millimetres per day was used for YOY recruits.

### 8.4.4 *Adult fish community*

System-wide fish community surveys of the Edward/Kolety-Wakool River system were undertaken as part of LTIM in year 1 (2014-15) and year 5 (2018-19) of the program (Watts et al. 2014). As part of the continuation of this monitoring in the Flow-MER Program, the next system wide fish community survey will take place in 2021-22. In the absence of fish community data for the current monitoring year (2020-2021), we present Category 1 fish community standardised survey data from the mid Wakool River - Zone 3.

Standardised sampling was undertaken in May 2021, and each site was sampled once using a suite of passive and active gears including boat-electrofishing (n=32 operations, each consisting of 90 seconds ‘on-time’), unbaited bait traps (n=10) and small fyke nets (n=10) (Hale et al. 2014). Decapods were also surveyed using baited opera house traps (n=5). All captures (fish and other non-target taxa) were identified to species level and released onsite. Where large catches of particular species occurred, a sub-sample of individuals was measured and examined for each gear type. For fyke netting, sub-sampling involved measuring all individuals for body size in each operation until 10 of a species was reached and then only counting the remainder of this species. For boat electrofishing, all individuals were measured for body size across operations until 50 individuals of a species were reached, and then only the first 20 individuals of this species were measured for body size in each operation while the remainder were only counted. Fish that escaped capture but could be positively identified were also counted and recorded as “observed” instead of “caught”.

Total catch of “caught” individuals was pooled for all sites and operations of methods. For visualisations, large-bodied longer-lived fish species were considered recruits when length was below the minimum that for a one year old (Table 8.4). Small-bodied short-lived species, that reach sexual maturity in less than one year, were considered recruits when length was less than the average length at sexual maturity. Differences in fish communities between years (2014-15 to 2020-21) in the Edward/Kolety-Wakool Selected Area were assessed by one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA, Anderson et al. 2008), with abundance and biomass data analysed separately. These analyses were performed with the vegan package (Oksanen et al. 2020) in R (R version 3.6.1, R Development Core Team 2019). Raw data were fourth root transformed and used to produce a similarity matrix using the Bray-Curtis resemblance measure. Tests were considered significant at $P < 0.05$. In cases that significant differences were identified, pair-wise post-hoc contrasts evaluated the year combinations that differed. Similarity percentage (SIMPER) tests determined individual species contributions to average dissimilarities between years. For the most abundant large-bodied fish species, differences in length-frequency distributions between years were determined with Komolgorov-Smirnov tests, and p values were adjusted to account for multiple comparisons (Ogle 2016).

**Table 8.4** Size limits used for assigning new recruits of each fish species. Values indicate length at one year of age for longer-lived fish species, or the age at sexual maturity for fish species reaching sexual maturity within one year.

| Fish species | Estimated length at 1 year old or at sexual maturity (fork/total length) | Reference |
|---|---|---|
| *Native species* | | |
| Australian smelt | 40 mm | Pusey et al. 2004 |
| bony herring | 67 mm | Cadwallader 1977 |
| carp gudgeon | 35 mm | Pusey et al. 2004 |
| flathead gudgeon | 58 mm | Llewellyn 2007; Pusey et al. 2004 |
| golden perch | 75 mm | Mallen-Cooper 1996 |
| Murray cod | 222 mm | Gavin Butler, unpublished data |
| Murray-Darling rainbowfish | 45 mm | Pusey et al. 2004 |
| silver perch | 75 mm | Mallen-Cooper 1996 |
| un-specked hardyhead | 38 mm | Pusey et al. 2004 |
| *Alien species* | | |
| common carp | 155 mm | Vilizzi and Walker 1999 |
| Eastern gambusia | 20 mm | McDowall 1996 |
| goldfish | 127 mm | Lorenzoni et al. 2007 |

With a golden perch slightly above the recruit size limit caught for the first time in Category 1 LTIM/Flow-MER sampling of the Edward/Kolety-Wakool River system, daily aging of this individual was performed for further information. Daily aging involved lethally sampling the fish and removing sagittal otoliths or ear bones. Methods for daily aging followed Stocks et al. (2019). In short, the otoliths were mounted atop a microscope slide with crystalbond adhesive, polished down to the core with 9 $\mu$m lapping film and examined with a camera-fitted compound microscope. Because ring visibility shifted during the polishing process, several images were needed to view rings, which were then overlaid on each other to allow aging. Daily rings were counted by an experienced ager from primordium to outer edge of otoliths. The daily age estimate obtained was then used to back-calculate the approximate time of spawning, which was assessed against corresponding daily mean flow and water temperature levels recorded at Wakool River at Barham Road (gauge no: 409045).

## 8.5 Results

### 8.5.1 *Fish spawning*

A total of 6,305 larvae and two eggs, representing six species, were collected in the 2020-21 monitoring year from a combination of light traps (n=4,657) and drift nets (n=1,651) (Table 8.5). Five of the six species detected to have spawned were native, however the total catch of larvae in 2020-21 was dominated numerically by carp larvae (n=4,798), which comprised 76% of the total catch.

The diversity of native fish detected to have spawned in 2020-21 (n=5) was the lowest recorded compared with previous years of LTIM and Flow-MER monitoring (2019-20 n=8; 2018-19: n=10; 2017-18: n=11, 2016-17: n=7, 2015-16: n=8, and 2014-15:  n=7). The five native species detected to have spawned were Murray cod (*Maccullochella peelii)*, river blackfish (*Gadopsis marmoratus*), Australian smelt (*Retropinna semoni)*, carp gudgeon (*Hypseleotris* spp.) and flathead gudgeon (*Philypnodon grandiceps*).

Carp gudgeon larvae were the most numerically abundant and widespread larvae (after carp) collected from light traps (n=1,280, 27% of LT catch) (Table 8.5). Found across all four focal zones, carp gudgeon larvae were most abundant in the Mid -Wakool River (Zone 3 and 4 respectively). Murray cod (*Maccullochella peelii*, n=126, 2.7% of LT catch) and flathead gudgeon (n=58, 1.2% of LT catch) larvae were the next most abundant and detected in each of the four study zones (Table 8.4). Australian smelt were also detected as larvae in all four study zones, albeit only in small numbers (n=7, <1% of LT catch). River blackfish were only recorded as larvae in the upper Wakool River (n=3).

Native fish species that are typically observed as larvae in the Edward/Kolety-Wakool Selected Area study zones, but were not caught in 2020-21 include: obscure galaxias (*Galaxias oliros*), bony bream (*Nematolosa erebi*), unspecked hardyhead *(Craterocephalus stercusmascarum fulvus*) and Murray River rainbowfish (*Melanotaenia fluviatilis*).

Native species that are regularly found as adults in the Edward/Kolety-Wakool system but rarely detected as eggs or larvae including silver perch and golden perch. No silver or golden perch larvae or eggs were detected in 2020-21. To date, silver perch have only been detected as eggs or larvae three out of seven years of monitoring, within the Yallakool Creek (Zone 1) or upper Wakool River (Zone 2) or mid Wakool River study zones (Zone 3 and Zone 4) since LTIM/Flow-MER monitoring commenced. In addition, no golden perch eggs or larvae have been detected to date.

**Table 8.5** Total abundance of fish larvae sampled using light traps (LT) and drift nets (DN) in the four study zones of the Edward/Kolety-Wakool River system in spring/summer 2020-21. Eggs are denoted by $_e$. Fish species listed are those known to occur in the Edward/Kolety-Wakool River system. To date, trout cod have not been detected in the four study zones, however they are known to be present in the wider Edward/Kolety-Wakool Selected Area.

| Common name | Yallakool Creek (Zone 1) | | Upper Wakool River (Zone 2) | | Mid. Wakool River (Zone 3) | | Mid. Wakool River (Zone 4) | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LT | DN | LT | DN | LT | DN | LT | DN | LT | DN |
| ***Native*** | | | | | | | | | | |
| Australian smelt | 1 | - | 2 | - | 3 | $2_e$ | 1 | - | 7 | - |
| carp gudgeon | 72 | | 33 | | 543 | | 632 | | 1280 | |
| flathead gudgeon | 7 | - | 7 | - | 42 | - | 2 | - | 58 | - |
| dwarf flathead gudgeon* | - | - | - | - | - | - | - | - | - | - |
| unspecked hardyhead | - | - | - | - | - | - | - | - | - | - |
| Murray River rainbowfish | - | - | - | - | - | - | - | - | - | - |
| obscure galaxias | - | - | - | - | - | - | - | - | - | - |
| bony herring | - | - | - | - | - | - | - | - | - | - |
| silver perch | - | - | - | - | - | - | - | - | - | - |
| golden perch | - | - | - | - | - | - | - | - | - | - |
| freshwater catfish | - | - | - | - | - | - | - | - | - | - |
| river blackfish | - | - | 3 | 1 | - | - | - | - | 3 | - |
| Murray cod | 48 | 18 | 43 | 18 | 31 | - | 4 | - | 126 | 36 |
| ***Introduced*** | | | | | | | | | | |
| gambusia | - | - | - | - | - | - | - | - | - | - |
| oriental weatherloach | - | - | - | - | - | - | - | - | - | - |
| redfin perch | - | - | - | - | - | - | - | - | - | - |
| carp | 3106 | 1614 | 1 | - | 74 | 1 | 2 | - | 3183 | 1615 |
| goldfish | - | - | - | - | - | - | - | - | - | - |

### *Targeted watering actions for spawning outcomes in 2020-21*

It was hypothesised that the abundance larvae across the 2020-21 spawning season would be significantly higher early spawning species than in previous non-flow years which did not receive large, late spring pulses like that experienced in 2020-21.

Australian smelt commence spawning in the Edward/Kolety-Wakool system in early spring, the appearance of larvae is typically widespread across the four study zones when water temperature ranges between 15-22°C (Figure 8.3a). Results from the generalised linear modelling showed both Year and Zone had a significant effect on total catch of Australian smelt (Year: $F_{6,132}$= 22.957, p<0.0001; Zone: $F_{3,129}$= 5.2557, p=0.0002). In contrast to the hypothesis, there were less Australian smelt caught in 2020-21 compared to all other years of since monitoring commenced in 2014-15 (Figure 8.4).

One of the most abundant small-bodied native fish in the Edward/Kolety-Wakool River system is carp gudgeon. Carp gudgeon are protracted spawners, commencing spawning in the Edward/Wakool River system in late spring/early summer when temperatures reach 23°C (Figure 8.3b). Appearance of larvae is greatest during the summer months, from December through to March. Generalised linear models found both Year and Zone had a significant effect on the total abundance of carp gudgeon larvae (Year: $F_{6,132}$= 11.271, p<0.0001; Zone: $F_{3,129}$= 26.634, p<0.0001). Zone explained a greater amount of variation in larval abundance than year, with greater numbers consistently found in the reaches of the mid-Wakool River (Zone 3 and 4). Similar to Australian smelt, there was no evidence to indicate carp gudgeon benefited from the watering actions delivered in 2020-21, with there being no significant difference between 2020-21 catches with five of the six years (Figure 8.4).

Similar to previous years, Murray cod larvae were detected in the Edward/Kolety-Wakool Selected Area mid-October to mid-December 2020 (Figure 8.3c). Also similar to previous years, cod larvae were detected in each of the four study zones, indicating widespread spawning throughout Wakool River and Yallakool Creek. Both Year and Zone had a significant effect on Murray cod larval abundance: with Year ($F_{6,132}$= 12.158, p<0.0001), explaining larger amount of variance than Zone (Zone: $F_{3,129}$= 3.6029, p=0.015). The number of Murray cod larvae caught in 2020-21 was the second lowest since monitoring commenced in 2014-15 (second lowest to the 2016-17) (Figure 8.4).

In 2020-21, flathead gudgeon larvae were present Yallakool Creek Zone 1, Upper Wakool River Zone 2, and Mid Wakool Zone 3 and Mid Wakool Zone 4 (Figure 8.3d). Year and Zone had significant effects on total flathead gudgeon larval abundance (Year: $F_{6,132}$= 7.536, p<0.0001; Zone: $F_{3,129}$= 24.7359, p=0.0036). Across the full data set from 2014-2021, flathead gudgeon was found in greater numbers in the Mid Wakool River Zone3 and 4, with Zone 4 catches significantly higher than those in Yallakool Creek Zone 1 and Upper Wakool River 2. The total number of flathead gudgeon was significantly higher in 2020-21 than better than previous two years (2017-18 and 2018-19) (Figure 8.4).

Carp are considered periodic spring-spawners, with increased inundation of off-channel habitats often attributed to substantial early life survival (Stuart and Jones 2006). Due to the highly skewed nature of the Edward/Kolety-Wakool carp larval abundance data, statistical analyses were not run, however a large number of carp larvae were observed in 2020-21 during the time of watering action in Yallakool Creek (Figure 8.3e) The appearance of carp larvae was highly localised and confined to the lower reaches of Yallakool Creek, and likely to have been spawned as a result of the inflows from Black Dog Creek, an ephemeral creek that received inflows during the spring fresh.

Drift net sampling, aimed at detecting a response of golden and silver perch spawning to CEW environmental water delivery, commenced 28 September 2020. The spring fresh watering action, aimed at promoting silver perch spawning (CEWO 2020), resulted in daily discharge increasing from 200 ML/day to 781 ML/day in the Mid Wakool River Zone 3, at the end of October/early November and returning back to 400 ML/day by early December. The water temperature increased from 18-27°C during this time. Neither silver perch or golden perch eggs or larvae were detected.

**a) Australian smelt**

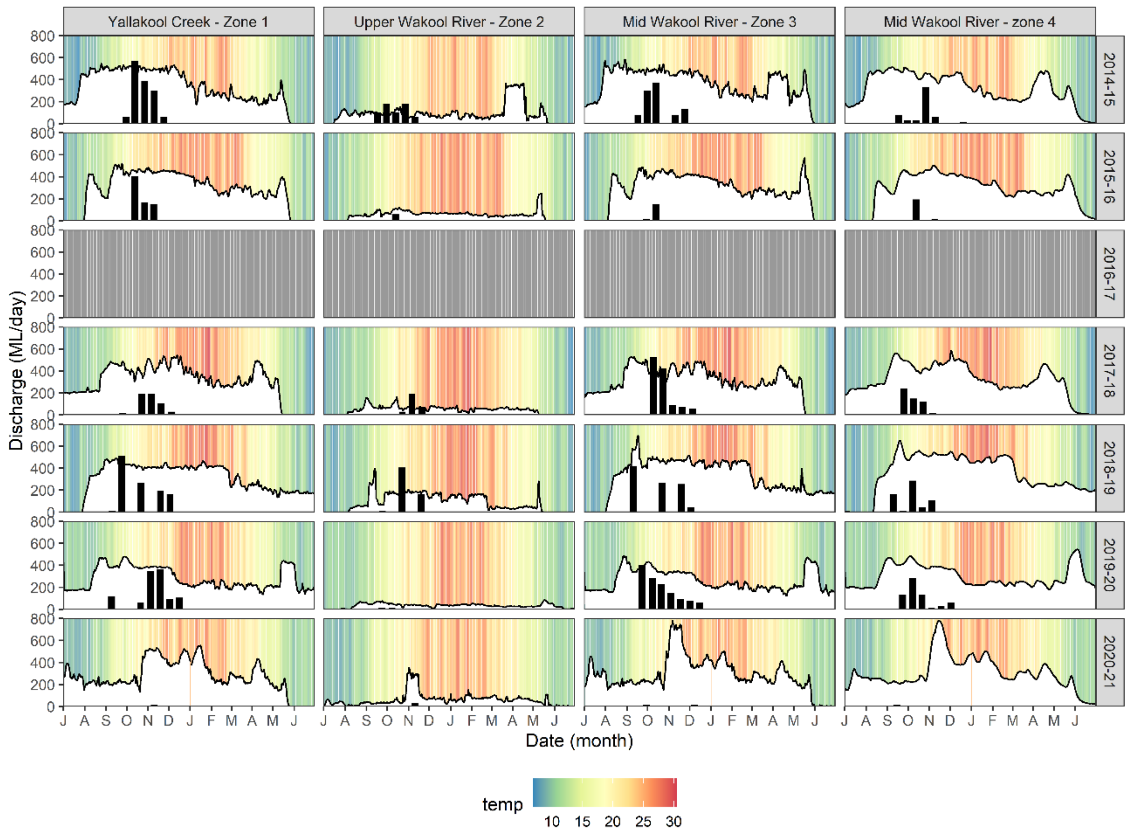
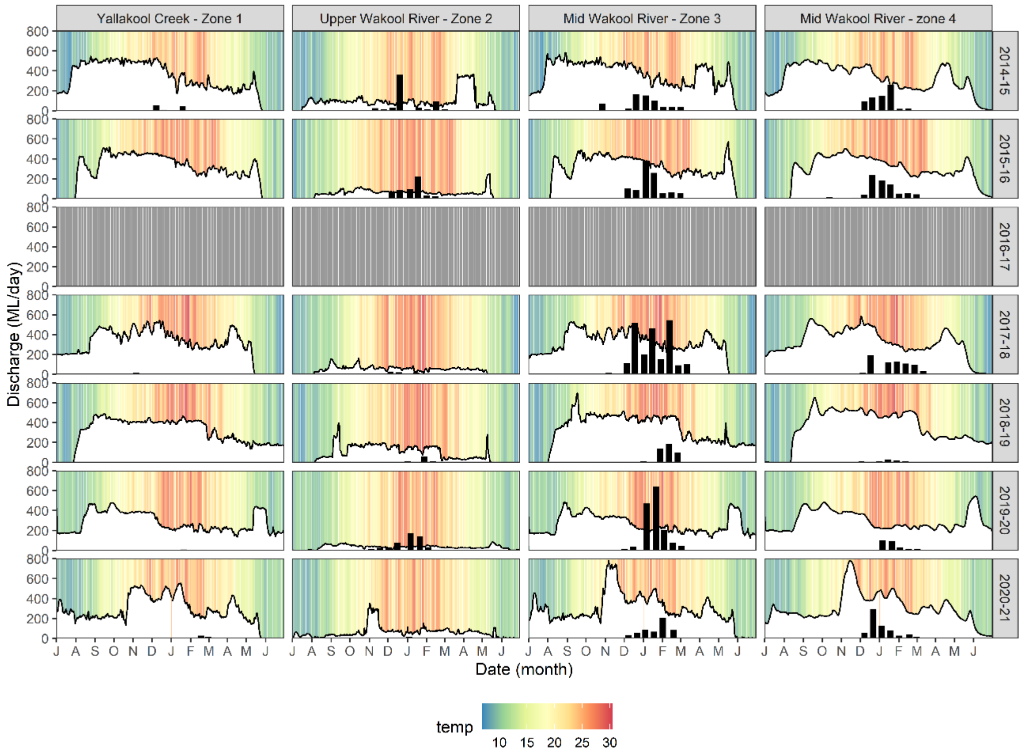
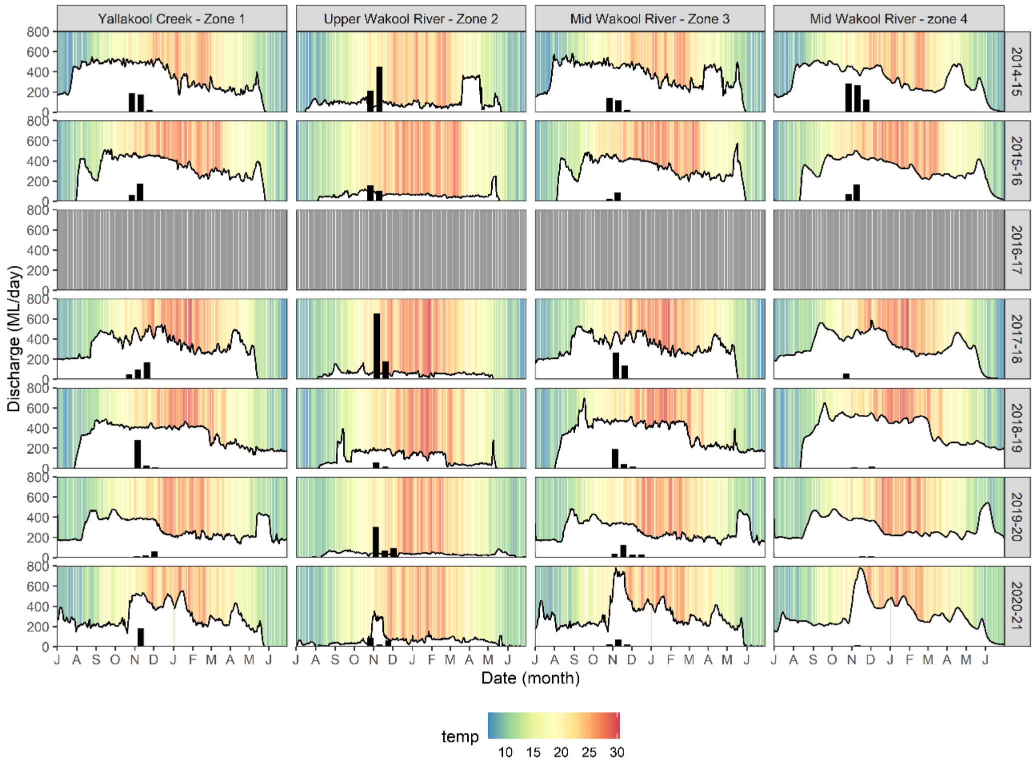



**Figure 8.3** Discharge, water temperature and abundance and timing of *a)* Australian smelt larvae in each of the four study zones, from 2014-15 to 2020-21. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light traps Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip: =234.) Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

**b) carp gudgeon**

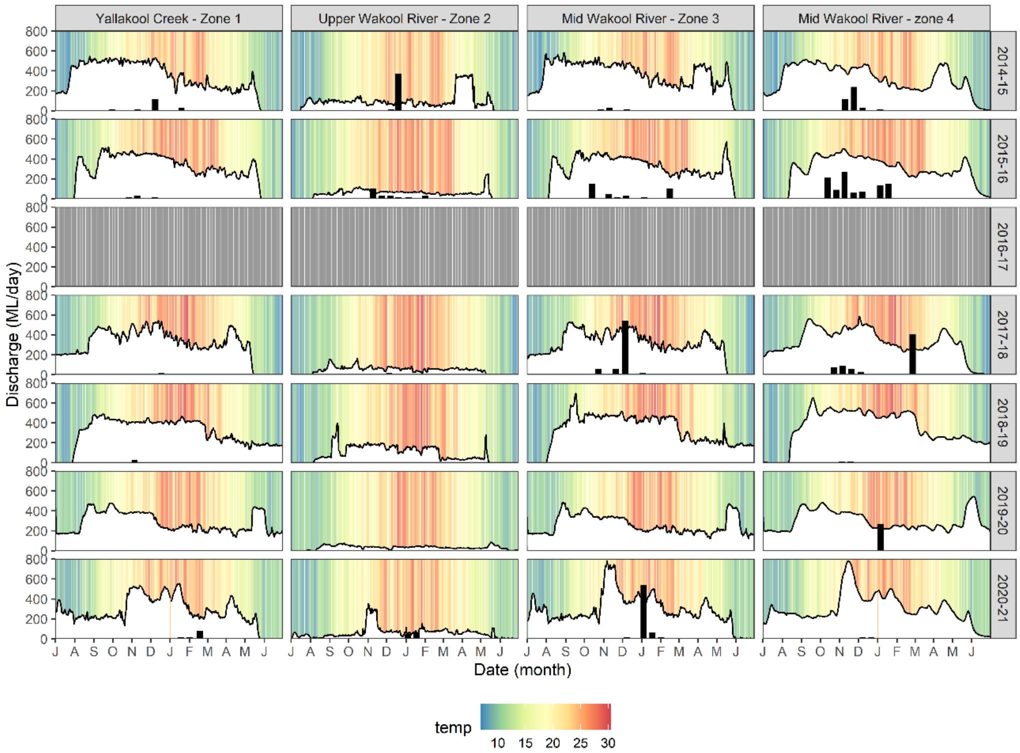



**c) Murray cod**

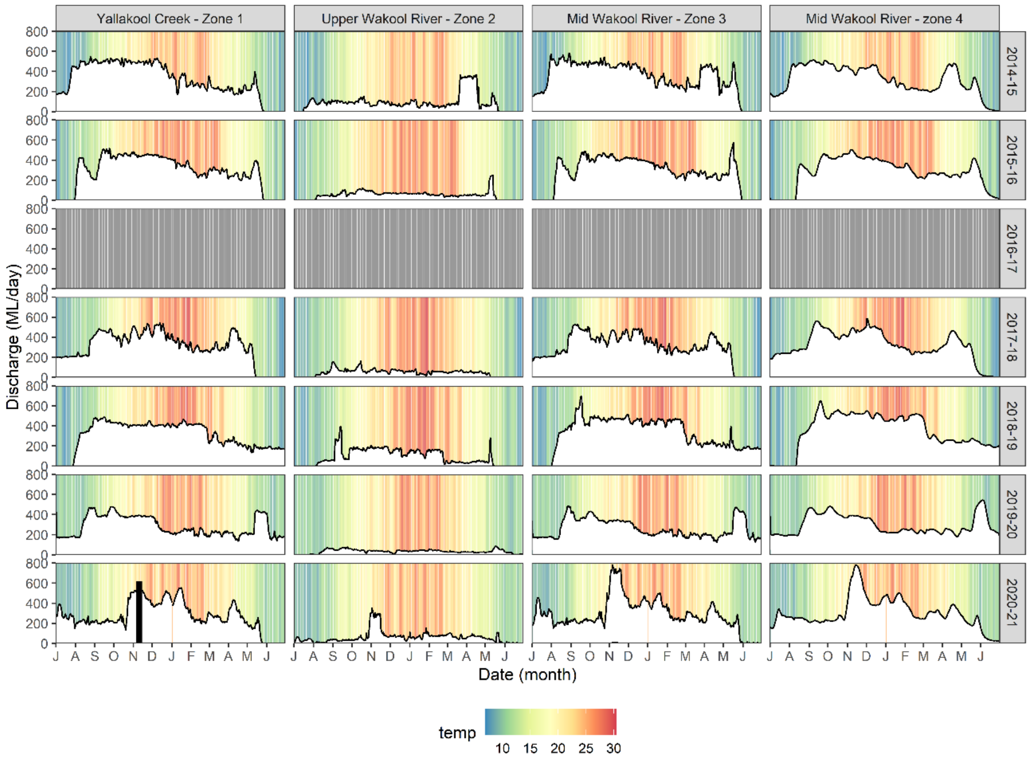



**Cont. Figure 8.3** Discharge, water temperature and abundance and timing of *b)* carp gudgeon *c)* Murray cod larvae in each of the four study zones, from 2014-15 to 2020-21. 2016-17 was a flood year, and it not plotted. Black column bars represent abundance of larvae collected fortnightly from Sep-Mar each year from light traps. Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip: carp gudgeon = 637, Murray cod = 164). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

**d) flathead gudgeon**

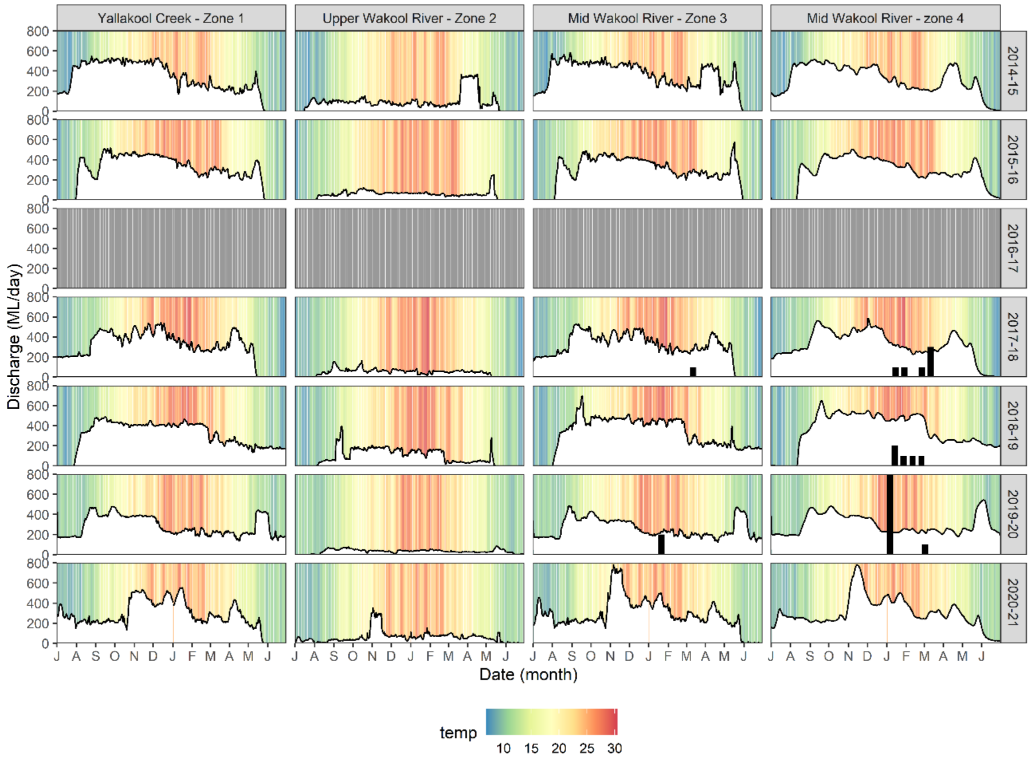



**e) carp**

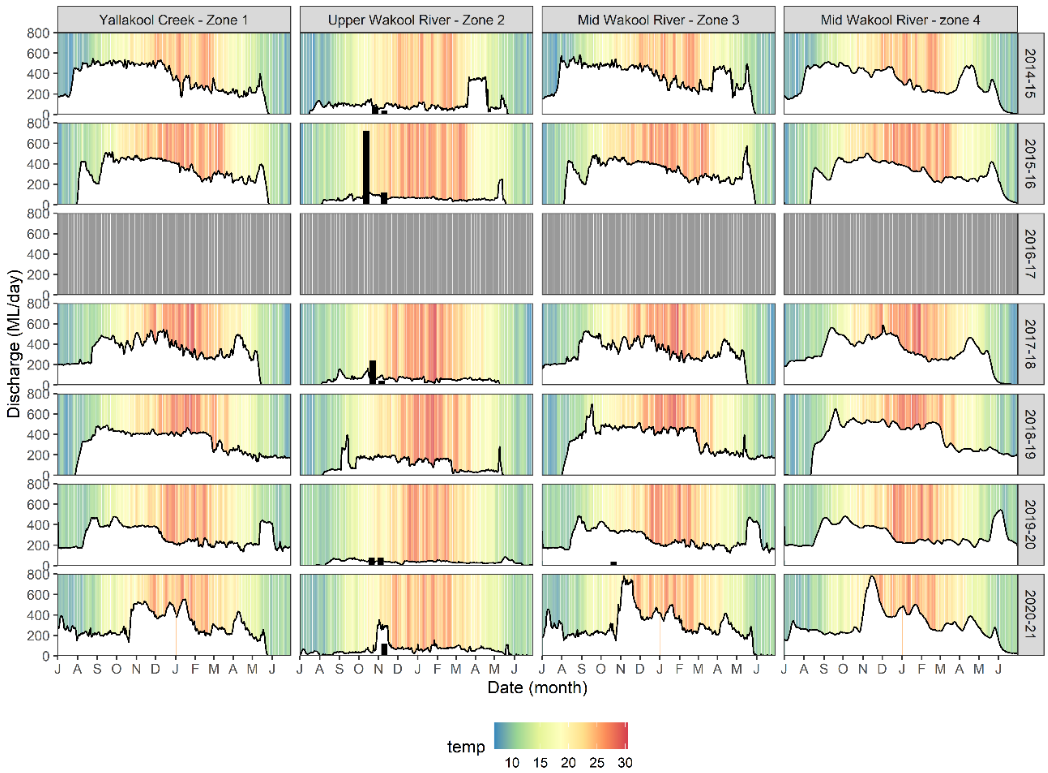



***Cont.* Figure 8.3** Discharge, water temperature and abundance and timing of *d)* flathead gudgeon and *e)* carp larvae in each of the four study zones, from 2014-15 to 2020-21. 2016-17 was a flood year, and it not plotted. Black column bars represent abundance of larvae collected fortnightly from Sep-Mar each year from light traps. Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip: flathead gudgeon =36, carp = 3106). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

**f)** **bony herring**

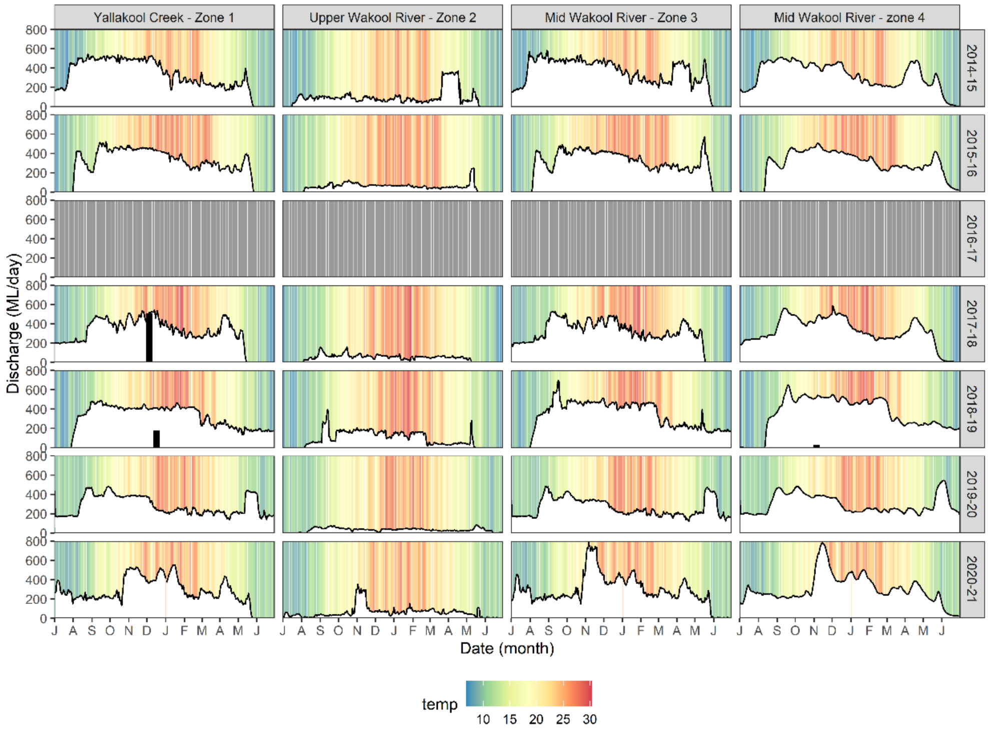



**g)** **river blackfish**

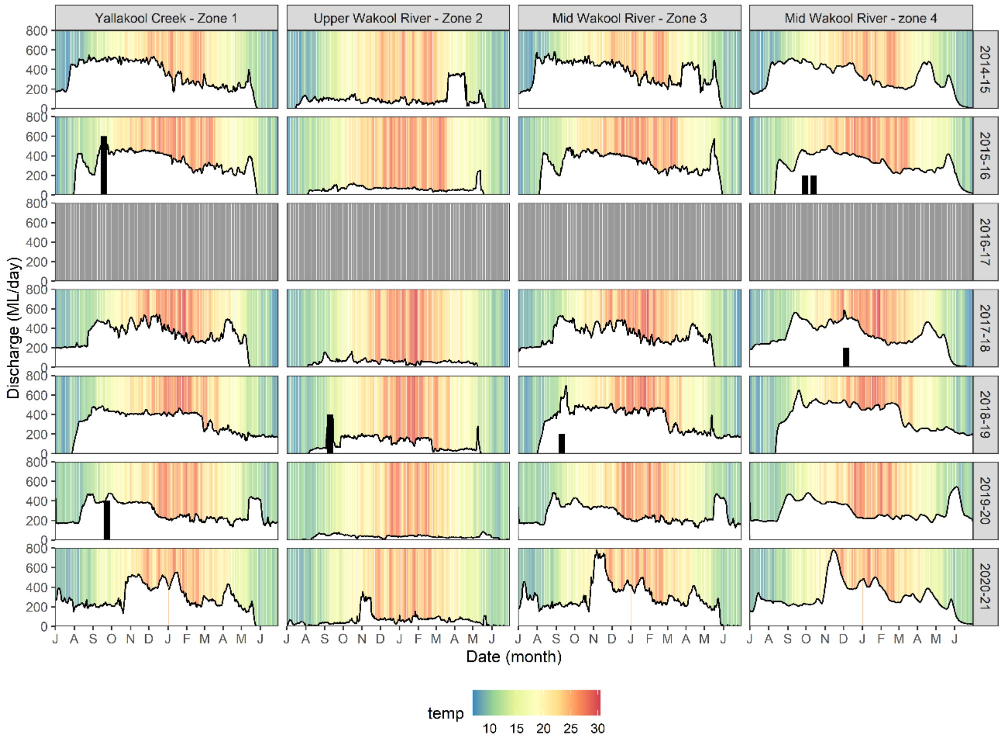



***Cont.*** **Figure 8.3** Discharge, water temperature and abundance and timing of *f)* bony herring and *g*) river blackfish larvae in each of the four study zones, from 2014-15 to 2020-21. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light traps. Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip: (Max no. caught: bony herring = 8, river blackfish = 18). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

