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Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project:

Edward/Kolety-Wakool River System Selected Area Technical Report 2021-22

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Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Edward/Kolety-Wakool River System Selected Area Technical Report 2021-22

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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 (EKW) system as part of the CEWO Flow-MER Program in 2021-22. This project was undertaken as a collaboration between Charles Sturt University, NSW DPI (Fisheries), Murray-Working Wetlands Group and La Trobe University.

This report has nine sections. The introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2021-22 (section 2). An overview of the monitoring, evaluation and research undertaken in this system for the Flow-MER project 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). Recommendations to inform adaptive management of environmental water in the EKW system in the future is presented in section nine. A summary report (Watts et al. 2022) provides an overview of the monitoring and key findings of the ecosystem responses to environmental watering actions in the EKW system in 2021-22 including findings across the eight years of the combined LTIM/Flow-MER program.

Monitoring and evaluation

The monitoring described in this report was undertaken using methods and approaches described in the EKW Flow-MER Plan (Watts et al 2019a). The Flow-MER project 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 Colligen Creek (zone 8) that were established during the LTIM project for water quality, stream metabolism, vegetation and fish were retained for the Flow-MER project.
- Twenty sites that were established for broad-scale 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 project and surveyed in year three of the project (2022).
- Additional water quality monitoring sites were added to the existing network of water quality monitoring sites. There are now 18 sites throughout the whole system.

An evaluation of the outcomes of Commonwealth environmental watering undertaken in 2021-22 was undertaken for the following indicators: Hydrology, Water quality and carbon, stream metabolism, aquatic and riverbank vegetation, and fish reproduction, recruitment, and adult community.

Responses to Commonwealth environmental water (CEW) 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. Where possible, indicators were calculated with and without 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 longer-term watering regimes. This was undertaken by comparing responses over multiple years, and/or comparing responses in reaches that had different sequence of environmental watering actions.

Environmental watering in the Edward/Kolety-Wakool system 2021-22

In 2021-22 there were 15 watering actions in the EKW system (WUM10117-1 to 10117-15), as described in the EKW 2021-22 Water Acquittal report (CEWO 2022). Some of the watering actions delivered entirely Commonwealth environmental water, and other actions delivered NSW water or a combination of Commonwealth and NSW water. In this report we focus our evaluation on seven watering actions (Table i) delivered in the 2021-22 water year specifically for the Edward/Kolety system. These relate to watering actions WUM 10117-1, WUM 10117-11, WUM 10117-12, WUM 10117-13, and WUM 10117-04 that delivered water to the rivers and creeks where Flow-MER long-term monitoring sites have been established.

To mitigate the risks from hypoxic blackwater in spring and summer Commonwealth environmental water was delivered to the Wakool-Yallakool system from the Wakool Escape (watering action 1), the Edward/Kolety system via the Edward Escape (watering action 2), and to the Colligen-Niemur system via the Niemur Escape (watering action 3) (Table i). These were pre-emptive watering actions that commenced following unregulated flows, to manage an increased risk of a hypoxic blackwater event developing. Three environmental watering actions were undertaken in Autumn 2022. There was an Autumn elevated variable base flow delivered to the upper Wakool system via the Wakool offtake from March until early May 2022 (watering action 4). An Autumn fresh was delivered to Yallakool Creek via the Yallakool offtake from late March to early May (watering action 5) and an Autumn fresh was delivered to Colligen Creek via the Colligen offtake in March (watering action 6). An elevated flow delivered to Tuppal Creek (watering action 7) was evaluated to water quality outcomes.

Environmental watering actions to ephemeral and intermittent creeks Jimaringle-Cockran-Gwynnes (WUM 10117-05), Murrain-Yarrien Creek (WUM 10117-06), Thule Creek (WUM 10117-07), Whymoul Creek (WUM 10117-08), Yarrien Creek (WUM 10117-09) and Buccaneit-Cunninyeuk Creek (WUM 10117-15) were only qualitatively evaluated in terms of their contribution to longitudinal connectivity. Environmental watering actions that delivered water to The Pollack (WUM 10117-02), Little Forest (WUM 10117-03), private wetlands (WUM 10117-10) and via Billabong/Finley escape (WUM 10117-14) were not monitored as part of the Flow-MER program.

In 2021-22 the southern spring flow delivered to the Murray River from Hume Dam also contributed environmental water to the EKW system via flows from Millewa Forest. These watering actions are described in Water Use Minute WUM10115-01 for River Murray Hume to South Australia and floodplain and WUM10115-08 for Barmah-Millewa Forest open regulators, in-channel flow (CEWO 2022). These actions were evaluated in conjunction with other watering actions.

Table i List of environmental watering actions evaluated in 2021-22 in the Edward/Kolety-Wakool system, with cross reference to the Water Use minute watering action reference number.

Action	System	Watering Action Reference Number	Type (Delivery point)	Dates
1	Wakool-Yallakool	WUM10117-11	Spring-summer hypoxic blackwater refuge (Wakool escape)	14/09/21 - 05/01/22
2	Edward/ Kolety	WUM10117-12	Spring-summer hypoxic blackwater refuge (Edward escape)	06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	WUM10117-13	Spring-summer hypoxic blackwater refuge (Niemur escape)	07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	WUM10117-1	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
5	Wakool-Yallakool	WUM10117-1	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
6	Colligen-Niemur	WUM10117-1	Autumn fresh (Colligen offtake)	03/04/22 -26/04/22
7	Tuppal Creek	WUM10117-4	Elevated flows	01/11/21-29/05/22

Outcomes of monitoring and evaluation of environmental watering

Key results from environmental watering actions in 2021-22 are presented in Table ii.

Table ii Results for each indicator in response to environmental watering actions in the Edward/Kolety-Wakool system in 2021-22.

Theme	Indicator	Key result
Hydrology	Maximum and minimum discharge	• The 2021-22 water year was very different to all seven previous years of the LTIM/Flow-MER program. • The spring environmental watering actions, combined with unregulated flows and the southern in spring flows in the Murray River, increased the total annual discharge (ML/year) in all reaches (14% increase in zone 1, 30% in zone 2, 20% in zone 3, 17% in zone 4 and 12% in zone 8) • Environmental watering actions 5 and 6 autumn freshes increased the maximum discharge of freshes compared to operational flows. • The watering actions did not change the minimum discharge in Wakool, Yallakool and Colligen Creek because all zones experienced a winter shutdown operational cease to flow in 2021-22.
	Flow variability	• There was a slight reduction in the coefficient of variation across the whole water year in zone 1 (8%), zone 2 (9%), zone 3 (5%), and zone 8 (6%). This was due to the return flow from Millewa Forest increasing base flows during spring, thus reducing the variation from trough to peak flows during spring/early summer. In Yallakool Creek the reduced variability was more pronounced in spring/early summer.
	Longitudinal connectivity	• The unregulated flows in spring increased longitudinal connectivity by initiating flows in several intermittent and ephemeral creeks that connect the main tributaries in the system. The delivery of CEW from the Wakool escape and the return flows of CEW delivered to Millewa Forest extended the recession of the events from November through to January, thus increasing the duration of these longitudinal connections.
	Lateral connectivity	• The unregulated flows and environmental watering actions during spring and autumn increased the lateral connectivity and hydraulic diversity in study reaches. The delivery of environmental water from the Wakool escape to the upper Wakool River and return flows of CEW from Millewa Forest extended the recession of the unregulated event from November through to January, thus increasing the duration of lateral connectivity.

Water quality and carbon	Dissolved oxygen concentration	• In 2021-22 there was a sustained period of unregulated flows and cooler temperatures over late spring/early summer. Widespread hypoxia was not present in the system during the unregulated flows and mostly DO was above the range of concern to fish populations (below 4 mg/L). • From early November to late December 2021 water temperature started to increase. The environmental watering actions in 2021-22 water year helped to maintain dissolved oxygen concentrations and prevented the development of widespread hypoxic blackwater events. However, in the upper reach of Edward/Kolety River with no environmental watering, dissolved oxygen concentrations were briefly below 4 mg/L. • Concentrations of dissolved oxygen in the upper Wakool River briefly dropped below 4 mg/L in February 2022 when watering actions 1, 2 and 3 ceased, although these were within the range normally measured at that time of year in the upper Wakool River. • Autumn variable base/fresh flow (watering actions 4, 5 and 6) maintained DO levels in the Wakool-Yallakool system and Colligen-Niemur River. • Watering action 7 in Tuppal Creek helped maintained dissolved oxygen levels in November 2021 and between mid-March and May 2022, but it did not prevent the decline in dissolved oxygen levels (below 2 mg/L) in the system during hot months.
	Nutrient concentrations	• Nutrient concentrations remained in the acceptable range in 2021-22. • Only small pulses of nutrients were detected in spring/early summer during the period of unregulated flows. • Commonwealth environmental watering actions 1, 2 and 3 delivered during the unregulated flows mitigated increases in nutrients. • The increase in nutrient concentrations in January and February 2022 were related to increased water temperature and reduced discharge. • Autumn variable base/fresh flow (watering actions 4, 5 and 6) maintained stable nutrients levels in the Wakool-Yallakool system and Colligen-Niemur River system.
	Dissolved organic matter	• In 2021-22 pulses of dissolved organic carbon were detected in the EKW River system and the organic carbon mix was similar across sites during the period of unregulated flows. Higher fluorescence was observed at all sites with a gradual increase downstream, indicating a combination of aged organic matter and very fresh leachates or algal organic matter introduced by unregulated flows. • Environmental water for the Murray River from Hume Dam increased DOC in the system, whereas watering action 1 delivery of water from Wakool escape mitigated the extent of increases in DOC and nutrients in the Wakool-Yallakool system. • Pulses of dissolved organic carbon detected in January and February 2022 were related to increased water temperature and reduced discharge. • The variable autumn watering actions 4, 5 and 6 diluted dark coloured water in the Wakool-Yallakool system and the Colligen-Niemur system.
Stream metabolism	Gross Primary Production (GPP)	• When GPP was calculated as the amount of organic carbon produced per day (kg C/day) then all environmental watering actions had a beneficial effect on increasing organic carbon production. The largest gross contribution of CEW occurred during the second high flows period from 19/10/21 – 05/01/22). 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 2-151% by environmental water, with a median across all sites and time periods of 27% more carbon produced during delivery of CEW compared to no CEW. Environmental watering actions did not substantially affect areal rates of

		gross primary productivity (mg O2/m2/day), which largely followed seasonal trends.
	Ecosystem Respiration (ER)	• When ER was calculated as the amount of organic carbon consumed per day (kg C/day), then watering actions had a beneficial effect on increasing carbon consumption. 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 2% and 145% by environmental water, with a median across all sites and time periods of 27% more carbon consumed during delivery of CEW compared to no CEW. As with GPP, areal rates of ecosystem respiration (mg O2/m2/day) were largely driven by seasonal trends.
Riverbank and aquatic vegetation	Total species richness	• The total number of taxa in zones 2, 3, 4 and 8 increased in 2021-22. There was a significant increase in a number of plant taxa in zone 2 in 2021-22, being the equal largest number of taxa recorded since the program commenced in 2014-15. In zone 4, the number of plant taxa were recorded in 2021-22 (n=29) was the largest since the program commenced. • The mean total richness in each of the five monitored zones has increased 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 flood. • The relationship between total annual discharge and total amphibious taxa showed a polynomial relationship in zones 2 and 4. Data from eight years of the LTIM/Flow-MER Program suggest that species diversity in these two zones is maximized when ecological disturbance is neither low (e.g., constant regulated flows) nor too frequent (e.g., large unregulated flood such as in 2016). The higher than regulated flows that were experienced in 2021-22 increased species richness in these two zones relative to highly regulated lower discharge years, and also compared to higher discharge unregulated flood year.
	Richness and percent cover of functional groups	• Following the 2016 flood there was a reduction in the richness and percent cover of riverbank and aquatic plant functional groups. The patterns varied within functional groups. • After the 2016 flood all submerged taxa were absent from monitored river zones. Since the flood, submerged taxa have recovered in all zones, but the total richness has not yet reached levels observed prior to 2016. In 2021-22 Chara was present in all zones, with strong increase in percent cover in zone 2. The relationship between total annual discharge and number of taxa of submerged taxa was not consistent among hydrological zones. However, in all of the zones during the flood year the number of submerged taxa reduced to zero. • 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 floating pondweed was previously the dominant amphibious taxa in zone 3 prior to the flood but significantly reduced in cover or was killed by the flood in 2016. In 2021-22 there was a significant increase in percent cover of floating pondweed in zones 3 and 4 but has not yet reached the same cover as prior to the 2016 flood.
	Other plant responses	• The inundation of riverbanks from to the watering actions combined with unregulated flows and return flows from Millewa Forest supported riverbank and aquatic plant germination.

Fish spawning	Larval abundance of periodic species	• Despite the high spring/summer in-channel freshes that characterized the 2021-22 water year, there was no evidence of local golden or silver perch spawning in the Wakool River or Yallakool Creek. This was further supported the absence of young-of-year (YOY) golden and silver perch caught in the targeted recruitment surveys. • While low numbers of carp larvae were detected in 2021-22, results of adult population surveys indicate that carp recruitment was widespread throughout the Selected Area, and a likely response to the high spring/summer in-channel freshes.
	Larval abundance of opportunistic species	• Evidence of spawning was observed in 2021-22 for four of the six small-bodied native fish species known to the Edward/Kolety Wakool River system. • Abundance of flathead gudgeon larvae were highest on record in 2021-22 and has been steadily increasing every year since 2018-19.
Fish recruitment	Murray cod, silver perch and golden perch recruitment	• Murray cod YOY abundance and growth rates were highest in 2021-22 than in previous two years. • Highest catch rates of 1+ silver perch were recorded in 2021-22 since monitoring commenced in 2015, with juveniles widespread throughout the Yallakool Creek and Wakool River study sites. • Two juvenile (1+) golden perch were caught in the Yallakool and Wakool River study sites for the first time since monitoring commenced in 2015. • The increase in juvenile golden and silver perch (species not known to spawn regularly in the Edward/Kolety Wakool System) may have been due to fish immigration into the system in response to the high unregulated flows and the Southern Connected Spring Flow.
Fish populations	Adult fish populations	• Broad-scale surveys across the Edward/Kolety Wakool System (Cat 3) • Catch rates of adult fish across the broader Edward/Kolety River system wide surveys were twice as high in 2022 than in previous surveys conducted in 2015 and 2019. The 2022 surveys also indicated high recruitment responses for small-bodied fish species, including Australian smelt, carp gudgeon, unspecked hardyhead and Murray Darling Rainbowfish as well as bony herring. Carp and goldfish also displayed strong recruitment in 2021-22 compared to 2015 and 2019. • Annual surveys of Mid Wakool River upstream Thule Creek (Cat 1) • Native bony herring abundance and biomass in mid-Wakool River upstream of Thule Creek in 2022 was higher than all previous years. Few of these fish were recruits, and may have been due to immigration into the system in response to the unregulated flows and Southern Connected Spring Flow.

Recommendations from previous reports (2014-2021)

A summary of recommendations from all previous EKW LTIM annual reports (Watts et al. 2015, 2016, 2017b, 2018, 2019) and EKW Flow-MER annual reports (Watts et al. 2020, 2021) 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 the management of environmental water

The following nine recommendations are based on findings from this report, with some reference made to recommendations and findings in previous reports.

Recommendation 1

The hydrographs in 2021-22 for the rivers and tributaries of the EKW system were more complex than in previous LTIM/Flow-MER years. The flows included unregulated freshes during spring and summer as well as delivery of Commonwealth environmental water from a wide range of sources; Edward escape, Wakool escape, Niemur escape, Yallakool offtake, Colligen Offtake, Wakool offtake, and return flows from Millewa Forest due to the delivery of environmental water from Hume Weir. At times there was more than one source of water contributing to the hydrograph.

The return flows from Hume Weir in combination with the unregulated freshes from mid-August to the end of December 2021, provided benefits for the EKW system by contributing carbon rich water to boost productivity. Compared to years when flows were highly regulated, the magnitude of variation between low flows and peak flows was larger in 2021-22 than in previous years. However, the environmental water returning from Millewa Forest to the EKW system in 2021-22 reduced the magnitude of variation between low flows and peak flows in Yallakool Creek, and Colligen Creek compared to what would have occurred in 2021-22 in the absence of CEW returning from MIllewa Forest. Thus, there is a trade-off of between the benefits of the EKW system receiving carbon rich water returning from Millewa Forest, versus possible detrimental effects of reduced variability of daily discharge.

Recommendation 1: Explore ways to gain benefits from Commonwealth environmental water returning from Millewa Forest, whilst at the same time maintaining variability of flows in the Edward/Kolety-Wakool tributaries.

Recommendation 2

Environmental water delivery to Wakool River and Yallakool Creek combined with unregulated flows in spring/early summer 2021-22 was the closest yet (since the LTIM/Flow-MER project commenced in 2014) to achieving environmental flows that included the timing, magnitude, duration of freshes that could potentially support spawning of golden perch and silver perch. The continued absence of any evidence of major spawning activity in these two species in Yallakool Creek and the Wakool River monitoring sites supports the hypothesis that these two river systems are not a key location for spawning of golden perch and silver perch.

Recommendation 2: Do not include spawning of golden perch as one of the key objectives for future environmental watering actions in Yallakool Creek and the Wakool River.

Recommendation 3

The outcomes of environmental watering actions in 2021-22, combined with outcomes from previous years, provide strong evidence that one of the key roles of the EKW system in the context of the broader Murray River system is to provide suitable spawning habitat for some fish species (e.g Murray cod, River blackfish, small bodied native fish), support recruitment and growth of juvenile fish, and provide habitat and refuge for adult fish. These benefits for fish and other components of the ecosystem can be supported by maintaining and enhancing connectivity within the system, and connectivity between the EKW system and Murray system throughout the year.

Recommendation 3: Undertake watering actions each watering year that promote connectivity within the EKW system, and connectivity between the EKW system and the Murray River. This includes; i) deliver in-channel freshes in late winter/spring that exceed the current normal operating rules to increase connectivity within tributaries and connectivity via runners between tributaries, ii) deliver continuous base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat and prevent negative consequences of winter cease-to-flow; iii) Undertake watering actions to improve the connectivity and other outcomes in intermittent and ephemeral streams and flood runners in the EKW system.

Recommendation 4

The management of the offtake regulator for Colligen Creek is automated, and thus can be more easily operated than some of the other manually operated regulators in the EKW system. In addition, Colligen Creek is closer to the Stevens Weir structure and the offtake for Wakool Main Canal, so it is more convenient for water managers to use the Colligen Creek offtake to facilitate the balance of operational water in Stevens Weir when there is excess water in the system, such as water orders being withdrawn due to rain.

Consequently, Colligen Creek continues to experience short-lived flow peaks and rapid recession of flows that can be detrimental for maintaining a balance of erosion and sedimentation on riverbanks. Rapid recession of flows means that the sediment removed by natural processes during a rise is not the replaced by deposition of sediment on recession. In addition to this negative physical outcome, rapid recession of flows can also have negative ecological outcomes such as reducing the replenishment of seedbank.

Recommendation 4: Mitigate the negative consequences of rapid rises and falls in Colligen Creek hydrograph by working with water managers and river operators to achieve better outcomes through planning options such as i) increasing the rate of recession following rapid rises in flows due to river operations, ii) delivery of the excess water to other parts of the system instead of delivering a short flow peak to Colligen Creek.

Recommendation 5

The delivery of environmental water through irrigation escapes to improve water quality has proven to be an effective management tool that has provided benefits but has not resulted in recorded negative outcomes in the river system.

Recommendation 5: Continue to include a water use option in water planning that enables environmental water to be used to mitigate adverse water quality events and potential fish kills. Work with a range of organisations and the community to 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}.

Recommendation 6

In 2020-21 and 2021-22 environmental watering actions from the Wakool escape delivered variable base flows to the upper Wakool River to maintain water quality during warmer months. In addition to achieving this water quality outcome, these watering actions provided other significant outcomes, including increasing longitudinal connectivity, increasing flow variability, and helping to improve riverbank plant outcomes. These findings suggest that there are benefits to be gained from using the Wakool Escape to deliver environmental water to the Wakool River, even at times when there are no refuge flows required.

Recommendation 6: Undertake further watering actions from the Wakool escape to improve the connectivity and ecosystem outcomes in the Upper Wakool River and reaches further downstream in the mid- and lower Wakool River. Deliver larger freshes with increased variability to maintain water quality, enable riverbank vegetation to establish and be maintained, and support good fish outcomes.

Recommendation 7

There are many ecosystem and cultural benefits to be gained from watering Werai Forest. The multiple unregulated pulses in 2021-22 resulted in high flows downstream of Stevens Weir and several events inundated Werai Forest and returned flows from Werai Forest to Colligen Creek. This did not result in adverse outcomes for water quality or any recorded deaths of fish in the Colligen-Niemur system in 2021-22. Research undertaken in 2021-22 showed that response of aquatic plants and algae in Werai Forest can assist the productivity and help maintain good water quality of outflows from the forest. Research on patterns of inundation in Werai Forest (Watts et al. 2022) showed that return flows from the forest into the Edward/Kolety River commenced when the discharge downstream of Stevens Weir was between 3,152 - 3,237 ML/d, and return flows from Tumudgery Creek into Colligen Creek commenced when the discharge DS Stevens Weir was between 5,471 ML/d and 9,340 ML/d.

Recommendation 7: Explore options to use environmental water to support high flow event downstream of Stevens Weir (>2700 ML/day) that inundates low lying parts of Werai forest. If possible, use environmental water to support higher flow events downstream of Stevens Weir (> 5471 ML/d) to inundate low lying part of Werai forest as well as support return flows to Colligen Creek and the Edward/Kolety River.

Recommendation 8

Evidence from the fish recruitment monitoring and adult fish strongly suggests that there was immigration of silvers and golden juveniles/sub adults into the EKW system during the high unregulated flows in 2021-22 which may have been enhanced by environmental water delivered from irrigation escapes. We continue to support recommendation 4 from 2019-20 report that encourages the use of environmental water to support movement of native fish.

Recommendation 8: 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.

Recommendation 9

The combination of unregulated spring/early summer flows in the Murray, environmental watering of ephemeral and intermittent creeks, and environmental watering from MIL escapes, created increased connectivity in the EKW system in 2021-22 more than has been seen in any other year, except during large flood years. The river ecosystem greatly benefits from connectivity, that includes the maintenance of flow during winter that promotes temporal availability and continuity of instream habitat, fish movement, and survival of aquatic plants.

Winter shutdown of regulators is an operational norm to facilitate maintenance of infrastructure. Unfortunately, this means that some of the benefits from the increased connectivity created by environmental watering in spring, summer and autumn will be diminished due to winter operational shutdown periods that occur in tributaries in the EKW system. It would maximise the benefit to the river ecosystem if an operational solution was implemented to enable the delivery of winter flows to the tributaries every year.

Recommendation 9: Facilitate the benefits of connectivity flows by working with river managers and river operators to maximise the opportunities to deliver environmental water to tributaries during winter and eliminate the impact of operational shutdowns in winter.

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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 (EKW) 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 2023.

This report describes the monitoring, evaluation and research activities that were undertaken in the EKW system as part of the CEWO Flow-MER Program from July 2021 to June 2022. This project was undertaken as a collaboration between Charles Sturt University, NSW DPI (Fisheries), Murray Working Wetlands Group, and La Trobe University. The monitoring described in this report was undertaken using methods and approaches described in the EKW Flow-MER Plan (Watts et al 2019a).

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 2021-22 (section 2). An overview of the monitoring and evaluation undertaken in this system for the Flow-MER project 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). Recommendations to help inform adaptive management of environmental water in the EKW system in the future is presented in section nine. A summary report (Watts et al. 2022) provides an overview of the monitoring and key findings of the ecosystem responses to environmental watering actions in the EKW system in 2021-22.

1.2 Edward/Kolety-Wakool Selected Area

The EKW river system is a large anabranch system of the Murray River in the southern MDB, Australia. The system begins in the Barmah-Millewa Forest and travels north and then northwest before discharging back into the Murray River (Figure 1.1). It is a complex network of interconnected streams, ephemeral creeks, flood-runners and wetlands including the Edward/Kolety River, Wakool River, Yallakool Creek, Colligen-Niemur Creek and Merran Creek. There are also many ephemeral or intermittent creeks in the EKW 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.

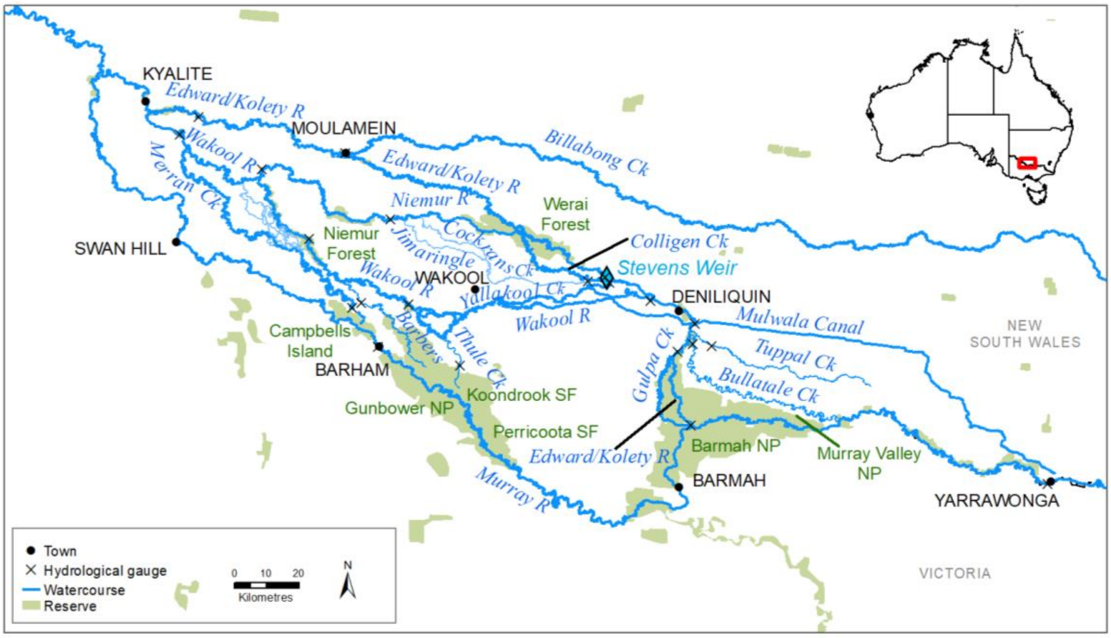


Figure 1.1 Map showing the main rivers and creeks in the Edward/Kolety-Wakool river system.

The area has a rich and diverse Indigenous history and supports a productive agricultural community and supports recreational uses such as fishing, bird-watching and bush-walking. First Nations including the Wamba Wamba (Wemba Wemba), Perrepa Perrepa (Barapa Barapa), Yorta Yorta, and Wadi Wadi maintain strong connections to the country.

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 EKW 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 EKW 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 EKW 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.

The EKW Selected Area can be broadly divided into three aquatic ecosystem types: 1) the permanent and semi-permanent flowing rivers, 2) the floodplain forests and woodlands, and 3) intermittent and ephemeral creeks. A brief description of each is provided below.

Permanent and semi-permanent rivers and creeks

The permanent and seasonal rivers and creeks support high regional biodiversity 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. The permanent river in this system is the Edward/Kolety River (Figure 1.2). The seasonal or semi-permanent rivers and creeks include the Wakool River, Yallakool Creek, Colligen-Niemur River (Figure 1.2).

Figure 2.2 Left: Edward/Kolety River. Right: Wakool River in the Edward/Kolety-Wakool River system.

Floodplain forests and woodlands

Within the EKW system there are floodplain forests and woodlands. Large forests include Werai Forest and Niemur Forest. There are redgum riparian forests along the rivers and tributaries within the system and on higher land there are blackbox forests.

Werai Forest is located downstream from Deniliquin along the Edward/Kolety River and has great 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).

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.

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 (Figure 1.3) with lower lying areas typically dominated by giant rush. The low-lying areas, floodrunners (Figure 1.3) 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.

Figure 3.3 Left: River red gum within Werai Forest. Right: A flood runner in Werai Forest.

Ephemeral and intermittent creeks

There are a large number of intermittent and ephemeral creeks and floodrunners in the EKW system including Cockrans-Jimaringle Creek, Tuppal Creek, Bullatale Creek, Thule Creek, Murrain-Yarrien Creek, Yarrien Creek, Whymoul Creek, and Buccaneit-Cunninyeuk Creek. Tuppal Creek (Figure 1.4) 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 state listed threatened and vulnerable species (Brownbill and Warne 2010; CEWO 2012c). Jimaringle Creek (Figure 1.4), Cockran and Gwynnes Creeks are examples of ephemeral creeks in this system that are considered a biodiversity hotspot of significant regional value.

Figure 4.4 Left: Tuppal Creek. Right: Jimaringle Creek (Photo Les Gordon)

2 Environmental water use objectives and watering actions in 2021-22

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).

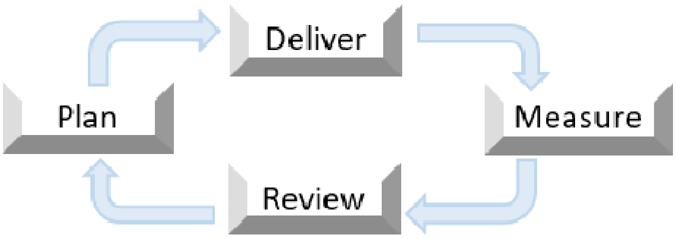


Figure 2.1. Annual cycle of ‘plan, deliver, measure and review’ (Source CEWO 2020a)

Each year the CEWO prepare a Water Management Plan 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 EKW 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 Commonwealth 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 per cent of the natural level.
- Contributing to a 30 per cent overall increase in flows in the River Murray.
- A 30 to 60 per cent 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 (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

Water Quality targets

Water quality targets for the Murray-Darling Basin are outlined in Chapter 9, Part 4, sub-section 9.14(5) of the Basin Plan (MDBA, 2012). The target for 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 EKW 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.

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

The main source of Commonwealth environmental water for the EKW system is from the Murray River through the Edward/Kolety River and Gulpa Creek. The main flow regulating structures within the EKW 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). Stevens Weirpool 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.

Water diverted into the Mulwala Canal from Lake Mulwala can also be delivered into the EKW system through irrigation '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). Escapes were also used to deliver environmental water as refuge flows in response to the 2016 hypoxic blackwater event (Watts et al. 2017b). There are numerous smaller escapes throughout the MIL network that can also be used to deliver small flows to the river system.

Environmental watering actions delivered for the Murray River channel from Hume to South Australia delivers water to Millewa Forest via Barmah-Millewa Forest regulators and some of this water exits via creeks and flood runners in Millewa Forest and influences the hydrograph at Toonalook gauge. However, some of the environmental water exits Millewa Forest via Tuppal Creek and Bullatale Creek, contributing to flows in the Edward/Kolety River downstream of the Toonalook hydrographic gauge. The current network of hydrographic gauges does not provide an adequate means to measure the contribution of Murray River watering actions in the Edward/Kolety River.

The ability to deliver environmental water to the EKW 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 of takes / regulators and irrigation escapes. Environmental watering may 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.
- channel constraints (e.g., to avoid third party impacts). 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. 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.
- the availability of third party infrastructure to assist in delivering water into the system
- existing flows and other demands on the system. If the system is receiving unregulated flows, there may not be enough capacity to deliver environmental water (Gawne et al. 2013).

2.3 Commonwealth environmental watering actions in the Edward/Kolety Wakool system 2009-2021

Commonwealth environmental watering actions have been undertaken in the EKW river system since 2009 (Table 2.3). Between July 2009 and June 2021 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.

The majority of the watering actions delivered between 2009 and 2021 were base flows and small freshes in tributaries, water delivered to ephemeral streams via irrigation infrastructure, and actions that contributed to recession flows. These actions have been the focus because delivery of larger within channel freshes is restricted by physical constraints and agreements to minimise third party impacts. For example, under current operational constraints (e.g., constrained to 600 ML/d at the confluence of the Wakool River and Yallakool Creek).

One Commonwealth watering action in 2009-10 was undertaken to deliver environmental water for Werai State Forest (DEE 2017) (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. 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 a second spring flow trial was undertaken in the Wakool-Yallakool system.

In addition to watering actions specifically targeted for the EKW system, water from upstream Commonwealth environmental watering actions and actions targeted for the Murray River influence the hydrograph of the EKW system in some years (Table 2.3). For example, in 2015-16 environmental water returning from Barmah-Millewa Forest influenced the hydrograph in the EKW system (Watts et al. 2016). Similarly, in 2019-20 the Southern Connected Flow in the Murray River influenced flows in the EKW system from 28 August to 9 September 2019, and 23 September to 1 October 2019. In 2020-21 a southern spring flow was delivered to the Murray River that influenced hydrology of the EKW system (Watts et al. 2020).

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 2021.

	In-channel environmental watering actions				Environmental watering actions using irrigation infrastructure			Unregulated overbank flows	Watering actions from Hume for Murray River
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	Contribute return flows to Edward/Kolety-Wakool system from Millewa Forest
2009-10							✓		
2010-11					✓	✓		✓	
2011-12	✓					✓			
2012-13	✓				✓	✓			
2013-14	✓	✓				✓			
2014-15	✓	✓				✓			
2015-16	✓	✓				✓			✓
2016-17	✓	✓			✓	✓		✓	
2017-18	✓	✓	✓			✓			
2018-19	✓	✓				✓			
2019-20	✓	✓	✓			✓			✓
2020-21	✓	✓			✓	✓			✓

[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

2.4 Environmental Watering Planning for 2021-22

Environmental demand and priority for watering, 2021–22, and outlook for coming year for the EKW River system as described by CEWO (2021) in the 2021-22 River Murray Valley water plan is presented in Table 2.4.