**h) silver perch**

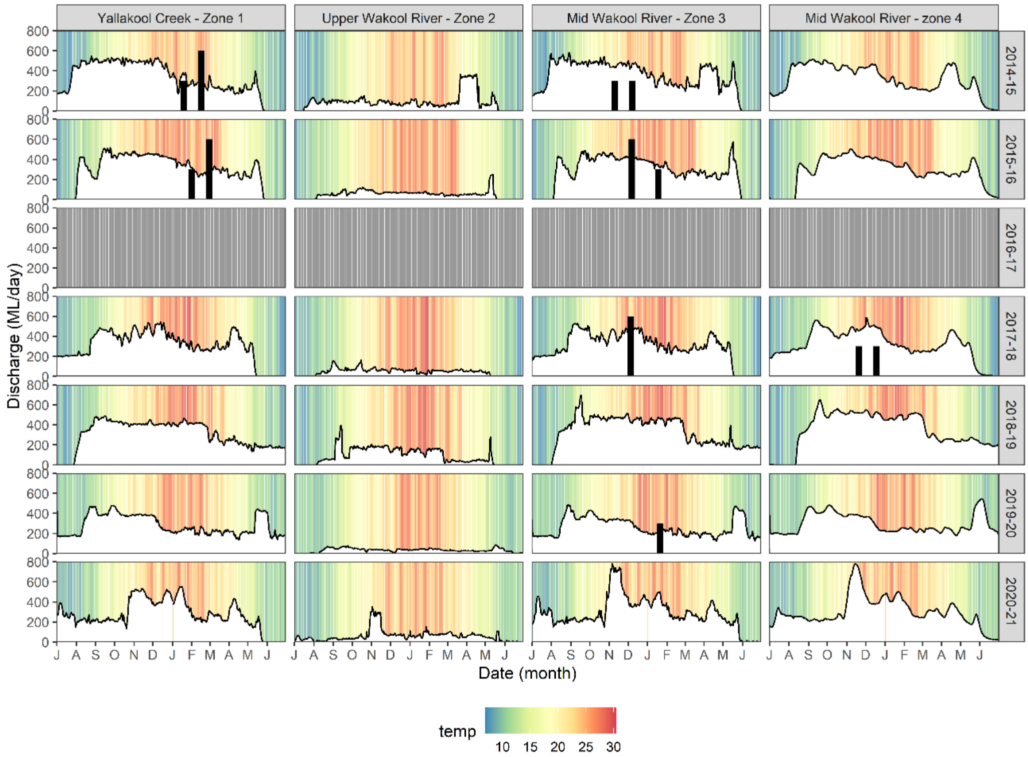



**i) obscure galaxias**

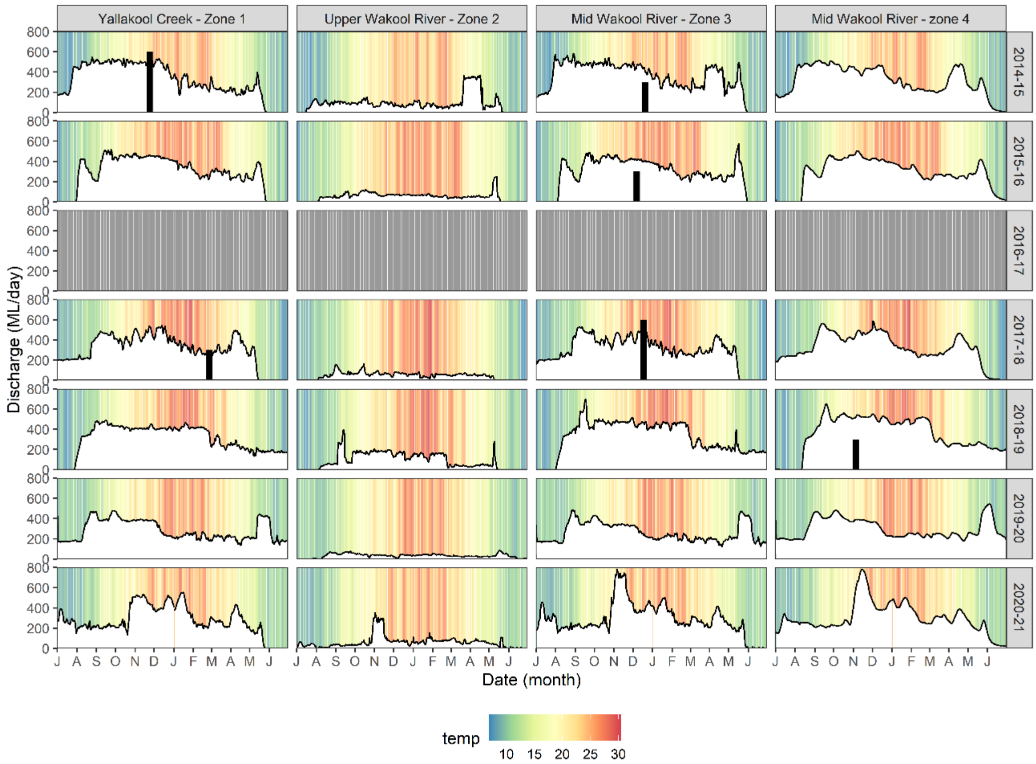



***Cont.* Figure 8.3** Discharge, water temperature and abundance and timing of *h)* silver perch and *i)* obscure galaxias larvae in each of the four study zones, from 2014-15 to 2020-21. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light traps (obscure galaxias) and drift nets (silver perch). Size of bars for each species determined by max number of individuals caught on one trip. Max no. caught on one trip: silver perch =1, obscure galaxias = 3). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

**j) unspecked hardyhead**




**k) Murray River rainbowfish**




***Cont.***

**Figure 8.3** Discharge, water temperature and abundance and timing of *j)* unspecked hardyhead and *k)* Murray River rainbowfish larvae in each of the four study zones, from 2014-15 to 2020-21. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light traps. Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip: unspecked hardyhead =2, Murray River rainbowfish = 2). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road.

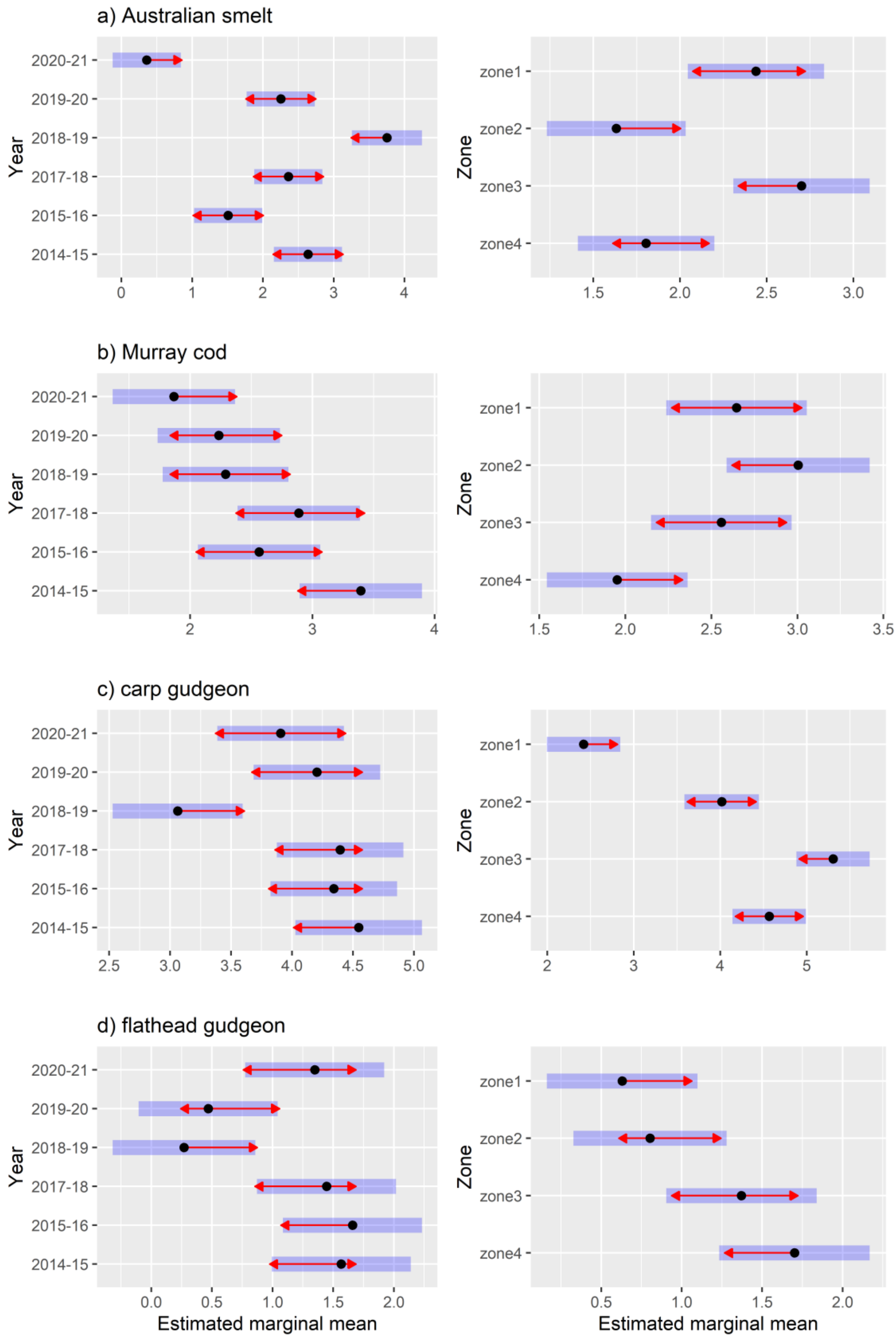



**Figure 8.4** Comparison of the estimated marginal means for the factors 'year' and 'zone' in the generalised linear models run for predicting larval light trap catch for a) Australian smelt, b) Murray cod, c) carp gudgeon and d) flathead gudgeon. Black dots represent the marginal means, and the purple shading represents the confidence intervals for each estimate.

### 8.5.2 *Fish recruitment*

A total of nine native fish species and five alien species were sampled between 2014-15 and 2020-21 as part of fish recruitment monitoring. Murray cod young-of-year (YOY) and 1+ recruits were detected in all zones for the second consecutive year since 2015-16 (Table 8.6). Five silver perch (*Bidyanus bidyanus*) age-class 1 (1+) recruits were in detected in Zone 4 (Table 8.6). Golden perch (*Macquaria ambigua*) new recruits (0+ or 1+) have not been detected during any year since surveys began, although one older juvenile was detected in Zone 1 for the first time. Trout cod recruits were detected in Yallakool Creek (Zone 1) for the first time during annual recruitment sampling. One previous individual had been captured in Yallakool Creek upstream of Zone 1 during system wide Category 3 sampling during 2019. Two individuals were captured by angling with another observed before getting off the line. The two captured measured 141 and 162 mm and are likely 1+ plus recruits based on length (not aged). This confirms their presence after eDNA sampling in 2020 detected them at that site (Watts et al. 2020). The downstream exapansion of trout cod is one of the outcomes from the Basin-wide Environmental Watering Strategy (MDBA 2014) (see section2).


**Figure 8.5** Images of fish surveyed during February 2021 Recruitment surveys.

**Table 8.6** Number of young-of-year (YOY), age class 1 (1+) recruits and older juveniles or adults (JA) of the three target species sampled in recruitment and growth monitoring in the Edward/Kolety-Wakool system for 2014-15 through 2020-21.

| | 2014-15 | | | 2015-16 | | | 2016-17 | | | 2017-18 | | | 2018-19 | | | 2019-20 | | | 2020-21 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zone | YOY | 1+ | JA | YOY | 1+ | JA | YOY | 1+ | JA | YOY | 1+ | JA | YOY | 1+ | JA | YOY | 1+ | JA | YOY | 1+ | JA |
| *Murray cod* | | | | | | | | | | | | | | | | | | | | | |
| Zone 1 | 5 | 15 | 17 | 2 | 8 | 1 | - | - | - | 2 | - | 4 | 5 | 2 | 1 | 4 | 15 | 8 | 2 | 7 | 29 |
| Zone 2 | 5 | 11 | 11 | 9 | 16 | 19 | - | - | - | 6 | 1 | 2 | 2 | 6 | 4 | 5 | 11 | 8 | 4 | 6 | 15 |
| Zone 3 | 3 | 14 | 13 | 8 | 9 | 16 | - | - | - | - | - | - | - | 2 | - | 4 | 12 | 17 | 2 | 16 | 27 |
| Zone 4 | 7 | 6 | 14 | 5 | 17 | 11 | - | - | - | - | - | - | - | - | - | 1 | 10 | 5 | 4 | 8 | 5 |
| *Silver perch* | | | | | | | | | | | | | | | | | | | | | |
| Zone 1 | - | - | 7 | - | 1 | 5 | - | - | 12 | - | - | 2 | - | - | 1 | - | - | 4 | - | - | 9 |
| Zone 2 | - | - | 2 | - | - | 3 | - | - | 3 | - | - | 1 | - | - | - | - | - | 1 | - | - | 8 |
| Zone 3 | - | - | 6 | - | 4 | 9 | - | - | 13 | - | - | 9 | - | 7 | 1 | - | - | 6 | - | 1 | 17 |
| Zone 4 | - | 1 | 1 | 5 | 15 | 14 | - | - | 7 | - | - | 14 | - | 3 | 4 | - | 1 | 14 | - | 4 | 18 |
| *Golden perch* | | | | | | | | | | | | | | | | | | | | | |
| Zone 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 |
| Zone 2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Zone 3 | - | - | 1 | - | - | 3 | - | - | - | - | - | - | - | - | - | - | - | 1 | - | - | 4 |
| Zone 4 | - | - | 2 | - | - | 1 | - | - | - | - | - | - | - | - | - | - | - | 4 | - | - | 2 |

## *Murray cod*

A total of 12 YOY and 37 1+ Murray cod recruits were detected in 2020-21 sampling (Table 8.6). This represents the second highest abundance of both classes of recruits since 2015-16 prior to the blackwater event in 2016 (Figures 8.6 and 8.7). Some of the apparent increased abundance of 1+ recruits may be attributable to the change in methods from backpack electrofishing to boat electrofishing at most sites, however the CPUE in Zone 2 where three out of the four sites were sampled with backpack electrofishing was comparable to 2015-16 (Figure 8.7).

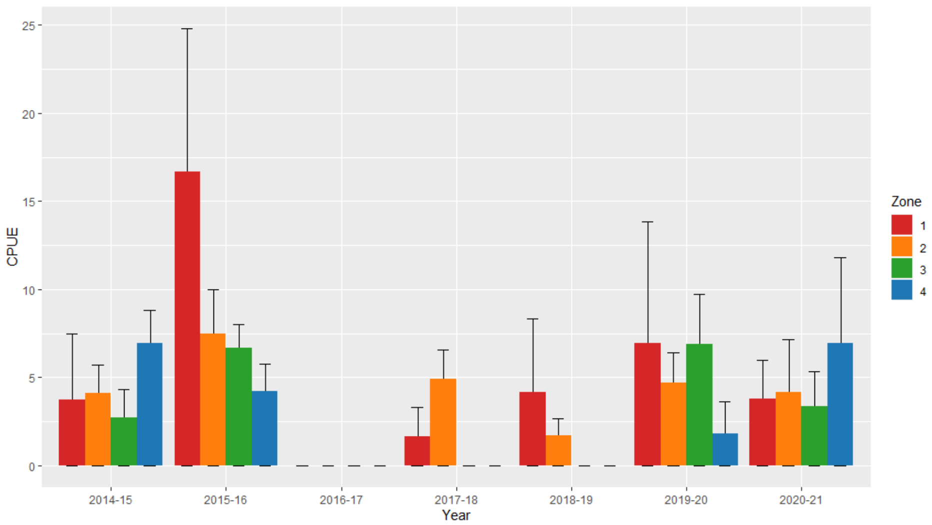



**Figure 8.6** Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of electrofishing) of YOY Murray cod in the Edward/Kolety-Wakool LTIM/Flow-MER zones from 2020-21.

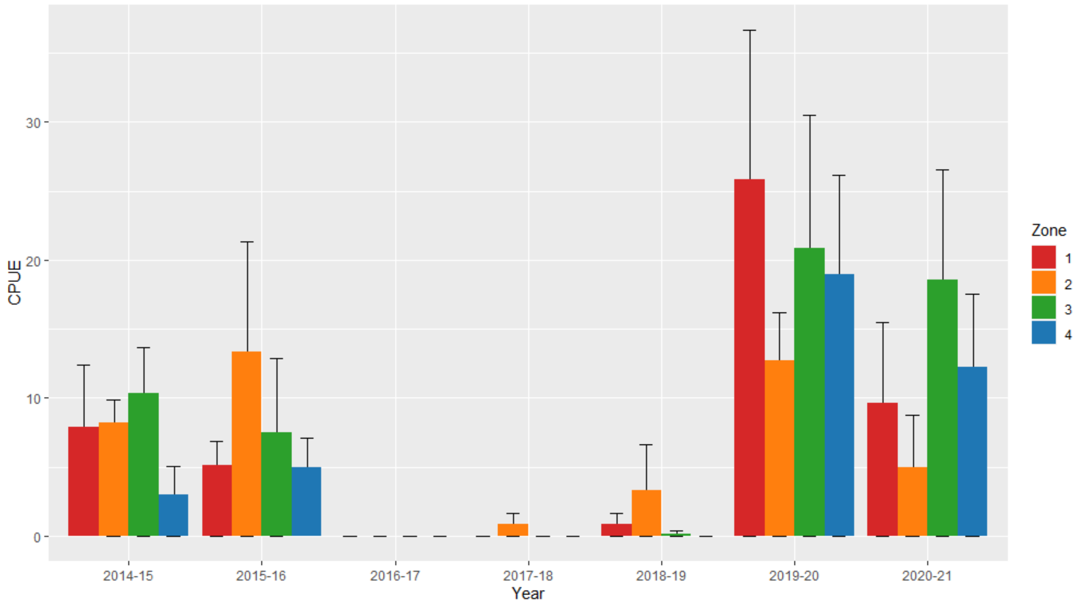



**Figure 8.7** Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of sampling time) of 1+ age class Murray cod in the Edward/Kolety-Wakool LTIM/Flow-MER zones using electrofishing, setlines and angling from 2014-15 to 2019-20.

### *Growth of Murray cod*

Growth per day (mm) of YOY Murray cod was similar to previous years except for 2017-18 which were the first cohort following the flood in 2016 (Figure 8.8). This trend is followed by the 1+ recruits in 2020-21 generally growing slower than in 2018-19 (the cohort spawned in 2017-18), with the exception of recruits in Zone 4 that displayed similar growth rates to those in 2018-19 from other zones (Figure 8.9).

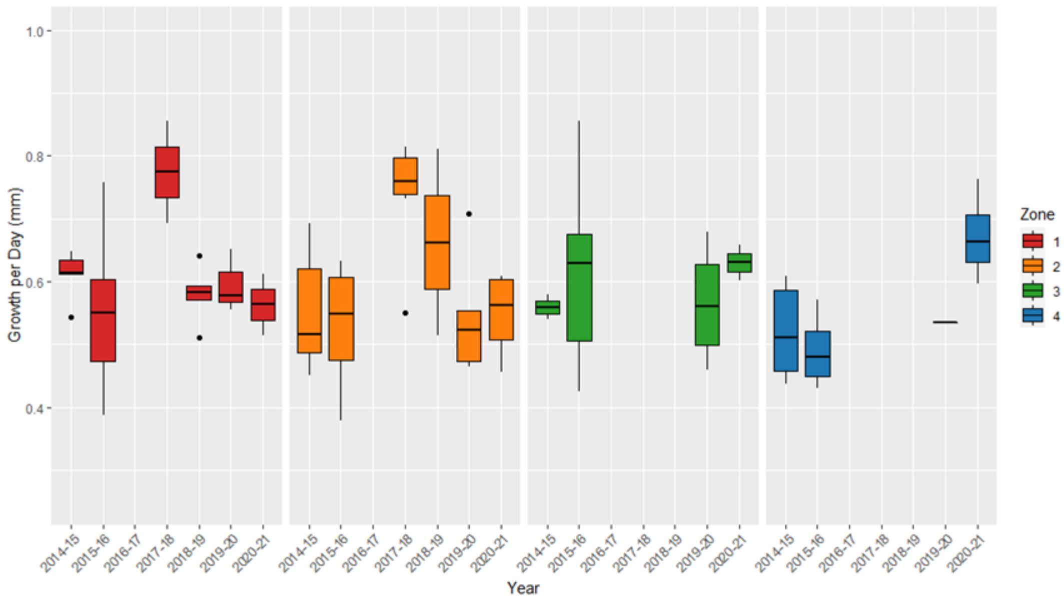



**Figure 8.8** Boxplots of the annual growth rates (mm per year) of YOY Murray cod in each zone between 2014-15 and 2020-21. Number of individuals (n) per zone: 2014-15 n = 5, 5, 3, 7; 2015-16 n = 20, 9, 8, 5; 2016-17 n = 0, 0, 0, 0; 2017-18 n = 2, 6, 0, 0; 2018-19 n = 5, 2, 0, 0; 2019-20 n = 4, 5, 4, 1; 2020-21 n = 2, 4, 2, 4.

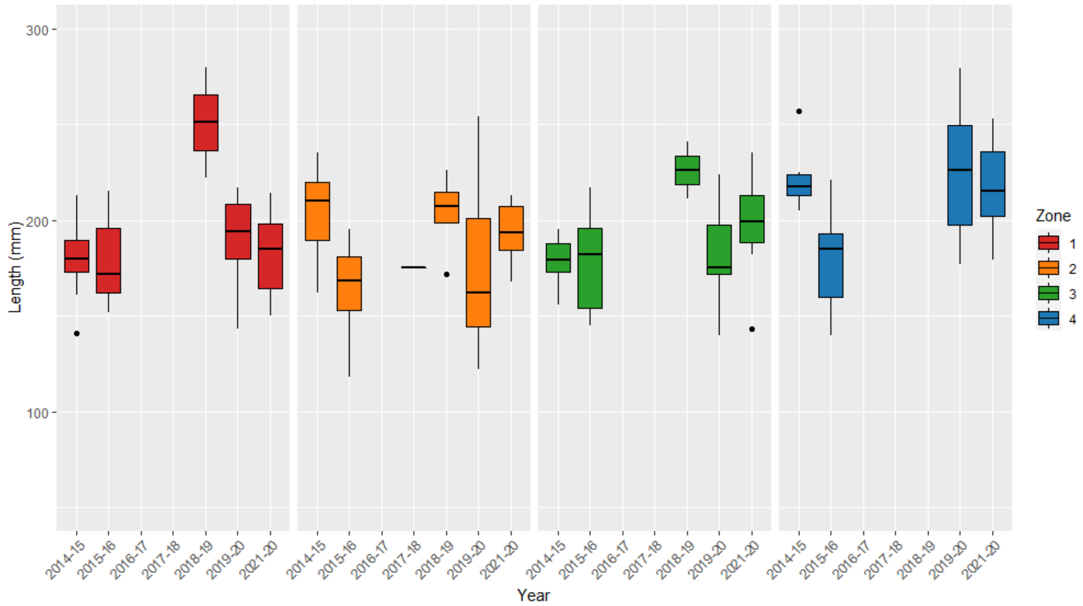



**Figure 8.9** Boxplots of the annual length-at-age (mm) for 1+ Murray cod in each zone between 2014-15 and 2018-19. Number of individuals (*n*) per zone: 2014-15 *n* = 15, 11, 14, 6; 2015-16 *n* = 8, 16, 9, 17; 2016-17 *n* = 0, 0, 0, 0; 2017-18 *n* = 0, 1, 0, 0; 2018-19 *n* = 2, 6, 2, 0; 2019-20 n = 15, 11, 12, 10; 2020-21 n = 7, 6, 16, 8.

### *Silver perch*

Fifty-two silver perch were captured using setlines and angling in 2020-21, ranging from 111 mm to 467 mm. This is the largest number of silver perch caught since surveys began in 2014-15 and includes the largest adult caught. Determination of age class recruits was done using length data from fish previously aged on this project.

Five fish captured were likely 1+ recruits with the majority of those caught in Zone 4 (Figure 8.10), with all other fish either other juveniles (2+) or adults.

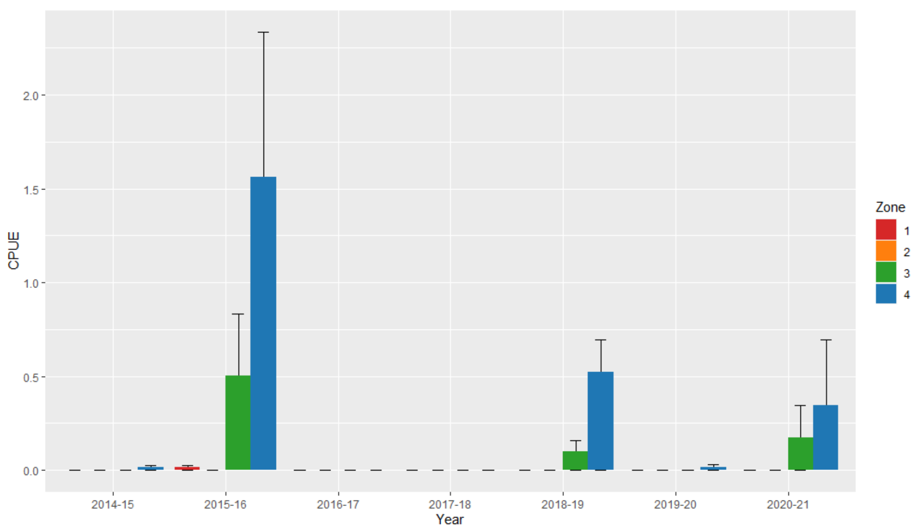



**Figure 8.10** Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of sampling time) of 1+ age class silver perch in the Edward/Kolety-Wakool LTIM/Flow-MER zones using setlines and angling from 2014-15 to 2020-21.

### 8.5.3 *Adult fish community*

Basin-scale Category 1 fish community sampling of the Edward/Kolety-Wakool River system (undertaken only in Mid Wakool River - Zone 3) identified 4,508 fish consisting of nine native fish species and three alien species in 2021 (Table 8.7, Figure 8.11 & 8.12). In order, carp gudgeon, Murray-Darling rainbowfish, common carp and Murray cod were the most abundant species in 2021 (Figure 8.13). While in order, common carp, Murray cod, golden perch and bony herring contributed the most to biomass (Figure 8.14).

In 2021, new recruits (juveniles) were found for only one long-lived native fish species (Murray cod at 10 of 10 sites) but for all five short-lived native species (Australian smelt at 1 of 10 sites, carp gudgeon at 10 of 10 sites, flatheaded gudgeon at 3 of 10 sites, Murray-Darling rainbowfish at 10 of 10 sites and un-specked hardyhead at 4 of 10 sites) (Figure 8.11). No new recruits of silver perch or bony herring were captured. New recruits were found for two alien species (common carp at 9 of 10 sites and goldfish at 5 of 10 sites), while no Eastern gambusia new recruits were detected.

One golden perch of 112 mm slightly above the new recruit length cut-off (75 mm for this species, Table 8.4) was captured at the Cummins site. Daily aging of an otolith from this individual revealed an age of 140 days, which corresponded to an estimated spawning date of 16 December 2020.

Significant differences in relative abundance ($Pseudo\text{-}F_{6, 63}$ = 8.922, $P < 0.001$) of the fish community were detected between years (Figure 8.13). Pair-wise comparisons revealed that abundance differed in all combinations of years, except between 2015 and 2016 (t = 2.127, $P$ = 1.000), 2017 and 2018 (t = 4.848, $P$ = 0.105), 2018 and 2019 (t = 5.010, $P$ = 0.063), 2019 and 2021 (t = 3.871, $P$ = 0.126). Differences in abundance were mainly explained by greater numbers of Murray cod in 2015 (up to 15% contribution) and 2016 (up to 18%); Eastern gambusia in 2015 (up to 16%), 2016 (up to 18%), 2017 (up to 17%) and 2018 (up to 17%); un-specked hardyhead in 2016 (up to 22%) and 2017 (up to 18%); carp gudgeon in 2017 (up to 12%) and 2018 (up to 15%); and bony herring in 2020 (up to 21%).

Differences in biomass ($Pseudo\text{-}F_{6, 63}$ = 4.746, $P < 0.001$) of the fish community were also found between years (Figure 8.16). Differences were evident between 2015 and 2017, 2015 and 2018, 2015 and 2020, 2016 and 2017, 2016 and 2018, 2016 and 2020, 2017 and 2020, and 2017 and 2021 (t > 5.824, P < 0.05). Dissimilarities were mostly driven by a greater biomass of golden perch in 2015 (up to 22% contribution) and 2016 (up to 24%); Murray cod in 2015 (up to 29%), 2016 (up to 28%), 2020 (up to 20%) and 2021 (up to 20%); and common carp in 2017 (up to 19%).

Abundance and biomass of native Murray cod and golden perch recovered considerably in 2021 relative to previous years after the flooding/hypoxia event 2016-2017 but were still lower than in 2015 and 2016 (Figure 8.13 & 8.14). Length-frequency distributions (Figure 8.15) indicated that Murray cod were significantly larger in 2017 immediately after the fish kills compared to other years excluding 2018 ($P < 0.05$). Distributions also differed in 2021 compared to 2015 and 2016 ($P < 0.05$) due to a higher proportion of smaller individuals present in the current year.

Native golden perch abundance and biomass were similarly elevated in 2021 compared to other years post-flooding/hypoxia in 2016/17, although below 2015 and 2016 levels (Figure 8.11 & 8.12). Analysis of length-frequency distributions (Figure 8.15) revealed that golden perch were significantly smaller in 2015 and 2016 compared to all other years ($P < 0.05$), but not different between 2015 and 2016 ($P = 0.297$) or other year combinations (P > 0.115). This was despite an increase in sub-adult fish between 100-300 mm in 2021 compared to other years. We considered sub-adult fish to be below the minimum size at sexual maturity of adult golden perch (325 mm, Mallen-Cooper 2003) but above the minimum length at 1 year cut-off which was used to assign the smaller juvenile or newly recruiting golden perch (75 mm, Table 8.4).

Native bony herring abundance in 2021 was below peaks of 2020 and 2018, but biomass was highest in 2021 compared to other years owing to the dominance of larger individuals (Figure 8.13 & 8.14). Differences in length-frequency distributions (Figure 8.15) between years confirmed there were larger fish in 2021 compared to all other years ($P < 0.05$) except 2016 ($P = 0.676$); smaller fish in 2020 compared to all other years ($P < 0.05$); and smaller fish in 2018 compared to all other years ($P < 0.05$) except 2020. There were also smaller fish in 2017 compared to 2016 ($P < 0.05$); and larger fish in 2016 compared to 2015 ($P < 0.05$).

Alien common carp abundance increased considerably in 2021 but was below that in 2017 following extensive recruitment following the flooding/hypoxia event in 2016/17 (Figure 8.13). However, common carp biomass in 2021 was lower than in 2015-2018 due, in part, to the presence of mostly new recruits in the population (Figure 8.14). Length-frequency distributions (Figure 8.15) revealed differences between all year combinations (P < 0.05) except between 2015 and 2016 (P = 0.052). Differences included smaller fish in 2017 compared to other years; smaller fish in 2021 compared to other years except 2017; and larger fish in 2015 and 2016 compared to 2017-2021.

**Table 8.7** Summary of fish captured during annual Category 1 standardised sampling from 2015–2021 in the Edward/Kolety-Wakool Selected Area. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

| Fish species | 2015 | | | | 2016 | | | | 2017 | | | | 2018 | | | | 2019 | | | | 2020 | | | | 2021 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | SFN | BT | **Total** | BE | SFN | BT | **Total** | BE | SFN | BT | **Total** | BE | SFN | BT | **Total** | BE | SFN | BT | **Total** | BE | SFN | BT | **Total** | BE | SFN | BT | **Total** |
| *Native species* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Australian smelt | 129 | 2 | - | **131** | 52 | 1 | - | **53** | 293 | 10 | - | **303** | 301 | 4 | - | **305** | 287 | 26 | - | **313** | 73 | 45 | - | **118** | 93 | 1 | - | **94** |
| bony herring | 31 | - | - | **31** | 27 | - | - | **27** | 108 | - | - | **108** | 148 | - | - | **148** | 20 | - | - | **20** | 320 | 5 | 1 | **326** | 72 | - | - | **72** |
| carp gudgeon | 47 | 4302 | 51 | **4400** | 68 | 2367 | 15 | **2450** | 165 | 6814 | 66 | **7045** | 52 | 7804 | 98 | **7954** | 23 | 2396 | 38 | **2457** | 4 | 4873 | 57 | **4934** | 51 | 3295 | 34 | **3380** |
| flathead gudgeon | - | - | 1 | **1** | - | - | 3 | **3** | - | - | - | **0** | - | - | - | **0** | - | - | - | **0** | - | - | - | **0** | - | 5 | - | **5** |
| golden perch | 107 | - | - | **107** | 116 | - | - | **116** | 19 | - | - | **19** | 38 | - | - | **38** | 39 | - | - | **39** | 27 | - | - | **27** | 59 | - | - | **59** |
| Murray cod | 210 | - | - | **210** | 333 | 1 | - | **334** | 12 | - | - | **12** | 21 | - | - | **21** | 43 | - | - | **43** | 66 | - | - | **66** | 164 | - | - | **164** |
| Murray-Darling rainbowfish | 339 | 168 | - | **507** | 353 | 77 | 5 | **435** | 650 | 19 | - | **669** | 518 | 19 | - | **537** | 508 | 83 | - | **591** | 424 | 83 | - | **507** | 398 | 33 | - | **431** |
| silver perch | 5 | - | - | **5** | 5 | - | - | **5** | 3 | - | - | **3** | 2 | - | - | **2** | 4 | - | - | **4** | 7 | - | - | **7** | 9 | - | - | **9** |
| un-specked hardyhead | 86 | 64 | - | **150** | 565 | 35 | - | **600** | 510 | 72 | - | **582** | 82 | 7 | - | **89** | 22 | 9 | - | **31** | 22 | 25 | - | **47** | 12 | 5 | - | **17** |
| *Alien species* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| common carp | 167 | - | - | **167** | 176 | - | - | **176** | 735 | 40 | 3 | **778** | 251 | 1 | - | **252** | 160 | 1 | - | **161** | 89 | - | - | **89** | 251 | 1 | - | **252** |
| Eastern gambusia | 18 | 175 | - | **193** | 36 | 366 | 1 | **403** | 31 | 125 | 8 | **164** | 2 | 53 | - | **55** | 2 | 10 | - | **12** | - | - | - | **0** | 2 | 4 | 2 | **8** |
| goldfish | 21 | - | - | **21** | 38 | - | - | **38** | 73 | 2 | - | **75** | 15 | - | - | **15** | 44 | - | - | **44** | 3 | - | - | **3** | 16 | 1 | - | **17** |

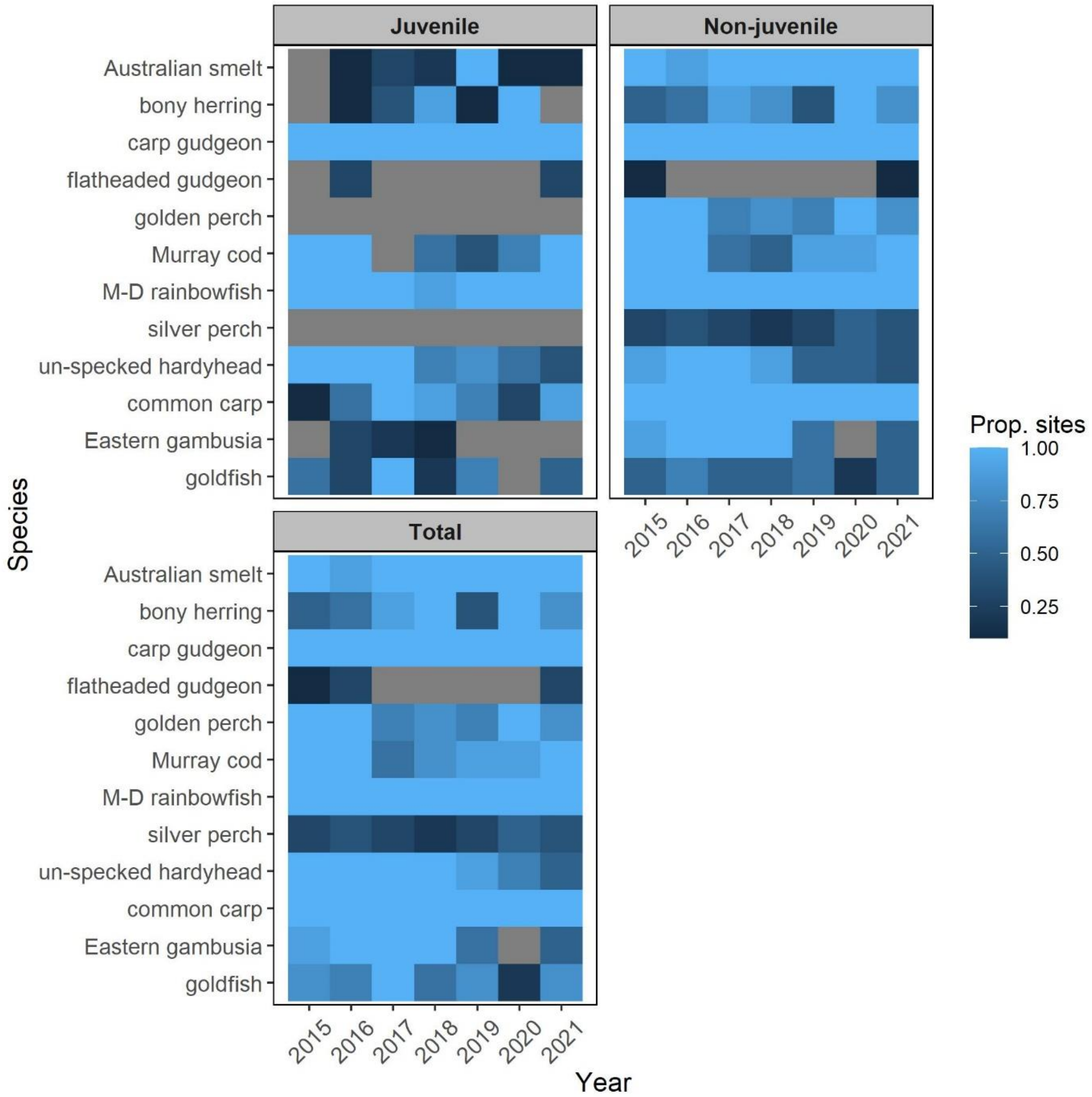



**Figure 8.11** Proportion of sites (blue colour coding, grey indicates no captures) that each fish species were caught at from 2015-2021, separated into juvenile (based on length cut-off's presented in Table 8.4), non-juvenile or total fish categories.

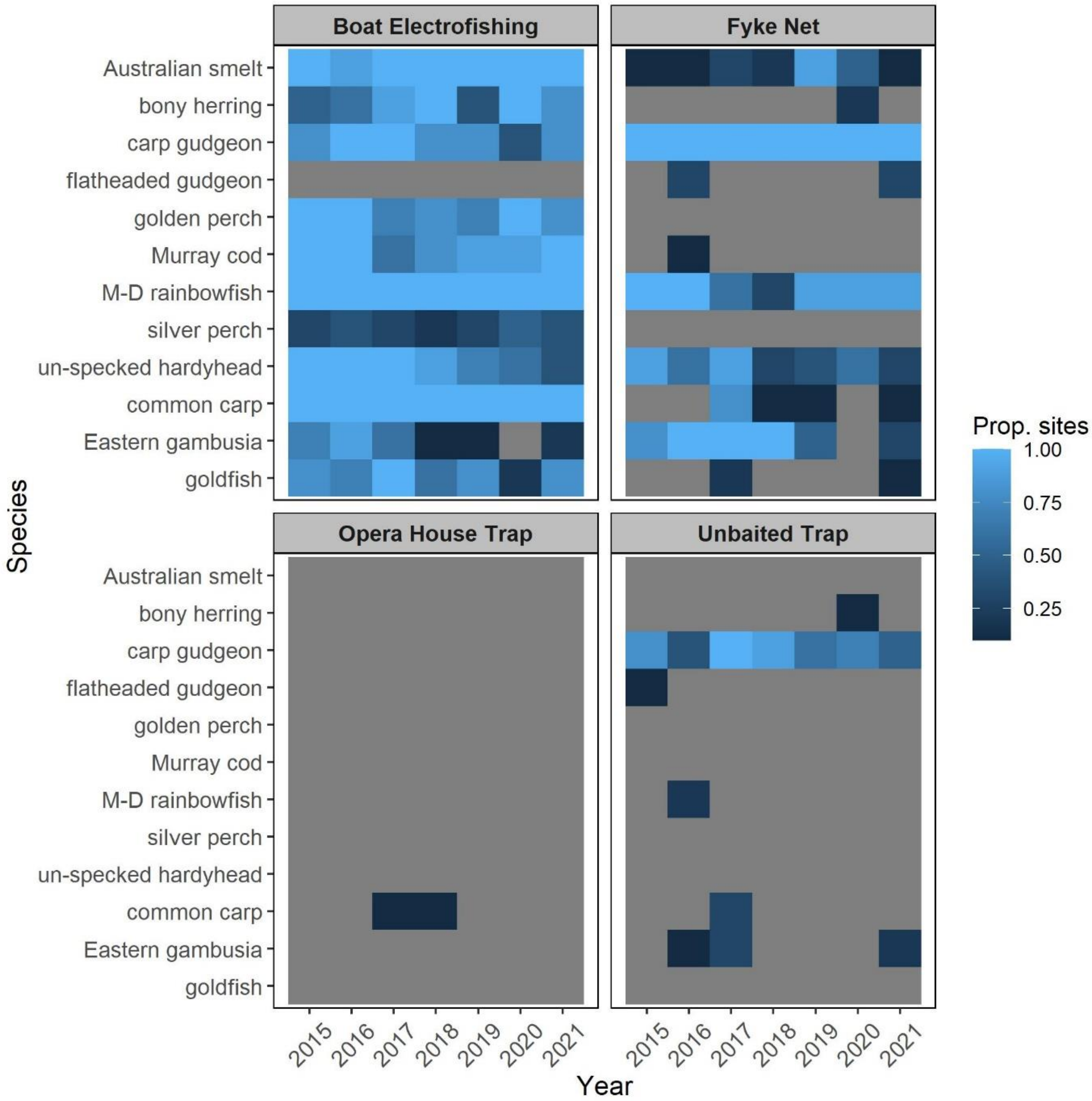



**Figure 8.12** Proportion of sites (blue colour coding, grey indicates no captures) that each fish species were caught at from 2015-2021, separated by capture method.

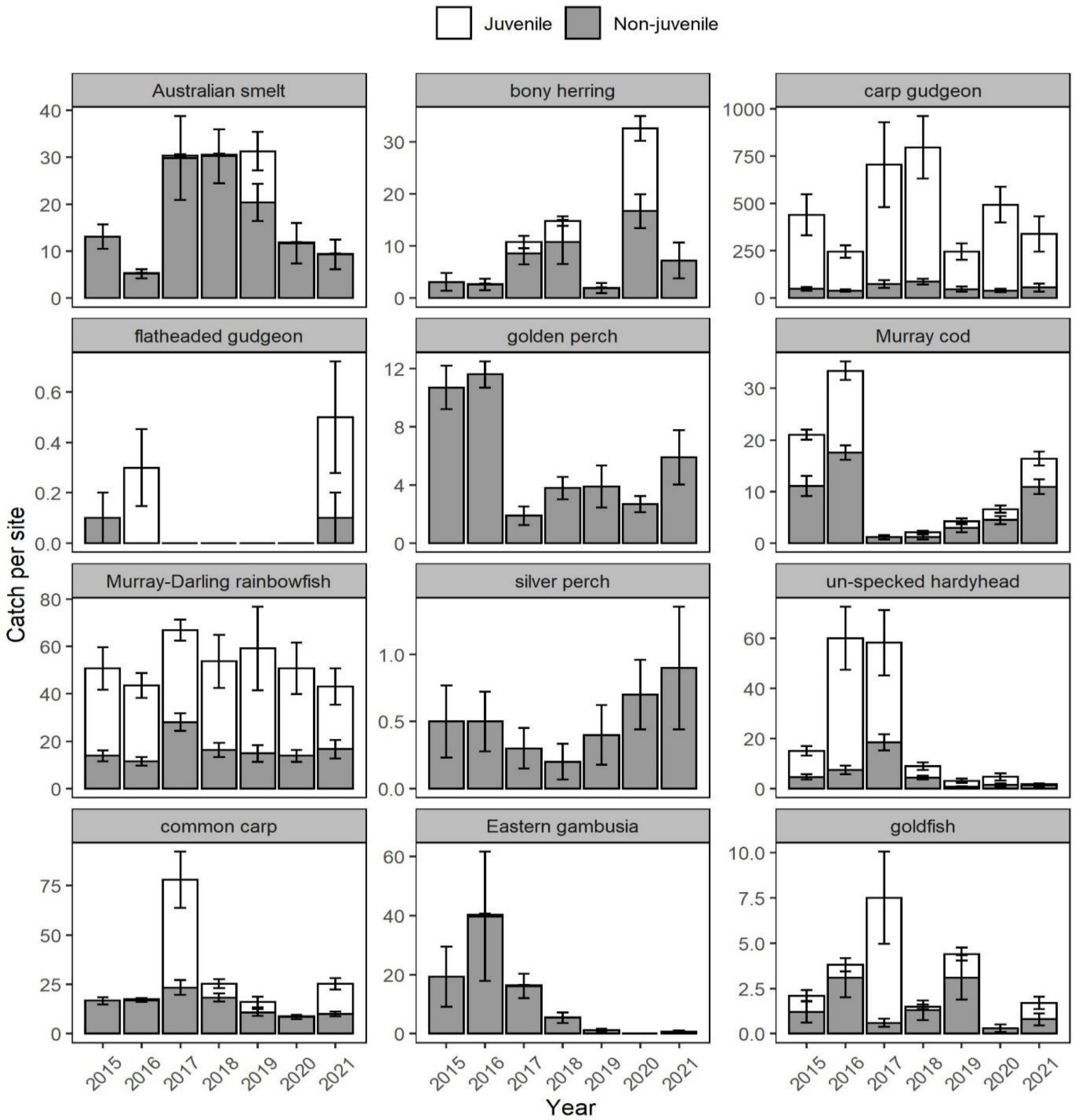



**Figure 8.13** Catch per site (number of fish; mean ± SE) for each fish species within the Edward/Kolety-Wakool Selected Area, sampled from 2015–2021. Cumulative stacked bars separate the catch of juveniles (white bars) based on length cut-off's presented in Table 8.4 and non-juveniles (grey bars).

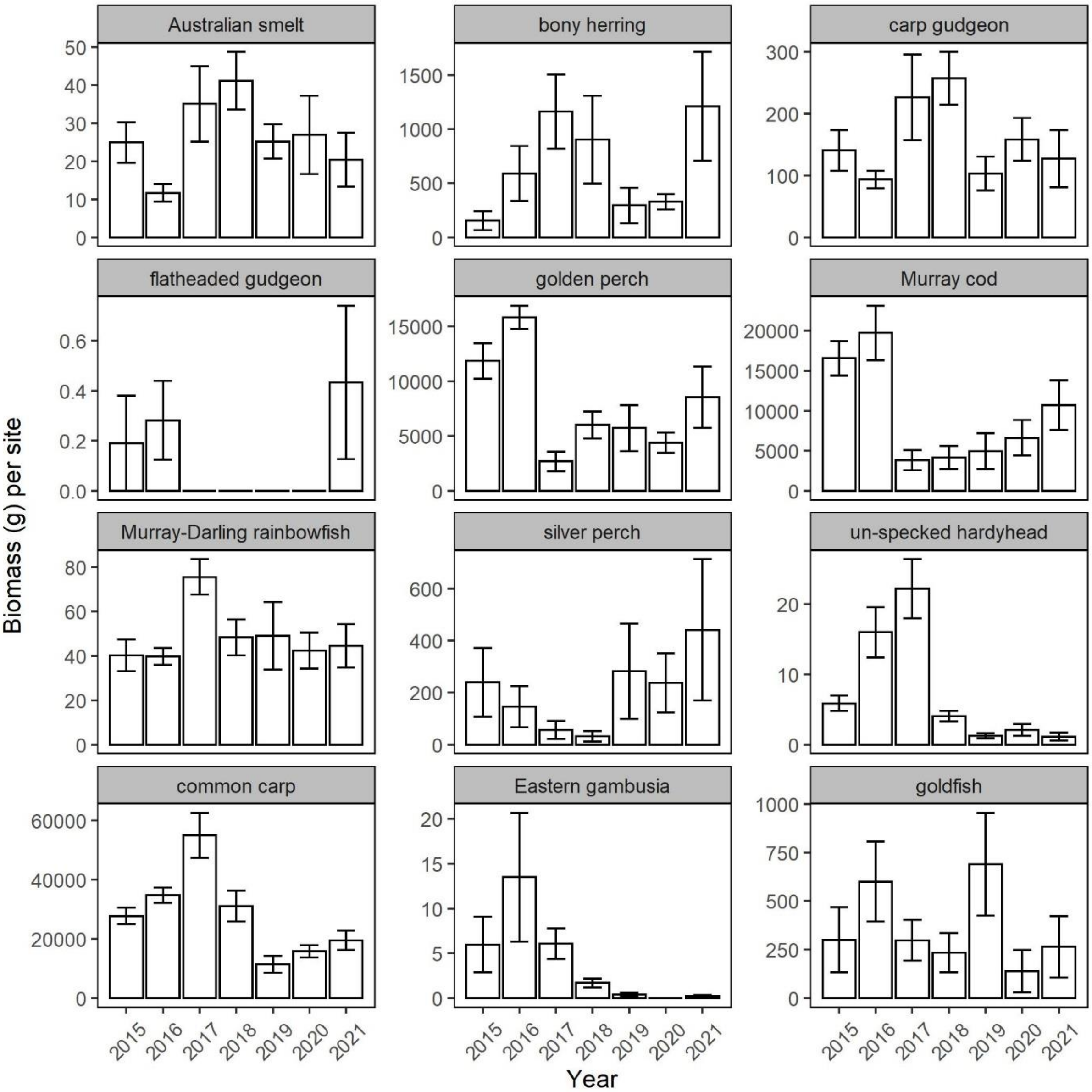



**Figure 8.14** Biomass per site (weight of fish; mean ± SE) for each fish species within the Edward/Kolety-Wakool Selected Area, sampled from 2015–2021.

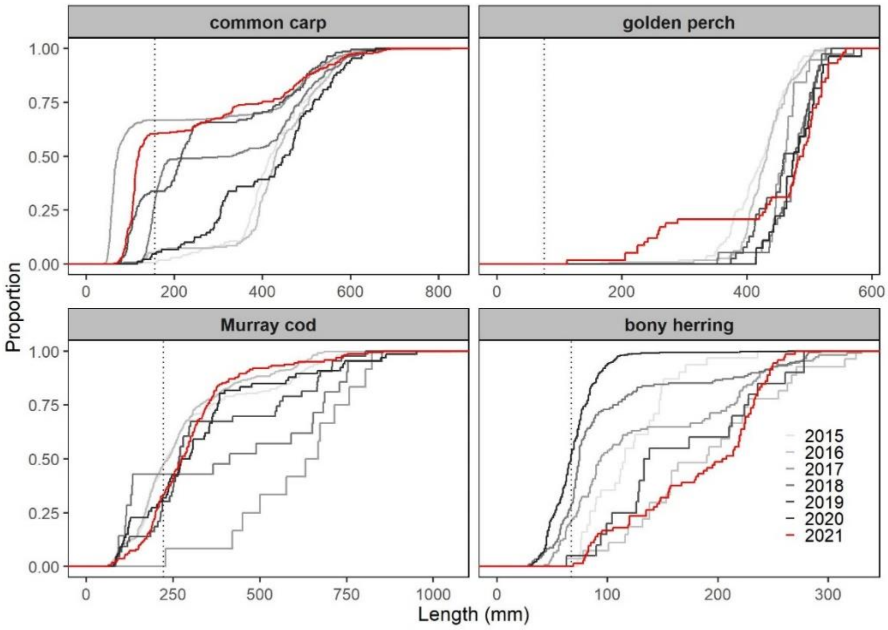



**Figure 8.15** Cumulative length-frequency histograms of the four most common large-bodied species captured during Category 1 sampling in the Edward/Kolety-Wakool Selected Area in 2015–2021. The dashed line indicates approximate length at one year of age found in Table 8.4 and annual sample sizes are provided for each respective species and sampling year in Table 8.7.

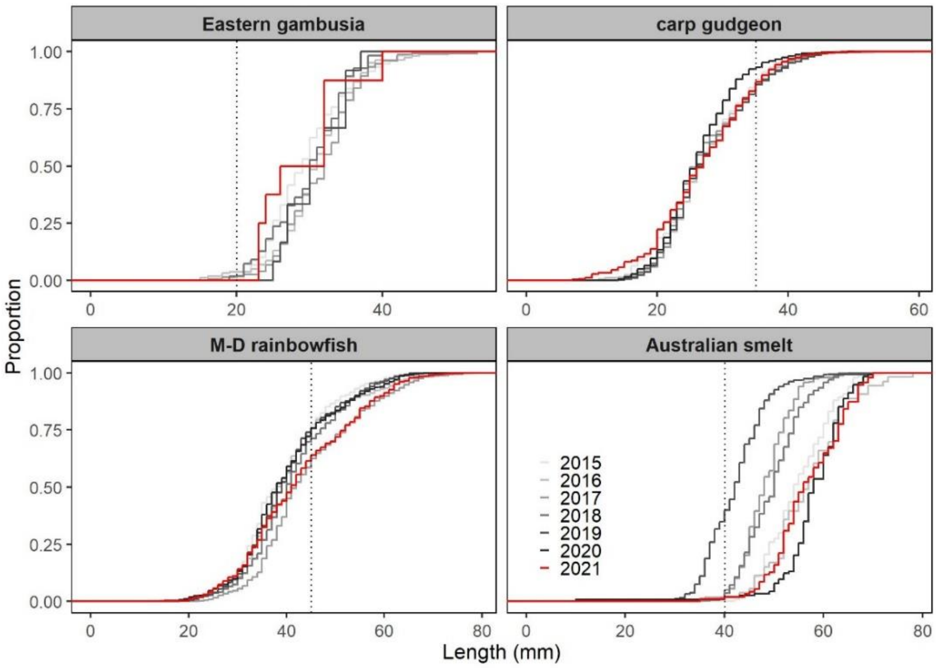



**Figure 8.16** Cumulative length-frequency histograms of the four most common small-bodied species captured during Category 1 sampling in the Edward/Kolety-Wakool Selected Area in 2015–2021. The dashed line indicates approximate length at sexual maturity specified in Table 8.4 and annual sample sizes are provided for each respective species and sampling year in Table 8.7.

## 8.6 Discussion

Here, we bring together our results from spawning, recruitment and adult fish community monitoring to provide an overview of how the fish community in the Edward/Kolety-Wakool has responded to targeted watering events and the broader hydrological conditions of 2020-21. A summary of the species of larvae, recruits and adults present in the system in 2020-21 is provided in Table 8.8. Using these multiple lines of evidence, we provide a summary on how fish responded to each of the watering actions delivered in 2020-21, and provide recommendations for future water delivery.

It is important to provide some context of the 2020-21 fish surveys. In 2016-17 the Edward/Kolety-Wakool River fish community, along with other regions in the southern Murray-Darling Basin, was heavily impacted by flood-induced hypoxic blackwater and that resulted in fish kills. These followed numerous fish kills in the preceding 6 years and prior to LTIM. Since this time, LTIM and Flow-MER fish monitoring are identifying a gradual recovery of the fish community. Promisingly, adults of most species have since been captured in the system, and regular spawning and recruitment through to the juvenile stage has been observed for numerous species (Table 8.9, Watts et al. 2019). Of the fourteen native fish species that have been recorded in the Edward/Kolety-Wakool Selected Area since LTIM commenced in 2014, eleven were detected as either eggs/larvae, recruits or adults in 2020-21 (Table 8.8).

**Table 8.8** Multiple lines of evidence: a summary of 2020-21 fish monitoring results in the Edward/Kolety-Wakool Selected Area, of the species known to occur in the area prior to 2020. For the 2020-21 sampling season – ticks denote the presence of larvae/eggs (indicating successful spawning), recruits (indicating successful recruitment) and adults. ^ denotes introduced species. [1] indicates species have been recorded in the focal areas as larvae, but not adults.

| 2014-2020 | 2020-21 | | |
|---|---|---|---|
| Fish species | Larvae/eggs | Recruits | Adults |
| *periodic species* | | | |
| bony herring | | | ✓ |
| golden perch | | ✓ | ✓ |
| silver perch | | ✓ | ✓ |
| common carp ^ | ✓ | ✓ | ✓ |
| goldfish ^ | | ✓ | ✓ |
| redfin ^ | | | |
| *equilibrium species* | | | |
| Murray cod | ✓ | ✓ | ✓ |
| river blackfish | ✓ | ✓ | ✓ |
| freshwater catfish[1] | | | |
| trout cod | | ✓ | |
| *opportunistic species* | | | |
| Australian smelt | ✓ | | ✓ |
| carp gudgeon | ✓ | ✓ | ✓ |
| Murray River rainbowfish | | ✓ | ✓ |
| flathead gudgeon | ✓ | ✓ | ✓ |
| unspecked hardyhead | | | ✓ |
| obscure galaxias | | | |
| dwarf flathead gudgeon[1] | | | |
| gambusia ^ | | | ✓ |
| oriental weatherloach ^ | | | |

## *Summary of Watering actions in 2020-21*

The CEWO's overarching objective for environmental watering for fish populations in the Edward/Kolety-Wakool River system for 2020-21 was to provide flows to "support recovery of native fish following low-oxygen blackwater event in 2016" (CEWO 2020). In 2020-21 CEWO delivered eight specific watering actions that targeted fish related outcomes. Four of these watering actions were delivered in the Yallakool-Wakool Rivers, in which routine fish monitoring takes place (spawning, recruitment and adult fish surveys), and four were delivered in the Colligen-Niemur Rivers were routine fish monitoring is absent. Flow objectives for the watering actions delivered to the Wakool-Yallakool River included to contribute to the: pre-spawning condition of native fish (Spring fresh - watering action 1), early season spawning native fish (watering action 1), maintain nesting habitat for Murray cod (elevate base flow - watering action 2), encourage silver perch breeding and spawning (summer freshes - watering action 3), to assist with larval and juvenile dispersal fish (watering action 3), and maintain fish resident fish populations (variable base flows watering action 4) (Table 8.9).

## *Summary of key fish findings 2020-21*

Across the spawning, recruitment and adult fish surveys conducted in 2020-21, a total of eleven native freshwater fish species two introduced species were recorded in the Edward/Kolety-Wakool River system. Murray cod, river blackfish, bony herring, Australian smelt, carp gudgeon, flathead gudgeon, unspecked hardyhead and Murray River rainbowfish are found to spawn and recruit most years in in the Edward/Kolety Wakool system. Golden perch and silver perch are known to occur as adults, however to date there has been no evidence of golden perch spawning and only limited evidence of localised recruitment (which may actually be driven by immigration) within the Selected Area. Murray cod spawn and recruit annually throughout the Edward/Kolety Wakool Selected Area, and their population showing a consistent, positive signs of recovery since the 2016-17 fish kills. Trout cod, are known in the Edward/Kolety River (and the broader Murray River which is most likely their source population), but recently detected in Yallakool Creek (eDNA surveys, Watts et al. 2019). not been detected in the monitored reaches in 2014-2020.

Native fish species that were historically likely to have been in the lowland central Murray region, which have not been detected in the Edward/Kolety-Wakool monitoring sites since LTIM and Flow-MER Programs commenced in 2014 include olive perchlet, Macquarie perch, Murray hardyhead, southern purple spotted gudgeon and southern pygmy perch.

In the context of these longer-term results, key findings from 2020-21 Edward/Kolety-Wakool fish population surveys include:

- **Increase in golden perch subadults in the Selected Area, including one golden perch young-of-year detected in the Mid Wakool** River (Zone 3). This is the first time Golden perch YOY have been detected in the Edward/Kolety-Wakool monitored sites since surveys commenced in 2014. Ageing using back-calculating counting of otolith daily increments provides a spawning date estimate of early December 2020, which coincides with the recession of the CEWO delivered 800 ML/day spring fresh.

**Table 8.9** Monitored outcomes of the fish-focussed CEWO watering actions in 2020-21. Note: watering actions that could not be monitored by the Flow-MER fish monitoring program are not listed here (e.g., watering actions 5-7).

| | Watering action | Dates | Rivers | Flow objectives | Monitored outcomes |
|---|---|---|---|---|---|
| 1 | Spring fresh | 20 Oct - 30 Nov 2020 | Yallakool Creek, upper and mid-Wakool River | To contribute to pre-spawning condition of native fish<br><br>To contribute to spawning in early spawning native fish | Increase in flatheaded gudgeon larvae and juveniles recorded from previous two years. |
| 2 | Elevated base flow | 30 Nov – 15 Dec | Yallakool Creek | To maintain nesting habitat for Murray Cod | Pre-spawning and nesting behaviour of Murray cod usually commences between in September and October, and there for the timing of watering action 2 may have been too late for achieving the flow objective. Providing flows in the upper Wakool of 200 ML/day that commence early September and are maintained until the end of the cod breeding season (early-mid December) may be more successful in maximising the availability of suitable nesting areas during Murray cod breeding season. |
| 3 | Summer freshes | 15 Dec – 15 Feb | Yallakool Creek | To influence and encourage silver perch breeding and movement<br><br>To assist with dispersal of larvae and juveniles of a number of fish species | No evidence of silver and/or golden perch spawning in the Wakool River or Yallakool Creek. Evidence from the Murrumbidgee Selected Area indicates that Golden Perch spawning would have occurred prior to this time/temperature.<br><br>The timing of this action may have assisted with in-situ dispersal, as well as both emigration from the system and immigration into the system. Based on previous evidence the latter is more likely to have contributed to the presence of golden perch juveniles. |
| 4 | Autumn fresh | 30 Mar – 6 May | Yallakool Creek | To influence and encourage fish movement.<br>To assist with dispersal of larvae and juveniles of a number of fish species | The timing of this action may have assisted with in-situ dispersal, as well as both emigration from the system and immigration into the system. Based on previous evidence the latter is more likely to have contributed to the presence of golden perch juveniles. |
| 8 | Variable base flows | 23 Jan – 9 Jun | Upper Wakool | To determine if a longer higher flow rate is better at maintaining fish | The variable base flows in the upper Wakool maintained good water quality through Autumn. DO levels did not fall to critical levels known ot be detrimental to fish. Therefore, the variable base flows will have assisted in maintain the health of fish populations within these reaches over summer and autumn |

- **The Highest number of juvenile/adult silver perch were recorded in 2020-21 than previous years.** This finding was consistent across both the targeted recruitment surveys that take place in summer across all four study zones, as well as the June adult surveys that take place in Mid Wakool River (Zone 3).
- The **Murray cod population continues to show a steady recovery post 2016-17 fish kills**. As with previous years, both spawning and recruitment appears widespread throughout the Edward/Kolety-Wakool Selected area. The adult population is largely dominated by smaller sized classes, indicating that recruitment is driving the recovery of the population, rather than immigration of larger, older individuals into the system.
- **1+ trout cod were collected in Yallakool Creek for the first-time** during February 2021 recruitment surveys. Adult trout cod are known to the Edward/Kolety-Wakool system, in sections of the Edward River upstream of Deniliquin, but previously not been detected in the monitored reaches of Yallakool Creek and Upper and Mid Wakool River.
- **Strong spawning and recruitment of flathead gudgeon** was recorded in 2020-21, as evidenced by higher catches of both larval and juvenile stages than in previous years.

We discuss these key findings in more detail below:

## *Periodic species (e.g., golden perch, silver perch, carp)*

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

### *Golden perch*

Subadult golden perch (100-300 mm), previously absent in surveys from 2014-2020, were detected in the Mid-Wakool River for the time during the May 2021 adult surveys, including a young-of-year individual. Daily aging of the YOY golden perch revealed the 112 mm fish was 140 days old, despite being above the minimum length of an 'average' 1-year old fish (75 mm). Back-calculating the age from the catch date provided a spawning date estimate of 16 December 2020. The timing of this estimated spawning date coincides with the recession of the CEWO delivered 800 ML/day spring fresh, and water temperatures of 21-26°C in the week prior. There are several possible explanations to account for the presence of YOY golden perch in the Edward/Kolety-Wakool system in 2021: 1) recreational stocking, 2) local spawning and recruitment occurring in the Edward/Kolety-Wakool system, and 3) spawning event occurred outside the Edward/Kolety-Wakool system, with subsequent movement (immigration) of YOY into the Selected Area in late summer/Autumn 2021. We discuss the likelihood of each explanation below.

Stocking of golden perch fingerlings is a common practice to boost recreational fish stocks throughout the Murray-Darling Basin (Hunt and Jones 2018), including in the Edward/Kolety-Wakool (Thiem et al. 2017), with variable success. A program exists (FishGen) that is used to house a genetic library of hatchery broodstock with which to compare wild-captured fish genetics samples to indicate hatchery or wild origin. The genetics sample from this YOY golden perch has been submitted to this program, although the results are not available at the time of reporting. Previous research has indicated limited contribution of stocking to golden perch populations in both the Edward/Kolety-Wakool system (Thiem et al. 2017) and the broader Murray River (Forbes et al. 2015).

Spawning of golden perch has not been detected in the Edward/Kolety-Wakool River system since monitoring commenced in 2014, or at least specifically in the Wakool River and Yallakool Creek where monitoring occurs. While localised spawning occurs regularly (typically annually) in the nearby Murray River (e.g., King et al. 2016) these populations are subject to substantial immigration, emigration (Lyon et al. 2019) and variable recruitment sources (Zampatti et al. 2018). Collectively, current evidence suggests that golden perch population processes occur over 100's-1000's of km (Stuart and Sharpe 2020) and are temporally and spatially dynamic which is consistent with their life-history strategy. The absence of golden perch eggs and larvae in 2020-21, and in other years of monitoring in the system, further supports our conceptual understanding of the role of the Edward/Kolety-Wakool River system in supporting juvenile and adult golden and silver perch as components of broader meta-populations.

The presence of subadult golden perch in the Edward/Kolety-Wakool River system is most likely explained by immigration from the nearby Murray River. Previous Flow recommendation provided to the CEWO have included the consideration of i) a late spring/early summer pulse to provide opportunities for silver and golden perch spawning, and ii) adaptive use of water to coincide with high Murray River flows to maximize attraction/immigration of upstream migrating juvenile golden perch (and silver perch) in late summer (Watts et al. 2000). In 2020-21, both recommendations were taken up with specific watering actions delivered with the objective of achieving these outcomes (watering action 1 (spawning), 3 and 4 (golden and silver perch movement). Results from 2020-21 suggest that the delivery of attractant flows after the Southern Spring Flow and 800 ML/day Spring fresh in the Yallakool and Wakool may have provided suitable immigration cues for subadults into the system.

### *Silver perch*

Along with the presence of sub-adults in the Edward/Kolety-Wakool River system for the first time, juvenile/adult silver perch were recorded in greater numbers in 2020-21 than previous years. Similarly, to golden perch, evidence of localised spawning and recruitment in silver perch is limited, although annual spawning and regular recruitment is documented from the nearby Murray River (Tonkin et al. 2019). The species are highly mobile (Thiem et al. 2020, 2021; Watts et al. 2018, 2019).

Recent evidence has demonstrated that movement from the Murray mainstem into major tributaries (including the Edward/Kolety-Wakool) is a function of the ratio of tributary to mainstem hydrology, with higher ratios of tributary inputs resulting in increased immigration into these systems (Koster et al. 2021). Similarly, elevated tributary hydrology such as that observed during 2016 floods in the Edward/Kolety-Wakool resulted in rapid emigration of resident silver perch (Thiem et al. 2020).

#### *Carp*

While delivery of watering actions delivered to the Edward/Kolety-Wakool River system in 2020-21 provided positive outcomes for some native species, responses by introduced species were also observed. Carp spawning and recruitment was associated with the 800 ML/day spring pulse, with abundance of carp larvae greater in 2020-21 than in previous (non-flood) years. Carp opportunistically take advantage of high flow years where newly inundated environments provide suitable nursery grounds resulting in strong recruitment outcomes (Stuart and Jones 2006). In 2020-21, in order to achieve 800 ML/day in the mid Wakool River, 600 ML/day passed through Yallakool Creek and 200 ML/day through the Upper Wakool River, resulting in flows through Black Dog Creek, an ephemeral floodplain creek. The capture of high numbers of common carp larvae was specific to the Black Dog Creek and Yallakool Creek junction, indicating potentially localised spawning. It is likely however that carp were also able to take advantage of other areas of newly inundated habitats that were created because of the in channel fresh, but outside the four hydrological zones studied.

Tradeoffs between timing of large spring pulses may need to be considered from a risk perspective when planning future environmental watering actions and balancing outcomes across the broader flow-ecology requirements of the system. For example, delivering earlier, cooler spring flows may reduce the likelihood of carp spawning and recruitment, whilst still providing positive outcomes for vegetation, but may be to be too cool for facilitating silver and golden perch spawning. Alternatively, King et al. (2016) proposed that spawning of common carp during environmental delivery actions might also be minimized if water delivery occurred once water temperatures had exceeded >24°C. Thus, consideration of future water deliveries aimed at targeting silver perch breeding, but minimising carp spawning, could consider delivery of freshes once temperatures had exceeded 24 degrees. Such an option would still allow for a potential silver perch (Mid-Murray: spawn between 20-26 degrees King et al. 2016), though not a golden perch response (Mid-Murray: spawn between 18-21°C King et al. 2016). If the scope of watering actions is likely to expand in the Edward/Kolety-Wakool River system (e.g., Werai Forest), acknowledging and quantifying the risk of carp spawning and recruitment opportunities as a result of increasing flows into distributary creeks and wetlands that connect back to the system will be important to take into account going forward.

### *Equilibrium species (e.g., Murray cod, trout cod, river blackfish, freshwater catfish)*

Equilibrium species are characterised by medium-late maturation, exhibit low fecundity and have a high energetic investment in offspring (i.e., few but large eggs and parental care) (King et al. 2013). Examples of equilibrium species in the Edward/Kolety-Wakool system are Murray cod, river blackfish, freshwater catfish and trout cod. While spawning activity in these species is considered somewhat independent of flow conditions, there is evidence from studies of Murray cod to suggest that flowing water habitats are required to promote larval survival (Rowland 1983) and subsequent recruitment (Stuart et al. 2019). All four species occur within the broader Edward/Kolety-Wakool system, although Murray cod, and to a lesser extent river blackfish, are the only species regularly captured as larvae, juveniles and adults across the routine monitored sites.