Objectives for planned watering actions in Yallakool-Wakool, Colligen-Niemur and Edward/Kolety River for 2021-22 are described in Water Use Minute WUM10117 (CEWO 2022) to achieve the following expected outcomes:

<u>Primary expected outcomes</u>

A. support the recovery of in-stream aquatic vegetation and large bodied native fish following the 2016 hypoxic blackwater event.

B. 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

C. maintain health of riparian and in-channel aquatic native vegetation communities

D. maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.

E. maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

F. support inundation of low-lying wetlands/floodplains habitats within the system.

<u>Secondary expected outcomes</u>

G. maintain habitat quality in ephemeral watercourses

H. support mobilisation, transport and dispersal of biotic and abiotic material (e.g., sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity.

Commonwealth environmental watering actions planned by the CEWO Central Delivery Team for the Yallakool-Wakool system in 2021-22 (Figure 2.2) were:

- Sequence of freshes (within operational constraints) in spring/early summer with a short recession between each fresh to improve flow variability. It was noted that it may be necessary to use the Wakool escape to try and reach the planned flow peaks in November or December. This would be subject to obtaining landholder agreement for any proposed high flows and consideration of how WaterNSW is managing the system, especially during the Murray spring pulse period where we will be prioritising flows downstream of Stevens Weir for Werai Forest
- Autumn fresh in Yallakool Creek
- Variable base flows in the upper Wakool River in late summer/autumn
- Environmental watering actions in ephemeral streams (not monitored as part of Flow-MER)
- Environmental watering actions in private wetlands (not monitored as part of Flow-MER).

Commonwealth environmental watering actions planned by the CEWO Central Delivery Team for the Colligen-Niemur system in 2021-22 (Figure 2.3) were:

- Sequence of freshes in Spring/early summer with a short recession between each fresh to improve flow variability.
- Late summer fresh
- Autumn fresh

Objectives for EKW system refuge flows that are usually triggered once dissolved oxygen levels reach 4.0 mg/L in line with Basin Plan water quality requirement were habitat flows, water quality and provision of refuges for native fish.

Commonwealth environmental watering actions planned for the Murray River channel by the Southern Delivery Team of CEWO outlined a number of triggers and delivery options for Murray channel flows that are influenced by water availability (ranging from extreme dry to wet year) (Figure 2.4). In 2021-22 a Southern Spring Flow was planned for the Murray River commencing in late winter continuing through spring 2021. Environmental water delivered to the Murray River flows into Millewa Forest and exits the forest through a number of regulators, creeks and flood runners and contributes to flows into the Edward/Kolety River.

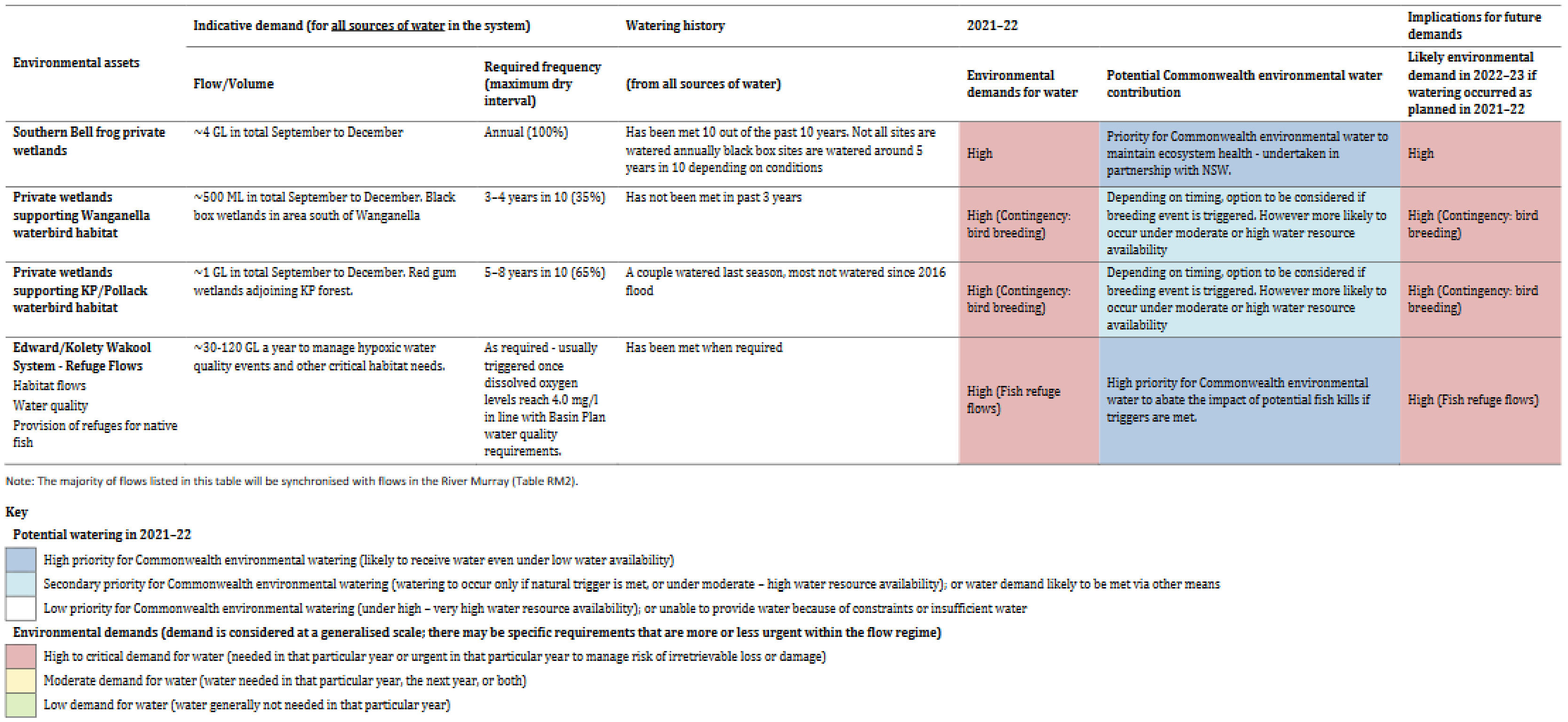
Table 2.4 Environmental demand and priority for watering, 2021–22, and outlook for coming year, for the Edward/Kolety-Wakool River system (Source CEWO 2021, Table RM3)

Environmental assets	Indicative demand (for all sources of water in the system)		Watering history	2021-22		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 2022–23 if watering occurred as planned in 2021–22
Yallakool - Wakool Maintenance of native fish habitat and instream aquatic vegetation Longitudinal connectivity Fish spawning, recruitment, and movement Nutrient cycling Water quality	~200 ML/day base flow for ~295 days during late winter to late Autumn (~59 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
	~580 ML/day peak for 10 days fresh over ~25 days in early spring with gradual recession (~11 GL, includes ~200 ML/day base flow. To assist in providing the spring pulse an additional ~3-4 GL through the Wakool escape may need to be needed).	Annual	Has been met 5 out of the past 5 years. Annual requirement therefore the environmental demand has been assessed as High.	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 (~17.6 GL in total, includes ~200 ML/day base flow)	Annual	Has been met 5 out of the past 5 years. Annual requirement therefore the environmental demand has been assessed as High.	High	Priority for Commonwealth environmental water to continue ecosystem recovery	High
	~600 ML/day peak for 5 days undertaken as 1 to 3 freshes in late spring/early summer to stimulate silver perch breeding with a gradual recession down to 220 ML/day at end of fish nesting period (from min. 20 days to max. 84 days) (~10.5 GL min to 38 GL max., includes ~200 ML/day base flow).	Annual	Has been met 3 times for 1 fresh out of the past 5 years and has not been met for 3 freshes.	Moderate	Option to be considered under a moderate to high water resource availability.	Moderate
	~510 ML/day peak for 4 days over 51 days fresh in autumn with a gradual recession (~16 GL, includes ~200 ML/day base flow).	2 in 3 years (2 years)	Has been met 3 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 first 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. Subject to Stevens weir pool being kept in over winter to enable connection to Colligen and Yallakool regulators.	High	Priority for Commonwealth environmental water to continue ecosystem recovery.	High
	Upper Wakool over summer and autumn to maintain water quality. 14 day increase stepwise of 30 ML/day up to a peak of ~110 ML/day for 14 days followed by stepwise decrease of 30 ML/day down to 50 ML/day for 14 days, then repeat to watering season end in early May.	Annual	Has been met 1 out of the past 5 years. Annual requirement therefore the environmental demand has been assessed as High.	High	Priority for Commonwealth environmental water to continue ecosystem recovery.	High
Colligen - Niemur As per Yallakool-Wakool above	The potential flow components for the Colligen-Niemur during 2021–22, 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.	As above.	As above.	As above.	As above.	As above.
Edward/Kolety River downstream of Stevens Weir	Above 2700 ML/day (constraint downstream of Stevens Weir) early spring pulse targeting Werai Forest (~15 GL) and late spring/summer pulse (~15 GL). Will need to align with delivery of RMC	Annual	Single fresh has been met 3 out of the past 5 years by unregulated flows. Annual requirement therefore the environmental demand has been assessed as High.	High	Flows up to constraint of 2700 ML/day are likely to be met by RMC operational flows during early spring and late spring/early summer.	High

Table 2.4 (continued) Environmental demand and priority for watering, 2021–22, and outlook for coming year, for the Edward/Kolety-Wakool River system (Source CEWO 2021 Table RM3)

Environmental assets	Indicative demand (for all sources of water in the system)		Watering history	2021–22		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 2022–23 if watering occurred as planned in 2021–22
	flows into Yallakool-Wakool and Colligen-Niemur systems.			🟥		🟥
Tuppal Creek	~5,500 ML in total spring fresh with variability flow during August to April (~2.75 GL of CEW + ~2.75 GL NSW).	Annual	Has been met 1 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	Low	A low priority for watering in 2021–22. Demand may be met by other means.	Low
Jimaringle, Cockran and **Gwynnes Creeks**	Total flow of ~10 GL deliverable preferably in August to November. 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)	Has been met 1 (65%) in 5 years. Last significant flow was the 2016 flood event.	Moderate	Option to be considered under a moderate to high water resource availability.	Moderate
Werai Forest	Linked to Edward/Kolety River action above. May need to call on MIL Edward Escape for ~15 GL to push flows over 2,700 ML/day D/S of Stevens Wier.	2-3 in 5 years (2 years)	First fresh has been met 5 out of the past 5 years. Second fresh has not been met in past 5 years. Forest in poor health therefore the environmental demand has been assessed as High for successive years.	High	Priority for Commonwealth environmental water to maintain ecosystem health – likely to be undertaken as part of the River Murray watering action (see Table RM2 above).	High
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.	2-3 in 5 years (2 years)	Minimum flow has been met twice (provided in 2019–20, similar to 2014–15 commissioning event). Forest in poor health therefore the environmental demand has been assessed as High for successive years.	High	Use of CEW in scope subject to support from local stakeholders and potentially affected landholders.	High
Pollack Swamp	~3 GL per year watering proposals for pumping to this site during late spring and summer developed by Forestry NSW and DPIE.	Annual	Has been met 5 out of the past 5 years. Annual requirement therefore the environmental demand has been assessed as High.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	High
Thule Creek	~750 ML top up to maintain water quality in Aug to April.	Annual	Has been met 2 out of the past 5 years	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	High
Murrain-Yarrein	Up to ~3 GL in total August to April	5 to 10 years in 10 years (75%)	Has not been met since 2016 flood.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	Moderate
Yarrein Creek	~5 GL to 10 GL total August to November	5 to 8 years in 10 years (65%)	Has not been met since 2016 flood.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	Moderate
Whymoul Creek	~500 ML in total August to April. Maintain for native fish particularly if threatened species are released into it.	Annual (100%)	Has been met once in 2021. Prior to that was the 2016 flood.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	Moderate
Buccaneit-Cunningyeuk Creeks	~2 GL in total August to April for refuge pools.	Annual (100%)	Has been met 2 out of the past 5 years. Prior to that was the 2016 flood.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	Moderate
Lake Agnes	~1 GL in total September to December.	5 to 10 years in 10 (75%)	Has been met once in 2021. Prior to that was the 2016 flood.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	Moderate
Mortons swamp	~800 ML in total September to December	5–8 years in 10 (65%)	Has not been met since 2016 flood.	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	Moderate

Table 2.4 (continued) Environmental demand and priority for watering, 2021–22, and outlook for coming year, for the Edward/Kolety-Wakool River system (Source CEWO 2021, Table RM3)



Environmental assets	Indicative demand (for all sources of water in the system)		Watering history	2021–22		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 2022–23 if watering occurred as planned in 2021–22
Southern Bell frog private wetlands	~4 GL in total September to December	Annual (100%)	Has been met 10 out of the past 10 years. Not all sites are watered annually black box sites are watered around 5 years in 10 depending on conditions	High	Priority for Commonwealth environmental water to maintain ecosystem health - undertaken in partnership with NSW.	High
Private wetlands supporting Wanganella waterbird habitat	~500 ML in total September to December. Black box wetlands in area south of Wanganella	3–4 years in 10 (35%)	Has not been met in past 3 years	High (Contingency: bird breeding)	Depending on timing, option to be considered if breeding event is triggered. However more likely to occur under moderate or high water resource availability	High (Contingency: bird breeding)
Private wetlands supporting KP/Pollack waterbird habitat	~1 GL in total September to December. Red gum wetlands adjoining KP forest.	5–8 years in 10 (65%)	A couple watered last season, most not watered since 2016 flood	High (Contingency: bird breeding)	Depending on timing, option to be considered if breeding event is triggered. However more likely to occur under moderate or high water resource availability	High (Contingency: bird breeding)
Edward/Kolety Wakool System - Refuge Flows Habitat flows Water quality 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	High (Fish refuge flows)	High priority for Commonwealth environmental water to abate the impact of potential fish kills if triggers are met.	High (Fish refuge flows)

Note: The majority of flows listed in this table will be synchronised with flows in the River Murray (Table RM2).

Key

Potential watering in 2021–22

🟦 High priority for Commonwealth environmental watering (likely to receive water even under low water 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); or unable to provide water because of constraints or insufficient water

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

🟥 High to critical demand for water (needed in that particular year or urgent in that particular year to manage risk of irretrievable loss or damage)
🟨 Moderate demand for water (water needed in that particular year, the next year, or both)
🟩 Low demand for water (water generally not needed in that particular year)

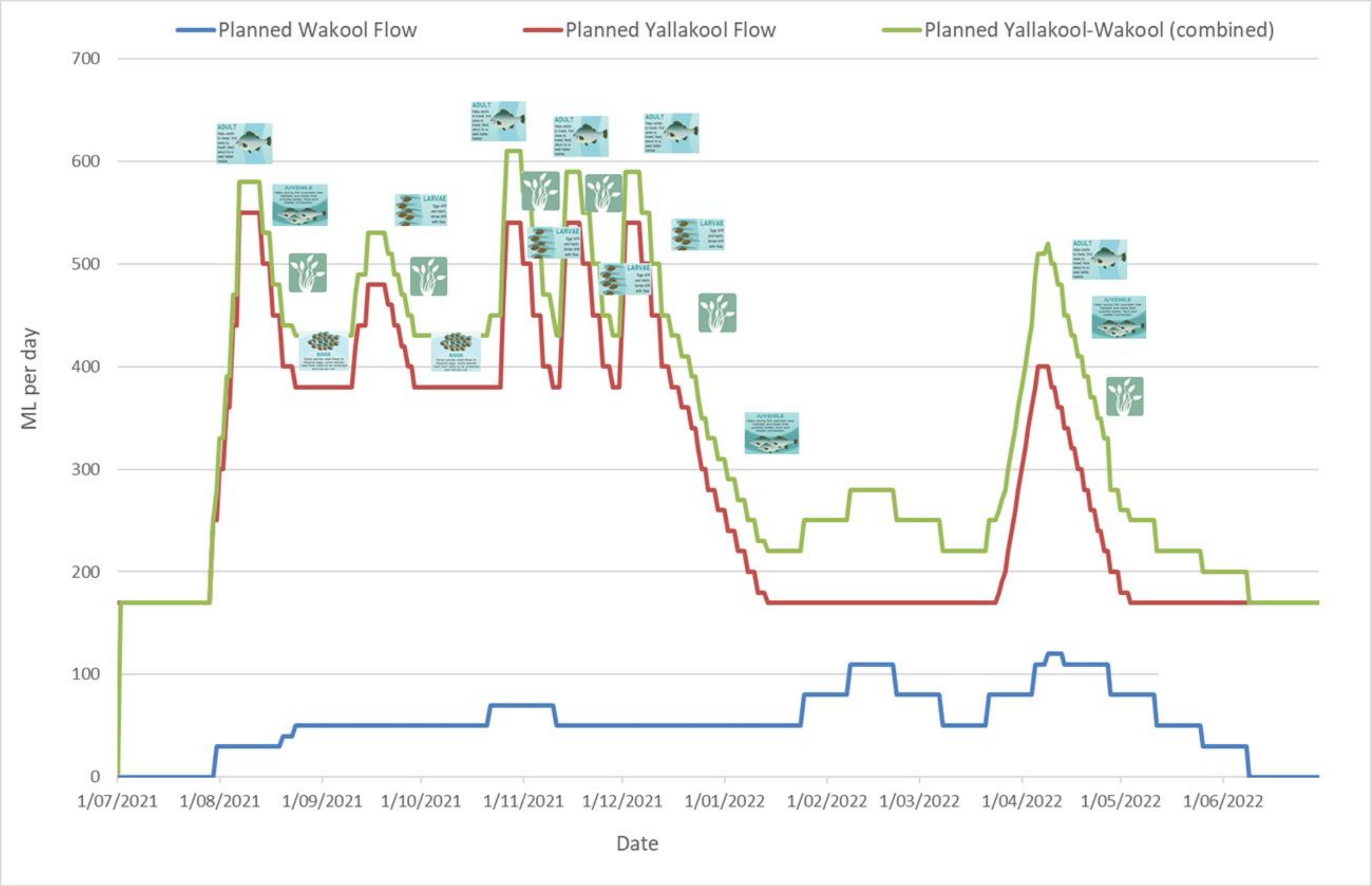


Figure 2.2. Annual hydrograph planned for Yallakool-Wakool planned hydrograph for 2021-22. (Source: Modified from CEWO 2022)