### *Murray cod*

The Murray cod population in the Edward/Kolety-Wakool River system continues to show a steady recovery towards pre 2016-17 fish-kill levels in terms of abundance, biomass and size structure. The current population predominantly comprises individuals less than 400 mm in size, reflecting a combination of 1) the loss of large adults from the population during fish kills, and 2) recent recruitment events emanating from a reduced number of adults. The current results are consistent with previous study of Murray cod populations in the region following earlier fish kills (Thiem et al. 2017). Murray cod reach sexual maturity from approximately 480 mm long and between 4-6 years of age (Rowland 1998). As such, the dominant size class of the Murray cod population may not yet have reached sexual maturity and may be another year or two from doing so. As more individuals reach sexual maturity, we hypothesize that the abundance of larvae and new recruits may further increase over time as more breeding pairs contribute to the population.

As with previous years, Murray cod spawning and recruitment in 2020-21 was wide-spread throughout the Edward/Kolety-Wakool system. The role of specific watering actions aimed at maintaining nesting habitat of Murray cod is less clear (watering action 1 and 2), as larval catches of Murray cod were lower in 2020-21 compared to 2018-19 and 2019-20.  Previous responses of Murray cod to elevated flows in the upper Wakool River were recorded in 2018-19, when record numbers of larvae were associated with the delivery of sustained 200 ML/day flows, which commenced from late September 2018 through to January 2019. In 2020-21, a similar increase from base flows was delivered (50 ML/day to 200 ML/day), however did not commence until November. Pre-spawning and nesting behaviour of Murray cod is likely to take commence sometime between in September and October, in 2018-19 nest-building and spawning would have taken place under 200 ML/day flows, while in 2020-21, flows were still at base levels (50 ML/day). The lower catch rates of Murray in the upper Wakool in 2020-21 compared to 2018-19 may be due to difference in the timing of the two watering actions. Consideration of future water delivery in the upper Wakool River that provides flows of 100-200 ML/day that commence in late September and are maintained until the end of the breeding season (early December) may be more successful in maximising the availability of suitable nesting areas during Murray cod breeding season.

### *Trout cod*

Trout cod are long-lived predatory native fish endemic to rivers of the Murray-Darling Basin. The species has undergone a significant range contraction over the past 40 or so years, and is listed as nationally Threatened (EPBC Act 1994). The Murray River between Yarrawonga and Cobram has long been considered the main self-sustaining population of the species in the southern Murray-Darling Basin (Koehn et al. 2013), and records over the past 20 years indicate this population has since expanded downstream to Torrumbarry. Captures of adult Trout cod have also been recorded in the

Edward/Kolety River upstream of Deniliquin. During February 2021 recruitment surveys, subadult (1+) trout cod were collected in Yallakool Creek. This finding, along with a previous capture of Trout cod in Yallakool Creek in Autumn 2019 (Watts et al. 2019), and eDNA sampling in spring 2020 further confirmed their presence in Yallakool Creek (Watts et al. 2020), provide evidence of further range expansion of the species. There is currently no evidence to suggest local spawning however, with genetic analyses of all early spawned cod from 2020-21 confirming all sampled larvae were Murray cod. Either low (undetected) levels of localised spawning or immigration of new recruits has contributed to the presence of trout cod in the system, although the mechanism is currently unknown and represents a knowledge gap. Given trout cod spawn at cooler water temperatures than Murray cod it may be worth considering introducing a stable but elevated baseflow through the Yallakool and Wakool systems as early as August to support nesting in this species.

### *Opportunistic species (e.g., Australian smelt, gudgeons, Murray River rainbowfish, unspecked hardyhead)*

Opportunistic fish species are characterised by being small bodied and having fast growth rates, small eggs and frequent reproduction over an extended spawning season (Winemiller and Rose 1992). There are six native small bodied opportunistic species known to the Edward/Kolety-Wakool Selected Area: Australian smelt, carp gudgeon, flathead gudgeon, unspecked hardyhead, Murray River rainbowfish and obscure galaxias. These species will spawn and recruit under a range of flow conditions, however the early life stages of these species are commonly found in slow flowing slackwater waters, suggesting that shallow, low flow environments are important nursery areas for this group of fish (Humphries et al. 1999, Lyon et al. 2010, Bice et al. 2014). Such conditions occur under two contrasting flow conditions, during spring/summer base flows, and during high flows if new suitable habitats are created through temporary inundation and connectivity of floodplain habitats including ephemeral creeks, backwaters, oxbow billabongs and the floodplain proper. When flooded, these areas create slow flowing, shallow habitats which provide protection from larger bodied predators, and increased food resources due to increased microinvertebrate abundance which are a key prey resource. Subsequently, flows that provide a significant increase in slackwater habitat are likely to result in an increase larval production and subsequent adult abundance (Humphries et al. 1999, Lyon et al. 2010).

We observed a mixed spawning response by opportunistic species to the 2020-21 hydrological conditions in the Edward/Wakool River system. Australian smelt did not appear to respond to the delivery of the spring fresh (watering action 1) which was aimed at enhancing the spawning of early spawning species. Australian smelt typically spawn from September through to December when temperatures 14-19°C (King et al. 2016). While the timing of the spring fresh coincided with Australian smelt spawning window, the lowest catches of Australian smelt larvae were recorded in 2020-21. This result contrasts with findings in previous years where higher catches of Australian smelt have previously been recorded in hydrological zones that received environmental flows during spring than zones that did not (Watts et al. 2018-19 and 2019-20). Catch rates of both juvenile and adult Australian smelt have declined since 2018-19, and so whether or not the poorer spawning response of Australian smelt in 2020-21 compared with previous years is due to potential decline of the adult population, or due to other environmental conditions, is not clear.

In contrast, strong spawning and recruitment in flathead gudgeon was recorded in 2020-21, with higher catches of both larval and juvenile stages recorded compared to all previous years of monitoring. The explanation for the increase in flathead gudgeon spawning and subsequent recruitment is unclear. Previous studies have found spawning of flathead gudgeon in the mid-Murray River to be related to temperature, but independent of flow related variables such as discharge, change in weekly discharge, or number of flood days in past 90 days (King et al. 2016). Other studies have found significant correlations of flathead gudgeon larval abundances with low flow conditions (Cheshire et al. 2016). Flathead gudgeon are a benthic species thought to prefer slow-flowing area of lowland rivers, creek and wetlands (Lintermans 2007). One possible explanation for the response of flathead gudgeon to the 2020-21 hydrological conditions might be the increase in inundated low-lying regions of the main river channels, as well as the filling of distributary channels such as Black Dog Creek.

Other small-bodied species known to occur in the Edward/Kolety-Wakool River system include unspecked hardyhead, Murray River rainbowfish and obscure galaxias. In the case of obscure galaxias, captures of larvae are typically very low, and have yet to be collected as adults during annual Category 1 adult surveys. As such, their detection in the system is too low to make definitive conclusions about their long-term population trends in the Edward/Kolety-Wakool. Whilst capture of Murray River rainbowfish during the larval stage are infrequent, the size of the adult population was remained relatively stable since 2014 and is one of the few native species that appeared relatively unaffected by the fish kills in 2016-17. Catches of adult unspecked hardyhead however indicate the population has still not recovered from the 2016-17 fish kills, with little evidence of recruitment or increase in adult catch or biomass in recent years. Eggs of Murray River rainbowfish and unspecked hardyhead are demersal, adhesive, and typically laid in amongst aquatic plants, where they are protected from flow and potential predators. The capacity for these two species to increase their populations therefore may be limited by the availability of suitable submerged plants in the region. Aquatic vegetation coverage in the Edward/Kolety-Wakool system declined significantly as a result of the 2016-17 floods. Whilst the recovery of submerged plant species has been slow, the provision of winter flows has allowed existing macrophytes to avoid further frost-related dieback in winter during operational draw-down has been beneficial (Watts et al. 2019, Watts et al. 2020). We hypothesise that further reestablishment of aquatic plant beds will have beneficial effects for native species such as Murray River rainbowfish and unspecked hardyhead.

### *Flow recommendations for fish outcomes*

- Environmental water delivery in the 2020-21 was the closest yet to achieving flows that are considered to be important for golden perch and silver perch, regarding the timing, magnitude, duration and extent in providing longitudinal connectivity with other flow freshes in the mid-Murray region required for spawning, recruitment and movement of juveniles. We recommend water managers consider delivering similar sequence of flows to that in 2020-21 when water available to complete the sequence of all actions in one year.
- Deliver elevated base flows (200 ML/day) to the Upper Wakool River from start of September to maximise nesting and spawning opportunities for Murray cod. Record catches of larvae have

been recorded when this type of watering action is delivered (2018-19). Given that trout cod spawn at cooler water temperatures than Murray cod, it may be worth considering introducing a stable but elevated baseflow through the Yallakool and Wakool systems as early as August to support nesting in this species.

- Consideration of water delivery in the Edward/Kolety-Wakool system that targets inundation of a greater diversity of creek systems, inluding distributary ephemeral and intermittent creeks, for the benefit of species such as flathead gudgeon. Consideration of timing of delivery that reduces opportunities for carp spawning whilst minimising hypoxic blackwater may need to also be taken in account.

# 9 RESEARCH: HOW DOES CONNECTIVITY OF WETLANDS ALONG THE EDWARD/KOLETY RIVER AFFECT TURTLE DISTRIBUTION, MOVEMENT AND BODY CONDITION?

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## 9.1 Introduction

Freshwater turtles are an important component of Australian river ecosystems, and are culturally important to local Traditional Owners. As major scavengers, they are likely to be important regulators of nutrient cycling in river systems, at least at their historic densities (Santori et al. 2020). In the Edward/Kolety-Wakool River system, turtles are important to both the Perrepa Perrepa and Wamba Wamba Peoples, as well as the nearby Yorta Yorta People (Deniliquin Local Aboriginal Land Council, 2016). Turtles are traditional food species for some Indigenous Peoples. The broad-shelled turtle (*Chelodina expansa*), or “Bayadherra” is a totemic species for the Yorta Yorta People and is important as a protector, provider, and guide associated with creation stories (Moama Local Aboriginal Land Council, 2016). Turtle surveys by the Yorta Yorta People have contributed to our knowledge of their decline in the central Murray-Darling Basin (Moama Local Aboriginal Land Council, 2016).

Despite their importance, about half of all Australian turtle species are currently listed as vulnerable, threatened, or endangered (Van Dyke et al. 2018), and many turtles are threatened globally (Stanford et al. 2020). Within the Murray-Darling Basin, freshwater turtle declines have been linked to high rates of nest destruction by foxes (Spencer and Thompson 2005; Van Dyke et al. 2019) as well as changes in hydrology (Chessman 2011). Both may reduce survivorship of eggs and juvenile turtles, leaving populations dominated by older adults. Populations can appear persistent until the lack of recruitment prevents replacement of old adults as they die, which has been termed the ‘perception of persistence’ (Lovich et al. 2018).

Freshwater turtle populations may be acutely threatened by winter drying of wetlands (Ultsch 1989). As aquatic ectotherms (ie, cold-blooded), freshwater turtles substantially reduce their activity rates during the cold of winter (Ultsch 1989). If they overwinter at a site that dries completely, they are likely to be exposed to mortality both as a result of environmental exposure and greater susceptibility to predators that they cannot escape (Brooks et al. 1991; Christiansen and Bickham 1989). A total drying of a wetland during winter could be catastrophic to a local population if turtles remain in the wetland during the winter drying event. Alternatively, if turtles leave wetlands likely to dry before winter, then they may be able to behaviourally avoid such events (Christiansen and Bickham 1989). Alternatively, environmental water flows that help maintain wetlands over winter could be a useful management option for protecting turtles from this potentially major source of mortality. The overwintering behaviour of freshwater turtles has received little attention, so it is unknown whether turtles are likely to avoid winter drying events, or whether management is needed to help protect them.

Almost all of the rivers in the Murray-Darling Basin are heavily regulated to provide water for irrigation and humans (Koehn 2013; Walker 2006). The Edward/Kolety-Wakool River system is an example. Long-term modelling indicates that the Edward/Kolety River historically experienced high flows from July-November in most years, and reduced flows in the summer (Watts et al. 2015). It now experiences much-reduced flows in July-November, and some associated wetlands dry completely (Watts et al. 2015). Environmental flows that protect wetlands from winter drying are likely to be highly beneficial to turtles in this system, if those turtles remain in wetlands that are likely to dry over winter. The current altered flow regime thus makes the Edward/Kolety-River an excellent model system for testing the impacts of altered flow regimes, and environmental flows on freshwater turtles. Three freshwater turtle species are found in the Edward/Kolety River: the broadshelled turtle, *Chelodina expansa*, eastern long-necked turtle, *Chelodina longicollis*, and the Macquarie River, *Emydura macquarii* (Figure 9.1).

In this project, we tested for how winter drying affects turtle populations in the Edward/Kolety River in two ways.

- We used repeated trapping surveys to compare turtle community and population structures between disconnected wetlands that were more likely to experience winter drying and connected wetlands that were unlikely to experience winter drying. Given the habitat preferences of the three species and their ecology, we assumed that *C. longicollis* would be most abundant in disconnected wetlands and *E. macquarii* would be most abundant in connected wetlands. However, this approach would not identify the cause of low *E. macquarii* abundance in disconnected wetlands in particular, which could be caused by general avoidance of disconnected wetlands, movement out of disconnected wetlands during certain times of year, or winter mortality after disconnected wetlands dried.
- We used acoustic telemetry to track a subset of individual *E. macquarii* tagged in both types of wetlands, to determine individual movement patterns and/or fates that might be driven by winter drying in disconnected wetlands. We focused on *E. macquarii* because they are the least-likely species to travel overland (Chessman 1988), and prefer to swim between habitats when there are water connections between wetlands and the river. They are thus the most-likely species to be affected by winter drying in disconnected wetlands.

We conducted the project in collaboration with Wamba Wamba and Perrepa Perrepa Traditional Owners, via the Yarkuwa Indigenous Knowledge Centre. Throughout the project, we provided training and experience in turtle ecology and conservation methods that they will be able to apply in their own future conservation work in Werai forest. The project facilitated reciprocal learning, as they also shared with us their perspectives and knowledge about turtles, wetlands, and conservation.

**Figure 9.1** Turtles of the Edward/Kolety-Wakool river system. *Top*: broadshelled turtle (*Chelodina expansa*) in the process of nesting. *Middle*: eastern long-necked turtle (*Chelodina longicollis*). *Bottom*: Macquarie River turtle, *Emydura macquarii.*

## 9.2 Methods

### *Sites*

Prior to the study, we identified six wetlands (3 connected, 3 disconnected) and arranged landowner permission for us to access them. Three of the wetlands (Horseshoe, Moonahcullah, and Billabong; Figure 9.2) were disconnected, meaning that there is at least a small area of dry land between them and the Edward/Kolety River at normal flows. At high flows, the river spills into Horseshoe and Billabong, and Moonahcullah is fed by a pipe which allows the wetland to fluctuate levels along with the river. The landowners at Moonahcullah report seeing turtles cross the levee at the site of the pipe, so we assumed the pipe does not allow turtles through (*K. and J. Hooper, personal communication*). The remaining three wetlands (Barratta, Yallakool, ad Dahwilly; Figure 9.2) all have a continuous open connection to the river, and their levels fluctuate long with river levels. Stevens Weir separates the study in half, and is located just downstream of Yallakool, and upstream of Moonahcullah.


**Figure 9.2** Locations of wetlands along the Edward/Kolety Riverwhere the turtle research took place in 2020-21. *Image from Google Earth, 2021.*

### *Turtle population and community surveys*

We trapped each wetland in October 2019, December 2019, February 2020, November 2020, and February 2021. During each trap session, we trapped each wetland continuously for 3 overnight periods (average 75.9 hours). We used a mix of cathedral traps, single-wing fyke nets, and crab pots baited at each wetland, and used 5 traps per wetland. Each trap was baited with offal and set in a location judged to maximise its effectiveness. For example, cathedral traps are ideal in depths greater than 1 m, whereas fykes and crab pots are both ideal for shallower water. Fykes are especially useful where the wing can be placed to cross a narrow channel such that turtles crossing would be guided into the cod end of the net. After setting, we checked, cleared, and rebaited traps twice per day, in the morning and late afternoon.

Every turtle captured was marked with a unique notching pattern for future identification. We measured the shell dimensions and weight of each turtle. We identified the sexes of *C. expansa* and *E. macquarii* based on the lengths of their tails. We recorded shell characteristics associated with sex in *C. longicollis* but could not identify sex based on tail length since males tightly retract their tails and this character is unavailable. After all processing was complete, turtles were released back to the wetland. Recaptures within a given 12-month period were recorded and released immediately. Recaptures more than a year after their previous measurement were re-measured.

We calculated separate catch-per-unit-effort (CPUE) values for each species within each wetland, within each trap session. Here, CPUE was the number of turtles captured divided by the product of the total number of traps set and the number of hours they were set, or turtles per trap-hour. We compared mean CPUE between connected and disconnected wetlands in SAS (OnDemand edition, Cary NC) using mixed models in PROC MIXED. The first model was used to compare within-species CPUE and included season (spring, summer) and wetland type (connected, disconnected) as main effects and whether the wetland was up- or downstream of Stevens Weir as a random effect. We also included trap session as a repeated effect. We also compared CPUE across species in a second model which also included the same parameters as listed for the first model.

We used our capture-mark-recapture data to model Jolly-Seber population estimates for each species within each wetland in Program MARK. We compared these estimates across the two wetland types in an identical analysis as described for CPUE.

We compared body conditions (mass relative to straight carapace length) of turtles across connected and disconnected wetlands within species and within sex (except for *C. longicollis*) following Petrov et al. (2020). Different analyses were used for different species and sexes because the relationships between mass and length differ in different species and between males and females (Petrov et al. 2020). We also pruned gravid females from the analysis, and any turtles for which we did not have both mass and length data, which occurred occasionally due to the electric scale battery dying. We calculated scaled mass indices (SMI) for each group following Peig and Green (2009). We used basin-wide turtle morphology data from Van Dyke et al. (2019) to derive population-mean lengths and regression scaling exponents (Petrov et al. 2020). We then compared mean SMI of turtles between connected and disconnected wetlands using mixed models in PROC MIXED, with location upstream or downstream of Stephens Wier set as a random effect. Since we had low and inconsistent recapture rates, we removed recaptures from the analysis.

Lastly, we plotted demographic structures for each species within each wetland for visual comparison, but did not compare these data statistically. We divided each species by straight carapace length (the length of the dorsal shell) into 25-mm increments, and used these graphs to show the number of individuals we captured within each size group. We separated turtles by sex and juvenile status where possible, following Van Dyke et al. (2019).

### *Acoustic Telemetry*

At each of the six wetlands, we established a network of Vemco VR2W-69 kHz acoustic telemetry receivers to record movements of tagged animals in and out of the wetland. Each receiver was anchored to the bottom of the water body with a concrete block, and a 5-mm stainless steel cable was crimped to a sunken tree root to hide and anchor the receiver in place. The receiver was then suspended from a white foam buoy approximately 1 meter above the concrete block. Each receiver has a range of approximately 200 m line-of-sight, so they created a 200 m detection radius at each location. We used 2-5 receivers to cover the entirety of each wetland, so that any tagged animal moving through the wetland would be identified at all times. We also placed two wetlands in the river adjacent to each wetland. These were placed upstream and downstream of the wetland's connection to the river. In disconnected wetlands, these locations were determined based on land height and the presence of damp, swampy soil. Indeed, at high water level, these locations were the areas that connected Billabong and Horseshoe lagoons to the river. At Moonahcullah, we placed the receivers upstream and downstream of the narrowest levee, where the wetland was closest to the river (Figure 9.3).

By placing the receivers in this pattern, we could detect A) when a turtle left a wetland, based on the ending of detections at the nearest within-wetland receiver, and B) when a turtle entered the river, based on its subsequent detection (usually within minutes) at the nearest receiver in the wetland. We could also determine when a turtle entered the wetland based on the ceasing of detections by the river receivers, and the start of detections by the wetland receivers. This approach allowed us to be sure of detecting all exits and re-entries from or into our study wetlands by any tagged turtle (Figure 9.3).


**Figure 9.3** Example of acoustic receiver array at Moonahcullah Lagoon. Each teal pin is the location of an acoustic receiver. Four are located inside the wetland, and two are located in the adjacent Edward/Kolety River to detect entries and exits. *Image from Google Earth, 2021.*

From October 2019 to February 2020, we attached Vemco V13T acoustic tags to the posterior carapace of adult *E. macquarii* turtles following the methods of Doody et al. (2009). This method allows the transmitter to remain attached without harming the turtle for at least a year (Figure 9.4), and detaches on its own sometime later (Doody et al. 2009). We aimed to attach transmitters to two male and two female *E. macquarii* from each wetland, and we tagged the first two adult male and non-gravid adult female turtles we caught. At Moonacullah we only caught 1 male until February 2020, so we attached transmitters to three females. Similarly, at Billabong we only caught 1 male until February 2020, and by that point we did not catch a third female, so we attached the last transmitter to a third female turtle at Yallakool.

**Figure 9.4** *Left:* Example of a brand-new transmitter attachment to an adult *Emydura macquarii*. *Right*: A re-captured turtle with a transmitter after 4 months. The yellow and green colour on the right turtle is algae adhered the to the transmitter, and the turtle was very healthy.

After tagging, the transmitter batteries should each last at least one year, so we downloaded data from all of the acoustic receivers every few months of the study from October 2019 to February 2021. This corresponded to data downloads in December 2019, February 2020, May 2020, September 2020, November 2020, and February 2021. By the last check in mid-February 2021, all transmitters were no longer detected, so we assumed all transmitter batteries had died and we removed the receiver array.

We downloaded all telemetry data into VUE 2.6.2. We identified all of each turtle's exits from and entries into wetlands by using the time series of receiver locations for an individual. Subsequent data wrangling was completed using the R statistical computing environment (v4.1.0) and the *tidyverse* (v1.3.1) and *lubridate* (v1.7.10) packages. Consecutive detections of an individual were recorded as "stationary", if both recordings were by the same receiver or "moving" if detections occurred at different receivers. Within "moving" there were 4 categories, "exit", "enter", "River" and "Wetland". If the original detection was measured by a receiver that as within a wetland and the subsequent record was by a receiver in the river then the movement was classed as "exit[ing]" the wetland. The opposite was true for "enter[ing]" a wetland where initial detection was by a river receiver and subsequently by a wetland receiver. Finally, if consecutive detections were at different receivers, though in the same environment (i.e. river or wetland), then the movement was recorded as the environment type. Only "exit and enter records were considered for this work. After the "stationary", "river" and wetland records were filtered from the dataset the remaining 228 observations of entry into or exit from wetlands made up the dataset for analysis.

After identifying each entry and exit, we analysed these data in several ways. First, we compared the numbers of turtles that exited their 'home' wetlands at least once between the two wetland types (connected, disconnected) using a binary logistic regression in PROC GLIMMIX in SAS. We included turtle sex and straight carapace length as factors in the analysis, and whether the wetland was upstream or downstream of Stevens Weir as a random effect. Second, we compared the total number of times each turtle exited and entered its home wetland over the course of the study between the two wetland types, using a Poisson logistic regression in PROC GLIMMIX. Again, we included turtle sex and straight carapace length as factors in the analysis, and whether the wetland was upstream or downstream of Stevens Weir as a random effect. These two analyses together tested whether there were any differences in turtles' propensity to leave and frequency of leaving their home wetlands between disconnected and connected wetlands.

Finally, we used a categorical analysis in PROC CATMOD to test for factors that were associated with turtle exits from and entries into wetlands. In this analysis, we included wetland type (disconnected or connected), season (summer or spring), turtle sex (male or female), adjacent river water level deviation, and the change in water temperature the turtle experienced as it left one water body and entered another. We calculated river water level deviation by identifying the date of the turtle movement, finding the local river level on that day from http://riverdata.mdba.gov.au (either upstream or downstream of Stevens Weir), and subtracting that value from the average calculated between October 2019 and February 2021. We then characterised water levels more than 0.1 m higher than average as "high", lower than 0.1 m lower than average as "low" and between +0.1 m and -0.1 m as "stable". We performed a similar process for temperature change. Since the transmitters we used were temperature-sensitive, we had continuous recordings of the water temperatures turtles experienced. Thus, if a turtle exited a wetland to the river, we had instant measurements of the wetland water temperature upon exit, and the river temperature upon entrance (or vice-versa). We calculated the difference in these two values, and arbitrarily defined any increase in temperature greater than 1 $^{o}$C as an "increase", any decrease greater than -1 $^{o}$C as a decrease, and any change less than +1 or -1 $^{o}$C as "stable".

For all analyses, means are reported ± 2 standard error, and significance was assessed against $\alpha$ = 0.05.

## 11.3 Results

### *Population and community analyses*

During the study, we caught 195 *C. expansa*, with 37 recaptures; 265 *C. longicollis*, with 62 recaptures; and 303 *E. macquarii*, with 33 recaptures. Catch-per-unit-effort (CPUE) did not differ between disconnected and connected wetlands for any of the three turtle species present (Figure 11.5A; *C. expansa* $F_{1,25} = 0.77$, P = 0.39; *C. longicollis* $F_{1,25} = 1.73$, P = 0.20; *E. macquarii* $F_{1,25} = 2.20$, P = 0.15). Within species, the only significant difference was that *C. expansa* CPUE was slightly higher in the summer trapping sessions than in spring sessions ($F_{1,25} = 14.98$, P < 0.01). The considerable variation in CPUE within individual wetlands appeared to drive the lack of differences based on wetland type (Figure 9.5), which indicates that wetland type alone is not a major driver of turtle abundance. However, there were significant differences in species CPUE within some wetland types (Figure 9.5A; $F_{2,52} = 5.20$, P < 0.01). Post-hoc tests revealed that *C. longicollis* CPUE was higher within disconnected wetlands than CPUE of both *C. longicollis* and *E. macquarii* (P < 0.05) and *E. macquarii* CPUE was higher within connected wetlands than CPUE of both *C. longicollis* and *C. expansa* (P < 0.05).

The species population estimates for each wetland provided by our analysis in MARK had substantial error so are not particularly robust. In spite of that error, our comparison detected a significant difference between species population estimates across wetland type (Figure 9.5B; $F_{2,24} = 6.37$, $P < 0.01$), which was driven by *E. macquarii* populations in connected wetlands being higher than those of *C. longicollis* and *C. expansa* ($P < 0.01$). However, the difference we observed in CPUE in disconnected wetlands between *C. longicollis* and the other two species was not replicated here, after recaptures were taken into account in the mark-recapture analysis.

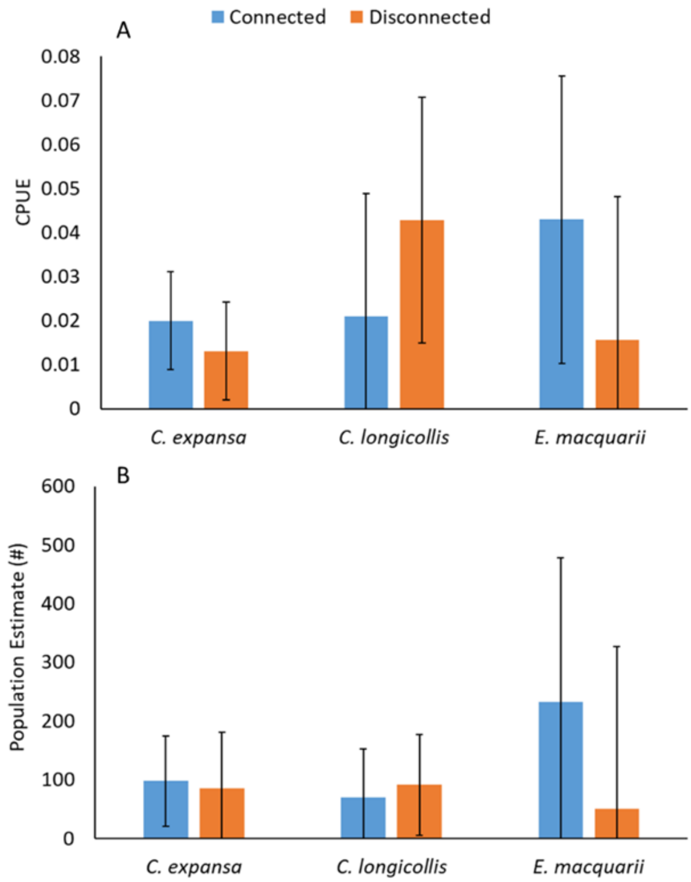



**Figure 9.5 A.** Mean catch-per-unit-effort (turtles per trap-hour) of all three turtle species in connected (blue) and disconnected (orange) wetlands. No one species had higher CPUE within either wetland type than in the other wetland type, but *E. macquarii* had higher CPUE in connected wetlands than the other two species, and *C. longicollis* had higher CPUE in disconnected wetlands than the other two species. **B.** Mean population estimate for each species within each wetland type. *Emydura macquarii* populations in connected wetlands were larger than those of *C. expansa* and *C. longicollis*.

The effect of wetland connectivity to the river on turtle body conditions differed across species and sexes (Figure 9.6). Female *C. expansa* exhibited higher body conditions in disconnected wetlands than in connected wetlands ($F_{1,25} = 15.40$, $P < 0.01$) but males exhibited no difference ($F_{1,113} = 0.02$, $P = 0.92$). *Chelodina longicollis* also did not exhibit a difference between connected and disconnected wetlands ($F_{1,235} = 1.88$, $P = 0.26$). Female *E. macquarii* exhibited higher body conditions in connected wetlands than in disconnected wetlands ($F_{1,123} = 9.01$, $P < 0.01$), but males exhibited no difference ($F_{1,121} = 1.64$, $P = 0.20$).

Demographics of all three species followed similar trends at all six wetlands (Figures 9.7-9.9). In all cases, larger adult turtles were present in higher numbers than juveniles. Juvenile *E. macquarii* were especially rare, with only one individual captured in Horseshoe Lagoon. More juvenile *C. longicollis* were present than in the other two species, but even these numbers only sum to 29 out of 265 turtles, or about 10.9 %.

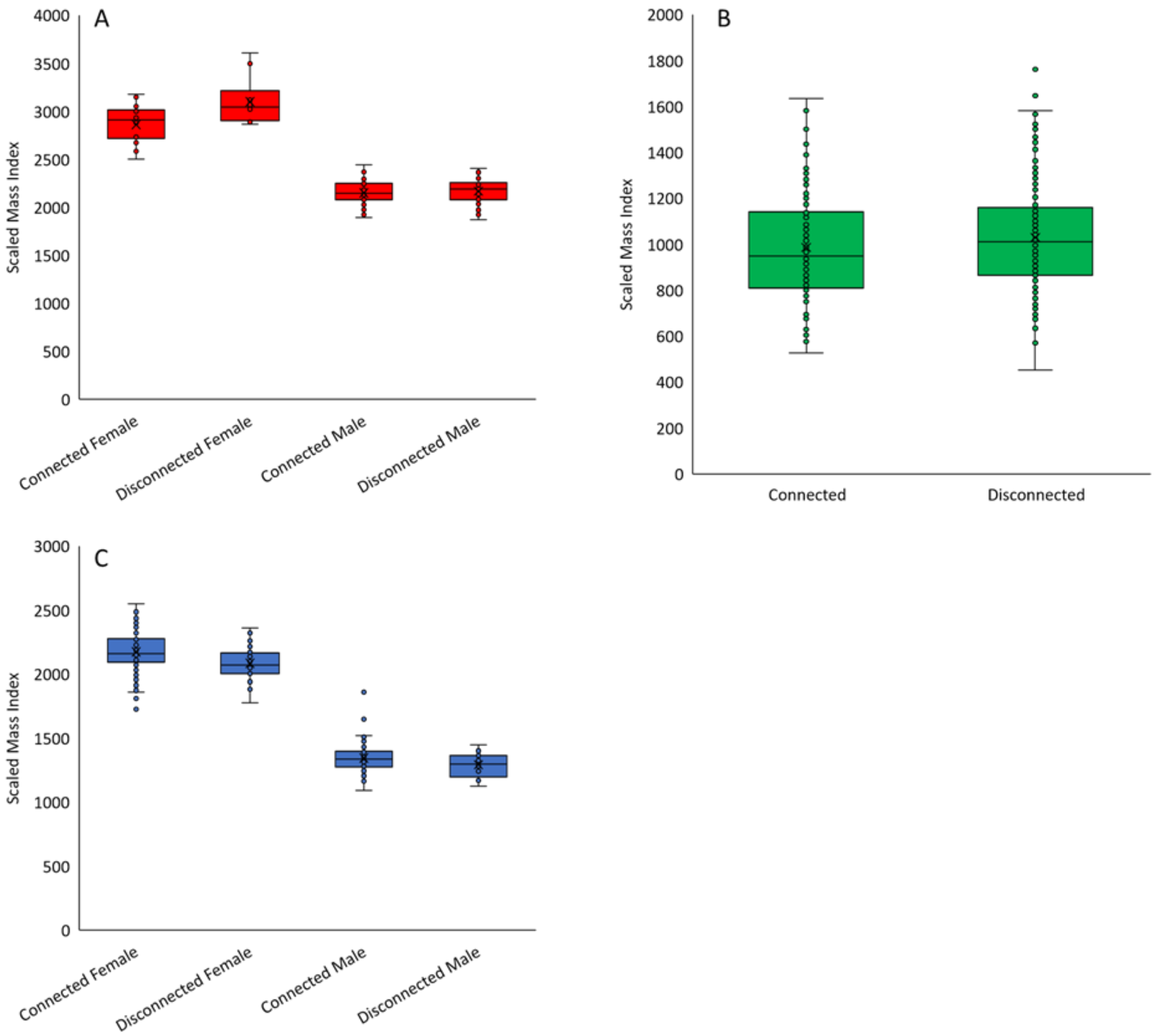



**Figure 9.6** Scaled mass indices for **A.** *Chelodina expansa*, in which females exhibited higher body condition in disconnected than in connected wetlands, but males did not differ. **B.** *Chelodina longicollis*, which exhibited no differences in body condition, but males and females could not be separated methodologically. **C.** *Emydura macquarii*, in which females exhibited higher body conditions in connected wetlands than in disconnected wetlands, but males did not differ.

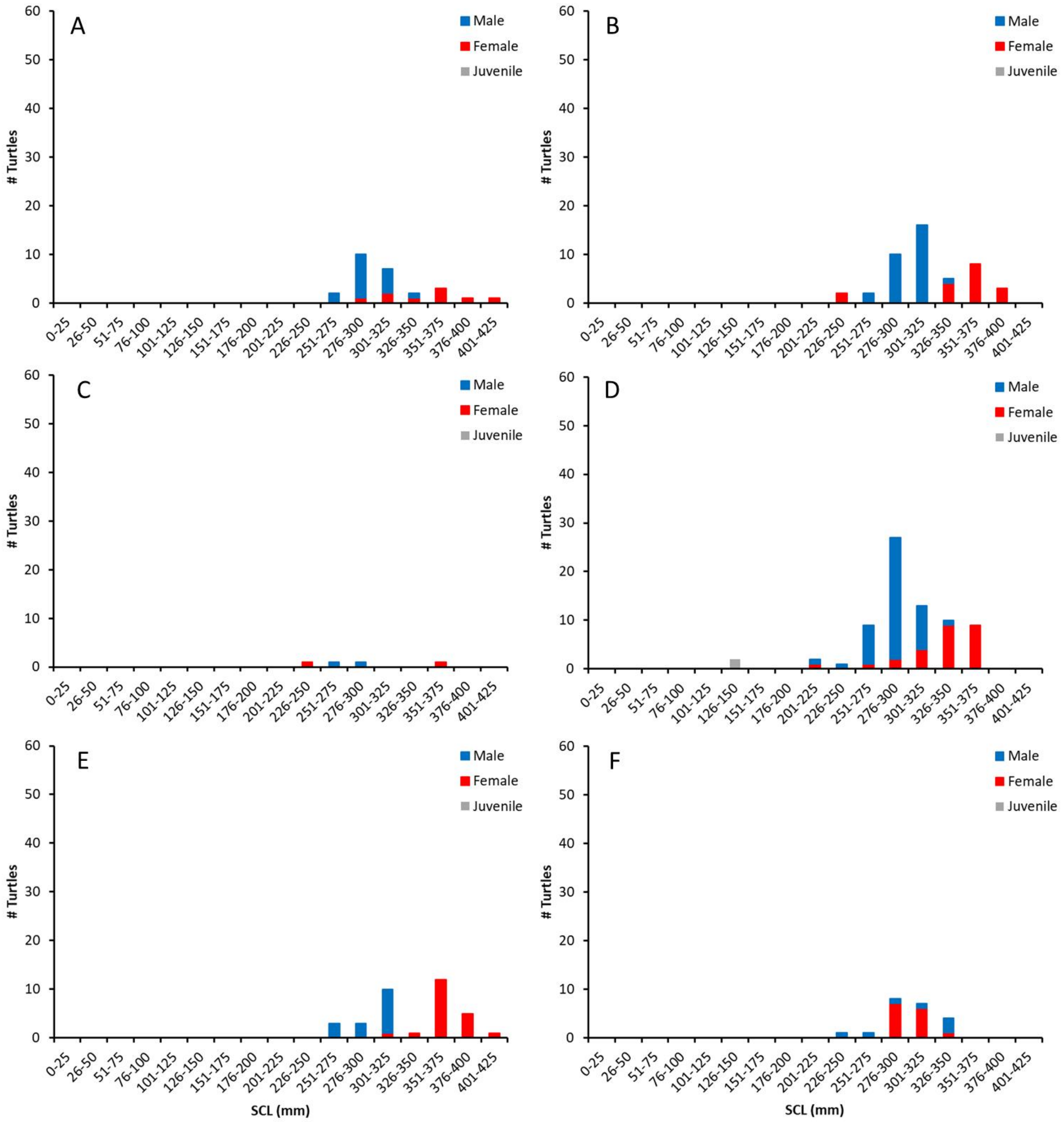



**Figure 9.7** Body size distributions for *Chelodina expansa* at the six wetlands in the study: **A:** Barratta Lagoon (connected); **B:** Horseshoe Lagoon (disconnected); **C:** Billabong Lagoon (disconnected), **D:** Dahwilly Lagoon (connected); **E:** Moonahcullah Lagoon (connected); **F:** Yallakool Lagoon (connected). SCL refers to straight carapace length. Minimum size of sexual maturity is 220 mm SCL. Males tend to be smaller than females, hence the differences in their distributions.

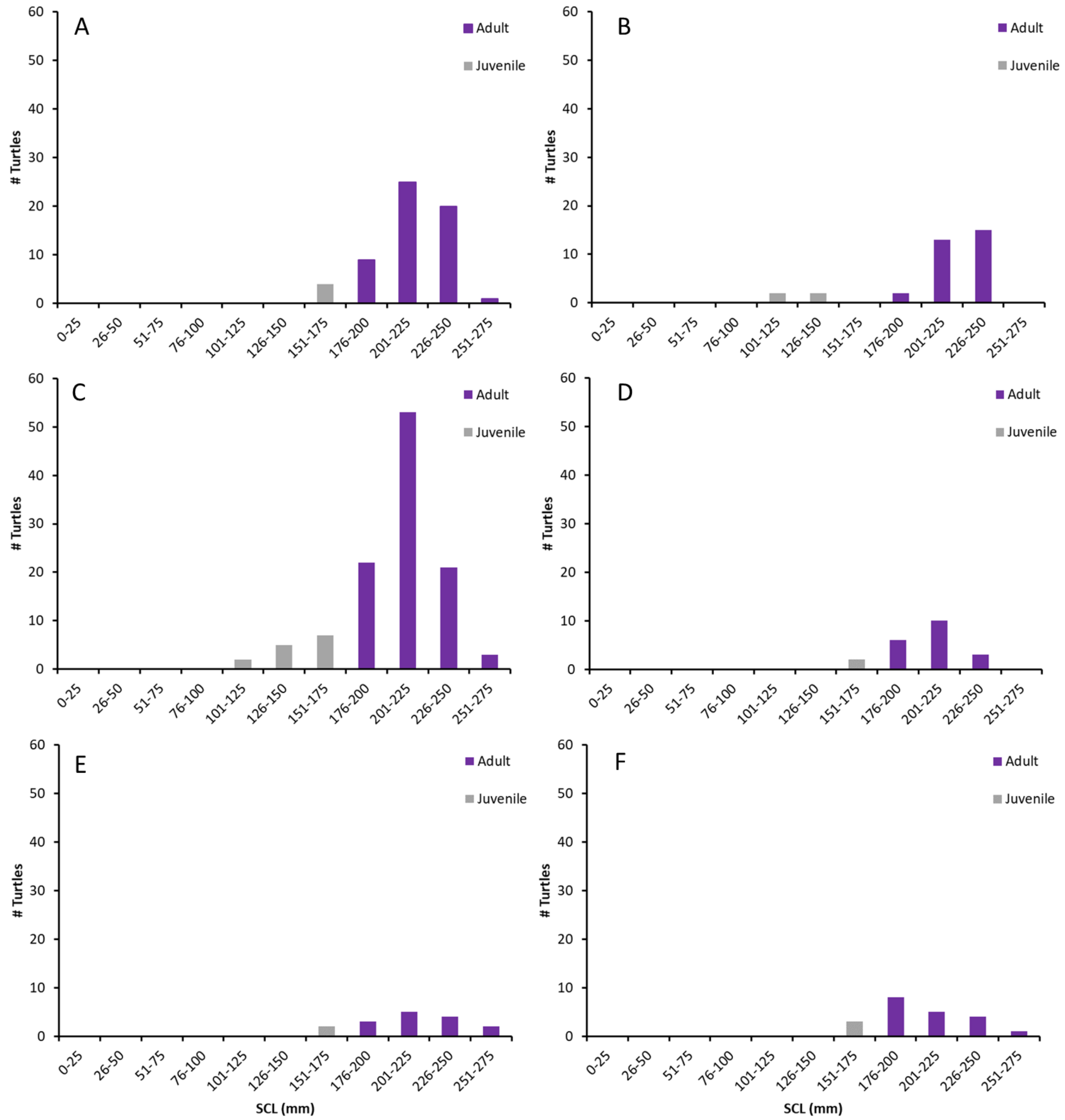



**Figure 9.8** Body size distributions for *Chelodina longicollis* at the six wetlands in the study: **A:** Barratta Lagoon (connected); **B:** Horseshoe Lagoon (disconnected); **C:** Billabong Lagoon (disconnected), **D:** Dahwilly Lagoon (connected); **E:** Moonahcullah Lagoon (connected); **F:** Yallakool Lagoon (connected). SCL refers to straight carapace length. Minimum size of sexual maturity is 175 mm SCL. *Chelodina longicollis* sex is not easily distinguished using external features alone because they hide their tails, so adults of both sexes are combined here.

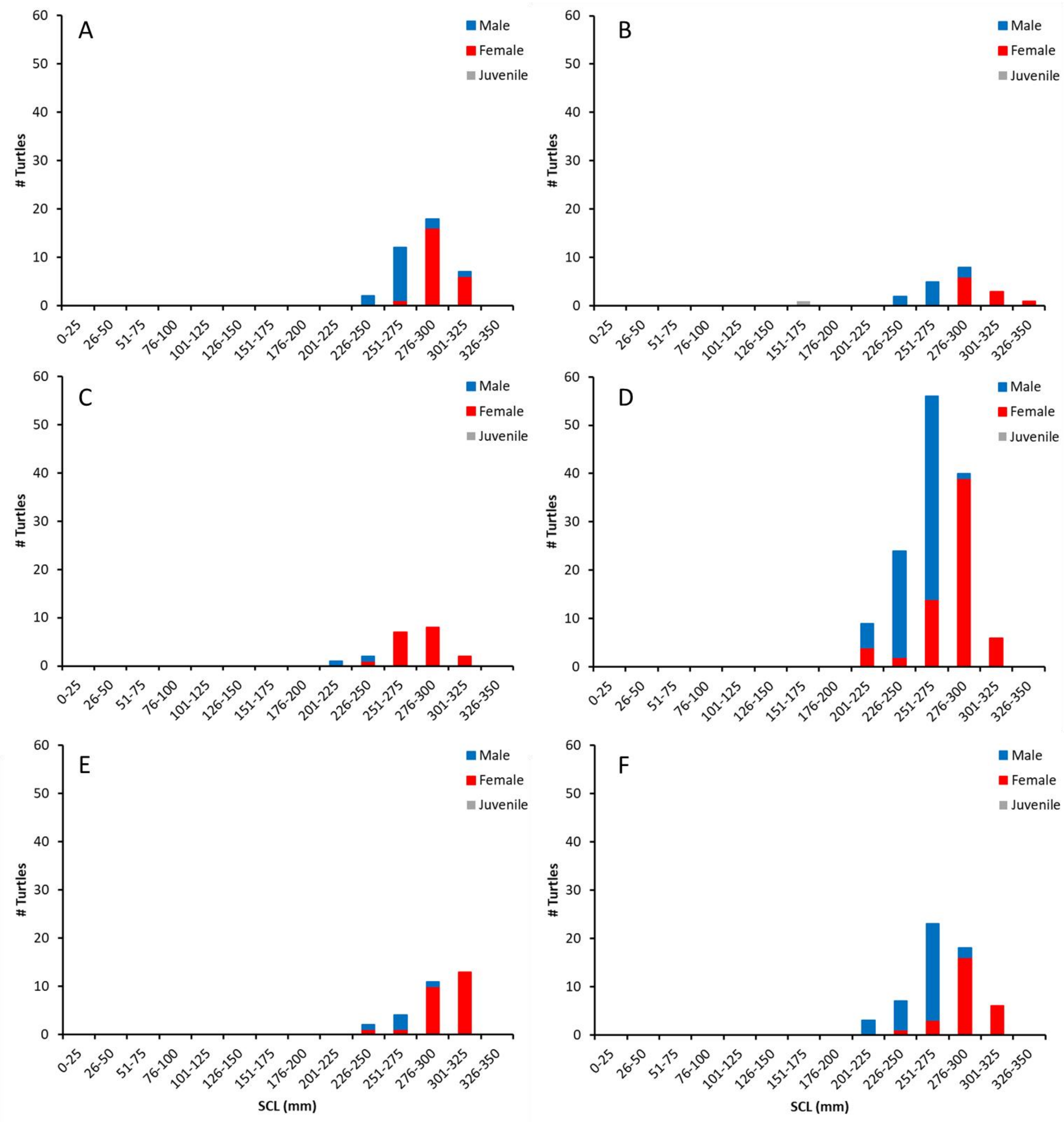



**Figure 9.9** Body size distributions for *Emydura macquarii* at the six wetlands in the study: **A:** Barratta Lagoon (connected); **B:** Horseshoe Lagoon (disconnected); **C:** Billabong Lagoon (disconnected), **D:** Dahwilly Lagoon (connected); **E:** Moonahcullah Lagoon (connected); **F:** Yallakool Lagoon (connected). SCL refers to straight carapace length. Minimum size of sexual maturity is 175 mm SCL. Minimum size of sexual maturity is 190 mm SCL. Males tend to be smaller than females, hence the differences in their distributions.

### *Telemetry Results*

During the study, we detected 121 exit events, where tagged *E. macquarii* exited a wetland into the adjacent river. We also detected 107 entry events, where tagged *E. macquarii* entered a wetland from the adjacent river. Most of the latter occurred when a turtle returned to the wetland in which it was first tagged (hereafter referred to as 'home' wetland), but some turtles moved to different wetlands. The discrepancy in the entries and exits reflects that some male turtles were not detected re-entering a wetland with telemetry receivers. Only one transmitter appeared to fail, as it disappeared hours after deployment (on a female in Billabong) and was never re-detected in either a wetland or the river. Across the study, female turtles tended to stay close to 'home' even if they exited their home wetland, whereas males tended to either disappear completely, leave their wetland and reappear in the river adjacent to a different wetland, or re-appear at their home wetland weeks to months after disappearance. These results indicate the potential for male *E. macquarii* to move large distances: one male was recorded to leave Horseshoe and re-appear at Moonahcullah more than 20 km upstream, and a second male made the opposite journey. Except for male turtles that disappeared, the remainder of the tagged turtles appeared to survive the study as movements were detected within or in/out of wetlands for at least a year, until the batteries failed.

The probability that a turtle would exit a wetland did not differ statistically between wetland type (Figure 9.10; $F_{1,13} = 0.01$, $P = 0.99$) or sex ($F_{1,13} = 0.03$, $P = 0.88$). Indeed, all but two female turtles (in disconnected wetlands) exited their home wetland at least once during the study.

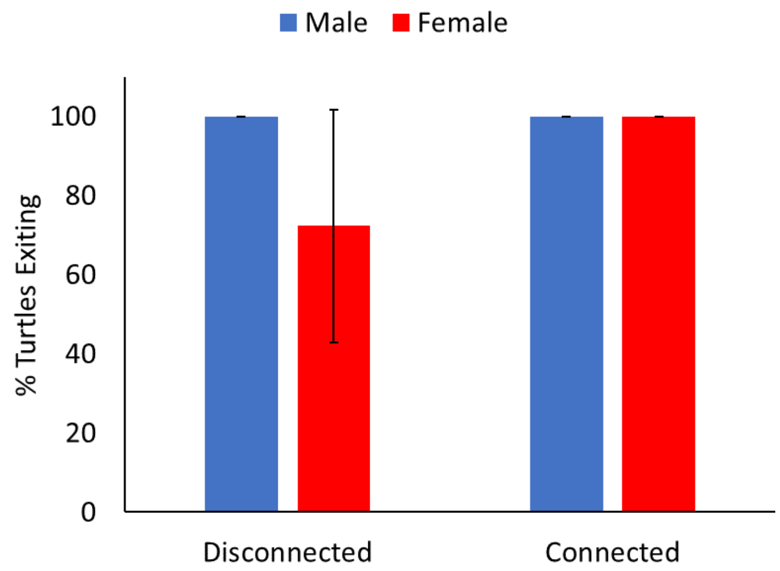



**Figure 9.10** The majority of tagged *E. macquarii* exited their 'home' wetland at least once during the study. Only two females from disconnected wetlands did not leave at least once. No statistical difference due to any factor.

In contrast, turtles from connected wetlands exited (and re-entered) their home wetlands much more frequently than turtles from disconnected wetlands (Figure 9.11; $F_{1,13} = 12.72$, $P < 0.01$), but there was no difference between sexes ($F_{1,13} = 0.66$, $P = 0.43$). Although there was no difference in number of exits and entries between sexes, sexes differed greatly in their behaviour. At disconnected wetlands, females had low exit rates because they exited once, at most, but re-entered their home wetland. Males had low exit rates because they never returned after exiting. At connected wetlands, females exited and re-entered their home wetlands repeatedly throughout the year. Males exited and re-entered their home wetlands several times, but three left for long periods of time. Only three males 'stayed home' during the study, and these were all relatively small, which may indicate a size-based pattern of dispersal in males.

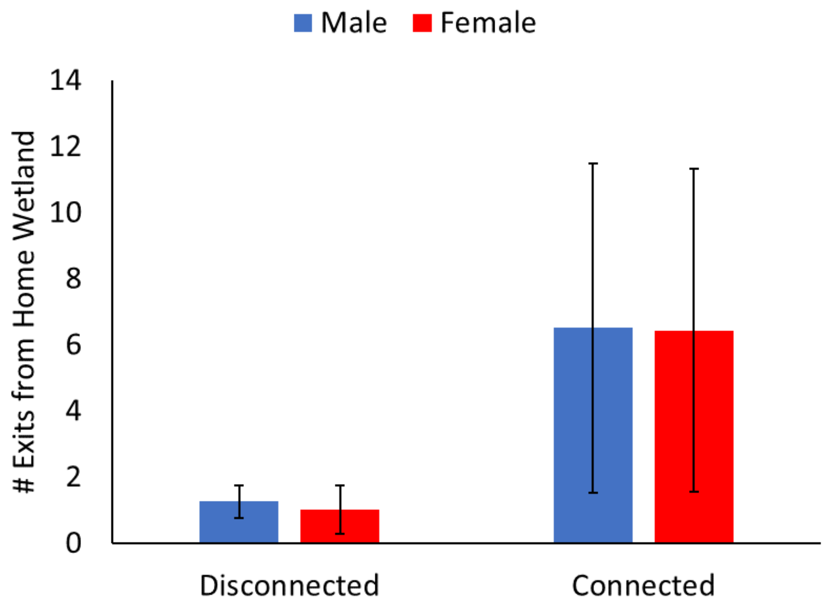



**Figure 9.11** Mean number of exits (and re-entries) from home wetland per turtle. Tagged *E. macquarii* in connected wetlands exited and re-entered their home wetlands significantly more frequently than those in disconnected wetlands

In our categorical analysis to link environmental factors to turtle exits from and entries into wetlands, the only statistically significant trend we detected was that turtle entries into wetlands was significantly associated with wetlands being warmer than the river (Figure 9.12A; $\chi^2 = 10.07$, $P < 0.01$). In other words, turtles entered wetlands when the wetlands were warmer than the river, and this trend occurred regardless of season. Because of our project focus on environmental water, we also report that water changes were not associated with turtles either exiting or entering wetlands (Figure 9.12B; $\chi^2 = 0.11$, $P = 0.95$).

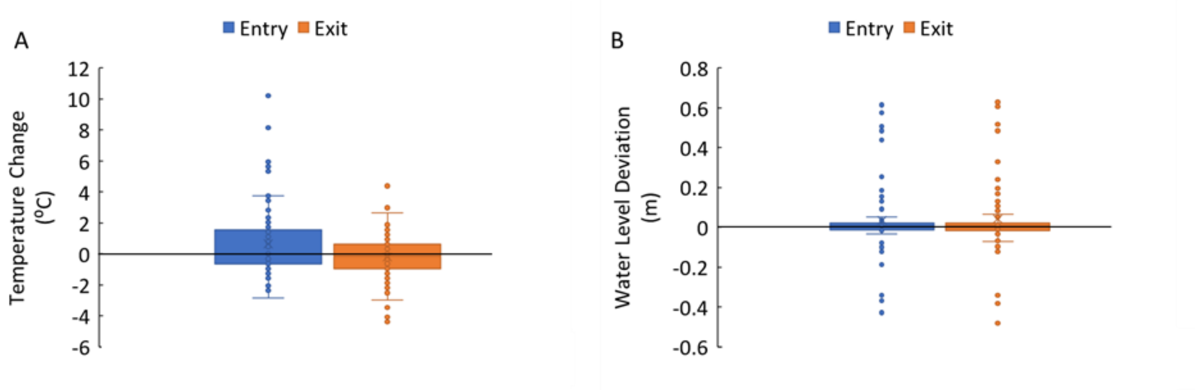



**Figure 9.12 A.** Change in temperatures tagged *E. macquarii* experience when entering or exiting a wetland. Entering wetlands was associated with turtles experiencing an increase in temperature, whereas exiting wetlands was not associated with a temperature change. **B.** River water level deviation was not associated with tagged *E. macquarii* either entering or exiting a wetland. Water level deviation was calculated as the difference between water level on the day of a turtle entering or exiting a wetland and the mean water level of the river. So, a positive number indicates the river is higher than normal, and a negative number indicates the river is lower than normal.

Despite the overall lack of an effect of river level, we did detect one case where river level likely influenced turtle movements. Our site Billabong Lagoon had dried nearly to empty by the late summer of 2020 and was less than 1 m deep. By this time, all tagged *E. macquarii* had left the wetland, and we caught only two *C. longicollis* in our February 2020 trapping session. The wetland continued to dry (and no tagged turtles were present) until October 2020. At this time, the river level rose, which flooded and filled Billabong to its highest extent. At this time, two tagged female *E. macquarii* entered Billabong and stayed until the end of the study (Figure 9.13). In our trap sessions after Billabong re-filled, between November 2020 and February 2021, we captured 1 *C. expansa*, 97 *C. longicollis*, and 18 *E. macquarii*, indicating rapid re-use of the re-filled wetland.

As our study aimed to determine how *E. macquarii* were affected by wetlands drying during winter in particular, we determined where as many tagged turtles spent the winter as possible. The majority of turtles left their home wetlands during winter, regardless of sex and wetland type (Figure 9.14). The majority of females spent the winter in the river adjacent to their home wetlands, though two left the area (Figure 9.14A). All of these tagged females returned to their home wetlands by the start of spring. Most males had disappeared from the receiver network by the start of winter so we cannot confidently state whether they overwintered in the river or in wetlands (Figure 9.14B).

Notably, the onset of winter and/or cold temperatures were not the triggers for turtles to exit their wetlands (Figure 9.12A). The 17 tagged turtles that overwintered outside of their wetlands all left their wetlands between October and March, and so had left before the beginning of winter and/or the seasonal drop in temperatures in April. They simply did not re-enter their home wetlands prior to winter beginning. If they did re-enter their home wetlands, they did so the following spring.

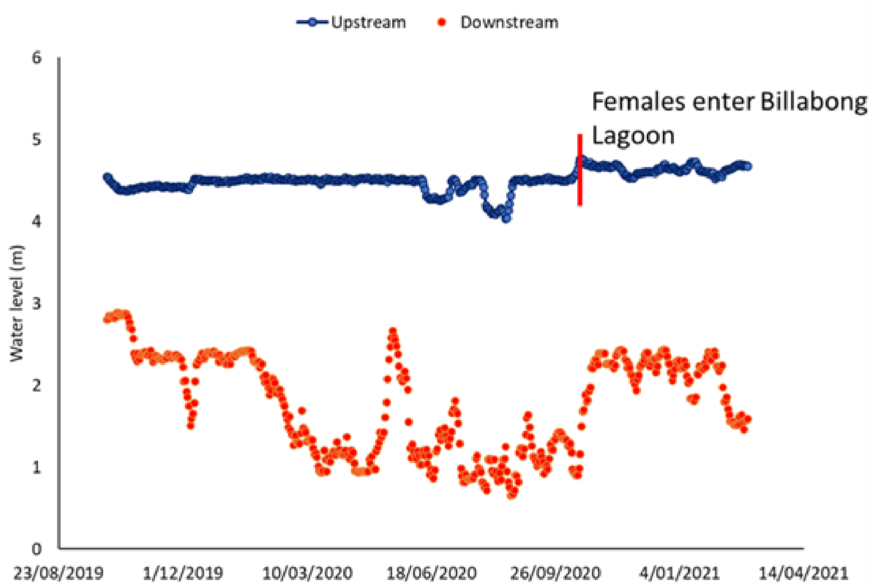



**Figure 9.13** Water levels recorded by gauges upstream (blue) and downstream (orange) of Stevens Weir over the course of the project. The upstream levels correspond to Dahwilly, Billabong, and Yallakool lagoons. The downstream levels correspond to Moonahcullah, Barratta, and Horseshoe lagoons. Billabong lagoon re-filled after a long drying period in late September 2020, and turtles rapidly re-entered soon after. Turtle movements at other wetlands were not clearly associated with river level changes, despite the large fluctuations downstream of Stevens Weir in particular. *Data from* *http://riverdata.mdba.gov.au*

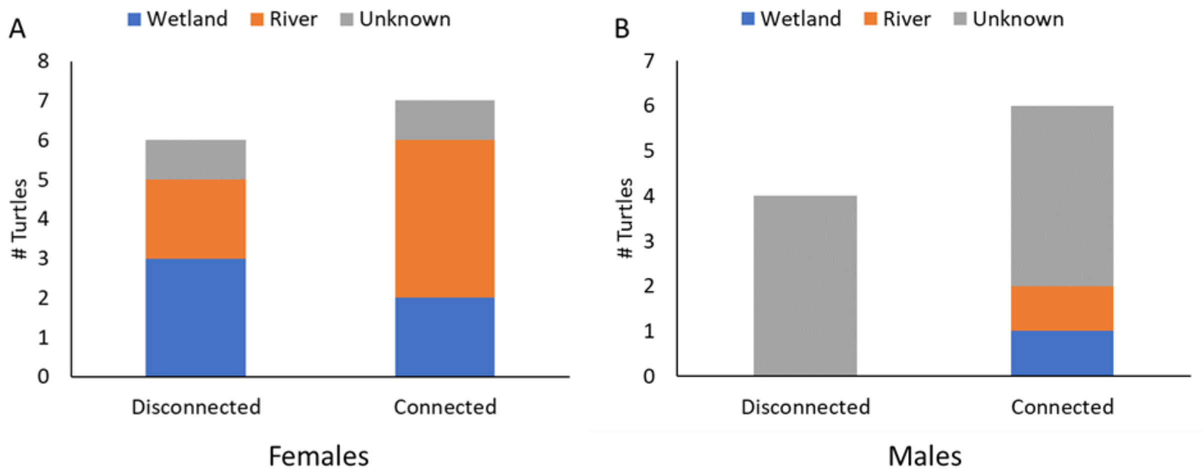



**Figure 9.14** Locations where tagged female (**A**) and male (**B**) *E. macquarii* overwintered during the study. Unknown indicates that the tagged turtle exited its home wetland into the Edward/Kolety River and disappeared for winter. River indicates the turtle spent the winter in the river adjacent to its home wetland. Wetland indicates the turtle spent the winter in its home wetland.

## 9.4 Discussion

Our project found no evidence that winter drying of disconnected wetlands is likely to be a major threat to freshwater turtles in the Edward/Kolety River. Our telemetry project did not detect any tagged *Emydura macquarii* to die as a result of being stuck in a disconnected wetland as the wetland dried during winter. Indeed, our telemetry provided no evidence of mortality in the turtles that remained in the study area, since all were actively moving between receiver stations until the time at which their transmitter batteries were expected to expire. Furthermore, the majority of our tagged *E. macquarii* left their home wetlands prior to winter and either overwintered in the main river channel adjacent to their home wetlands, or overwintered somewhere else that required them to exit their home wetlands and travel to it via the river channel. There was a difference between sexes here, as female *E. macquarii* were much more likely to remain either within, or close to, their home wetlands. In comparison, males were much more likely to leave the area near their own wetlands and either never re-appear, or re-appear later at a different wetland more than 15 km distant from their starting point. Most of our tagged female *E. macquarii*, and some males, re-entered their home wetlands in the following spring.

We did observe several tagged *E. macquarii* to remain in their home wetlands during winter, even in some wetlands that were disconnected. However, these wetlands did not dry over the winter of 2020. In contrast, one disconnected wetland (Billabong) did dry down to a low level between December 2019 and February 2020, and all of our tagged turtles exited that wetland long before winter. Indeed, by February 2020 we detected almost no turtles present in Billabong at all, tagged or otherwise. Billabong did not re-fill until September-October of 2021, and after it re-filled we detected all three species there, including both tagged and untagged *E. macquarii* and a large number of *C. longicollis*. However, instead of water level, the only driver of movements that we detected consistently across our study was that turtle entries into wetlands were associated with the wetlands being warmer than the river that they were leaving. Many of these movements occurred at the beginning of spring, as female turtles re-entered their home wetlands after winter, but the pattern was not restricted only to the spring period and occurred throughout warmer months of the year.

There is little published research describing *E. macquarii* movements in river systems for us to compare to. *Chelodina expansa* exhibit a similar sex difference in movement behaviour, where females have small, defined home ranges within or close to specific wetlands, whereas males can move very large distances in river channels (Bower et al. 2012). *Chelodina longicollis* has been radiotracked in drier landscapes with networks of disconnected wetlands, and exhibits numerous overland movements to wetlands as they fill, and from wetlands as they dry (Roe and Georges 2008b). Furthermore, *C. longicollis* often retreat to permanent waterbodies prior to winter (Roe and Georges 2007), likely to avoid winter exposure mortality due to cold temperatures slowing their ability to move and escape predators This so-called “winterkill” event may be common in turtles from temperate latitudes (Ultsch 2006), and has been observed in two North American freshwater turtle species, *Chrysemys picta* and *Kinosternon flavescens* (Christiansen and Bickham 1989). Prior to the winterkill event, *K. flavescens* abandoned the drying pond and experienced low mortality, whereas *C. picta* did not abandon the drying pond and experienced extensive mortality (Christiansen and Bickham 1989). Christiansen and Bickham (1989) suggest that *K. flavescens* detect lowering water levels prior to winter and abandon such sites prior to the onset of cold temperatures, whereas *C. picta* are much less willing to abandon such sites. The Edward/Kolety River historically would have undergone substantial seasonal fluctuations in river level (Walker 2006), and our results suggest that all three of its local turtle species have evolved to move out of potentially-drying wetlands prior to winter, similarly to *K. flavescens* and differently from *C. picta*.

In addition to our telemetry results, our trapping surveys did not indicate that winter exposure was a source of mortality for turtles in disconnected wetlands. All three species were captured in all six wetlands, though at varying abundances. The patterns we observed in both turtle populations and communities reflect more general trends in the Murray-Darling Basin as a whole. First, our results reflect the habitat preferences and typical abundances of all three species: *C. longicollis* was more common than *E. macquarii* in disconnected wetlands, whereas *E. macquarii* was more common than *C. longicollis* in connected wetlands. These trends reflect that *C. longicollis* prefers temporary and disconnected wetlands, and moves widely over terrestrial areas between wetlands, whereas *E. macquarii* prefers permanent wetlands that are close enough to rivers to be regularly flooded by river flooding (Chessman 1988; Roe and Georges 2008a; Roe and Georges 2008b). Of the three species, *C. expansa* was usually the rarest for us to capture, which reflects its typical lower abundance (Chessman 2011; Van Dyke et al. 2019).

In our body condition analysis, only female *E. macquarii* presented a pattern consistent with a potential risk in disconnected wetlands, because they had lower body conditions than females from connected wetlands. Lower body condition is often associated with poorer food availability (Petrov et al. 2020) and our results could indicate that disconnected wetlands have less available food for *E. macquarii*. However, this difference could also reflect that disconnected wetlands are not their preferred habitat (Chessman 1988), rather than a higher risk of mortality, particularly due to winter exposure. Indeed, our telemetry data show that female turtles are capable of moving out of disconnected wetlands, so they should not be viewed as 'trapped' in disconnected wetlands, even if the wetlands are poorer habitat than connected wetlands. Given their high survival rates, and that females did not abandon disconnected wetlands despite their ability to do so, their lower body condition does not appear to indicate a risk of negative health consequences in disconnected wetlands. The absence of a similar difference in male *E. macquarii* probably reflects the much higher movement rates of males, as demonstrated by our telemetry data.

We detected very few juveniles of all three species, and all populations were dominated by older, larger adults. This trend is widespread in the Murray-Darling Basin, and indicates that turtles suffer from low recruitment rates (Chessman 2011; Van Dyke et al. 2019). Low recruitment has been linked to both high nest predation rates by foxes (Spencer and Thompson 2005; Thompson 1983; Thompson 1993), and potentially post-hatch low rates of survival in juveniles (Chessman 2011). Long-term low recruitment rates may cause seemingly-abundant populations to disappear rapidly once old adults die of old age (the 'perception of persistence'; Lovich et al. 2018).

### *Implications for winter environmental watering*

Our results indicate that winter environmental watering to prevent disconnected wetlands from drying during winter may not be necessary to reduce winter turtle mortality in the Edward/Kolety River, since the turtles behaviourally avoid those mortality events. However, our results do indicate that environmental water events more generally are likely to benefit turtle populations. Tagged *E. macquarii* from connected wetlands exited (and re-entered) wetlands 6 times more frequently than did those from disconnected wetlands. Thus, a constant connection of a wetland to the river permits more frequent movements out of and into the wetland, possibly in response to thermal cues. Furthermore, female *E. macquarii* had higher body condition scores in connected wetlands than in disconnected wetlands, so there is a possibility that connecting these wetlands with high environmental flows could provide some food benefits, if they either introduce novel food into the wetland, or permit more frequent turtle movements to alternative foraging areas.

When disconnected wetlands are filled by high environmental flows (and essentially, become temporarily 'connected'), the opportunity for turtles to move should be increased. Environmental flow events may mimic the flood events that would have historically connected disparate wetlands in the river floodplain to the river itself (Walker 2006). These events were probably important for allowing turtles to access different locations and food resources (Chessman 1988; Chessman 2011). This interpretation is supported by our observations of Billabong Lagoon. Turtles abandoned it as it dried, but as soon as the river levels raised high enough to spill into and fill Billabong, a large number of turtles rapidly entered it. *Chelodina longicollis* abundance in particular increased massively after Billabong re-filled, and tagged *E. macquarii* also moved in soon after it refilled. These high environmental flow events that allow the river to 'connect with' and fill dried, or drying, wetlands may thus be important opportunities for freshwater turtles to move into and utilize floodplain wetlands that cycle between drying when disconnected and flooding when connected.

## Cultural Outcomes

### *Tracy Hamilton*

Working with Van and my work colleagues on the turtles was great, and getting to go out on country every day and learn about the turtles was interesting. Van taught us a lot about the turtles, and how they differ from one another. I never really thought anything about them until now like how the different species travel different distances in the water at different times of year. Learning how to measure the turtles, record the information about them, and see how the ultrasound shows their eggs was very interesting. I can pass on my new knowledge about protecting turtles to the next generation.

**Figure 9.15** Joseph Briggs and James Van Dyke check a trap for turtles. – *photo by Tracy Hamilton*

### *Liticia Ross*

One thing I will take away from this experience that I didn't know before is to identify the different kinds of turtles, but what I have learnt will be passed onto the next generation. We all have different knowledge of country that we were able to share and learn with each other which I feel was a great contribution to the project.

### *James Van Dyke*

Working with Tracy Hamilton, Liticia Ross, and Joseph Briggs (Figure 9.15 and 9.16) was the most rewarding aspect of the project for me. Liticia taught me the local names for the eastern longnecked turtle (Turmi-Mum) right away, because one of its meanings is 'stinky turtle', which reflects the odoriferous musk they secrete from the bridges of their shells when captured. We also discussed the names for the Macquarie River turtles (Nyim) and broad-shelled turtles (Pil-Wil Lerngət), neither of which are as stinky. As we spent many days together at the wetlands, Tracy and Joe taught me how to recognise scarred trees and places where the landscape had potentially been modified and raised up into small platforms for historical use by their people. Interestingly, those raised mounds sometimes had evidence of turtle nesting activity, probably because the soil was soft and uplifted, which turtles prefer for nesting. I was able to use those examples to show the team what kinds of habitat turtles prefer to nest in, which will be very useful for future fox control work to protect turtle nests in Werai Forest, if they choose to do so.

I am extremely grateful to Tracy, Liticia, Joe, and the rest of the Yarkuwa team for being involved in this project. In addition to the reciprocal learning we were able to do, we also identified some ways to work together to continue turtle conservation work, beyond the Flow-MER Program. We are establishing a continuing collaboration supported by Murray Local Land Services to implement and test the effectiveness of 1080 poison baiting for fox control at some of the same wetlands used in this study. Hopefully, that work will be able to improve hatchling turtle recruitment at these wetlands, which we have identified as a problem in this report. Yarkuwa staff will also be able to use their experience, combined with that gained from the Flow- MER Program, to design and implement further turtle conservation works in Werai Forest.

Further information about his project is also available in the Flow-MER feature article '*Tracking turtles in the Edward/Kolety River system*' (available from https://flow-mer.org.au/tracking-turtles-in-the-edward-kolety-river-system/} and article *Learning with locals in monitoring and research* (https://www.dcceew.gov.au/water/cewo/working-with-first-nations/learning-with-locals).

**Figure 9.16** The turtle team. L*eft to right*: Liticia Ross, James Van Dyke, Tracy Hamilton, and Joseph Briggs (and a large female *Emydura macquarii*), *Photo by Liticia Ross*

# 10 Research: Edward/Kolety-Wakool Social Research

Authors: Catherine Allan and Wendy Minato

## 10.1 Summary

This research considers the knowledge, values and opinions of people with some form of 'stake' in the Edward/Kolety-Wakool in relation to environmental water and its use in that river system, specifically:

1. How are knowledge, information and learning (i.e., acting, adapting and accepting) understood and experienced by stakeholders in the Edward/Kolety-Wakool River system?
2. What are the current Edward/Kolety-Wakool River system stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water?
3. What institutional, social and/or cultural interventions could improve the acceptance and impact of Commonwealth environmental water for this and other sites?