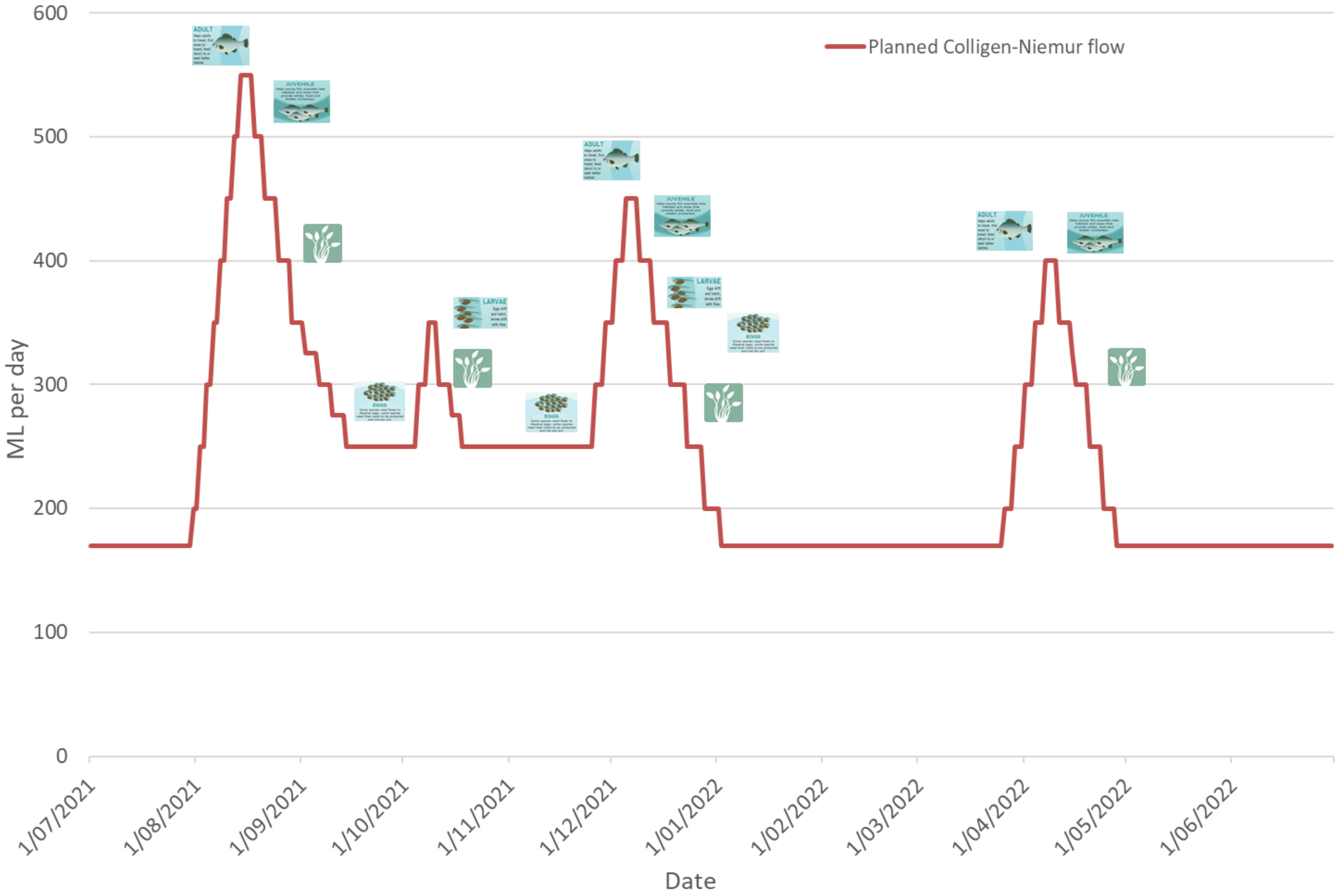
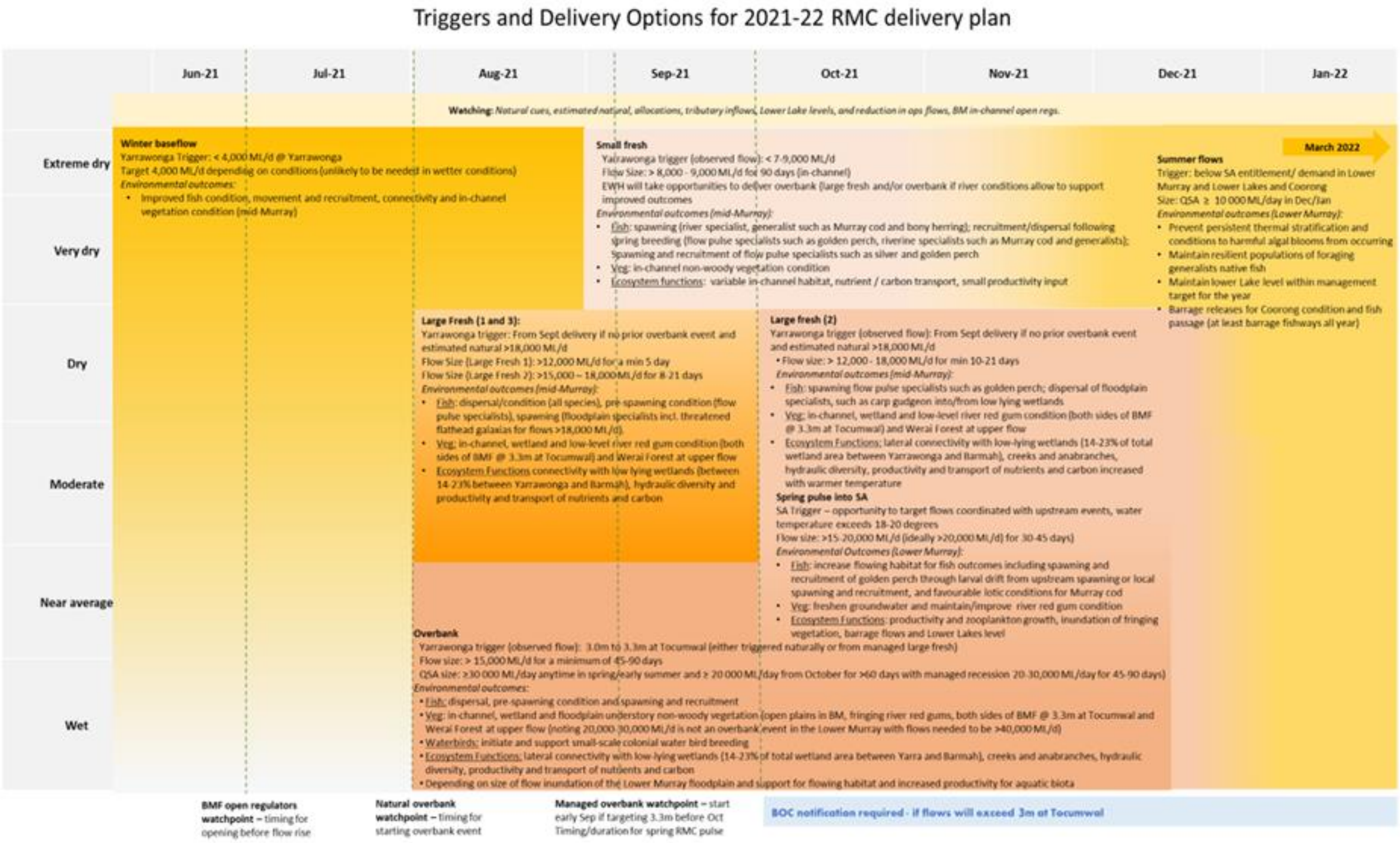


Figure 2.3. Annual hydrograph planned for Colligen-Niemur for 2021-22. (Source: CEWO 2022)



Watching: *Natural cues, estimated natural, allocations, tributary inflows, Lower Lake levels, and reduction in ops flows, BM in-channel open regs.*

Winter baseflow
Yarrawonga Trigger: < 4,000 ML/d @ Yarrawonga
Target 4,000 ML/d depending on conditions (unlikely to be needed in wetter conditions)
Environmental outcomes:
- Improved fish condition, movement and recruitment, connectivity and in-channel vegetation condition (mid Murray)

Small fresh
Yarrawonga trigger (observed flow): < 7-9,000 ML/d
Flow Size: > 8,000 - 9,000 ML/d for 90 days (in-channel)
EWH will take opportunities to deliver overbank (large fresh and/or overbank if river conditions allow to support improved outcomes
Environmental outcomes (mid-Murray):
- Fish: spawning (river specialist, generalist such as Murray cod and bony herring); recruitment/dispersal following spring breeding (flow pulse specialists such as golden perch, riverine specialists such as Murray cod and generalists); Spawning and recruitment of flow pulse specialists such as silver and golden perch
- Veg: in-channel non-woody vegetation condition
- Ecosystem functions: variable in-channel habitat, nutrient / carbon transport, small productivity input

Summer flows
Trigger: below SA entitlement/ demand in Lower Murray and Lower Lakes and Coorong
Size: QSA ≥ 10 000 ML/day in Dec/Jan
Environmental outcomes (Lower Murray):
- Prevent persistent thermal stratification and conditions to harmful algal blooms from occurring
- Maintain resilient populations of foraging generalists native fish
- Maintain lower Lake level within management target for the year
- Barrage releases for Coorong condition and fish passage (at least barrage fishways all year)

Large Fresh (1 and 3):
Yarrawonga trigger: From Sept delivery if no prior overbank event and estimated natural >18,000 ML/d
Flow Size (Large Fresh 1): >12,000 ML/d for a min 5 day
Flow Size (Large Fresh 2): >15,000 – 18,000ML/d for 8-21 days
Environmental outcomes (mid-Murray):
- Fish: dispersal/condition (all species), pre-spawning condition (flow pulse specialists), spawning (floodplain specialists incl. threatened flathead galaxias for flows >18,000 ML/d).
- Veg: in-channel, wetland and low-level river red gum condition (both sides of BMF @ 3.3m at Tocumwal) and Werai Forest at upper flow
- Ecosystem Functions connectivity with low lying wetlands (between 14-23% between Yarrawonga and Barmah), hydraulic diversity and productivity and transport of nutrients and carbon

Large fresh (2)
Yarrawonga trigger (observed flow): From Sept delivery if no prior overbank event and estimated natural >18,000 ML/d
- Flow size: > 12,000 - 18,000 ML/d for min 10-21 days

Environmental outcomes (mid-Murray):
- Fish: spawning flow pulse specialists such as golden perch; dispersal of floodplain specialists, such as carp gudgeon into/from low lying wetlands
- Veg: in-channel, wetland and low-level river red gum condition (both sides of BMF @ 3.3m at Tocumwal) and Werai Forest at upper flow
- Ecosystem Functions; lateral connectivity with low-lying wetlands (14-23% of total wetland area between Yarrawonga and Barmah), creeks and anabranches, hydraulic diversity, productivity and transport of nutrients and carbon increased with warmer temperature

Spring pulse into SA
SA Trigger – opportunity to target flows coordinated with upstream events, water temperature exceeds 18-20 degrees
Flow size: >15-20,000 ML/d (ideally >20,000 ML/d) for 30-45 days)
Environmental Outcomes (Lower Murray):
- Fish: increase flowing habitat for fish outcomes including spawning and recruitment of golden perch through larval drift from upstream spawning or local spawning and recruitment, and favourable lotic conditions for Murray cod
- Veg: freshen groundwater and maintain/improve river red gum condition
- Ecosystem Functions: productivity and zooplankton growth, inundation of fringing vegetation, barrage flows and Lower Lakes level

Overbank
Yarrawonga trigger (observed flow): 3.0m to 3.3m at Tocumwal (either triggered naturally or from managed large fresh)
Flow size: > 15,000 ML/d for a minimum of 45-90 days
QSA size: ≥30 000 ML/day anytime in spring/early summer and ≥ 20 000 ML/day from October for >60 days with managed recession 20-30,000 ML/day for 45-90 days)
Environmental outcomes:
- Fish: dispersal, pre-spawning condition and spawning and recruitment
- Veg: in-channel, wetland and floodplain understory non-woody vegetation (open plains in BM, fringing river red gums, both sides of BMF @ 3.3m at Tocumwal and Werai Forest at upper flow (noting 20,000-30,000 ML/d is not an overbank event in the Lower Murray with flows needed to be >40,000 ML/d)
- Waterbirds: initiate and support small-scale colonial water bird breeding
- Ecosystem Functions: lateral connectivity with low-lying wetlands (14-23% of total wetland area between Yarra and Barmah), creeks and anabranches, hydraulic diversity, productivity and transport of nutrients and carbon
- Depending on size of flow inundation of the Lower Murray floodplain and support for flowing habitat and increased productivity for aquatic biota

BMF open regulators watchpoint – timing for opening before flow rise

Natural overbank watchpoint – timing for starting overbank event

Managed overbank watchpoint – start early Sep if targeting 3.3m before Oct Timing/duration for spring RMC pulse

BOC notification required - if flows will exceed 3m at Tocumwal

Figure 2.4. Triggers and timeframe for the 2021-22 River Murray Channel delivery (CEWO 2021).

2.7 Commonwealth watering actions in 2021-22 delivered to the Edward/Kolety-Wakool system

In 2021-22 there were 15 watering actions in the EKW system (WUM10117-1 to 10117-15), as described in the EKW 2021-22 Water Acquittal report (CEWO 2022). Some of the watering actions delivered entirely Commonwealth environmental water, and other actions delivered NSW water or a combination of Commonwealth and NSW water.

In this report we focus our evaluation on seven watering actions (Table2.5) delivered in the 2021-22 water year specifically for the Edward/Kolety system. These relate to watering actions WUM 10117-1, WUM 10117-11, WUM 10117-12, WUM 10117-13, and WUM 10117-04 that delivered water to the rivers and creeks where Flow-MER long-term monitoring sites have been established. The watering actions that are evaluated in this report have been numbered actions 1 to 7 (Table 2.6).

Table 2.5 Environmental watering actions as stated in Water Use Minute WUM10117 (Source: CEWO 2022). Only those actions that are evaluated in the Flow-MER report are listed. All actions for 2021-22 are listed in Appendix 1.

Watering Action Reference Number	System	Type (delivery point)	CEW volume used	Other volume used	Dates (Start/end)
WUM10117-1	Yallakool-Wakool Colligen-Niemur	Spring fresh, elevated spring baseflow, three summer freshes and autumn fresh.	0 (Unregulated flows prevented CEW delivery)	NSW EHG provided a total of 8,156ML below choke for Autumn pulse in both Colligen/ Niemur and Yallakool/Wakool	01/07/21 to 30/06/22
WUM10117-4	Tuppal	20ML/d baseflow maintained through summer and autumn	3,591 ML	NSW 500ML.	01/11/21 to 29/05/22
WUM10117-11 WUM10117-12 WUM10117-13	Wakool, Edward & Niemur escape	fresh	73,422.1 ML	0	10/09/21 to 15/01/22

Table 2.6 List of environmental watering actions evaluated in 2021-22 in the Edward/Kolety-Wakool system, with cross reference to the Water Use minute watering action reference number.

Action	System	Watering Action Reference Number	Type (delivery point)	Dates
1	Wakool-Yallakool	WUM10117-11	Spring-summer hypoxic blackwater refuge (Wakool escape)	14/09/21 - 05/01/22
2	Edward/ Kolety	WUM10117-12	Spring-summer hypoxic blackwater refuge (Edward escape)	06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	WUM10117-13	Spring-summer hypoxic blackwater refuge (Niemur escape)	07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	WUM10117-1	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
5	Wakool-Yallakool	WUM10117-1	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
6	Colligen-Niemur	WUM10117-1	Autumn fresh (Colligen offtake)	03/04/22 -26/04/22
7	Tuppal Creek	WUM10117-4	Elevated flows	01/11/21-29/05/22

The planned sequence of freshes in spring/early summer for the Wakool-Yallakool system and the Colligen-Niemur system (Figures 2.2 and 2.3) were not delivered because there were already freshes in these river systems due to unregulated flows and water flowing into the Edward/Kolety River from Millewa Forest following the Murray River Spring pulse.