An online questionnaire was developed to be administered with the Charles Sturt University's Survey Monkey licence. It used a semi-standardised format that included pre-structured choices and opportunity for respondents to formulate their own responses. A list of themes, topic areas and potential questions were developed in consultation with willing stakeholders, and piloted. Sections related to: the respondent population and their involvement in the Edward/Kolety-Wakool river system; their knowledge and understanding of water in the Edward/Kolety-Wakool river system; their understanding and perceptions of environmental water planning and management and their forms of communication and information sources.

Survey respondents in the Edward/Kolety-Wakool River system monitoring area were predominately men over 40 years of age who have lived in the area, either on the river or in the towns for most or all of their lives. All of the respondents, whatever age or gender, were clearly well connected to the river system. They are interested in all of the river system, not just parts of it and they are concerned not only about the health of the river but also with its relationship to personal livelihood and the local community.

All of the respondents agree that healthy rivers are necessary for healthy societies. It is rare to have 100% agreement to a value statement in such a contested area of activity, and this could, perhaps should, be a pivot point for information exchange in the future. What health means in each in instance will vary for each individual, group and organisation, but the common shared agreement of purpose can provide a solid foundation for working with those variances. Some, but not all, agree that water for the environment can play a role in achieving river health.

The respondents have a good understanding of the roles of various government agencies and groups that have a role in water management in the Edward/Kolety-Wakool system, while the trust in those groups is more varied. The qualitative data indicate that dissatisfaction relates to perceptions of low consultation and poor accountability around environmental water, and water in general.

This group of respondents want to know about the responses of animals, plants and water quality to the used of environmental water. They support the focus of existing monitoring programs.

The data from the survey suggests:

1. Using the results of this survey as an object for conversations within the communities (including scientists) associated with the Edward/Kolety-Wakool River system and Flow-MER Program.
2. Reducing the narrow scientific focus on water for the environment that separates the program from the river system communities, who relate to all of the water.
3. Making more information about river health and water quality should be more available in locally relevant and accessible ways. Detailed information about the Flow-MER Program is available on websites, but locally focused, locally accessible and even locally verified or voiced information is also needed. What this involves should form part of the discussions noted in 1, but could include, for example, one or two large, current water quality graphs in publicly accessible sites (see for example the Saltwatch, program) or regular columns on river health in the local newspapers, and or involvement of schools in water quality management.
4. Continuing to work with the expertise and passion that at local people have for the Edward/Kolety-Wakool river system.

This survey instrument appears to be valuable, and we recommend that it is used for further exploration of the social acceptability of the use of water for the environment in the Edward/Kolety-Wakool river system. Involving specific social groups that are underrepresented in this report would be valuable. This includes women, Traditional owners, young people, and water planner/ water managers. Mitchell and Allan (2018) found that over one-third of respondent groups (in their NSW based survey took up the recommendation of completing a survey as a group exercise, and this may be needed to increase the number and range of responses if the survey is administered again.

Engagement of these groups may also be of paper-based survey, offers to assist in group settings, and targeted use of social media.

## 10.2 Introduction

### *Background*

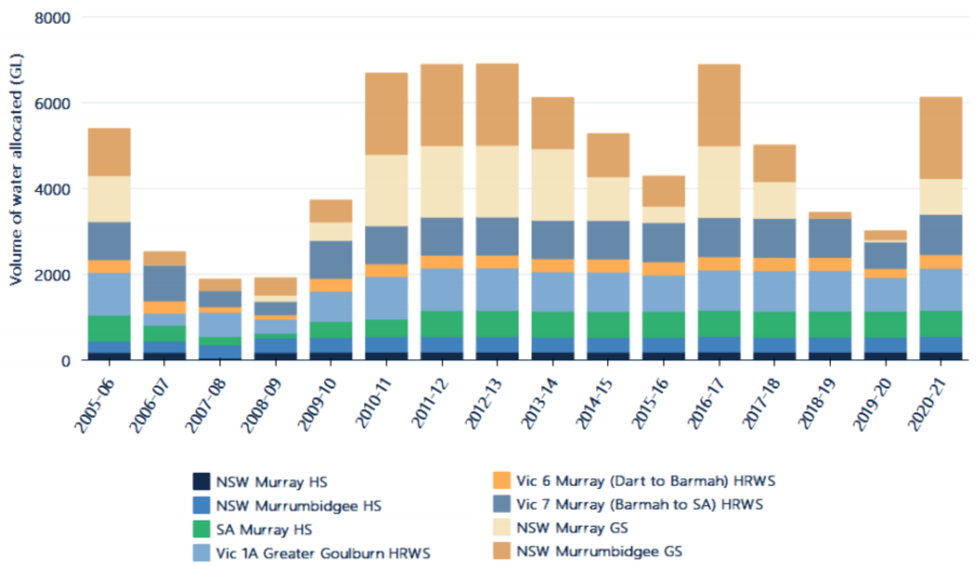
This research considers the knowledge, values and opinions of people with some form of ‘stake’ in the Edward/Kolety-Wakool in relation to environmental water and its use in that river system. Environmental water has been an aspect of water management in the Edward/Kolety-Wakool for the past decade, but it is just one of the many impacts on the river environment over that time. To understand the responses to a survey about environmental water requires some understanding of the context of both environmental water and the research surrounding it. This background gives a brief introduction to both.

The Murray-Darling Basin is a large, dryland river system with multiple calls on its limited water, across five jurisdictions (Chen et al., 2020). Australian states have primary responsibility for water resource management, including the creation of water rights and the establishment of water trading rules. Although details vary from state to state, water rights include a water entitlement, which is the ongoing right to receive water from a specified consumptive pool and a water allocation, which is the volume of physical water assigned to water access entitlements in a given year, or as specified with a water resource plan (Bureau of Meteorology, 2021).

National Water Initiative (NWI), adopted by the Council of Australian Governments (COAG) in 2004, aimed to  phase out overuse of water, reform the water entitlement system and promote active water trading (Hart, 2016). The water market 'experiment' in the Murray-Darling Basin means that it is one of the world's largest water markets (Grafton and Horne, 2014) with both water entitlements and allocations being traded.

Extending and partly building on the NWI was the Commonwealth Water Act 2007; the Murray-Darling Basin Authority was formed to meet its aims (Connell, 2011). It developed the Murray-Darling Basin Plan (the Basin Plan). The Basin Plan has been, and continues to be, the focus of much public discussion and disagreement (see, for example, Colloff and Pittock, 2019). One aim  of the Basin Plan- to restore water dependent ecosystems- is achieved partially through allocating water entitlements purchased from irrigators to the environment (Grafton et al., 2014). The delivery of that water is referred to as an 'environmental flow', or, 'water for the environment'. The purchase of water by Commonwealth and State governments for the environment was facilitated by the Murray-Darling Basin being the most active region for water trading with 80% of Australia's water trading activity (Garrick et al., 2018).

While water markets were being developed, and some entitlements to water were purchased for the 'environment', Australia's notoriously variable climate created variable amounts of actual water for allocation, as indicated in Figure 10.1. This summary, from Aither (2021) shows the total water allocated in the Southern Basin Irrigation areas between 2005/2006 to 2020/2021.




Source: Aither 2021. Based on Victorian, New South Wales and South Australian water registers, 2021.

Note: Allocations to all entitlement categories are shown, including allocations to environmental water and Victorian water corporation holdings. Excludes carryover and distributions from irrigation corporations.

**Figure 10.2** Water allocations in southern Basin 2005-2021, from (Aither, 2021)

The 'Brisbane Declaration' describes environmental flows as "*the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems*" (Arthington et al., 2018). Despite the inclusion of human livelihoods in this definition much of the academic focus on environmental water is biophysical aspects such as the frequency and magnitude of flows, in-channel geomorphology, hydrology, in-channel habitat, and aquatic biota.

Water for the environment has been delivered as environmental flows in the Edward/Kolety-Wakool system since 2010, accompanied by an extensive program of biophysical monitoring and evaluation of its impact (e.g., Watts et al., 2020; Watts et al., 2013; Watts et al., 2016). However, the societal impact of using environmental water has not received nearly as much attention, and there is little known about the levels of knowledge and acceptance of the use of environmental water by individuals and communities. Lukasiewicz et al. (2013) note that not involving local people in decision making can create issues of procedural justice; a concern in itself but also for environmental management as decisions not seen to be fair or equitable are less likely to be socially acceptable. It is increasingly apparent that attention needs to be given to both social and ecological dimensions of a situation to enable effective governance and management in complex and contested areas (Voyer et al., 2015).

To learn what people really know and feel about concept and use of environmental water, funding was allocated to one of the seven Flow-MER sites in the Murray-Darling Basin, the Edward/Kolety-Wakool.

The Edward/Kolety-Wakool River system sits within the Australian Bureau of Statistic's 'Deniliquin Region' and 'Deniliquin' areas (Figure 10.2). Some of the key statistics for these areas are presented in Table 10.1.

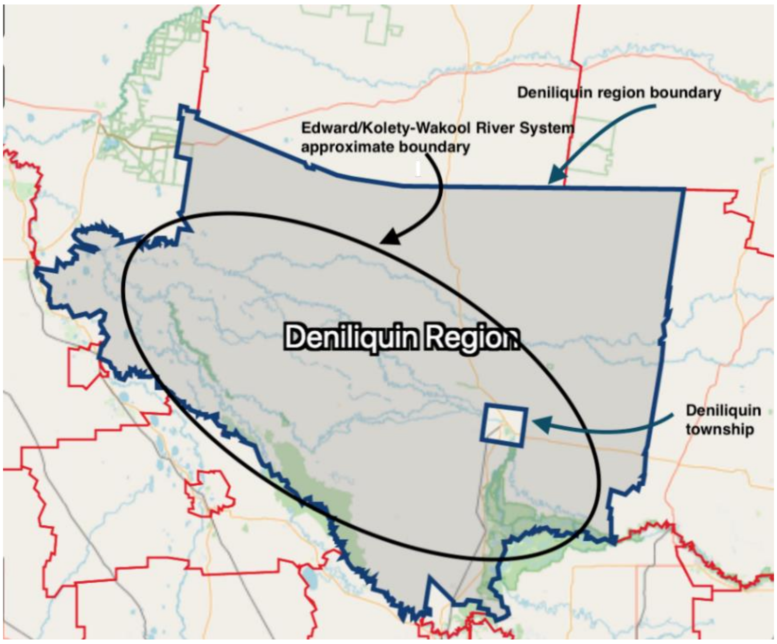



**Figure 10.3** The study area (oval) superimposed on two Australian Bureau of Statistics areas Deniliquin region, and Deniliquin township, showing as a separate square.

**Table 10.1** Summary of ABS population data for Deniliquin area and township.

| Description | Year | ABS Deniliquin Region | ABS Deniliquin |
|---|---|---|---|
| Estimated resident population | 2019 | 6735 | 7624 |
| Estimated resident male population | 2019 | 3482 | 3731 |
| Estimated resident female population | 2019 | 3253 | 3894 |
| Estimated Aboriginal and Torres Strait Islander population | 2016 | 271 | 417 |
| Median age persons | 2019 | 49.4 | 45.3 |
| Number of agricultural, forestry and fishing businesses | 2020 | 595 | 144 |
| Number of businesses total | 2020 | 977 | |
| People employed in agricultural, forestry and fishing businesses | 2016 | | 7.1% |

The rivers and creeks dominate the visual landscape of the study area and, anecdotally, the lives and interests of people with some sort of 'stake' in it. The use of environmental water is likely to impact different stakeholders in different ways, and there is continued effort to inform stakeholders about the value and impacts of environmental water, and increasingly to engage them in activities such as scientific monitoring.

There has been, however, only limited research that explores the knowledge, values and opinions of Edward/Kolety-Wakool stakeholders in relation to environmental water. Allan and Watts (in press) have undertaken exploratory research that suggests a range of perspectives/perceptions held by stakeholders. This current research continues that theme by seeking contributions from the wider stakeholder community. This broad-based research provides improved understanding as well as a baseline for future evaluation of communication ad community engagement activities.

### *Research questions*

1. How are knowledge, information and learning (i.e., acting, adapting and accepting) understood and experienced by stakeholders in the Edward/Kolety-Wakool river system?
2. What are the current Edward/Kolety-Wakool River system stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water?
3. What institutional, social and/or cultural interventions could improve the acceptance and impact of Commonwealth environmental water for this and other sites?

These questions are being addressed through an online anonymous questionnaire; the social survey described below.

## 10.2 Method

The research was conducted in accordance with approval from the Charles Sturt University Human Research Ethics Committee, reference number H21089.

### *Survey Design*

This project sought to collaborate with the stakeholder community in developing a relevant and acceptable survey instrument. Stakeholders in this instance are defined as anyone with an interest in and/or is impacted by environmental flows in the Edward/Kolety-Wakool river system. A comprehensive list of stakeholder types was developed (Table 12.2). This list provided potential survey co-designers as well as survey respondents. Note that the stakeholders in Table 1 include communities of practice and communities of place (Harrington et al., 2008).

**Table 12.2** Stakeholder groups identified prior to commencing research

| | |
|---|---|
| River | Irrigators<br>Dryland farmers<br>Landholders with river frontage<br>River groups |
| Special Interest Groups | Environmental e.g., Lagoon restoration group<br>Recreational fishing<br>Skiing/Boating<br>Speak up campaigners<br>4 wheel drive groups |
| Other Groups | Murray Regional Strategy Group<br>Regional Development<br>Landcare<br>Land for Wildlife<br>Indigenous groups<br>National Parks & Wildlife |
| Specialist Knowledge | Water Managers<br>Water Operators<br>OEH, CEWO, MI, Water NSW, LLS<br>Community Engagement – LEO, REO<br>University researchers |
| Business/Tourism | Local councils<br>Tourist parks<br>Shires<br>Forestry |
| Media | Local paper and radio |

Ideally the survey should be designed with a range of individuals in a group setting to ensure relevance to local communities and assistance in promoting the survey (Luke et al., 2021). However, individuals were reluctant to participate in group survey design sessions, citing lack of knowledge, time constraints, unease about the COVID-19 situation, and the controversial nature of environmental water. Anecdotal evidence suggested that in a small community it was not always prudent to voice an opinion in public. Based on this feedback selected individuals were provided with draft surveys during the development phase for comment, as described below.

### *Developing the survey instrument*

An online questionnaire was developed to be administered with the Charles Sturt University's Survey Monkey licence.

This project developed a semi-standardised questionnaire that included pre-structured choices and opportunity for respondents to formulate their own (Sarantakos, 2013). A list of themes, topic areas and potential questions were developed from earlier qualitative research on environmental flows in the area (Allan and Watts, 2017; Allan and Watts, in press) and via phone conversations and email responses from individuals. For each question we considered why the question was being asked, what we might learn and how that information might usefully be applied. The questionnaire format was 'mixed' in that it followed the logic of the project, shifting from general to specific as required (Sarantakos, 2013). Sections related to: the respondent population and their involvement in the Edward/Kolety-Wakool river system; their knowledge and understanding of water in the Edward/Kolety-Wakool river system; their understanding and perceptions of environmental water planning and management and their forms of communication and information sources.

Many of the structured questions were formulated as Likert scales, a summative process that is intuitive to respondents (McIver and Carmines, 1981). For these questions respondents were provided with a statement and asked their level of agreement on a five point scale from Strongly Disagree to Agree. Other questions encouraged respondents to choose options from a menu of choices, with 'other' included. There were also open questions in each section to enable respondents to expand on their answers, or to raise issues that they thought were missing from the questionnaire.

A rough draft of the survey topics and questions was sent out to a small number of individuals with a professional interest in the research outcomes. A draft questionnaire was then sent out to the four individuals who were willing to provide feedback. The draft was subsequently modified to reduce its length and make it more relevant to the local community.

A pilot version of the online survey was tested by members of the Murrumbidgee Field Naturalist's group. A zoom meeting was set up and three volunteers worked their way through the questions providing feedback as they went. Several minor but useful wording improvements were made.

### *Questionnaire distribution*

The sampling was purposive. As the aim was to enable all stakeholders to be invited to contribute, a range of platforms and processes were used to spread the link and its invitation as widely as possible. The link to the questionnaire was sent to all individuals who were contacted during Stage 1 of the research, with the request that they not only complete the survey, but pass the link on and encourage others. The link was included in local and specialist group newsletters, the Edward/Kolety-Wakool Flow-MER newsletter, and the Deniliquin Pastoral times, and promoted on ABC Regional radio and in local newspapers. Because of the anonymity of the survey, and the snowball distribution method it was not possible to send reminders to those who might have received the survey but not completed it.

The online survey was open for six weeks, between June 15 and July 24, 2021. Survey respondents were asked at the completion of the survey whether or not they would like a copy of the findings / report and so communicating the findings.

### *Data analysis*

Data analysis was both quantitative and qualitative. The initial analysis involved presentation of the raw, organised quantitative data as charts, and presentation of the qualitative data verbatim. Many of the structured questions were formulated as Likert scales, a process designed to scale respondents not attitude items – that is it about how many respondents select parts of the scale (McIver and Carmines, 1981). For clarity in the descriptive charts the five options in the scale were reduced to three, such that Strongly Agree and Agree are represented as Agree, and Strongly Disagree and Disagree are represented as Disagree, with the central category untouched. Data responses for each question are presented in ranked order, rather than question order. The qualitative data are presented in text boxes related to the questions in the survey instrument, but with some simple thematic organisation within the text box.

## Results

The sections present a combination of graphs and short summaries that reflect the responses to numeric questions in the survey. When "other" was selected by respondents in answer to some questions the text related to the other is included with the graphical response to the menu questions. Other free text from the survey is presented in text boxes. All free text responses are presented verbatim and unabridged, with some ordering, and some comments which may be considered offensive were removed.

### *The respondent population and their involvement in the Edward/Kolety-Wakool River System*

Between 40 and 57 individuals responded to the survey, the number varying depending on the question being answered.

Of the respondents who answered the demographic questions most (71%) were male, who were represented in all five age categories. The majority of all respondents, and almost all female respondents, are aged between 40 and 80 years (Figure 12.3). No respondents identified as being Traditional owners/ First Nations/ Indigenous.

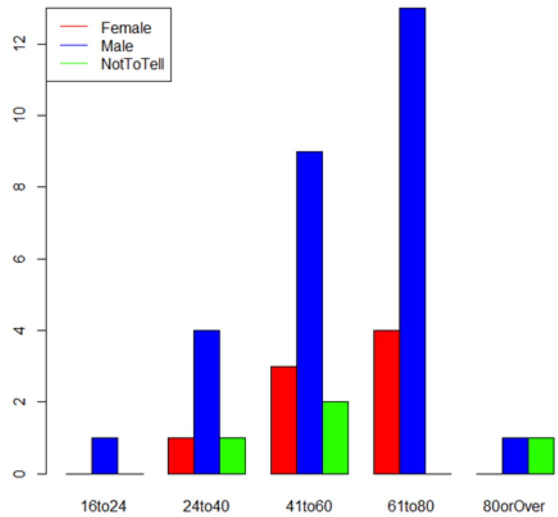



**Figure 12.4** Age and gender distribution of respondents.

**Relationship to the Edward/Kolety -Wakool River system #1**

- Life
- It is my home, my land and future for my children
- I've lived my whole life in the region & have a strong interest in the health of our rivers. The connection that people have to the country is strong, it's difficult to explain & it's like you become one with the rivers & the country.
- Using the river system for recreational fishing for the last fifty years
- Watching our farmers being deprived of the water that's needed for producing their crops to feed our country. The water that's being wasted & regulated are ruining the rivers creating much erosions.
- As a farmer, poor environmental outcomes get us a bad name.

Other than one response from the ACT, the respondents who identified their area of residence were from NSW in postcodes local to the Edward/Kolety-Wakool River system. Around a third (13) are from the lower, Barham part of the survey area and the remaining 22 are from the upper, Deniliquin, part. Over half (57%) described themselves as living on rural properties, with the remainder living in towns. Around two thirds of respondents (69%) hold some sort of water licence. Almost all of the respondents have a very long association with the Edward/Kolety-Wakool River system, with nearly 80% indicating either more than 20 years, or a lifelong association.

While over half of the respondents indicated their interest was in the whole of the Edward/Kolety-Wakool River system, individual rivers and creeks were also of special interest to some respondents as shown in Figure 4. The number of responses is higher than the number of respondents because they could indicate all, and one or more areas of interest.

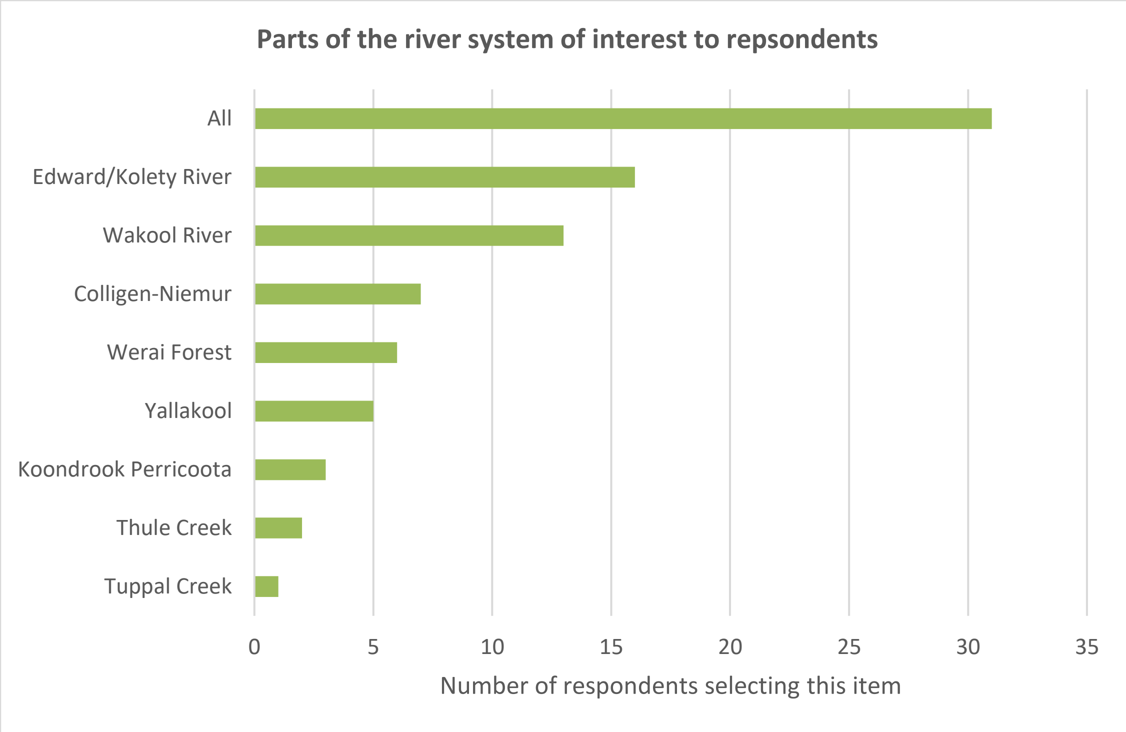



**Figure 12.5** Parts of the river system identified as of interest by respondents.

In the past two years 70% of respondents undertook fishing, 60% camping and 52% boating (Figure 12.5). The least selected activity (18%) was volunteering.

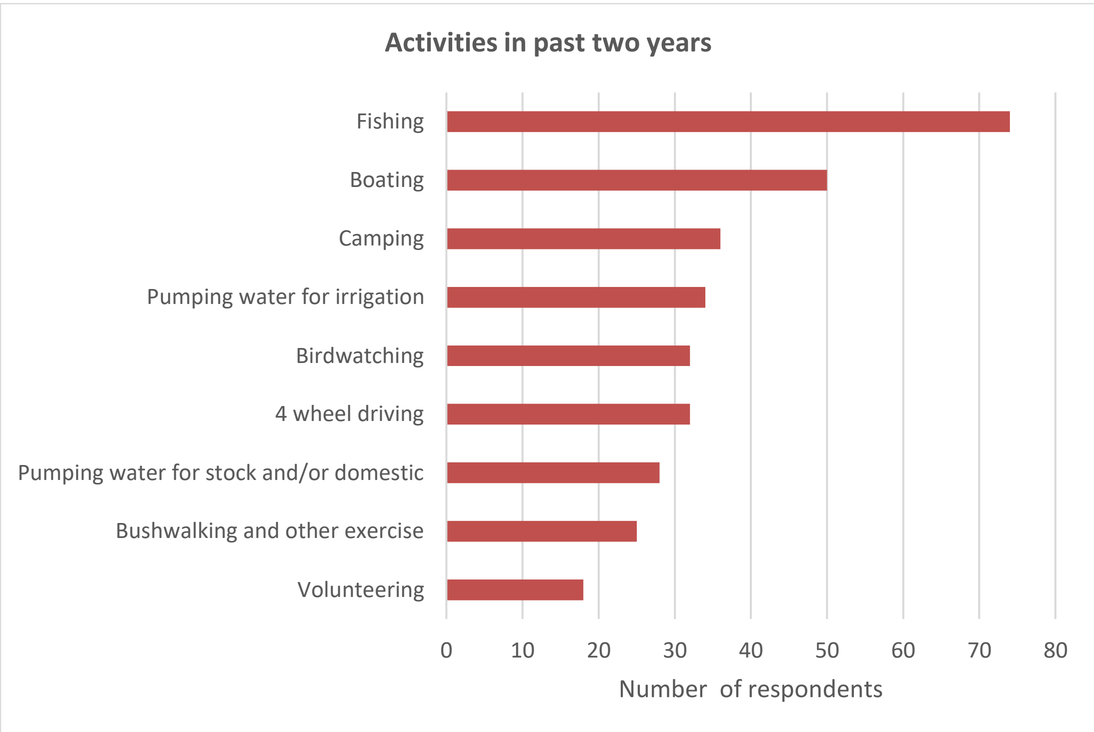



**Figure 12.6** Activities undertaken by respondents in past two years.

"Other" activities undertaken (free text) included:

- Farming and grazing merino ewes and prime lambs
- Live on the bank of the Edward at Deniliquin
- Conducted community tours of forests and wetlands and developed a Koondrook Perricoota Community Visioning Statement with the involvement of 160 people
- Employment as environmental consultant
- Environmental and cultural management
- Swimming, picnics, identifying plants, bike riding
- Landscape conservation
- Research
- Strong physical connection to land /water, recreation and business
- Farming
- Working on the planning and delivery of e-water
- Unable to get there due to covid
- Cleaned up after flooding event from 2016 - MAN MADE FLOOD
- Kayaking
- Research, field days, NRM projects
- Live on it
- Being involved with families within the Moulamein & District for over 40 years.

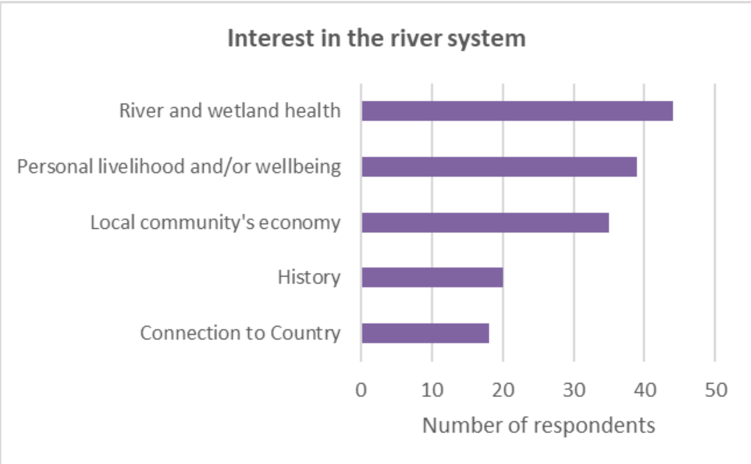



**Figure 12.7** Stakeholders' interest in the Edward/Kolety-Wakool River system.

Other interests (free text) included:

- Current and future management
- Without river and wetland health everything else, economy etc, suffers.
- When outlining Connection to Country do you mean for non-Indigenous people as well? The current ban on Murray Cray fishing is having a huge impact on personal well-being and Connection to Country and tradition.
- Multi-generational connection to land. Farm business operations within region. Strong connection to community through representational role. Chair of organisation seeking increased Government/Science/educators capacity to design and implement more positive pathways for community engagement and importantly partnerships, where local communities are at the forefront of helping making decisions, not recipient of external decisions made by Governments/politics/interest groups outside the region. Region could showcase more positive pathways for community/government partnerships, but too often Government processes are 'top down', not partnerships derived on a genuine basis 'bottoms up

**Relationship to the Edward/Kolety=Wakool River system #2**

- Residing adjacent to the Werai Forest we have been in the position where we were able to offer passage of water through our land to flood an area of the Werai currently not able to be flooded because of illegal levee banks along the Edward River.
- We have lived beside the Wakool River for 50 years and it was our sole source of water for 40 of those years. We have had to install a bore because the river is now allowed to cease running
- The Mid Murray region is highly regarded for its current ecological status by regional communities, farmers, scientists. The attributes of the region during management of waterways during the Millennium Drought and development of the Murray Darling Basin Plan, have not been fully appreciated or understood by politicians or the Murray Darling Basin Authority (MDBA) As an example, requests for environmental flows to maintain refugia for native fish species during the drought were not supported and instead, higher values were & continue to be placed on the artificial Lower Lakes in South Australia. During the Millennium Drought, the death of thousands of Murray Cod due to lack of baseline flows, this included the Bullatale Creek (regulated permanent flow section), & the Edward/Wakool system. The Murray Darling Basin Plan, still places higher value based on the artificial South Australian Lower Lakes and this is causing poor decisions on managing water in the Southern Basin, including decisions to maximise flows to the Lower Lakes despite known natural Murray River capacity limitations As Chair of an organisation seeking to promote positive and genuine Government/Science/community partnerships, it is extremely disappointing that politics and bureaucratic decisions continue to undermine the high potential for long term sustainable outcomes in the Mid Murray for the environment, people and local economies It is important to point out, that there is a lot of political rhetoric about 'partnerships', but there too many past & present examples where statements are made about partnerships, but actual on ground reality is not true to the meaning of the term
- The river levels change daily, up a meter down a meter, doing damage to the banks and native fish in river system
- I work on the planning and delivery of e-water and through this work I have met a number of people in the local community. During the last five years it has become clear that both local community members and scientists are concerned about the health of the river system.
- I am involved in the planning and delivery of environmental water. Through this process I have become familiar with the river system and have got to know a lot of people in the local community. Through this work I have observed a highly modified river system that locals and scientists are concerned about.
- Owning both sides of our creek system - our - the community relationship is strong. We are all guardians of what Mother Nature has provided.
- I grew up on the Edward Kolety but my understanding of its importance has really grown since then. There is so much hidden beneath the surface. The connections between different animals and plants are really intricate. Our town relies on the river, and there is so much more to it that we should try to understand. The river is the reason we are here and able to make a living, have a drink and enjoy the wildlife that the river supports. It's a part of us.
- Concerns that in parts of the system, recreational fish numbers still haven't recovered from hypoxic events.
- Has improved this year due to constant flow
- Wakool and Niemur need a higher net flow.
- Since the removing of water allocations via the MDB Plan local towns, communities, industry's and services have suffered and are in serious decline. Local aquatic life has suffered from black water events from artificially flooding forests and continuous high flows with associated bank erosion and formation of sand slugs. Also with the decline of irrigation in the environment there has been a decrease in birdlife and aquatic species from this environment. The removable of water from this

**Relationship to the Edward/Kolety=Wakool River system #3**

- Long-time farming
- Property owner and custodian of the land
- I have been here for 17 years with the river as our back yard and in that time I have lost approx 2 metres of river bank in sections due to high flows
- Small-bodied fish needs targeted action for improvement.
- I have noticed there are heaps less fish in our river system after black waters from flooding the forests
- I grew up knowing the Edward/Kolety as 'dirty' and was astonished to learn from older people that they swam in it as children when it ran with clear water. I had no idea that it should be a clear river or that it was not unusual to see platypus in it and the banks even in the middle of Deniliquin. It is horrendous what has been lost and degraded. I am tired of hearing farmers call themselves the custodians of the river and that they know what is best. They are wilfully ignorant of how much damage agriculture does, they complain about bank erosion yet how many actively revegetate them? Farmers and politicians have been arguing about water rights since European settlement of the area. We must acknowledge the limitations of our environment regarding food production and find smarter ways to produce food appropriate to the area. Local aboriginal people have stoically persevered in surviving colonisation and must be given a much greater role in managing the river system. Their knowledge and rights are crucial. It is sickening to hear farmers complain they are a 'dying breed' and they have a right to water and farming when you consider what has been inflicted upon and what has been taken away from the original inhabitants of this area.

### *Knowledge and understanding of water in the Edward/Kolety-Wakool River system*

Respondents were asked their opinion on the current and future health of Edward/Kolety-Wakool River system (Figure 12.7).

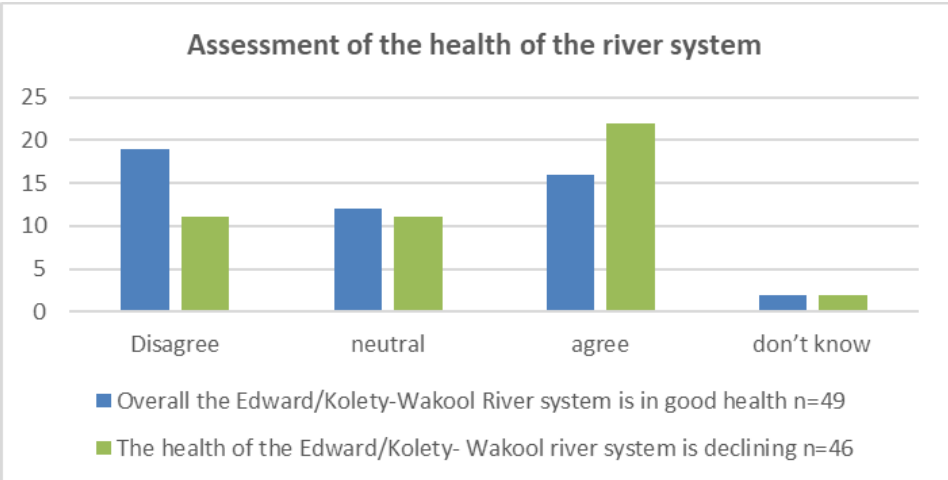



**Figure 12.8** Respondent's opinions on river system health and trend.

**Biggest risks to river health in this area #1**

- Far too much water forced down stream year around
- Edward river flowing at high level for extended periods causing river bank slumping and trees to fall into river
- Bank slumping from high environmental flows
- Too much flow eroding the river bank
- Ski boats ban the fucken things. They erode the riverbanks and upset the wildlife It is not so much the river in bad health it is our forest they are being flooded too much doing too much damage causing dry rot in all the red gum timber
- Hypoxic Blackwater
- 1. River ops current management of the system. 2. Downstream transfers. 3. Political pressure. 4. Lack of community involvement in decision making. 5. Poor community knowledge and understanding.
- The fish decline has been noticed in the rivers near me
- Loss of river and riparian vegetation, invasive animal and plant species, withdrawing water from the system, artificial water flows.
- European carp. Insufficient natural flooding. Too many high river flows in summer.
- Too much water and being pumped down and bank erosion.
- Load, erosion, volume
- Loss of flow and natural flow patterns
- Forced zero flow on the Wakool, bank erosion, rubbish dumping
- Management of waterways that are politically based as opposed to scientific or community /government partnership based. Risks include decisions not made in conjunction with local communities, stakeholders or local farmers within the region. Politics and the current version of the Murray Darling Basin Plan are likely to result in , (1) elevated flooding risks in the pursuit of delivering political objectives /new flow targets to the Murray Mouth 2) River operational changes that are designed to meet those political objectives 3) concentration of use of environmental water in spring, without consideration of need for use of E-Water to maintain baseline flows through year (i.e. sufficient refugia; sufficient stock and domestic supply, irrigation flows that have dual purpose environmental/social) 4) Concentration of Basin Plan to rely on the Murray and Goulburn River as the primary source to meet political objectives to SA, eg Darling River co-contributions to SA will be less under the Basin Plan putting increased flow pressure on the Murray/Edward System. New irrigation developments downstream of the Barmah Choke, where new increased demands is exceeding natural Murray/Edward River capacities and thus increased bank erosion

**Box 3. Biggest risks to river health in this area #2**

- Aboriginal interference, government stupidity, city community ignorance, do-gooders and well-intentioned but misguided academics and leftist greenies.
- Erosion, trees falling in blocking and choking river
- Dirty water (carp)
- Speed boats, house boats, water sports, chemicals entering system
- River regulation
- River regulation and climate change
- The draining of the system and then flooding - weeds and debris build up
- Unnatural quantities of water being forced down the Murray and Edward causing massive and irreparable erosion to the river banks and consequent silting up of the river channel. Overwatering of the Gunbower Island causing destruction of the understory and declining tree health
- Misunderstanding about the needs of the river system; mistrust of information sources; delays in implementing the Basin Plan
- Hypoxic black water events, bank erosion, reducing aquatic vegetation
- Erosion
- Salt and low flows
- Silting, carp, timber in the river, bank degradation, low summer flows
- Excessive flows causing increased erosion and ecological damage
- Treating the river system like an irrigation channel!!
- Mismanagement of the waterways thus creating much stress on the river & its environment.
- Blackwater, invasive species, ineffective management.

As indicated in the Introduction, there are many different types of water moving though the Edward-Kolety/ Wakool River system. Survey respondents were provided with the following information:

Some water managers distinguish three types of water in the Edward/Kolety-Wakool River system -

- water used for irrigation
- water used in communities and towns
- water used for the environment

'**Water for the environment**' refers to a portion of water which is delivered specifically to improve the health of rivers, creeks, wetlands and floodplains.

Water for the Environment is also referred to as 'environmental water', and is sometimes delivered in the form of environmental flows or pulses, and sometimes pumped into wetlands.

Federal and state environmental water holders make decisions about when, where and how much water is released for the environment.

They were then asked to indicate what they thought the proportion of each type of water went though the river system in the past year, with the results presented in Figure 12.8.

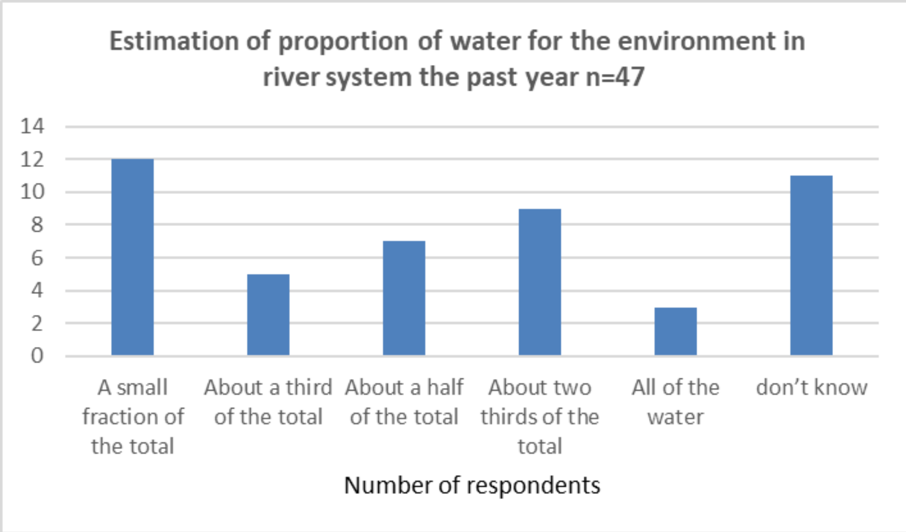



**Figure 12.9** Perceptions of the types of water flowing in the river system in the past year.

Forty-four people responded to the question about who they think is managing the three types of water. They considered all of the potential organisations/ groups to have some role in managing all three types of water (Figure 12.9).

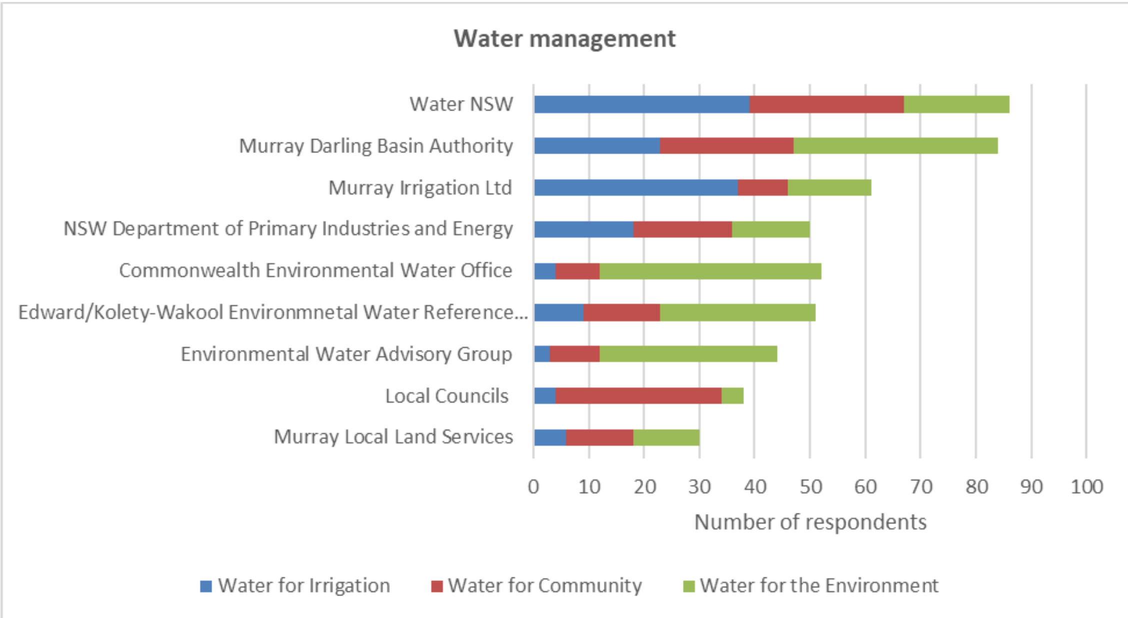



**Figure 12.10** Respondent's understanding of which groups/ organisations have a role in managing the three types of water in the river system.

**Organisations and the use of water in the Edward/Kolety-Wakool River system #1**

- Community groups should be members of the Koondrook Perricoota Operating Committee (KPOC) to provide input about local knowledge and for local communication and information sharing purposes.
- Question 7 doesn't define the "role" or "managing" so it's very difficult to answer accurately. For example, the MLLS could be included in all three categories or none.
- Last year we had 50 percent of our water so all the water flowing past was not for irrigators. At some stage the river was high after rain and yet we had no off-allocation water available. I phoned water NSW looking for off allocation to be told there was none even though plenty flowing past. The previous 2 years we had no allocation to use and yet again at times heaps of water flowing past which is a real kick in the guts. Where the hell is it going and we can’t touch any of it. Just not fair at all and yet the Victorians get heaps more than us hard to watch,
- Before colonisation all of the water was for the environment. The system cannot survive or be healthy on bare minimums. The focus of all organisations needs to be environment first; without a healthy environment human endeavour will fail.
- There are a lot of organisations and it looks like a mess. It's really hard to tell who is responsible for what and makes it easy for those organisations to pass the buck to others. Then nothing gets done.
- Too many of them
- Overly excessive water allocated for misguided environmental purposes.
- Note: The ticks indicate primary interest - but as there is often a combination of water in the system all groups have some interest in all water types.
- Be consistent with supply and transparent in dialogue - act with integrity for and by the community
- There's a bit of confusion in the community about what departments manage which parcels of water.
- I believe the volume of e-water used is low compared to the total but the figure should be better publicised to reduce misinformation.
- The Edwards is now a main delivery channel for the objectives and policy changes that have seen the largest geographical shift of water since federation
- The MDBA and Murray Irrigation are incapable of controlling the water for irrigation
- This survey reflects the gaps in managing environmental water in the Murray Edward/Kolety-Wakool River system This survey at this point appears focussed on Edward/Wakool, but is missing the sections of the Murray and Bullatale (regulated section) that also have major influences on flows /ecological health/and importantly opportunities CEWH: has recognised the value of the Edward Wakool system but has no active reference group upstream (i.e. Murray/Edward/Bullatale MDBA: focussed on delivering Basin Plan objectives which are topped down, inflexible, and processes have been adverse to encouraging community partnerships/engagement in achieving broader environmental outcomes. There is a strong localised concern about MDBA culture, its decision making, its consultation methods, its inflexibility, unwillingness to respect or listen to local knowledge NSW DPIE: policy makers that do so in isolation from community, even isolation from Water NSW. There is no capacity to have effective dialogue with policy makers in DPIE apart from opportunities achieved through personal contact to departmental people. However, this is not effective nor does it result in positive decision making Murray Irrigation Limited: MIL is focussed on its own internal areas of management, it does not effectively engage with people outside of its own area. However some improvements can occur through regional stakeholder groups, however decisions remain largely internal and confidential until publicly announced Local Councils: Local councils are not considered to be placed or have sufficient organisational capacity to make decisions on river management. Most regional community members do not view Councils involvement in water as effective or required if decisions are made without consultation with communities or without necessary skills sets to make informed decisions Murray Local Land Service: do not have role in managing water, however they do have a role in delivering Government funded environmental programs. Again, as with councils, concerns about levels of involvement, if staff do not have skills sets or LLS does not engage with communities effectively, processes /decisions can further alienate local people Environmental Water Advisory Group: it is unclear which group this question relates to. However it is fair to say that too often environmental water advisory groups do not have a good connection to all people in the Murray, Edward Wakool region. In some areas, there are good examples, but there are significant gaps. Equally a more 'consultative method' to adjacent landholders as a whole in the region would produce more effective relationships and opportunities.

Respondents were asked to consider how water for the environment had been used in the past five years, and also what they think it should used for in the future (Figure 12.10).

Stakeholders were also asked if they were aware of scientific monitoring for environmental outcomes from using water for the environment, and 78% of the 45 respondents had. Those who answered yes were then asked about the type of monitoring they think has been occurring and their responses are presented in Figure 12.11.

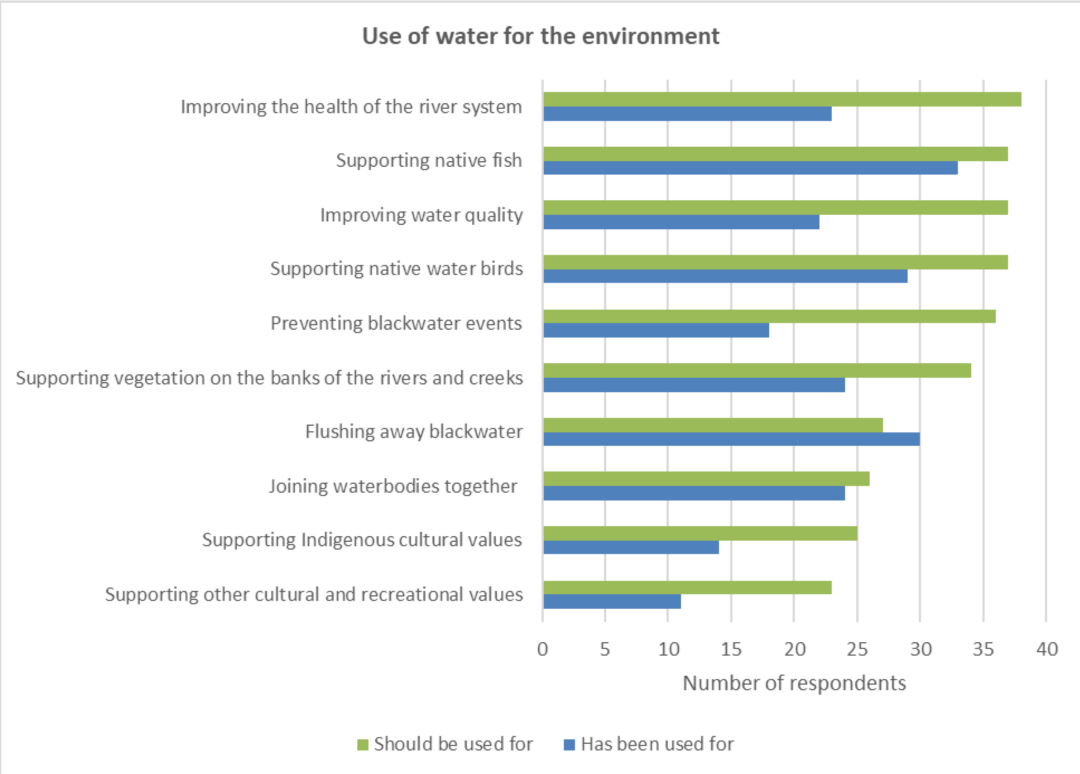



**Figure 12.11** How water for the environment has and should be used.

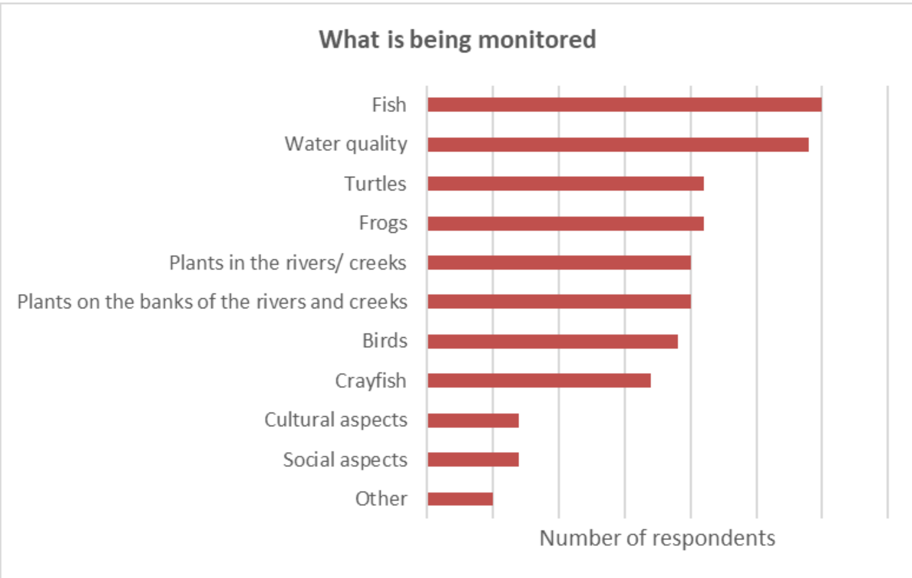



**Figure 12.12** Scientific monitoring of water for the environment.

Other monitoring (free text) included the following responses:

- There were some surveys done with crayfish a few years ago but that seems to have stopped due to lack of funding.
- Macroinvertebrates, threatened species, pest animal and plant species, fauna
- Traditional aboriginal farming techniques embracing arson.
- Not aware of details
- Information on the response to e-water on these indicators is difficult to find for the public.

The values held and assigned by stakeholder respondents were explored by seeking their level of agreement with a number of statements (Figure 12.12).

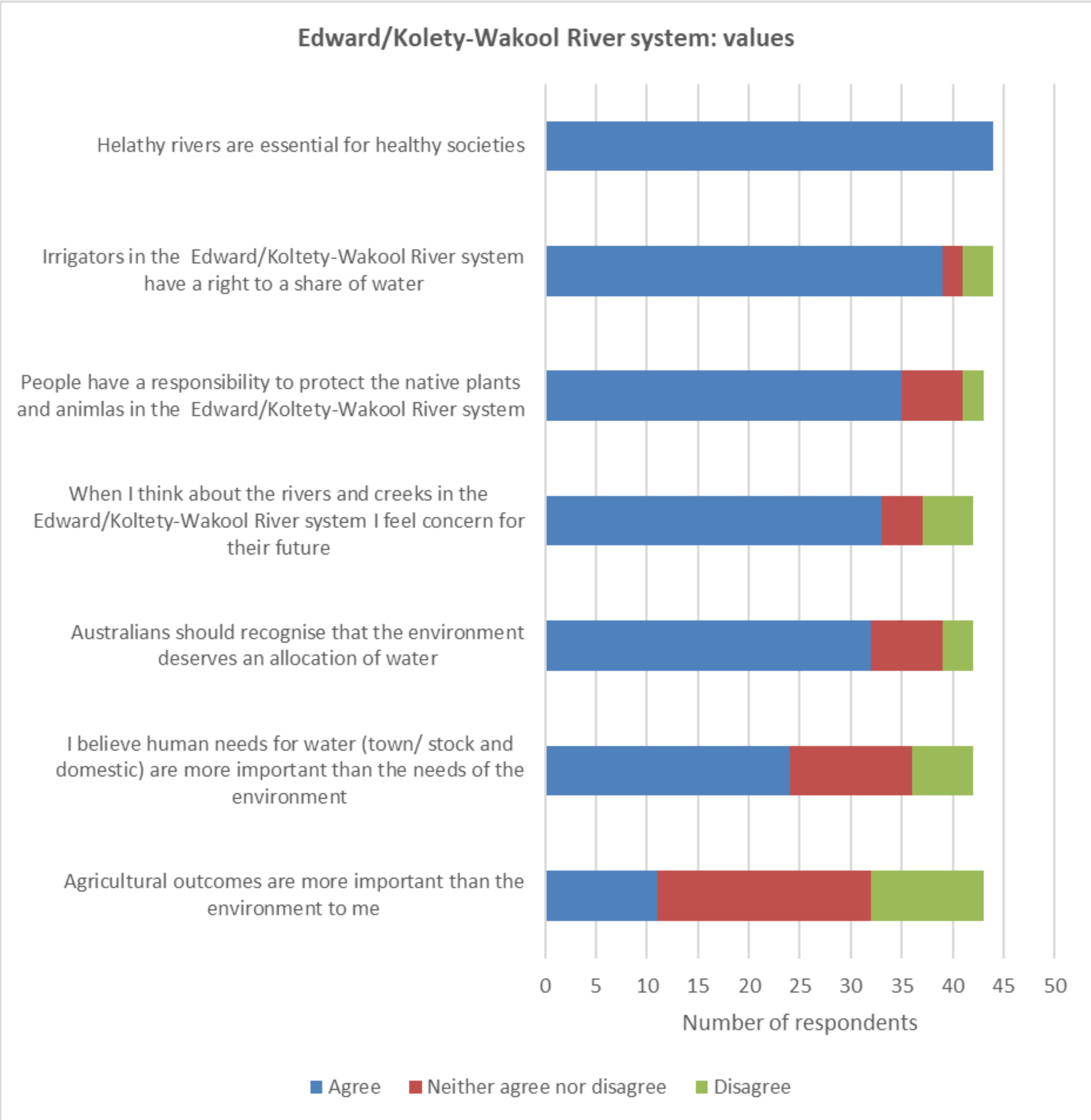



**Figure 12.13** Values associated with the Edward/Kolety-Wakool River system.

The responding stakeholders were also their level of agreement with a number of reflective statements about the use of environmental water (Figure 12.13).

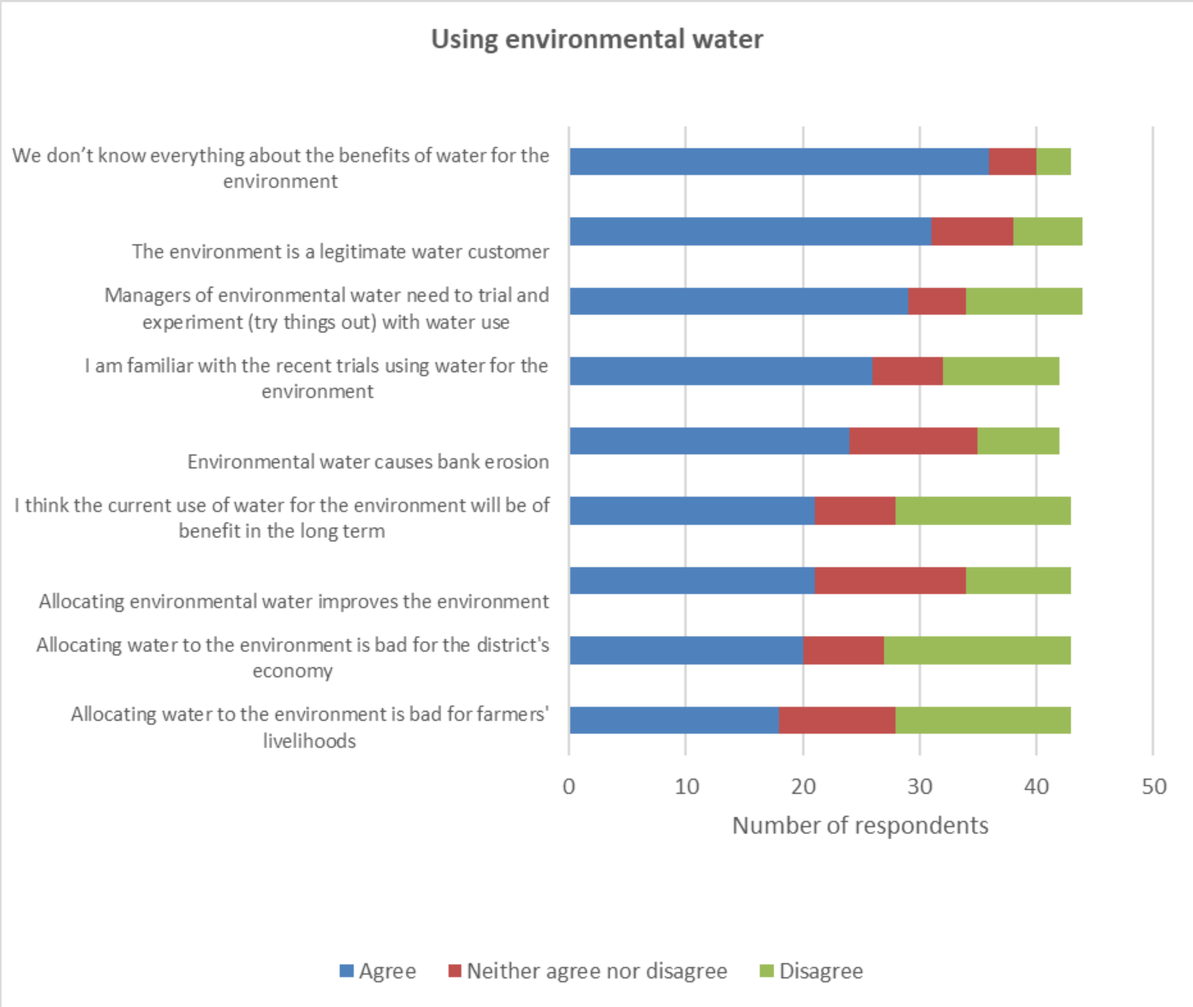



**Figure 12.14** Reflections on the use of water for the environment in the Edward/Kolety-Wakool River system.

**Using environmental water and/or monitoring in the Edward/Koelty Wakool River system #1**

- The river system should have small amounts of water level changes just slight increases and decreases to levels not massive peaks and troughs to levels it's killing the river system Banks trees, native fish, tourism are all suffering Its not a Channel system its a river system
- environment water has been a good tool to keep the system joined or linked the past few years also with the water pulses that have been used for fish breading have been affective also the quality of the water has been good.
- Environmental water is the tool to boost river health. Monitoring can tell us about the outcomes.
- Generally, I think the use of e-water is accepted. There are good examples of smaller, targeted, example sites that can be monitored closely that have community support. The broad scale 'more water is better' approach is less popular as the water accounting and outcome measurement is more difficult.
- I believe most of the environmental water in this system is enroute to SA and is being used in a way which is doing untold environmental damage to the Edward/Kolety-Wakool River
- Get back to engagement with the communities, has this survey even gone in the local independent papers?
- Perhaps LLS style newsletters could be used to inform everyone what is happening. Little is known about this.
- E water used in close consultation with local Landholders is usually a win win situation

**Using environmental water and/or monitoring in the Edward/Koelty Wakool River system #2**

- It should only be used for rivers and creeks. Too much is being wasted in swamps and wetlands.
- A lot of the issues I have raised here with river bank erosion has little to do with environmental flows but excessive flows through to South Australia due to political reasons
- Let the lakes in South Australia go back to saltwater the way nature intended can't keep wasting all our precious water for a few yachts to sail on
- More effort should be made for monitoring to be undertaken by locals.
- The environment gets plenty of water when irrigators have water the rivers and the creeks get water the trees and the birds and fish all get water.
- I would appreciate knowing how the health of monitored species is preforming against their health at the time of colonisation and also from the view of indigenous knowledge.
- Extremely concerned about the declining health of the Ramsar-listed Werai Forest. There are some blocked effluent creeks that, as a start, should be opened to allow natural flood flows and environmental water piggybacked on low flood events or transmission of irrigation water and start to restore the health of the forest including the high probability that colonial nesting water birds would re-occupy their lagoon nesting area that has been decimated by the illegal banking across these effluent streams.
- I would like to see it used all year round not just big flushes.
- Go lightly and watch your step, lest a strong-willed backlash emerge victorious.
- Have personally experienced and have heard from others in the farming community, while access to private farm land has been granted to researchers, on a number of occasions, the capacity or willingness to re-engage directly with those farmers as a mutually beneficial relationships exercise, is not always forthcoming Again, in some specific areas, there has been good outcomes, with information available, however, also if conducted by external providers (eg Outside of the region researchers) often I have had conversations with people that feel their voluntary participation is not as valued. Also that research outcomes are not necessarily directly reported back to the farmers, instead outcomes appear in brochures or more general reports. Most farmers are interested in positive partnerships where they feel an equal partner and can contribute in actual decision making where appropriate, however such an approach is not always the case sadly

### *Environmental water planning and management*

Among other questions we asked how much people know about, and also how much they trust, a number of organisations (Figure 12.14). The number answering each question varied greatly, so this is presented as percentages of the number answering, rather than the numbers as in other figures.

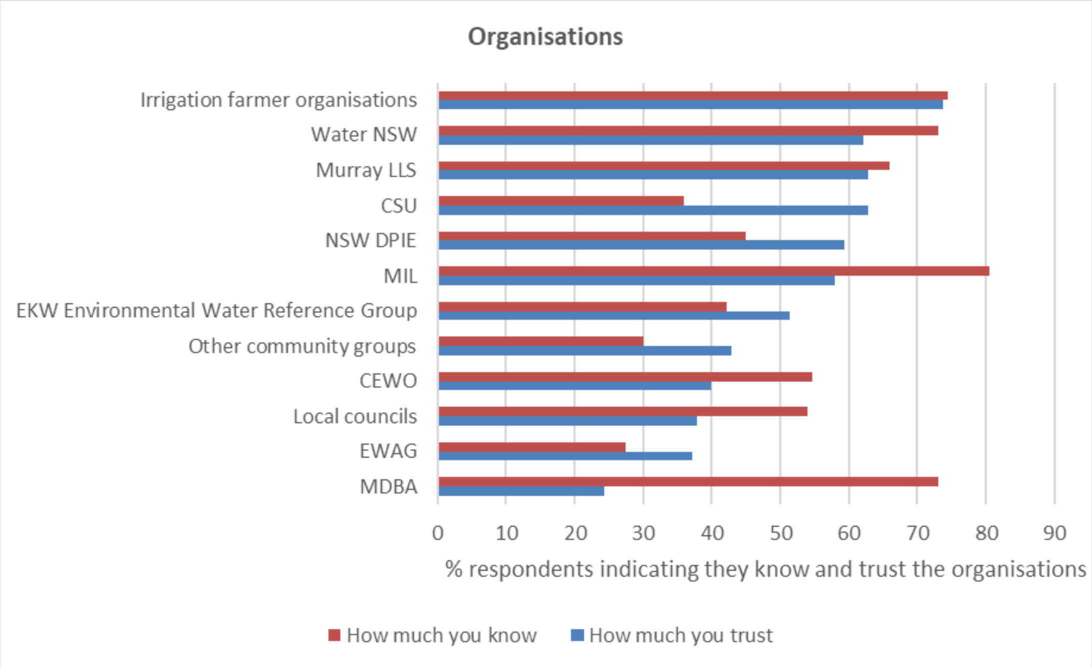



**Figure 12.15** Levels of knowledge and trust in organisations. This shows the respondents who answered a lot and a reasonable amount.

**How water for the environment is planned and managed #1**

- Too much water is being wasted by flooding Barmah and Milewa forests every year. Red gums are dying from overwatering. The Barmah choke is being pushed beyond its limits. Too many permanent plantings below the choke. Rapid expansion causing too much stress on the river capacity. Too much water sent to the lower lakes when a local solution to the southern Coorong is needed.
- I don't believe the community was effectively listened to regarding concerns about the CEWO's desire to reinstate the Stevens Weir pool to provide environmental water to the Wakool River over winter. The Weir pool needs a drying and wetting phase. The decision to remove the weir pool annually was made by respected scientists, with community backing. There should have been more timely data collection to validate change to conditions.
- These statements are poorly phrased generalisations and will not provide accurate indicators.
- It seems like an impenetrable maze of obfuscation.
- Unfortunately the way the questions are limited is not effective in providing responses. eg as per Question 21 and 22.there are individual scientific researchers doing excellent research work, but even these individuals can come up against politicisation of science in the Basin and/or against the preconceived concepts of the Murray Darling Basin Authority. CEWH has demonstrated good pathways, but it could do more in other areas. There is a strong difference in trust between CEWH as compared to the MDBA. CEWH is more effective at community engagement and listening, the MDBA culture is polar opposites
- Atrocious planning and atrocious outcomes. They don’t know what they are doing and they lie about the outcomes. Stuff up big time then publicly congratulate themselves. It makes me sick. Parts of the Gunbower Forest get flooded repeatedly for five or six years destroying the environment they are supposed to be helping. They have more water than they know how to use. Hattah Lakes are an example of bad management. The bird watchers are not happy, canoeists are not happy. A lake which historically flooded once every 100 years is now flooded repeatedly.

Respondents also indicated their level of agreement with some reflective statements about those involved in water planning (Figure 12.15).

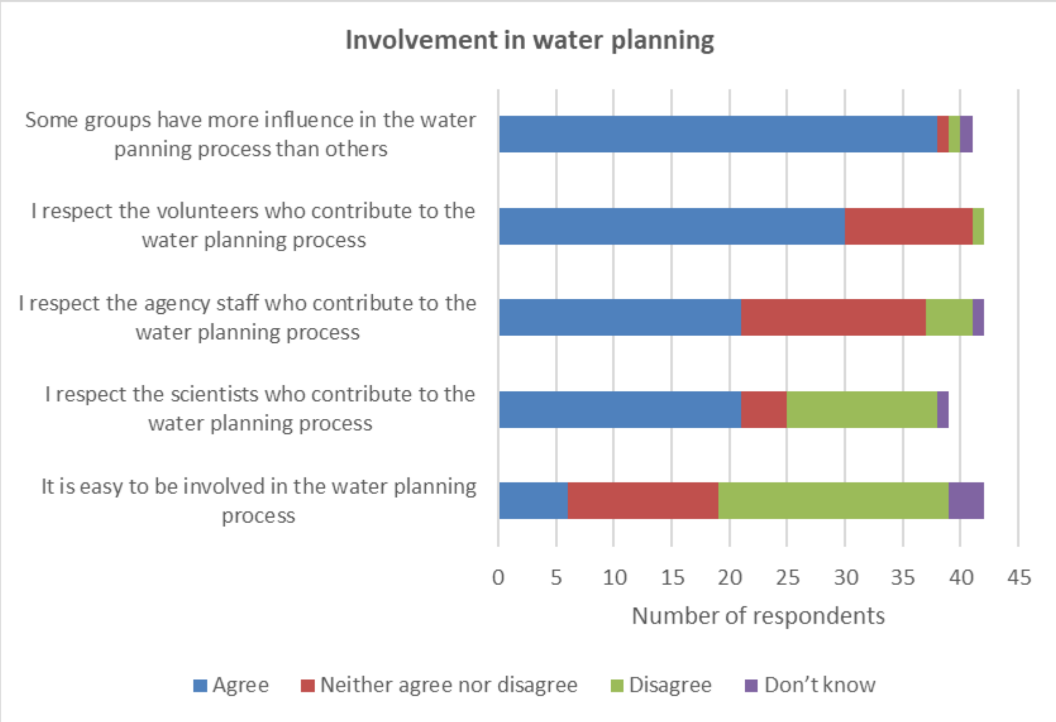



**Figure 12.16** Reflections on involvement in water planning

**How water for the environment is planned and managed #2**

- We were flooded out in 2016 - disaster. No one in the dept took ownership or apologised! They were warned about the significant rainfall and FAILED US all. Appalling.
- It's pretty complex. That makes it hard to get your head around. There's a lot of negativity without much balance when it comes to good news (there is good news, but it gets a bit lost). That makes it hard to persist in maintaining an interest. I have a lot of respect for the people working in this space. They do a tough job working to maintain the health of the river that benefits us all in the long run.
- I don't imagine it is easy to be involved in the water planning process
- In answering this survey I take the view that the environment is made up of the rivers creeks and environs along with the reserves parks, farms, towns and communities and most of all the people who live in these communities who deserve a lot more respect from the MDBA than they have had since the MDB Plan was initiated.
- A lot of the questions seem quite two dimensional; there are problems on all sides of this debate
- Not very well managed!!
- There seems to be a lot of water going down the river systems under different banners, when in fact a lot of the water is environmental, and or an excuse to get it to SA. The 1850 GL to SA should be reduced by 39% when the Darling in not flowing. Fix the Darling and many of the problems of the Murray and its tributaries will dissipate. Should have happened years ago. And some controls on land use. I expect the almond plantations will go the same way as the blue gum plantations in SW Victoria.

Respondents indicated their level of agreement with a number of statements about information and evidence (Figure 12.16).

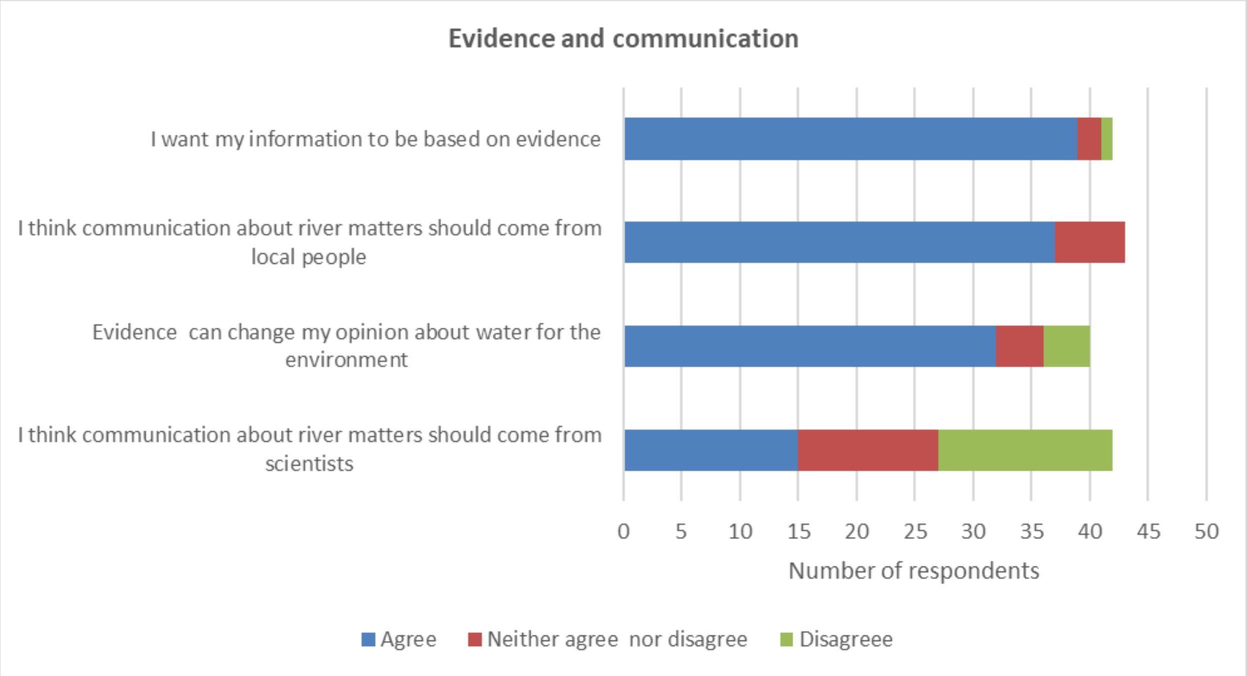



**Figure 12.17** Reflections on information and evidence.

**Information and communication about water for the environment #1**

- Don't waste our precious water by sending it all the way to the lower lakes in South Australia to evaporate. We need it to grow food and fibre in the Deniliquin region.
- An annual information sharing forum should be held in conjunction with local groups regarding Edward - Kolety / Wakool River Flow-MER Program findings
- There needs to be awareness of how degraded the environment has become, how many species have been lost and are endangered, most people think what they see is how it has always been.
- Not enough information and communication is available. Local media is biased towards the never-ending complaints from irrigators and their associations about the supposed failures of the Murray Darling Basin Plan.
- As mentioned before, while focus has been on the Edward/Kolety-Wakool River system, one whole section of the system (ie eastern side of Deniliquin) where Murray and its related creeks etc create the connection to the Edward/Wakool system. This area is not represented, not studied and therefore how water flows and its ecological relationship between upstream and downstream is not highly regarded or considered However to progress forward, to get a higher percentage of people involved, it is best to involve all landholders in a region or at least give them all equal opportunity to make decisions for their local area. Currently Governments cherry pick individuals to go on 'advisory groups' but this may or may not be as effective as having more localised meetings with all farmers so all can put forward their views and become part of equalised decision making. If this was achieved many more research opportunities would become available

Respondents also indicated where they sourced their information about water for the environment, choosing as many options as appropriate (Figure 12.17).