To mitigate the risks from hypoxic blackwater in spring and summer, Commonwealth environmental water was delivered to the Wakool-Yallakool system from the Wakool Escape (watering action 1), the Edward/Kolety system via the Edward Escape (watering action 2), and to the Colligen-Niemur system via the Niemur Escape (watering action 3) (Table 2.6). These were pre-emptive watering actions that commenced following unregulated flows, to manage an increased risk of a hypoxic blackwater event developing. These were pre-emptive watering actions that commenced following the unregulated flows, that brought with them an increased risk of a hypoxic blackwater event developing. Managers had learnt from experience during the 2016 floods, that it is important to start delivering environmental water early to create refuges and attract fish into them before the oxygen levels in the water decreases. Accordingly, in September 2021 (prior to dissolved oxygen concentrations falling below critical levels) water managers commenced the delivery of environmental water via a number of irrigation escapes to create fish refuges in the creeks and rivers in the Edward/Kolety system.

Three environmental watering actions were undertaken in Autumn 2022. There was an Autumn elevated variable base flow delivered to the upper Wakool system via the Wakool offtake from March until early May 2022 (watering action 4). An Autumn fresh was delivered to Yallakool Creek via the Yallakool offtake from late March to early May (watering action 5) and an Autumn fresh was delivered to Colligen Creek via the Colligen offtake in March (watering action 6). An elevated flow delivered to Tuppal Creek (watering action 7) was evaluated to water quality outcomes.

Environmental watering actions to ephemeral and intermittent creeks Jimaringle-Cockran-Gwynnes (WUM 10117-05), Murrain-Yarrien Creek (WUM 10117-06), Thule Creek (WUM 10117-07), Whymoul Creek (WUM 10117-08), Yarrien Creek (WUM 10117-09) and Buccaneit-Cunninyeuk Creek (WUM 10117-15) were qualitatively evaluated in terms of their contribution to longitudinal connectivity.

Environmental watering actions that delivered water to The Pollack (WUM 10117-02), Little Forest (WUM 10117-03), private wetlands (WUM 10117-10) and via Billabong/Finley escape (WUM 10117-14) were not monitored as part of the Flow-MER program.

In 2021-22 the southern spring flow delivered to the Murray River from Hume Dam also contributed environmental water to the EKW system via flows from Millewa Forest. These watering actions are described in Water Use Minute WUM10115-01 for River Murray Hume to South Australia and floodplain and WUM10115-08 for Barmah-Millewa Forest open regulators, in-channel flow (CEWO 2022). These actions were evaluated in conjunction with other watering actions in spring/summer (Table 2,7).

2.8 Commonwealth watering actions from Hume Dam to River Murray in 2021-22 that contributed water to Edward/Kolety-Wakool system

In 2021-22 the southern spring flow delivered to the Murray River from Hume Dam contributed water to the EKW system via return flows from Millewa Forest (Figure 2.4).
These watering actions are described in Water Use Minute WUM10115 for River Murray Hume to South Australia and floodplain and WUM10115-08 for Barmah-Millewa Forest open regulators, in-channel flow (CEWO 2022).

Figure 2.4. Map of southern Murray-Darling Basin with dark blue lines showing pathway of 21/22 Southern Spring flow. (Source CEWO 2022)

Watering actions for River Murray in 2021-22 that impacted on Edward/Kolety River flows

Figures 2.5 and 2.6 are hydrographs showing recorded flows, operational releases and environmental water downstream of Yarrawonga Weir from 1 July to 31 December 2021. These figures show that environmental water actions from Hume Dam were made between airspace releases from Hume Dam.

Spring pulse following natural overbank event described by CEWO (2022) as:

- Wetter antecedent conditions provided natural cues in preceding months. Modelled natural flows downstream of Yarrawonga showed a late June pulse of ~30,000 ML/d and two pulses >45,000 ML/d in late July and in early August.
- Over 100 gigalitres of environmental water was released from Hume Dam between 12 August and 1 September 2021 (20 days) with e-watering commencing from Yarrawonga on 15 August. From 20 October to 9 Nov (20 days)
- Environmental water was made available for use when airspace operations ceased as part of a ‘managed recession’ strategy to avoid a ‘cliff-drop’ hydrograph.

In channel managed deliveries with regulators part opened described by CEWO (2022) as:

- Action from 8 December to 10 January (33 days) and 23 January to 25 February (33 days)
- This action comprised a ‘managed recession’ once the regulated flow returned to 15,000 ML/d downstream of Yarrawonga
- Environmental releases were made between airspace operations
- The fish exit strategy was started/stopped numerous times due to rainfall events which required regulators to remain, or be re-opened.

A detailed breakdown of River Murray watering actions 10115-01 and 10115-08 in 2021-2022 that contributed return flows to the EKW system are described in Table 2.7.

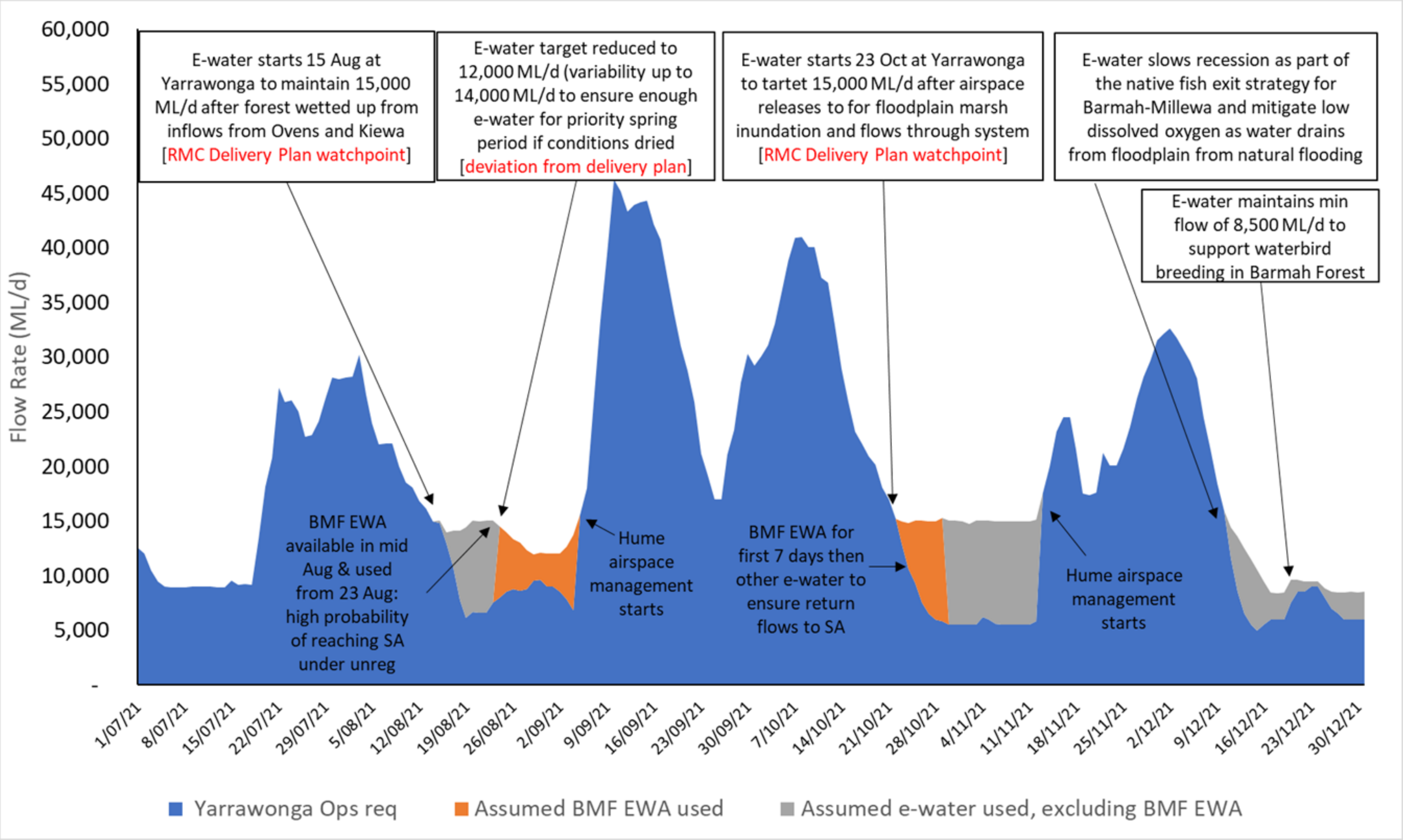
Ecological objectives of Murray River environmental watering actions

The ecological objectives identified in the River Murray Channel Delivery Plan 2021/22, while largely focussed on expected outcomes for River Murray channel, include several objectives that refer to expected benefits for anabranches. Expected outcomes identified in the Plan include:

1. Maintaining current species diversity, extending distributions and improving breeding success and numbers of short, moderate and long-lived native fish species by:
   - Providing in-stream habitat for fish and thereby supporting recruitment of fish (including golden and silver perch spawned in 2016–17, 2018–19 and Murray cod, trout cod, golden perch and silver perch in 2019-20 and 2020-21), particularly by increasing the availability of food resources and habitat during periods where flows would be unnaturally low.
   - Increasing the presence of fast flowing fish habitat along the River Murray and, where feasible, increased lateral connectivity with anabranches and low elevation floodplain wetlands.
   - Improving the body condition of mature fish during winter/spring (pre-spawning conditioning) and providing opportunities for spawning during spring (subject to appropriate seasonal conditions).
   - Contributing to the maintenance of critical habitat, water quality and the provision where possible of localised refuge sites as required.
2. Maintaining the extent and condition of riparian and in-channel vegetation by:
   - Increasing periods of growth for non-woody vegetation communities (including Moira grass) that closely fringe or occur within the River Murray channel, anabranches and low elevation floodplain wetlands.
   - Maintaining the extent and condition of inundation dependent river red gum, black box, lignum and non-woody vegetation within low-lying areas of floodplain, with scale of contribution subject to seasonal conditions.
3. Maintaining current species diversity, extending distributions and improving breeding success and numbers of water dependent bird species by:
   - Supporting suitable habitat conditions and food resources for waterbird growth and survival, maintenance of population condition and diversity along the River Murray valley.
   - Supporting waterbird breeding events if seasonally appropriate.
4. Contributing to riverine functioning by:
   - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.
   - Supporting the managed export of salt and nutrients from the River Murray system.
   - Maintaining lateral and longitudinal flow integrity.

The Watering Action Acquittal Report for the River Murray Flows and Barmah-Millewa Forest Regulators 2021-22 (CEWO, 2022) describes ecological objectives from increased flow rates to include improved:

- area of river red gum forest, understory vegetation, moira grass and wallaby grass inundation
- forest / wetland connectivity
- carbon and nutrient flushing and transportation
- access to habitat and faster flows for native fish supporting dispersal, pre-spawning condition, spawning and recruitment
- improved breeding outcomes for the endangered flatheaded galaxias in the mid Murray wetlands, River Murray channel and creeks in the EKW system.
- river rises in spring, coinciding with higher water temperatures to trigger golden perch breeding (to improve demographics of ageing golden perch population).



E-water starts 15 Aug at Yarrawonga to maintain 15,000 ML/d after forest wetted up from inflows from Ovens and Kiewa [RMC Delivery Plan watchpoint]

E-water target reduced to 12,000 ML/d (variability up to 14,000 ML/d to ensure enough e-water for priority spring period if conditions dried [deviation from delivery plan]

E-water starts 23 Oct at Yarrawonga to tartet 15,000 ML/d after airspace releases to for floodplain marsh inundation and flows through system [RMC Delivery Plan watchpoint]

E-water slows recession as part of the native fish exit strategy for Barmah-Millewa and mitigate low dissolved oxygen as water drains from floodplain from natural flooding

E-water maintains min flow of 8,500 ML/d to support waterbird breeding in Barmah Forest

BMF EWA available in mid Aug & used from 23 Aug: high probability of reaching SA under unreg

Hume airspace management starts

BMF EWA for first 7 days then other e-water to ensure return flows to SA

Hume airspace management starts

Figure 2.5 Hydrograph downstream of Yarrawonga Weir from 1 July to 31 December 2021 showing actual flows, operational releases and environmental water (all e-water products) (Source: MDBA River Murray Operations). Environmental water depicted as grey represents 'held' products or portfolio, while orange depicts Barmah Millewa Environmental Watering Allowance (BM-EWA). BM-EWA was replaced by held environmental water from late October to enable return flows to South Australia. (Figure source CEWO 2022)

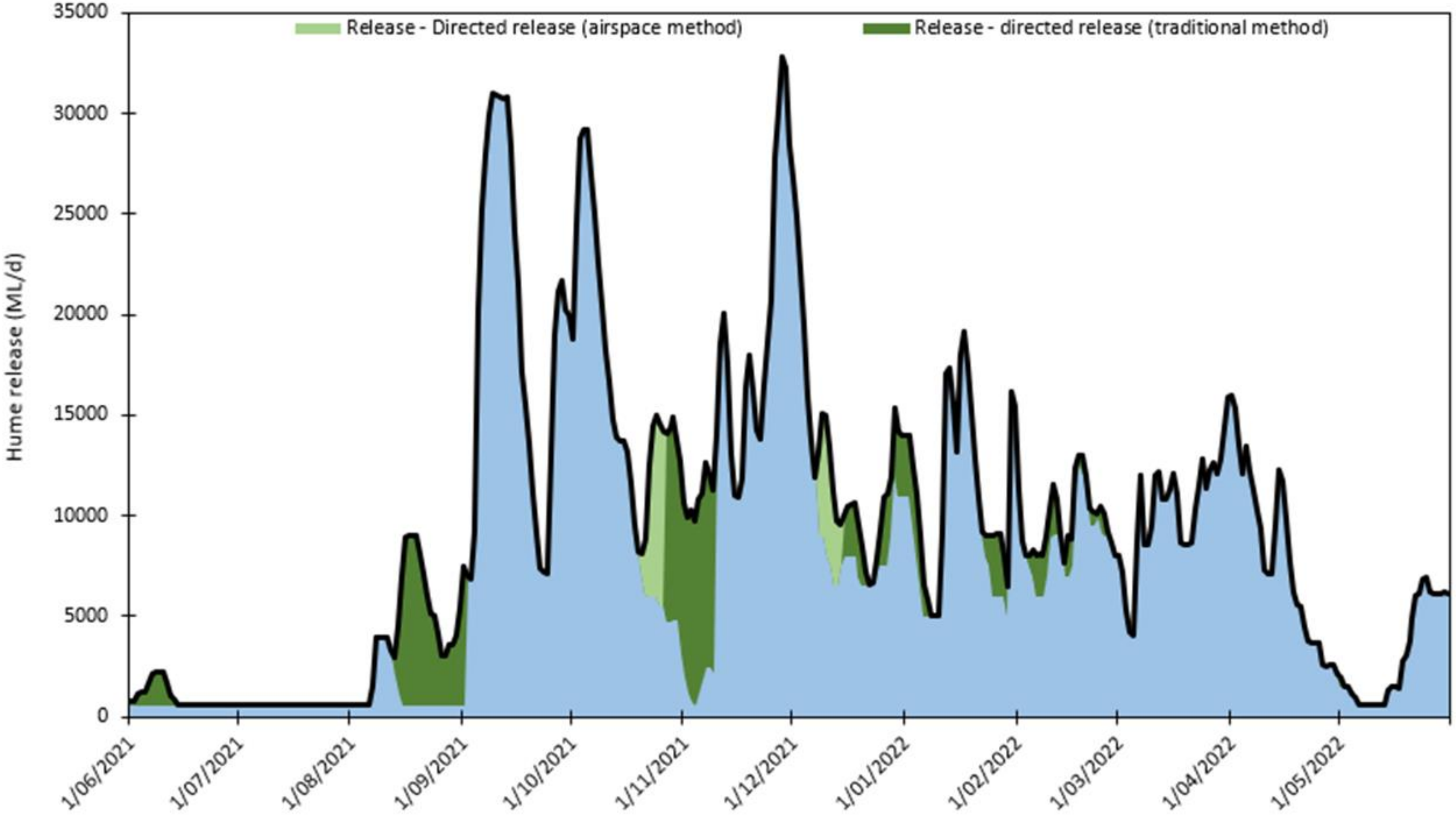


Figure 2.6 Hydrograph showing components of environmental water delivered as Directed Releases from Lake Hume June 2021 to June 2022. Environmental water component is shown as green (dark and pale), with airspace release component of environmental release shown as pale green (Source: MDBA). (Figure Source CEWO 2022)

Table 2.7. Detailed breakdown of watering actions for 2021-2022, showing watering action reference, delivery dates, objectives and water source (see also Figures above for hydrographs of each flow component). Note: Volumes represent approximate splits between components of the flow event, see Section 1 above for exact total usage figures. Note: higher levels of rainfall resulted in numerous breaks in planned watering actions, typically due Hume airspace releases. As a result, multiple date ranges may be shown for a single watering action. (Source: Modified from CEWO 2022)

Dates (start / end) @ d/s Yarrawonga Weir (Note: actual release date below is from Hume Dam)	**Target asset**	**Watering Action Reference No. (WAR)**	**Flow component type and target duration/ extent**	**CEW and other e-water volumes released from Hume and/or delivered to Barmah-Millewa Forest (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may affect expected outcomes**
Spring Pulse following natural / actual overbank event 12 August – 1 September (20 days) 20 October – 9 November (20 days)	• River Murray channel • Creeks, anabranches and wetlands of Barmah and Millewa Forests • Low lying Barmah Millewa Forest Floodplain	10115-01	Large fresh. Managed overbank flows targeting 15,000 ML/d d/s Yarrawonga (with variability 14,500 to 15,000 ML/d) as part of multi-site event. Total duration was 40 days. *NB - order amended to 12,000 ML/d d/s Yarrawonga (with variability 12-14,000 ML/d) for 12 days – 20 Aug to 1 Sept.	CEW Vic: 77,517.5 CEW NSW: 71,994 TLM Vic: 4,476 TLM NSW: 20,000 VEWH: 10,000 BM-EWA Vic: 47,893 BM-EWA NSW: 47,893 RMIF Vic: 0 RMIF NSW: 0	• Supply nutrients and carbon to rivers to support aquatic food webs • Mobilise and export organic matter from low-lying wetlands in cooler months (reducing risk of low-oxygen water events) • Build native fish condition, movement and spawning • Boost productivity • Support riparian vegetation fringing the river and creeks, and in low-lying wetlands. • Increase the availability of habitat and food for native fish and waterbirds • Support native fish spawning	• Wetter antecedent conditions provided natural cues in preceding months. Modelled natural flows d/s Yarrawonga showed a late June pulse of ~30,000 Ml/d and two pulses >45,000 Ml/d in late July and in early August. • Environmental releases were made between airspace operations – see **Figure 4.** • Water order was reduced to 12,000 ML/d for 12 days to conserve the water resource for the primary Spring Action but returned to 15,000 ML/d once resource availability improved. • Environmental water was made available for use when airspace operations ceased as part of a 'managed recession' strategy to avoid a 'cliff-drop' hydrograph. See discussion below for detail. • Note: the planned flow target of 18,000 ML/d d/s Yarrawonga could not be delivered due to Bullatale Creek community concerns. See discussion below. • For additional information on decision making rationale see Spire record #003880121.
In-channel managed deliveries – regulators part opened 8 December – 10 January 2022 (33 days) 23 January – 25 February (33 days)	• River Murray channel • Targeted wetlands in Barmah and Millewa Forests	10115-08	Wetland. Managed in-channel flows with a managed recession from 15,000 Ml/d to target 8,500 ML/d d/s Yarrawonga. Total duration 66 days. Water delivery via gravity-fed regulators into low-lying creeks of Barmah-Millewa Forests while flows remained in-channel	CEW Vic: 30,176.5 CEW NSW: 40,177 TLM Vic: 3,061.5 TLM NSW: 0 VEWH: 10,000 BM-EWA Vic: BM-EWA NSW: RMIF Vic: 25,000 RMIF NSW: 25,000	• Support colonial waterbird breeding in Boals Deadwoods (Barmah Forest). • Support waterbird breeding in the Gulpa wetlands complex (Millewa Forest) • Provide cues to native fish—Fish Exit Strategy—to support fish departure from the forest once *all* forest regulators are closed.	• This action comprised a 'managed recession' once the regulated returned to 15,000 ML/d d/s Yarrawonga, targeting a daily recession rate of 500 ML/d to reach final flow target of 8,500 ML/d. • Environmental releases were made between airspace operations – see **Figure 4.** • Fish Exit Strategy was started/stopped numerous times to rainfall events which required regs to remain, or be re-opened

3 Monitoring, evaluation and research

The overarching principle that underpins this monitoring, evaluation and research in the EKW 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 Flow-MER project (Figure 3.1). The monitoring and research have a strong focus on fish (including reproduction, recruitment and adult populations) and water quality. The EKW 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 EKW 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 EKW system.

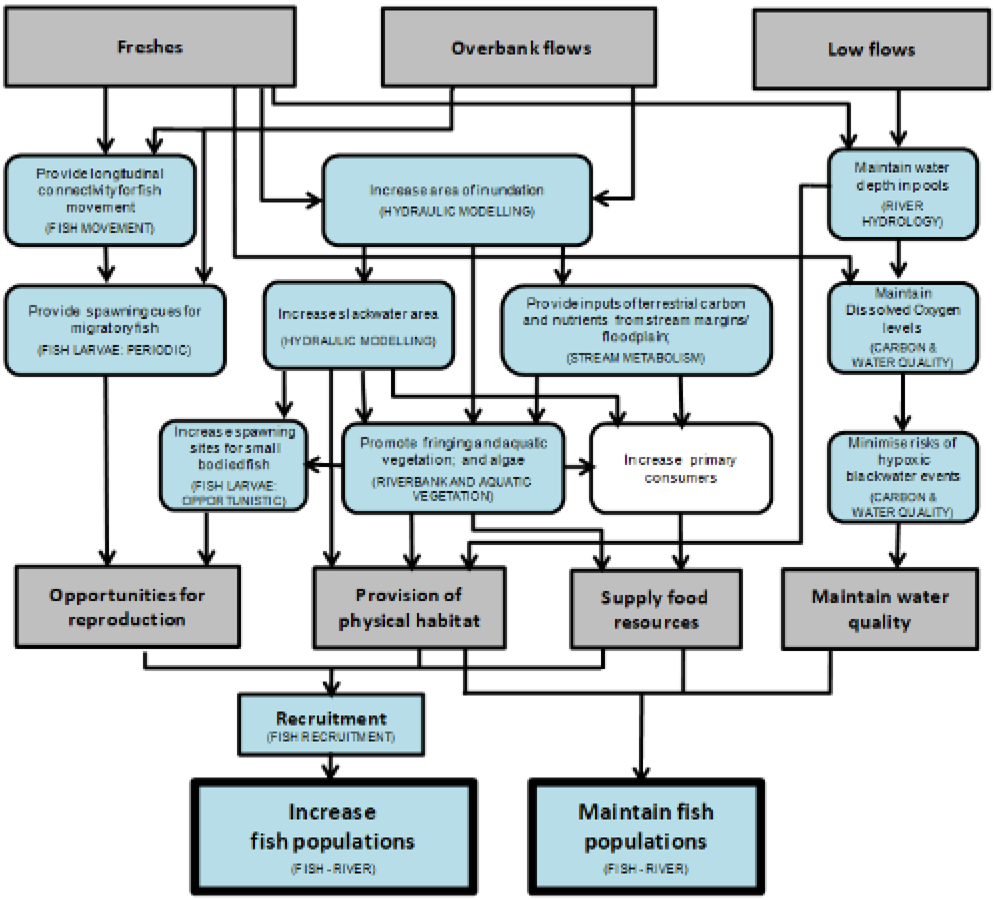
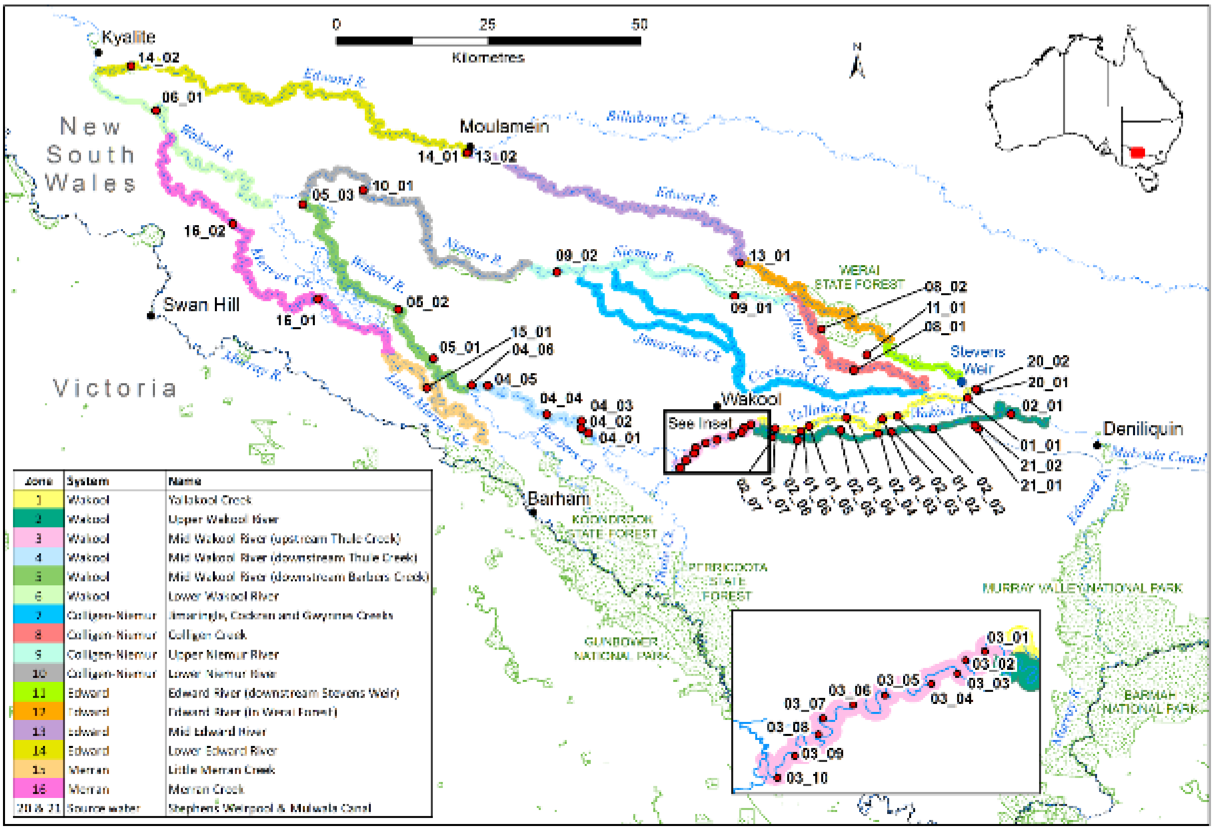


Figure 3.1 Conceptual diagram illustrating three main flow types (low flows, freshes, overbank flows) and their influence on ecosystem components and processes that, in turn, influence fish population dynamics. Indicators included in the Edward/Kolety-Wakool Flow-MER Plan are shown in brackets in boxes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

3.2 Monitoring zones and sites

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

At the commencement of the LTIM program daily discharge data from 14 hydrological stations in the EKW 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.



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

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

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

Figure 3.2 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 Project 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 is not possible to undertake monitoring and evaluation in all sixteen of the hydrological zones identified in the EKW 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 project includes monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the EKW 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 project.
- 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 project and will be surveyed for fish community indices in year three of Flow-MER (2022).
- Additional sites were added to the existing network of water quality monitoring sites established during LTIM project. For the Flow-MER project 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 and the Edward/Kolety River at Stephens Weir. New sites for Flow-MER expanded the water quality monitoring to further downstream in the Wakool River as well as in Tuppal Creek, 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 EKW system.

The Milewa Forest and Koondrook-Perricoota Forest are not included in the Flow-MER project 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 project 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 the Flow-MER project (2019-2022) 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 EKW 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 EKW 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 EKW 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 EKW 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 Flow-MER).

The rationale regarding the selection of indicators is outlined in the EKW Flow-MER Plan (Watts et al. 2019a). Indicators are monitored to contribute to the EKW Selected Area Evaluation and/or the Whole of Basin-scale evaluation Flow-MER project 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) Project 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 MER evaluations, 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 project so that the evaluation of this indicator will be undertaken across the whole EKW 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 project. 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 project 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 project)

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

Indicator	Evaluation questions
Hydrology	*Short and long-term questions* • What was the effect of CEW (Commonwealth environmental water) on the hydrology of the rivers in the EKW system? • What did CEW contribute to longitudinal connectivity?
Carbon and water quality	*Short and long-term questions* • 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? • What did CEW contribute to dissolved oxygen concentrations? • What did CEW contribute to nutrient concentrations? *Question for contingency monitoring* • 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* • What was the effect of CEW on rates of GPP, ER and NPP • What did CEW contribute to total GPP, ER and NPP? • Which aspect of CEW delivery contributed most to productivity outcomes?
Riverbank and aquatic vegetation	*Long-term questions* • 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? • How do vegetation responses to CEW delivery vary among hydrological zones? *Short-term questions* • What did CEW contribute to the percent cover of riverbank and aquatic vegetation? • What did CEW contribute to the diversity of riverbank and aquatic vegetation taxa?
Fish movement	*Short term questions* • Does CEW facilitate longitudinal connectivity for periodic species during winter?
Fish reproduction (Cat 1)	*Long term questions* • What did CEW contribute to native fish populations? • What did CEW contribute to native fish species diversity? *Short term questions* • What did CEW contribute to native fish reproduction? • What did CEW contribute to native fish survival
Fish reproduction	*Short and Long-term questions* • What did CEW contribute to the spawning of 'Opportunistic' (e.g., small bodied fish) species? • What did CEW contribute to spawning in ‘flow-dependent’ spawning species (e.g., golden and silver perch)?
Fish recruitment	*Short and Long-term questions* • What did CEW contribute to native fish recruitment to the first year of life? • What did CEW contribute to native fish growth rate during the first year of life?
Fish river (Cat 1)	*Long term questions* • What did CEW contribute to native fish populations? *Short term questions* • What did CEW contribute to native fish reproduction? • What did CEW contribute to native fish survival?
Fish community	*Long-term question* • How does the fish community in the EKW system vary over 3-5 years, and does this link with sequential flow characteristics?

3.3 Evaluation of monitoring outcomes

The outcomes of Commonwealth environmental watering undertaken in 2020-21 were evaluated using 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:

i) Indicators that respond quickly to flow (e.g., hydrology, water quality and carbon, stream metabolism, germination and percent cover of riverbank plants, 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., diversity of riverbank and aquatic plants, 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.

New approach to evaluation of environmental watering actions for 2021-22 water year

Previous annual reports for the EKW system as part of the LTIM program (2014-2019) and Flow-MER program (2019-2022) have evaluated the effect of Commonwealth environmental water actions on the hydrology of the EKW system. In each of these reports the evaluation was based on the contribution of CEW watering actions to deliver environmental water that was targeted specifically for use in the EKW system, to be delivered via offtake regulators or Murray Irrigation limited irrigation escapes within the system.

In addition to environmental watering actions that were specifically targeted for the EKW system, in some years water delivered to the Murray River channel from Hume Dam has indirectly influenced the hydrology of the EKW system when environmental water targeted for the Murray River flowed into the EKW system (Table 2.3). It was not previously possible to evaluate the impact of these actions on the system because there was no modelling available to estimate the contribution of CEW from Hume to the EKW system hydrographs. In the years when environmental water was delivered to the Murray River and Millewa Forest, it is likely that some of the environmental water contributed to environmental outcomes in EKW system. Thus, it is likely in previous evaluation reports we have underestimated the influence of Commonwealth environmental water.

An evaluation of watering actions in 2021-22 annual report will be undertaken using new approach. In addition to evaluating the outcomes of watering actions targeted specifically for the EKW system, we have included an evaluation of the outcomes of watering actions delivered from Hume Dam for the Murray River on the hydrology of the EKW system (Table 3.4). New hydrological modelling and additional calculations were undertaken in 2021-22 that has facilitated this new approach to evaluation.

Table 3.4 Delivery points of Commonwealth environmental water that influence the hydrology of rivers the Edward/Kolety-Wakool River system in 2021-22.

Source	Rivers in the Edward/Kolety-Wakool system affected by watering actions from these delivery points	Included in evaluations pric to 2021-22	Included ir 2021-22 evaluation
Wakool Offtake from Stevens Weir	Entire Wakool River	Yes	yes
Yallakool Offtake from Stevens Weir	Yallakool Creek, Wakool River downstream of junction with Wakool River	Yes	yes
Colligen Offtake regulator from Stevens Weir	Colligen Creek, Niemur River downstream of junction with Colligen Creek	yes	yes
Wakool escape from Mulwala canal to Wakool R	Entire Wakool River downstream of Wakool escape	yes	yes
Niemur escape from Northern Branch Canal to Niemur River	Niemur River downstream Niemur escape, Wakool River downstream of junction with Niemur River	yes	yes
Edward Escape from Mulwala canal to Edward River	Edward/Kolety River downstream of Edward escape, Wakool River, Yallakool Creek, Colligen Creek, Niemur River	Not included as component of tributary flows	yes
Hume Weir delivery to Murray River	Entire Edward/Kolety-Wakool system downstream of return flows from MIllewa Forest	no	yes

3.4 Research

As part of the Edward/Kolety-Wakool Flow-MER Program (2019-2022) there were 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 EKW system.