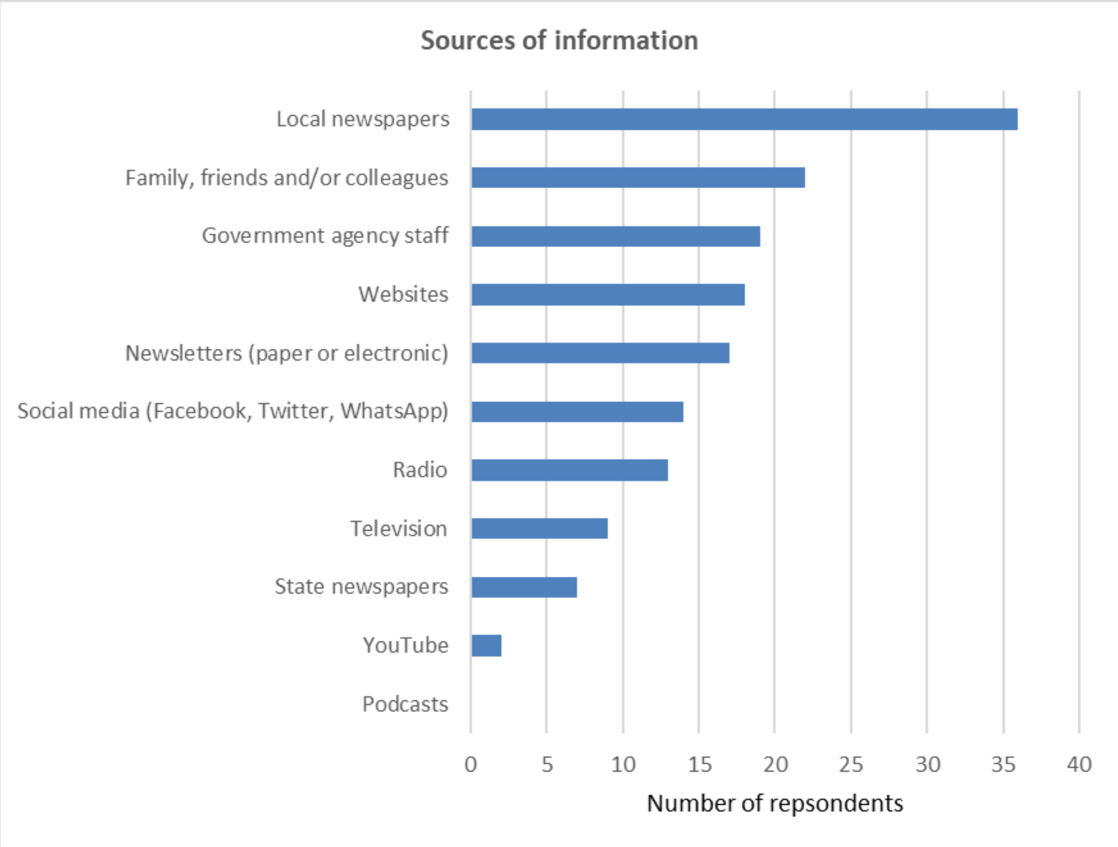



**Figure 12.18** Sources of information.

**Information and communication about water for the environment #2**

- Too much water is being pushed down our river systems, they are not channels
- Having well informed locals talking accurately about e-water in the community needs to be an important component of future communication and engagement.
- Return the water to the system as a consistent supply - it IS THE ENVIRONMENT
- More information can only be a good thing. Information that can be shared like videos, Facebook or Twitter posts. Schools are a great place to share information with communities.
- Communication and information should come from scientists which is peer reviewed and not from scientists who give evidence that their employer wants to see.
- Information and evidence is only as good as the methodology, ethics and robustness of the work conducted. I have a constant barrage of reports that do not meet with these properties I consider critical
- The fact that this survey is happening is a big improvement. We need to make better use of the water before it gets wasted on South Australia.

77% of the respondents indicated there is insufficient publicly available information available about water for the environment in the Edward/Kolety-Wakool River system. Water quality was the most frequently nominated topic about which they thought more information should be available, but all topics provided were selected to some extent, and some other topics were nominated (Figure 12.18).

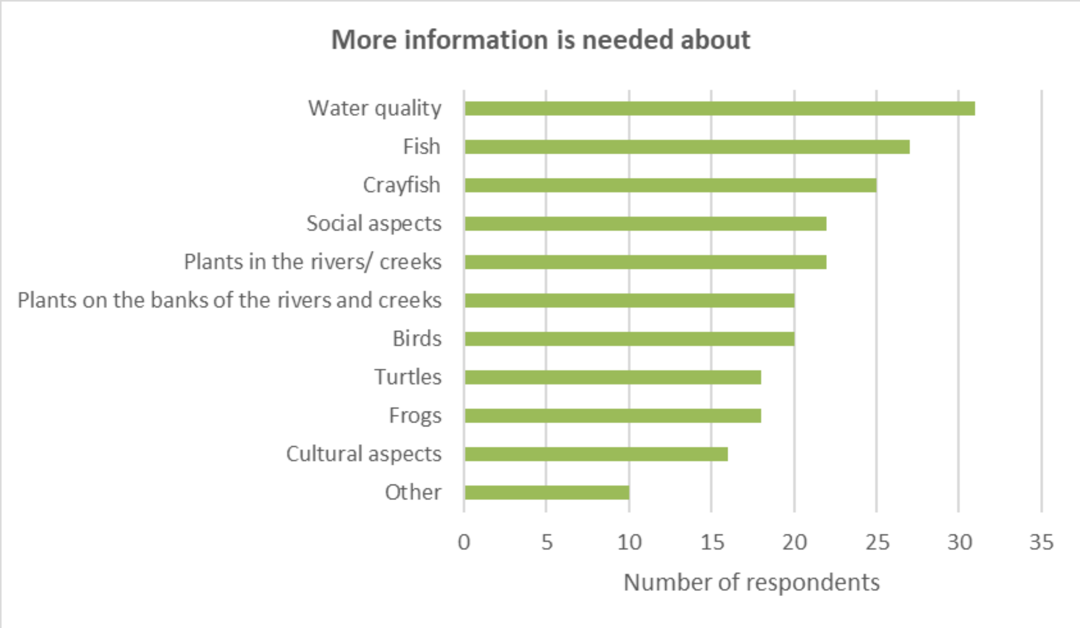



**Figure 12.19** Aspects of the river system for which there should be more publicly available information.

Other topics (free text):

- Re plants impacts of frost this year on water plants in Wakool River vs other years when environmental water was used for winter watering
- All of the above
- Information needs to be provided prior to, during and immediately following events.
- Far too much weight is given to boating in the media and recreation. Not enough weight given to non-indigenous and scientific on the ground groups.
- The motives and credentials of the conga-line of the so-called experts and advisors.
- Too often the positives of what local communities have achieved through environmental programs is not reported, equally, too often the region is portrayed as being in environmental decline with the blame attributed to irrigation extractions. This is not reflective of the region and is highly negative towards achieving on ground outcomes. Too often also, researchers or organisations tend to claim negative environmental scenarios as this is seen as a more effective way to obtain Government funding. Reporting and communication needs to highlight both negatives and positives based on sound and truthful information. in this way Governments/Scientists/People can learn and invest on environmental programs and outcomes more constructively
- Flow information and underpinning reasons for the flows
- All of the above
- All of the above. People need education to make sensible decisions
- Importance of water to produce food & fibre

A comparison between what respondents think is being monitored, and what they want more information on is provided in Figure 12.19.

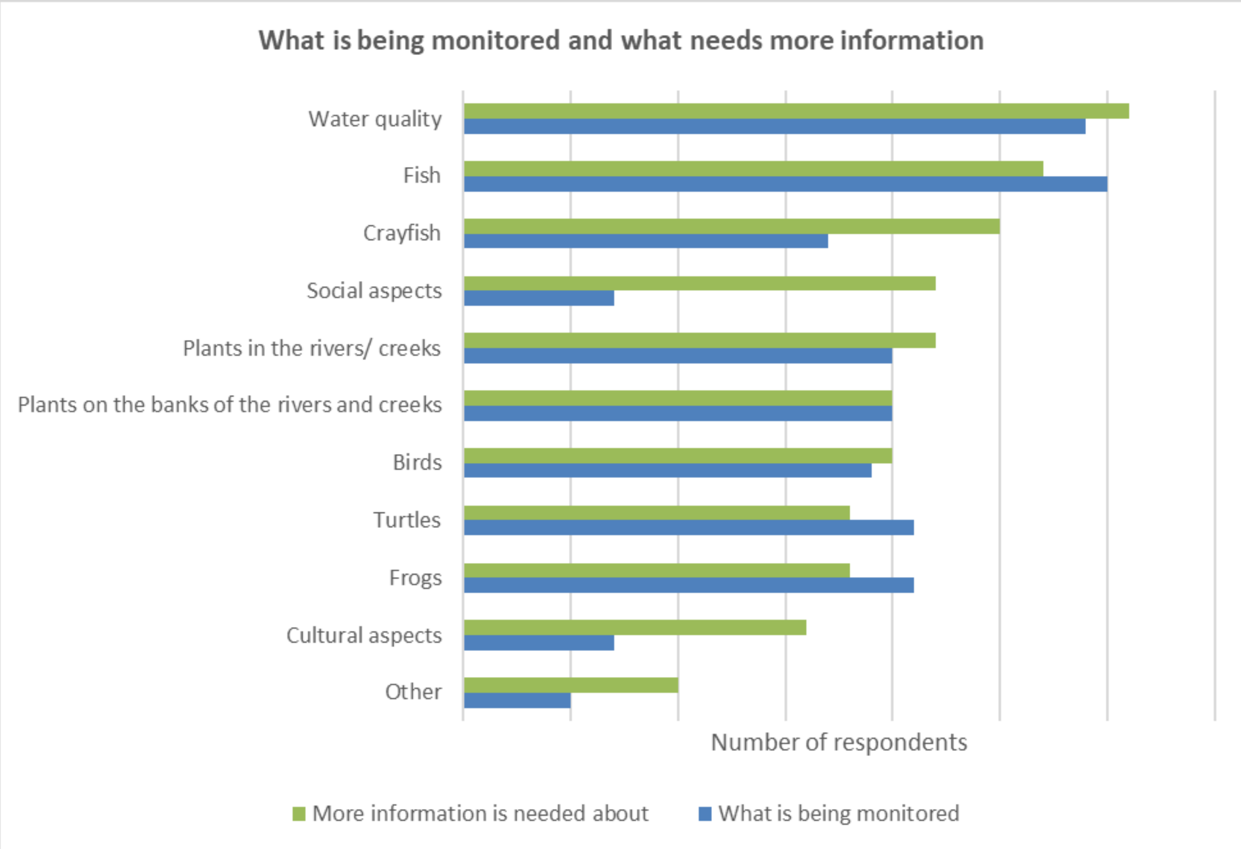



**Figure 12.20** Comparison between what respondents think is being monitored, and what additional information should be available

At the conclusion of the survey 26 respondents indicated that they would like a copy of the findings and 12 that they would like to be invited to contribute to future research.

## Discussion

The presentation of descriptive statistics and all the free text responses allows readers to view the data and draw their own conclusions about what is known perceived and valued by respondents to this survey about water in the Edward/Kolety-Wakool river system. The discussion below is therefore selective, and focused on aspects of the data that an inform potential future action.

### *Response and generalisability*

Response rates to social surveys are steadily declining (Stedman et al., 2019), a trend reflected in fewer than 60 people returning this questionnaire. However, the results are an important data set if its limits and strengths are understood. Almost all respondents were local, and the population of the local area is just over 14 000, but it is not possible or sensible to extend the results of this survey to everyone in the study area. The people in the sample population are not randomly selected, but have self selected as having an interest in, and knowledge of, the Edward/Kolety-Wakool river system. If any people in the Edward/Kolety-Wakool are likely to know about water for the environment it is this group of people. Their knowledge, interest and connection to the river system is apparent in the large amount of qualitative data from the free text responses.

A broad snapshot of this respondent population is that it is mostly non-Indigenous men aged between 40 and 80 who live in the local area, and have done so for a long time, often their whole lives. Half live in towns, half on rural properties (a reflection of the ABS area population), and many have water licences and have been fishing in the past two years. The respondent population's predominant concern is the health of the rivers and wetlands.

### *How knowledge, information and learning (i.e. acting, adapting and accepting) are understood and experienced by stakeholders in the Edward/Kolety-Wakool River System*

There is great variety among the respondents in their assessment of the health of the Edward/Kolety-Wakool River system, with a slight majority of respondents indicating that the health is not good, and is declining. Of the important perceived risks to river is the amount of water in the system- both too little and too much, or at the wrong time.

A general impression of these respondents is that they are interested in large, integrated systems over time. They are overwhelmingly interested in the whole of the Edward/Kolety-Wakool River system (and beyond), and use and enjoy it in multiple ways. One important example of this wide view of the system is in relation to the proportion of water for the environment in the river system. Commonwealth environmental water is a relatively small proportion of what once flowed through the Murray-Darling system. The government currently holds entitlements to 1,836 billion litres, which is less than 6% of the rainfall that makes it into the Basin's river system (Webb et al., 2018). This translates to only a small fraction of the water flowing through the Edward/Kolety-Wakool system being environmental water. Yet 24 the 47 respondents considered that between a third and all of the water in this system over the past year was water for the environment, while another five did not know. This variation in understanding is not surprising, even among this interested and knowledgeable local cohort. As explained in the introduction, environmental water is not the only change in water ownership and movement that has occurred in the past 15 or so years. Low rainfall periods have regularly reduced the overall water available, water markets have shifted entitlements to, for example, high value horticultural crops in South Australia, and the variation in jurisdictional processes have led to comparatively low allocations in the Murray in the past few years. The variation in understanding could also be because the question is, to many people, very odd. The separation of water into types assists governance and management, but the lived reality for many people associating with the river system is of water, and how it relates to their land and lives; it is possible that some may consider all water to be water for the environment, regardless of the definitions provided. Reduction and parcellation is a particular way of framing water that may not resonate with everyone. While this is a well-informed group, it is clear that even for them the information available is disjointed and confusing. Information about environmental water to the non-scientific community may be better understood and received if presented in the context of all water in the system and beyond.

### *The attitudes to, and acceptance of, the concept and use of Commonwealth environmental water by the responding Edward/Kolety-Wakool River system stakeholders*

All of the respondents agree that healthy rivers are necessary for healthy societies. It is rare to have 100% agreement to a value statement in such a contested area of activity, and this could, perhaps should, be a pivot point for information exchange in the future. What health means in each in instance will vary for each individual, group and organisation, but the common shared agreement of purpose can provide a solid foundation for working with those variances. Some, but not all, agree that water for the environment can play a role in achieving river health.

The respondents have a good understanding of the roles of various government agencies and groups that have a role in water management in the Edward/Kolety-Wakool system. The trust in those groups is more varied, with the largest percentage of respondents indicating trust in the irrigation farmer organisations, Water NSW, and Murray LLS, with the least number of respondents trusting the Murray-Darling Basin Authority. Trust and knowledge are not closely matched- for example, fewer respondents indicated that they knew about Charles Sturt University yet over 60% of the cohort were willing to trust it, while most respondents knew about the Murray-Darling Basin Authority, but few indicated their trust in it. Knowledge about and trust were not always inversely related, for example, the highest percentage of respondents indicated that they knew about Murray Irrigation Limited, and it has almost the same percentage of people trusting it as does Charles Sturt University. These nuances suggest a discerning respondent population rather than a population simply trusting local over non-local. For this report it is relevant to note that around 55% of the respondent population indicated that they knew something to a lot about the CEWO and around 40% indicated trust. The nuances of this relationship will be explored with the Bayesian analysis. The qualitative data indicate that dissatisfaction relates to perceptions of low consultation and poor accountability around environmental water, and water in general.

This group of respondents want to know about the responses of animals, plants and water quality to the used of environmental water. They support the focus of existing monitoring programs related to the use of water for the environment, although there is some misunderstanding apparent in this area. Turtles were correctly identified as being monitored, but the same number of respondents indicated that frogs are being monitored in the system, which is not the case for the Flow-MER Program, but frogs are being monitored by other programs.

It is also apparent that more monitoring or research about the social and cultural impacts of using water for the environment would be welcomed by these respondents.

### *Institutional, social and/or cultural interventions that could improve the acceptance and impact of Commonwealth environmental water for this and other sites*

Further analysis of the quantitative data will inform this section, but in brief the social acceptability of the use of water for the environment will be enhanced by:

1. Using the results of this survey as an object for conversations within the communities (including scientists) associated with the Edward-Kolety/Wakool River system and the Flow-MER Program.
2. Reducing the narrow scientific focus on water for the environment that separates the program from the river system communities, who relate to all of the water.

3. Making more information about river health and water quality available in locally relevant and accessible ways. Detailed information about the Flow-MER Program is available on websites, but locally focused, locally accessible and even locally verified or voiced information is also needed. What this involves should form part of the discussions noted in 1, but could include, for example, one or two large, current water quality graphs in publicly accessible sites (see for example the Saltwatch, program), or regular written columns on river health in the local newspapers.
4. Continuing to work with the expertise and passion that at local people have for the Edward-Kolety-Wakool river system.

### *Future research with this instrument*

This survey was self-administered and electronic. The survey was distributed via an electronic link so access to a computer/phone or tablet was assumed. Electronic survey administration can impose a significant cognitive burden on respondents and is associated with low response rates (Bowling, 2005). In addition we were unable to engage well with Indigenous groups in this research, a wider issue identified by (Finn and Jackson, 2011). Young people were also poorly engaged in this survey, and women were under represented.

This survey instrument itself appears to yield useful and useable information, and we recommend that it is used for further exploration of the social acceptability of the use of water for the environment in the Edward/Kolety-Wakool river system. Involving specific social groups that are underrepresented in this report would be valuable. This includes women, Traditional Owners, and water planner/ water managers. Mitchell and Allan (2018) found that over one-third of respondent groups (in their NSW based survey took up the recommendation of completing a survey as a group exercise, and this may be needed to increase the number and range of responses if the survey is administered again.

Engagement of these groups may also be of paper-based survey, offers to assist in group settings, and targeted use of social media.

This work was presented in the Flow-MER seminar series and can be viewed at https://www.youtube.com/watch?v=FnBHu8sF3Tw

# 11 Recommendations for future management of environmental water

## Recommendations from previous annual reports (2014-2020)

A summary of recommendations from previous Edward/Kolety-Wakool LTIM annual reports (Watts et al. 2015, 2016, 2017b, 2018, 2019) and the 2019-20 Edward/Kolety-Wakool Flow-MER annual report (Watts et al 2020) is provided in Appendix 1. These recommendations relate to the use and/or contribution of Commonwealth environmental water to different types of watering actions including:

- Base flows
- Small freshes
- Medium and larger in- channel freshes
- Recession flows
- Winter flows
- Mitigate issues arising during hypoxic blackwater events
- Mitigate issues associated with managed flows operations, including constant regulated flows, (low variability), rapid recession of flows, and winter cease to flow.

Some of the flow recommendations in appendix 1 refer to specific targeted ecological objectives, such as fish movement, spawning of Murray cod, or river productivity. In previous LTIM/Flow-MER reports there are also some recommendations that have addressed more general aspects of environmental water management, such as the need to implement flow trials, the setting of flow objectives, and the need to improve sources of hydrological data to facilitate the evaluation of environmental watering actions.

## Recommendations for management of environmental water

The following ten recommendations are based on findings from this 2020-21 annual report, with some reference made to recommendations and findings in previous reports.

**Recommendation 1:**

Environmental water delivery in 2020-21 was the closest yet (since the LTIM/Flow-MER Program commenced in 2014) to achieving environmental flows that included the timing, magnitude, duration and extent and provided longitudinal connectivity with other flow freshes in the mid-Murray region required for spawning, recruitment and movement of juvenile golden perch and silver perch. The sequence of flows over spring/summer in 2020-21 also supported the germination and survivorship of riverbank plants that play an important role in stabilising riverbanks, riverine productivity and food webs, and provides habitat for fish, frogs, birds and invertebrates.

| |
|---|
| Recommendation: Deliver a sequence of flows over the period from late winter/spring/early summer to support the spawning, recruitment and movement of juvenile perch, support aquatic and riverbanks plants, riverine productivity, and provide habitat and food for other aquatic animals. |

**Recommendation 2:**

Although small watering actions have provided a beneficial outcome for the riverine ecosystem productivity, the findings of the stream metabolism evaluation suggest that reconnecting backwaters and the floodplain to the river channel would result in much larger positive productivity outcomes.

Recommendation: Consideration be given to providing a more variable flow regime that reconnects low lying parts of the floodplain to the river channel.

**Recommendation 3:**

Positive spawning responses of Murray cod during elevated flows in the upper Wakool River were recorded in 2018-19, and record numbers of larvae were associated with the delivery of sustained 200 ML/day flows, which commenced from late September 2018 through to January 2019. In 2020-21, a similar increase from base flows was delivered, however this did not commence until 30 November 2020. Monitoring results have shown that the number of Murray cod larvae caught in 2020-21 was the second lowest since monitoring commenced in 2014-15 (second lowest to the 2016-17 during the 2016 flood).

Pre-spawning and nesting behaviour of Murray cod is likely to commence between September and October. In 2018-19 nest-building and spawning would have taken place under 200 ML/day flows, while in 2020-21 flows were still at base levels (50 ML/day) in September. The lower catch rates of Murray cod in the upper Wakool in 2020-21 compared to 2018-19 may have been due to difference in the timing of the two watering actions. The timing of watering action 2 (elevated base flow) in late November 2020 may have been too late for achieving the flow objective.

Consideration of future water delivery to tributaries of the Edward/Kolety-Wakool system that commences in September may be more successful in maximising the availability of suitable nesting areas during the Murray cod breeding season. As trout cod spawn at cooler water temperatures than Murray cod, it may be worth considering introducing an elevated baseflow through the Yallakool and Wakool systems as early as August to support nesting in this species. Consideration of future water delivery of elevated base flows (200 ML/day) to the Upper Wakool River from start of September to maximise nesting and spawning opportunities for Murray cod.

**Recommendation:** Deliver elevated base flows from the start of September to maximise nesting and spawning opportunities for Murray cod. Record catches of larvae have been recorded in 2018-19 when this type of watering action was delivered.

**Recommendation 4:**

The '2020 Southern Spring Flow' (SSF) was a river pulse in the Murray River that was designed by timing releases of water for the environment in the Murray, Goulburn and Murrumbidgee rivers to deliver water to five wetlands of international significance, to provide a system-wide productivity boost and improve connectivity down the river to the Coorong and Murray Mouth (SCBEWC, 2021). CEWO (2020) states "Where possible, water for the environment will be managed to benefit multiple sites enroute and will be coordinated with other sources of water".

Instead of commencing in mid-July, the water delivery for the SSF in 2020 was delayed until October 2020. Due to this delay, all of the planned watering actions in the Edward/Kolety-Wakool were also delayed, because there was an aspiration in CEWO to gain maximum benefit of water from the SSF returning from Millewa Forest to deliver the planned watering actions in the Edward/Kolety-Wakool system. Thus, watering action #1 (spring fresh) in Yallakool-Wakool commenced on 20 October 2020, and watering action #2 (elevated base flow in Wakool-Yallakool system that aimed to maintain nesting habitat for Murray cod) was delayed until 30 Nov to 15th December. The lower catch rates of Murray cod larvae in the upper Wakool in 2020-21 may have been due to the delayed timing of this watering action (see recommendation 3).

As environmental water delivery from Hume Dam to the Murray River can strongly influence outcomes in the anabranches and distributaries of the Murray River (e.g., the Edward/Kolety-Wakool system) there is a need for a more integrated, system-wide approach to the planning of environmental watering in the Murray River. The watering actions from Hume Dam need to be designed in a holistic manner, with expected outcomes for the anabranches and distributaries included in the planning, with consideration of the benefits and risks of coordinated actions. The planning should include options to enable watering actions to be 'un-linked' if circumstances change and the integrated actions cannot be delivered to achieve the planned outcomes. This would enable environmental watering actions to be independently implemented in parts of the river system, if necessary, to achieve outcomes. This holistic approach will require more complex and integrated planning than has been implemented in previous water years.

**Recommendation:** Undertake integrated, system wide planning of environmental water actions for the Murray River that includes watering of anabranches and distributaries, such as the Edward/Kolety-Wakool system. Planning should include options to 'un-link' watering actions in different parts of the Murray system if circumstances arise that prevent the integrated actions from being delivered in the way they were initially planned.

**Recommendation 5:**

In 2020-21 watering action 8 delivered variable base flows to the upper Wakool River to prevent a potential hypoxic water event, provide longitudinal connectivity, flow variability and potential refuge. This watering action produced positive outcomes.

**Recommendation:** Undertake further watering actions to improve the connectivity and aquatic and riverbank vegetation outcomes in the Upper Wakool River. Deliver larger freshes with increased variability to enable riverbank vegetation to establish and be maintained.

**Recommendation 6:**

Some fish (e.g., flathead gudgeon) and plants may benefit from water delivery in the Edward/Kolety-Wakool system that targets inundation of a greater diversity of creek systems, including distributary ephemeral and intermittent creeks.

**Recommendation:** Undertake watering actions to improve the connectivity and other outcomes in intermittent and ephemeral streams and flood runners in the Edward/Kolety-Wakool system. Consideration of timing of delivery that reduces opportunities for carp spawning whilst minimising hypoxic blackwater may need to also be taken in account.

## Recommendations for future monitoring and research

We make the following four recommendation about communications, monitoring and research in the Edward/Kolety-Wakool system.

**Recommendation 7:**

The Southern Spring Flow in the Murray River in 2019-20 and 2020-21 resulted in flows returning from Millewa Forest to the Edward/Kolety-Wakool system. Results from 2020-21 monitoring suggest that these return flows had an impact on water quality, productivity and fish outcomes in the Edward/Kolety-Wakool system. At present there is no hydrological model that can provide estimates of daily discharge returns from the Murray watering actions.

**Recommendation:** Hydrological models be developed that will enable daily returns from Murray River environmental watering actions to be estimated in the Edward/Kolety River, so it is possible to evaluate all sources of environmental water that influence the Edward/Kolety hydrology.

**Recommendation 8:**

The social research found that more information and research about the social and cultural impacts of using water for the environment would be welcomed by the community. The research also suggested that more information about river health and water quality is sought that is presented in locally relevant and accessible ways. Detailed information about the Flow-MER Program is currently available on websites, but locally focused, locally accessible, and even locally verified or voiced information is also needed. The social research also found that community members considered that the information available about water delivery is disjointed.

**Recommendation:** Share more information with the community about social and cultural impacts of using water for the environment and present it in locally relevant and accessible ways. When developing communication products about environmental water for the non-technical community, present Information about environmental water in the context of all water in the system.

**Recommendation 9:**

Several social groups were underrepresented in the social research project undertaken in 2020-21. The under-represented groups were women, Traditional Owners, young people, and water planners/water managers. The current research was undertaken by online survey, and a paper option was available but not taken up. Future social research may require implementation of a different survey options survey, such as offers to assist in group settings, and targeted use of social media to engage these under-represented groups. The research should be co-designed with the community.

**Recommendation:** Undertake more social research about the social and cultural impacts of using water for the environment, and in particular co-design the research with the community to facilitate the engagement of previously under-represented groups in the community.

**Recommendation 10:**

The turtle research project was undertaken in collaboration with Wamba Wamba and Perrepa Perrepa Traditional Owners, via the Yarkuwa Indigenous Knowledge Centre. Through this project Traditional Owners were provided training and experience in turtle ecology and conservation methods that they will be able to apply in their own future conservation work in Werai forest. The project facilitated reciprocal learning, as the Traditional Owners also shared their perspectives and knowledge about turtles, wetlands, and conservation.

**Recommendation**: Future monitoring and research projects should, where possible, be undertaken in collaboration with Traditional Owners and other community groups to facilitate co-learning and engagement of the community in water planning, management, monitoring and research.

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# 13 APPENDIX 1

Summary of recommendations from Edward/Kolety-Wakool LTIM annual reports (2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20) showing year implemented. R = recommendation number from stated report.

| Recommendation | Year(s) recommended | Year(s) implemented |
|---|---|---|
| 1. Consider a trial to increase the delivery of environmental water to the upper Wakool River<br><br>Undertake watering actions to improve the aquatic and riverbank vegetation outcomes in the Upper Wakool River. | 2014-15 (R3)<br>2015-16 (R6)<br>2016-17 (R5)<br>2019-20 (R9) | 2018-19<br>2020-21 |
| 2. Consider the implementation of an environmental watering action in the Edward/Kolety River to target golden perch and silver perch spawning. | 2014-15 (R8)<br>2015-16 (R4)<br>2016-17 (R4)<br>2017-18 (R3) | Not yet implemented |
| 3. In collaboration with stakeholders explore options to implement a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/d at the Wakool-Yallakool confluence. This would facilitate a test of the hypothesis that larger in-channel environmental watering action will result in increased river productivity.<br>Implement a second flow trial in-channel fresh in late winter or early spring that exceeds the current normal operating rules, to increase the lateral connection of in-channel habitats and increase river productivity. The earlier timing of flows would help to prime the system and thus increase the outcomes of subsequent watering actions delivered later in spring or early summer. | 2014-15 (R7)<br>2015-16 (R3)<br>2017-18 (R4)<br><br>2018-19 (R3) | 2018-19 |
| 4. Each year plan to deliver at least one flow event with higher than normal operating discharge to the upper Wakool River. This may include delivery of water through the Wakool offtake regulator or via the Wakool escape | 2018-19 (R1) | 2018-19<br>2020-21 |
| 5. Increase the duration of the recession of environmental watering actions relative to the Yallakool Creek environmental watering actions in 2012-13 and 2013-14 | 2014-15 (R1)<br>2015-16 (R8) | 2015-16<br>2016-17<br>2017-18 |
| 6. Consider the delivery of continuous base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat<br><br>Prevent negative impacts of aseasonal cease-to-flow events by delivering winter base flows to promote temporal availability and continuity of instream habitat for aquatic vegetation.<br>Discharge and wetted area are maintained during low flow periods to maintain zooplankton and other invertebrates that feed on phytoplankton and periphyton, and in turn increasesfood availability for fish and other higher order consumers during periods in which food availability might otherwise be low. | 2014-15 (R4)<br>2015-16 (R2)<br>2016-17 (R3)<br>2019-20 (R7,R8)<br><br>2019-20 (R6) | Winter 2017 |
| 7. Implement a second trial of continuous base winter environmental flow (no winter cease to flow) in tributaries of the Edward/Kolety-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist recovery of submerged aquatic plants. | 2017-18 (R2) | Winter 2019 |
| 8. Avoid long periods of constant flows by introducing flow variability into environmental watering actions.<br>Include variation in the timing of environmental watering actions among water years to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist recovery of submerged plants. | 2014-15 (R2)<br>2015-16 (R5)<br>2018-19 (R2)<br>2019-20 (R1) | 2015-16<br>2016-17<br>2018-19<br>2020-21 |
| 9. Implement environmental watering actions for freshes in spring and early summer (October to December) that include flow variability up to a magnitude of + 125 to 150 ML/d. Undertake trials to improve understanding of the magnitude of variability that provides beneficial ecosystem outcomes. | 2017-18 (R1) | |
| 10. Explore options to implement in-channel pulses at any time of the year to connect additional in-channel habitats and increase river productivity. | 2018-19 (R4) | Not yet implemented |
| 11. Continue to include a water use option in water planning that enables environmental water to be used to mitigate adverse water quality events | 2014-15 (R5)<br>2015-16 (R7) | 2014-15<br>2015-16<br>2016-17<br>2017-18<br>2018-19 |

| | | |
|---|---|---|
| 12. If there is an imminent hypoxic blackwater event during an unregulated flow and the quality of source water is suitable, water managers in partnership with local landholder and community representatives should take action to facilitate the earlier release of environmental water on the rising limb of the flood event to create local refuges prior to DO concentrations falling below 2 $mgL^{-1}$.<br>In watering years where risk of hypoxic blackwater events is probable, consider how CEW watering actions could be used to mitigate effects on fish populations. One option to explore could be use of flows to encourage movement out of high risk reaches. | 2016-17 (R1)<br>2019-20 (R5) | Not yet implemented |
| 13. Trial a carefully managed environmental watering action through Koondrook-Perricoota Forest via Barbers Creek to improve the productivity of the mid and lower Wakool River system. | 2017-18 (R5) | Not yet implemented via Barbers Ck |
| 14. Explore and develop a range of options for the delivery of environmental water during times of drought to ensure connectivity of habitat and avoid damage to key environmental assets. Inform the community of the factors limiting water delivery in extreme drought. | 2018-19 (R5) | Not yet implemented |
| 15. Set watering action objectives that identify the temporal and spatial scale at which the response is expected and are realistic given the magnitude of watering actions proposed | 2014-15 (R6) | ongoing |
| 16. Undertake a comprehensive flows assessment for the tributaries of the Edward/Kolety-Wakool system to better inform future decisions on environmental watering in this system. | 2014-15 (R9)<br>2015-16 (R1) | Partly undertaken |
| 17. Collaborate with other management agencies and the community to maximise the benefits of Commonwealth environmental watering actions | 2014-15 (R10) | ongoing |
| 18. The installation of a DO logger on a gauge downstream of Yarrawonga and upstream of Barmah-Millewa Forest should be considered a priority. Consideration should also be given to installing DO loggers, both upstream and downstream of other forested areas that influence water quality in the Edward/Kolety-Wakool system | 2016-17 (R2) | Not yet implemented |
| 19. Undertake in-channel habitat mapping for key reaches of the Edward/Kolety-Wakool system, which could then be combined with existing hydraulic modelling to facilitate learning about this system | 2016-17 (R6) | Implemented in part by NSW DPI |
| 20. Undertake a review of the 2016 flood and subsequent hypoxic blackwater event in the Murray system and support further research & understanding these events | 2016-17 (R7) | 2017 |
| 21. Deliver a series of freshes to increase the wetted area of the bank. Late winter/ early spring freshes that inundate slackwater areas, in-channel benches or low-lying areas of riverbank within the channel to trigger emergence of plants. | 2019-20 (R2) | 2020-21 |
| 22. Consider a late spring/early summer pulse, immediately after Murray cod larvae have left the nest, to support food resources for Murray cod larvae while at the same time providing opportunities for spawning to occur in silver perch and golden perch. | 2019-20 (R3) | 2020-21 |
| 23. Consider adaptive use of water to coincide with high Murray River flows to maximise attraction/immigration of upstream migrating juvenile golden perch and silver perch in late summer. | 2019-20 (R4) | 2020-21 |
| 24. Deliver elevated base flows to the Upper Wakool River from September-December to maximise nesting and spawning opportunities for Murray cod. | 2019-20 (R10) | 2020-21 |
| 25. Explore options for a high flow event downstream of Stevens Weir (>2700 ML/day) that inundates low lying part of Werai forest and is likely to return flows to either Colligen Creek or the Edward/Kolety River. | 2019-20 (R11) | Not yet implemented |