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 3.5). 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 3.5).

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. Yarkuwa Indigenous Knowledge Centre is a collaborative partner on the research on turtles and understorey and groundcover vegetation in Werai Forest. The Werai Forest project was completed in 2022 and has been published in a separated stand-alone report (Watts et al. 2022) https://www.dcceew.gov.au/water/cewo/publication/edward-kolety-wakool-mer-project-werai-forest-report-2022.

Table 3.5 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 Edward/Kolety-Wakool 2019-20 annual 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 mammals in the Edward/Kolety river system	2019-2020	Completed. Outcomes published in Edward/Kolety-Wakool 2019-20 annual report
Turtles	How does connectivity of wetlands along the Edward/Kolety River affect turtle distribution, movement and body condition?	2019-2021	Completed. Outcomes published in Edward/Kolety-Wakool 2020-21 annual 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	Completed. Outcomes published in Edward/Kolety-Wakool 2020-21 annual 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	Completed. Published in Werai Research Report 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	Completed. Published in Werai Research Report 2022
Werai Forest primary productivity	Does connectivity of flows into Werai Forest contribute to primary productivity outcomes in the Edward/Kolety River?	2019-2022	Completed. Published in Werai Research Report 2022

4 Hydrology

Author: Robyn Watts

Key findings	
Maximum and minimum discharge	• The spring environmental watering actions, combined with unregulated flows and the southern spring flows in the Murray River, increased the total annual discharge (ML/year) in all reaches (14% increase in zone 1, 30% in zone 2, 20% in zone 3, 17% in zone 4 and 12% in zone 8) • Commonwealth environmental watering actions 5 and 6 autumn freshes increased the maximum discharge of freshes compared to operational flows. • The watering actions did not change the minimum discharge in hydrological zones because all zones experienced a winter shutdown operational cease to flow in 2021-22.
Flow variability	• There was a slight reduction in the coefficient of variation across the whole water year in zone 1 (8%), zone 2 (9%), zone 3 (5%), and zone 8 (6%). This was due to the return flow from Millewa Forest increasing base flows during spring, thus reducing the variation from trough to peak flows during spring/early summer. In Yallakool Creek the reduced variability was more pronounced in spring/early summer.
Longitudinal connectivity	• The unregulated flows in spring increased longitudinal connectivity by initiating flows in several intermittent and ephemeral creeks and flood runners that connect the main tributaries in the system. The delivery of CEW from the Wakool escape and the return flows of CEW delivered to Millewa Forest extended the recession of the events from November through to January, thus increasing the duration of these longitudinal connections.
lateral connectivity	• The unregulated flows and the environmental watering actions during spring and autumn increased the lateral connectivity and hydraulic diversity in study reaches. The delivery of environmental water from the Wakool escape to the upper Wakool River and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event from November through to January, thus increasing the duration of the lateral connectivity.

4.1 Background

Like many rivers of the MDB, the flow regimes of rivers in the EKW 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 EKW 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. During this period localised fish deaths were recorded on several occasions including in 2006 and 2009. At the break of the drought after many years without overbank flows, 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. In the Murray catchment, Murray River flows at Yarrawonga in October were the highest since 1993 (MDBA River Murray Weekly Report, 7th Dec 2017). The unregulated flows from the Murray River inundated the floodplain including Barmah Forest and Koondrook–Perricoota Forests and agricultural land, and resulted in a very large flood event in the EKW system (BOM 2017). In association with the floods there was a hypoxic blackwater event that extended throughout the Murray River system, including the EKW system.

In some years environmental water delivered to the Murray River channel from Hume Dam has indirectly influenced the hydrology of the EKW system. This occurs when environmental water targeted for the Murray River flows into Millewa Forest and then drains into the Edward/Kolety River, thus also contributing to flows in the Wakool River, Yallakool Creek and Colligen-Niemur system. For example, in 2019 environmental water delivered from Hume dam to the Murray River (Southern connected flows or multi-site flows) resulted in some environmental water flowing from Millewa Forest to the Edward/Kolety River. Similarly, environmental water delivered to the Murray River from Hume Dam in 2021-22 will have influenced the hydrology of the EKW system in 2021-22, and those return flows from Millewa Forest will be evaluated in this report.

It was not previously possible to evaluate the impact of these actions on the system because there was not an appropriate model available to estimate the contribution of CEW from Hume to the EKW system hydrographs. Thus, it is likely in previous evaluation reports we may have underestimated the full influence of Commonwealth environmental water by not including this component. In 2021-22 a different approach was used to calculate the contribution of CEW to this system. This chapter reports on the hydrology of the EKW system from 1 July 2021 to 30 June 2022.

New approach to evaluation of Commonwealth environmental watering actions for 2021-22

Previous annual reports for the EKW system as part of the LTIM program (2014-2019) and Flow-MER program (2019-2021) have evaluated the effect of Commonwealth environmental water actions on the hydrology of the EKW system. In each of these reports the evaluation was based on the contribution of CEW watering actions undertaken to deliver environmental water ordered specifically for targeted use in the EKW system, to be delivered via regulators or Murray Irrigation limited irrigation escapes within the system.

In addition to environmental watering actions that were specifically targeted for the EKW system, in some years water delivered to the Murray River channel from Hume Dam has indirectly influenced the hydrology of the EKW system when environmental water targeted for the Murray River flowed into the EKW system. It was not previously possible to evaluate the impact of these actions on the system because there was no modelling available to estimate the contribution of CEW from Hume to the EKW system hydrographs. In those years when environmental water was delivered to the Murray River and Millewa Forest, it is likely that some of this environmental water contributed to flows in EKW system. Thus, it is likely in previous years we have underestimated the influence of Commonwealth environmental water due to this omission.

In the 2021-22 annual report we are taking a new approach. In addition to evaluating the outcomes of watering actions targeted specifically for the EKW system, we have evaluated the outcomes of watering actions delivered from Hume Dam for the Murray River on the hydrology of the EKW system (Table 4.1). New hydrological modelling and additional calculations have been undertaken in 2021-22 that has enables us to undertake this new approach to evaluation.

Table 4.1 Delivery points of Commonwealth environmental water that influence the hydrology of rivers the Edward/Kolety-Wakool River system in 2021-22.

Source	Rivers in the Edward/Kolety-Wakool system affected by watering actions from these sources	Included in evaluations prior to 2021-22	Included in 2021-22 evaluation
Wakool Offtake from Stevens Weir	Entire Wakool River	Yes	yes
Yallakool Offtake from Stevens Weir	Yallakool Creek, Wakool River downstream of junction with Wakool River	Yes	yes
Colligen Offtake regulator from Stevens Weir	Colligen Creek, Niemur River downstream of junction with Colligen Creek	yes	yes
Wakool escape from Mulwala canal to Wakool R	Entire Wakool River downstream of Wakool escape	yes	yes
Niemur escape from Northern Branch Canal to Niemur River	Niemur River downstream Niemur escape, Wakool River downstream of junction with Niemur River	yes	yes
Edward Escape from Mulwala canal to Edward River	Edward/Kolety River downstream of Edward escape, Wakool River, Yallakool Creek, Colligen Creek, Niemur River	Not included as component of tributary flows	yes
Hume Weir delivery to Murray River	Entire Edward/Kolety-Wakool system downstream of return flows from MIllewa Forest	no	yes

4.2 Environmental watering actions 2021-22

Actions targeted for the Edward/Kolety-Wakool system

Six watering actions were delivered during the 2021-22 water year to the Wakool-Yallakool system and the Colligen-Niemur system (Table 4.2). The water for actions 1 to 3 was sourced from Murray Irrigation Limited (MIL) canal network and delivered through irrigation escapes. The environmental water for actions 4 to 6 was sourced from the weirpool in Stevens Weir.

Table 4.2 List of environmental watering actions evaluated in 2021-22 in the Edward/Kolety-Wakool system, with cross reference to the Water Use minute watering action reference number.

Action	System	Watering Action Reference Number	Type (delivery point)	Dates
1	Wakool-Yallakool	WUM10117-11	Spring-summer hypoxic blackwater refuge (Wakool escape)	14/09/21 - 05/01/22
2	Edward/ Kolety	WUM10117-12	Spring-summer hypoxic blackwater refuge (Edward escape)	06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	WUM10117-13	Spring-summer hypoxic blackwater refuge (Niemur escape)	07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	WUM10117-1	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
5	Wakool-Yallakool	WUM10117-1	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
6	Colligen-Niemur	WUM10117-1	Autumn fresh (Colligen offtake)	03/04/22 -26/04/22

Environmental watering actions 2021-22 to Murray River from Hume Dam

Between August 2021 to February 2022 Commonwealth environmental watering actions in the Murray River using water delivered from Hume Dam were delivered as part of the Southern Connected Flow in the Murray River. These actions delivered water to Millewa Forest, and some of this environmental water flowed into the EKW system.

Goulburn Broken Catchment Management Authority (GB CMA) (2022) describes the flooding in Barmah-Millewa Forest in 2021-22. Selected comments from Table 5 (GB CMA 2022) and section 5.5 relevant to the Edward/Kolety system are as follows:

- *Five main natural flood peaks occurred in late-July to early-December, the largest briefly peaking at 46,700 ML/d from Yarrawonga on 11 September 2021.*
- *Translucent Regulator operations in August and September (water losses to the forest were underpinned by environmental water accounts) progressively diverted some water through both Barmah and Millewa forests until environmental water releases commenced in mid-October and progressively ceasing mid- to late-December.*
- *Air space management of Hume Reservoir during spring provided benefit to the flooding of Barmah-Millewa Forest without cost to e-water accounts.*
- *The bulk of environmental water releases were made in mid-October to mid-November (at maximum permissible constraint of 15,000 ML/d from Yarrawonga) to target Floodplain Marshlands (Moira Grass plains). Natural flooding in mid-November finished the need for most*

of the forest e-watering before tapering back to regulated river channel capacity of 9,000ML/d in mid-December.

- *Approximately 45% of Barmah Forest and 55% of Millewa Forest floodplain was inundated (based on Keogh 2012 model runs at 35,000ML/d for a month).*
- *Some unseasonal flooding occurred in mid-January (peaking at 17,600 ML/d) and early-February (peaking at 25,600 ML/d), caused by high rainfall totals in the upper catchment. As the peaks exceeded the level that could be preferentially managed into Millewa Forest (given that the 2020-21 year was scheduled to be the year that water management was to bias that side of the river) then both Barmah and Millewa forest regulators were all fully opened during those flows. As such, much of the lower B-M floodplain was reflooded during summer which resulted in some hypoxic blackwater to develop and return to the Murray and Edwards rivers. Hypoxic blackwater development in January and February fortunately did not result in any known fish deaths incidents. It is likely that higher dissolved oxygen concentrations in the Murray River provided adequate refuge for any fish that could have escaped from the lower forest waterways back into Barmah Lake and the adjoining river.*

Figure 4.1 sourced from GB CMA (2022) shows the extent of Barmah-Millewa floodplain inundation following the larger of the natural flood peaks to have occurred during spring 2021 (briefly peaking at 45,700ML/day downstream of Yarrawonga on 11 September 2021). GB CMA (2022) estimate that approximately 55% of the active floodplain (or 50% of the forest reserve) was inundated at the peak of natural flooding in spring 2021 (based on hydrodynamic modelling of 35,000ML/d for a month run; Keogh 2012). In Figure 4.1 there are extensive inundated areas in Millewa Forest that would have drained into the Edward/Kolety River.

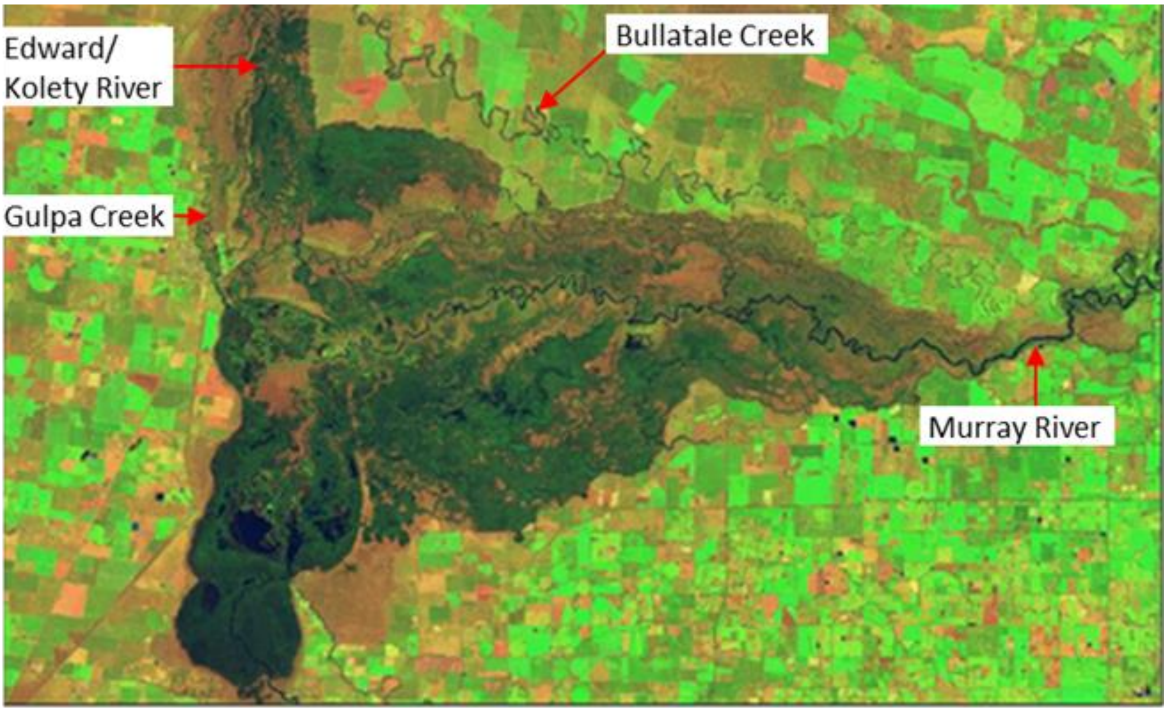


Figure 4.1 Colour enhanced Sentinel-2 satellite image of Barmah-Millewa Forest, taken 22 October 2021 representing nearest cloud-free image to the flood peak 42 days earlier at 45,700ML/d at Yarrawonga), showing extent of floodplain inundation and water flow path from Millewa Forest to the Edward River (from Sentinel-hub 2021).

4.3 Selected Area evaluation questions

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

Total annual discharge

The total annual discharge (ML/year) for each of the study zones was calculated by adding the daily discharge from 1 July 2021 to 30 June 2022 for each of the study zones.

Observed vs modelled natural flows

Modelled natural conditions at Toonalook gauge and Downstream of Stevens Weir gauge in the Edward/Kolety River are modelled scenarios assuming no dams, weirs or consumptive diversions from the river, but does not exclude the impact of land use changes or levees in the river system. Plots of modelled natural flows were generated by the MDBA using MSM-Bigmod.

Daily discharge for automated gauges

Daily discharge data for automated hydrometric gauges (Table 4.3) 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.

Table 4.3 Details of Water NSW hydrometric gauges used to obtain discharge data. Zone codes are as described in Table 3.1.

River	LTIM zone	Gauge number	Name of gauge
Murray River		409025	Yarrawonga
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		409048	Niemur@ Barham-Moulamein Rd
Niemur River	10	409086	Niemur at Mallan School
Edward/Kolety River		409008	Edward River Offtake
Edward/Kolety River		409047	Edward River Toonalook
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

Daily discharge for monitoring reaches that do not have automated gauges

Some of the monitored reaches (Wakool River zone 2 downstream of the Wakool escape, and Wakool River zone 3) do not have automated hydrometric gauging stations.

The total daily discharge data for sites in the Wakool River zone 2 downstream of the Wakool escape 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.

Sources of Commonwealth environmental water

In 2021-22 a new approach was used to calculate the source of CEW in the EKW system. Sources included in the analysis are described in Table 2.1. In 2021-22 Commonwealth environmental water in the EKW system was provided from seven sources:

- Wakool Offtake from Stevens Weir
- Yallakool Offtake from Stevens Weir
- Colligen Offtake regulator from Stevens Weir
- Wakool escape from Mulwala canal to Wakool R
- Niemur escape from Northern Branch Canal to Niemur River
- Edward Escape from Mulwala canal to Edward River
- Hume Weir delivery to Murray River

Calculation of contribution of Commonwealth environmental water to daily discharge

Details of source of data and calculations are provided in Table 4.4.

The daily Commonwealth environmental water that was specifically ordered and delivered to Wakool River, Yallakool Creek and Colligen Creek was provided by WaterNSW and the CEWO.

Details of daily CEW use at the Wakool Escape and Edward Escape were provided by Murray Irrigation Limited.

The total daily discharge within Stevens Weir that was available as the source for delivery of water to tributaries was calculated by adding daily discharge DS Stevens Weir (409023), daily discharge Yallakool Creek (409020), daily discharge Wakool offtake (409019), daily discharge Colligen Creek (409024) and daily discharge Wakool Main canal (data sourced from MIL).

The daily proportion of CEW from Edward Escape that was in Stevens Weir was calculated as daily delivery of CEW from Edward escape/ daily total within Stevens Weir.

The daily proportion of CEW from delivered from Hume Weir to Murray River that was available within Stevens Weir was calculated using a hydrological model undertaken by MDBA. The model estimated the contribution of CEW from Hume Dam at Toonalook and the gauge downstream of Steven Weir. Calculations usingdaily observed discharge were undertaken to estimate the proportional contribution of CEW from Hume Dam flowing through the Yallakool, Wakool, Colligen Creek regulators.

Table 4.4 Details of source of CEW for each monitoring zone, and details of calculations.

Source of CEW	Components of CEW	Calculation
Yallakool Creek (zone 1 site 5)	CEW ordered from Yallakool offtake Proportion of CEW Edward escape of total discharge at Yallakool offtake Proportion of CEW Hume Dam of total discharge at Yallakool offtake	Daily CEW use provided by Water NSW and CEWO Proportion_usStevens_edwardEscape_cew * zone1_total proportion_usStevens_hume_cew * zone1_total
Wakool River (zone 2, site 4)	CEW ordered from Wakool (zone 2) offtake CEW ordered from Wakool escape Proportion of CEW Edward escape of total discharge at Wakool offtake Proportion of CEW Hume Dam of total discharge at Wakool offtake	Daily CEW use at Wakool offtake provided by Water NSW and CEWO Daily CEW use from escape provided by MIL Proportion_usStevens_edwardEscape_cew * zone2_offtake proportion_usStevens_hume_cew * zone2_offtake
Wakool River (zone 3, site 5)	Daily component of CEW from Wakool offtake, Yallakool offtake, Edwad Escape, Wakool Escape, Hume Dam	(zone1_cew+zone2_cew)* zone3_seasonal.loss + 4 days travel
Wakool River (zone 4 site 5)	Daily component of CEW from Wakool offtake, Yallakool offtake, r Escape, Wakool Escape, Hume Dam	zone3_cew * zone4_seasonal.loss + 5 days offset
Colligen Creek	CEW ordered from Colligen offtake Proportion of CEW Edward escape of total discharge at Colligen offtake Proportion of CEW Hume Dam of total discharge at Colligen offtake	Daily CEW use provided by Water NSW and CEWO Proportion_usStevens_edwardEscape_cew * colligen_offtake proportion_usStevens_hume_cew * colligen_offtake

Flow metrics

Daily discharge data were used to produce hydrographs showing the overall daily discharge and the proportion of that flow that is Commonwealth environmental water for five hydrological zones (zone 1 Yallakool Creek, zone 2 upper Wakool River, zone 3 mid-Wakool River upstream Thule Creek, zone 4 mid-Wakool River downstream Thule Creek, zone 8 Colligen Creek). The total annual discharge (ML) minimum daily discharge (ML/d), maximum daily discharge (ML/d), mean daily discharge (ML/d), median daily discharge (MLd/) and coefficient of variation (SD/mean) of the annual daily discharge was calculated with and without Commonwealth environmental water.

Longitudinal connectivity

The extent of longitudinal connectivity was evaluated qualitatively, by examining Sentinel-2 images from during the unregulated flow event.

Lateral connectivity

The extent of lateral riverbank inundation was undertaken using the results of 2-dimentsional hydraulic modelling undertaken at reaches in the EKW system by in Watts et al. (2015). A 2D hydraulic model was created for nineteen river reaches each 4 km in length. 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 were 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 was used to estimate the daily wetted area due to operational discharge and discharge including Commonwealth environmental water.

Comparison of CEW contribution to flows in 2021-22 to approach used in previous water years

The percent CEW of the total discharge during each watering action was calculated in two ways to facilitate a comparison of the current and previous method for estimating contribution of CEW to daily discharge in a zone:

i) Method used for 2021-22 reporting - Representing all CEW components. This was calculated by adding the daily discharge for all of the components of CEW in that zone, divided by the daily discharge for that zone

ii) Method for watering years prior to 2021-22 - Representing only CEW that was ordered to be delivered at the offtakes. Discharge of CEW delivered at a given offtake divided by total daily discharge for that zone.

4.5 Results

Weather in the mid-Murray in 2021-22 water year

In 2021 the rainfall was above average in the upper and mid-Murray catchment (Figure 4.2), with unregulated flows commencing in August and continuing through to October 2021. The mean temperature in the catchment through 2021 was average (Figure 4.3).

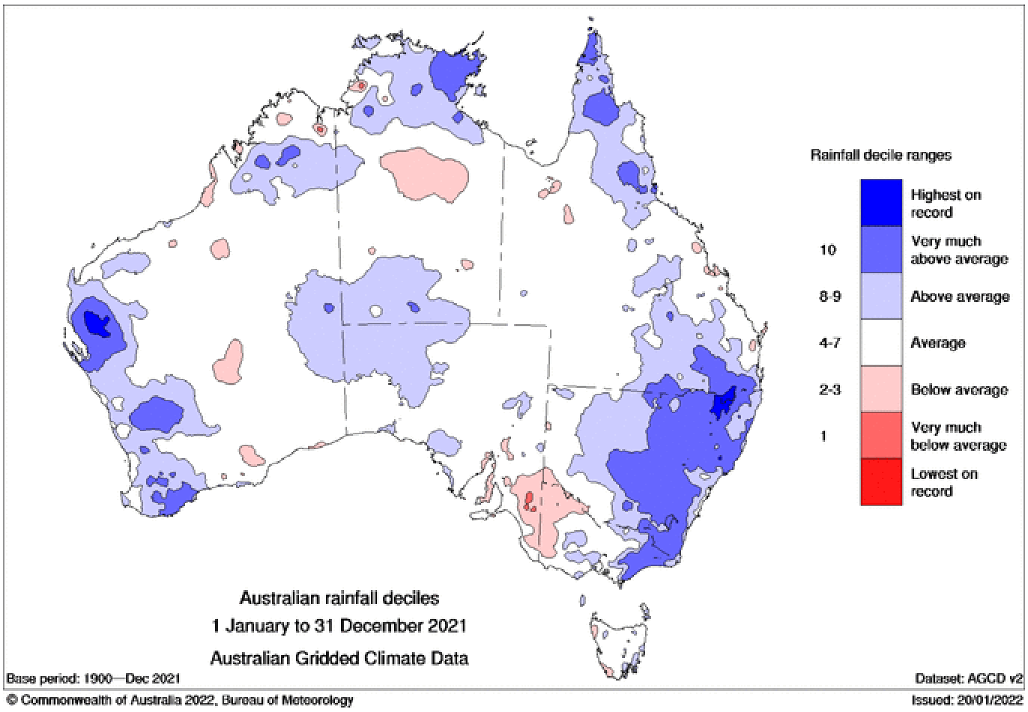


Figure 4.2 Rainfall deciles for 2021 (Source: Bureau of Meterology).

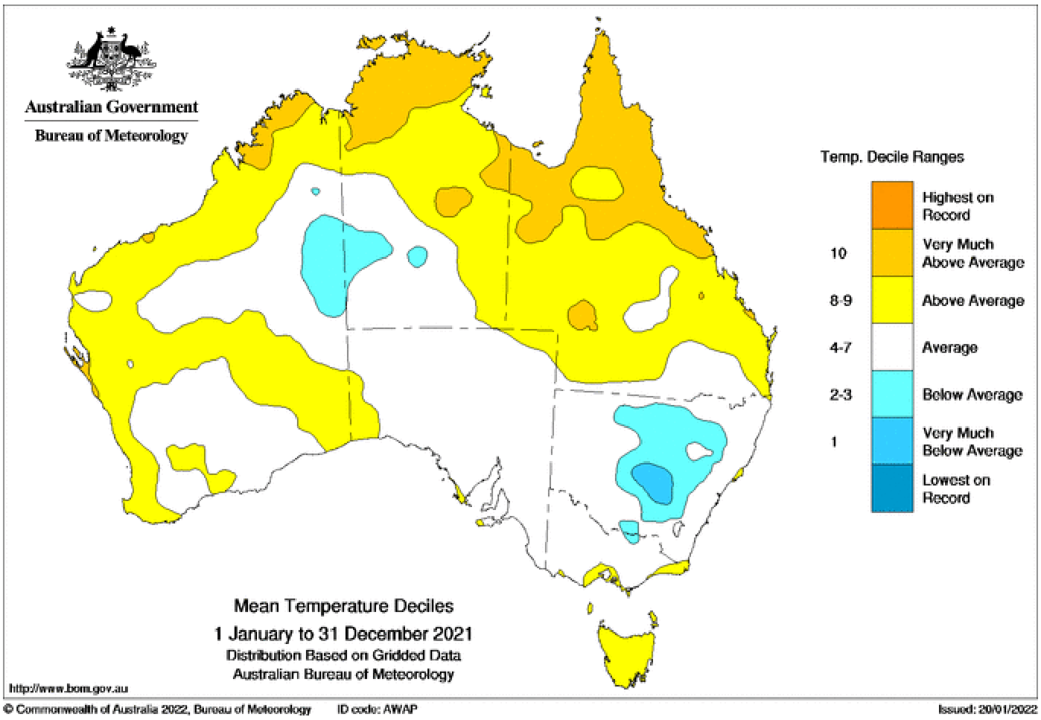


Figure 4.3 Average temperaturedeciles for 2021 (Source: Bureau of Meterology).

Comparison of hydrology across 8 years of LTIM/Flow-MER program (1/7/2014 - 30/6/2022)

The LTIM/Flow-MER program has been underway for eight water years, since July 2014. Over the eight years there has been a wide range of hydrology experienced in the hydrological zones in the EKW system.

In six of the water years (2014-15, 2015-16, 2017-18, 2018-19, 2019-20, 2020-21) there were only small freshes delivered in the EKW system. The flows were largely constrained by normal regulated operating rules, with exception of two flow trials which delivered smaller freshes up to 800 ML/d in Wakool/Yallakool2018-19 and 2020-21.

In 2016-17 there was a very large unregulated flood, when flows were unregulated and resulted in widespread flooding and widespread hypoxic blackwater throughout the Murray River downstream of Yarrawonga Weir.

The 2021-22 water year had very different hydrology to all other years over the eight years of LTIM/Flow-MER program. In 2021-22 there was an extended period of unregulated flows (Figures 4.4 and 4.5). Consequently, all study reaches in the Edward/Kolety-system experienced a total annual discharge (ML/ year) that was larger than all years of the LTIM/Flow-MER program, except 2016-17 (Figure 4.6). Downstream of Stevens Weir, this exceeded the threshold at which water flows over the Tumudgery Creek regulator into Werai Forest (Figure 4.4). This contrasting hydrology in 2021-22 provides an opportunity to compare responses to flows under different conditions to those that have previously been evaluated as part of the LTIM/Flow-MER program. The total discharge and relative contribution of environmental water to zone 2 (upper Wakool River) was considerably larger in 2021-22 than in previous years (Figure 4.6).

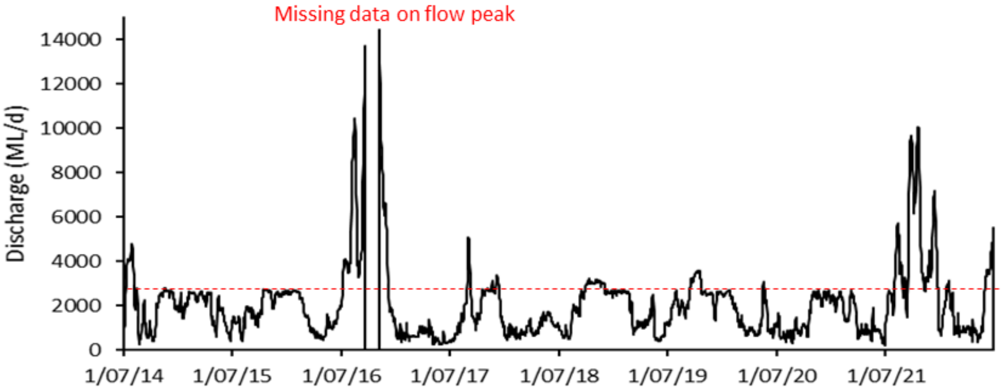


Figure 4.4 Hydrograph showing daily discharge (ML/d) in the Edward/Kolety River downstream of Stevens Weir from 1/7/2014 to 1/7/2022. The horizontal dashed red line indicates the threshold at which water flows over the Tummudgery regulator into Werai Forest

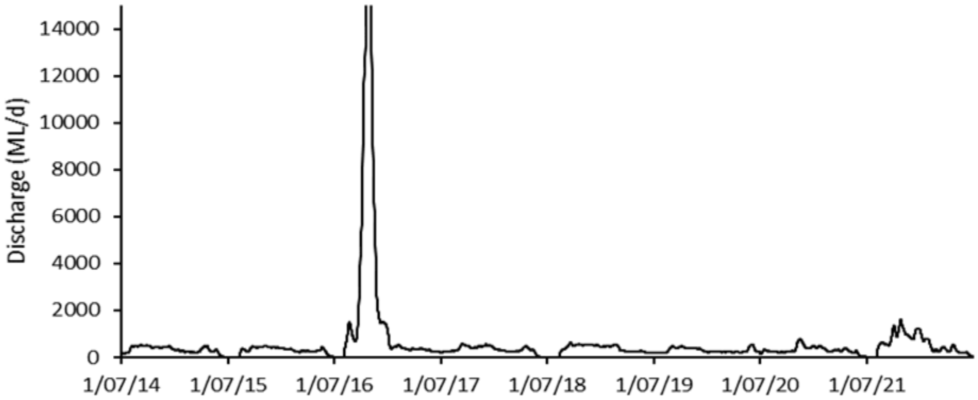


Figure 4.5 Hydrograph showing daily discharge (ML/d) in the Wakool River at the gauge at Wakool Barham Road from 1/7/2014 to 1/7/2022.

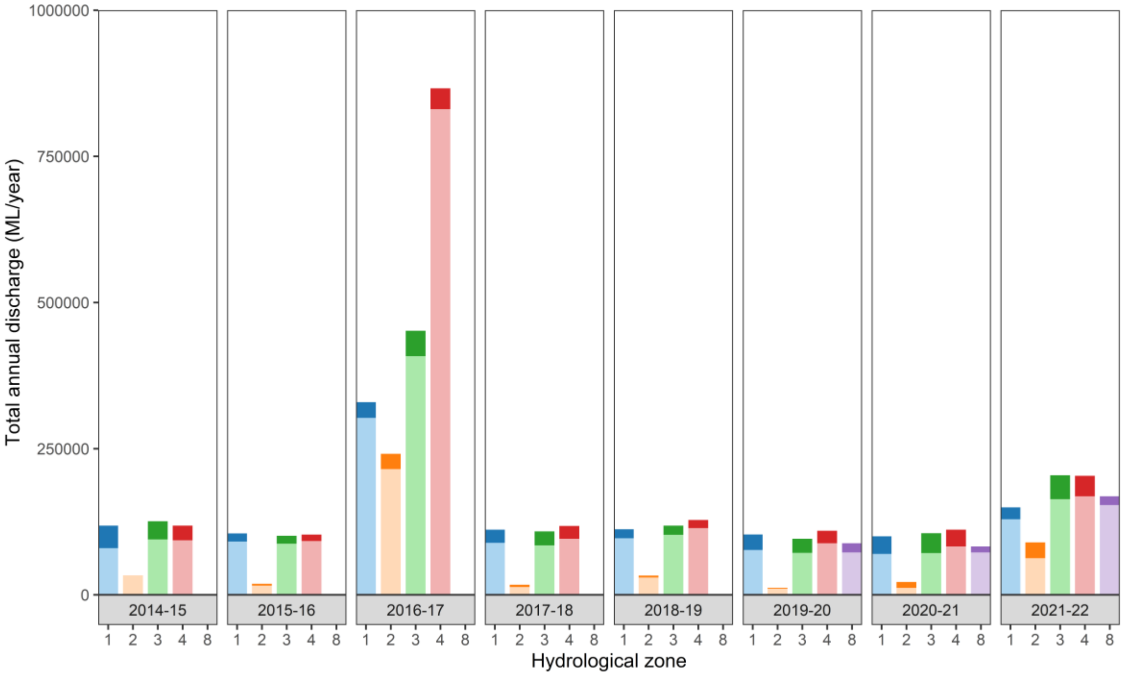


Figure 4.6 Total annual discharge (ML/year) for each of the study zones in the Edward/Kolety-Wakool system, calculated from 1/7/2014 to 1/7/2022. Dark portion of each column indicates the contribution of Commonwealth environmental water to the total annual discharge. Zone 1 Yallakool Creek (Blue), zone 2 upper Wakool River (orange), zone 3 mid-Wakool River upstream of Thule Creek (green), zone 4 mid Wakool downstream of Thule Creek (red), zone 8 Colligen Creek (purple).

Observed and modelled natural flows 2021-22

The observed vs modelled natural conditions at Toonalook gauge and the gauge downstream of Stevens Weir in the Edward/Kolety River are presented in Figure 4.7. Under modelled natural scenario there would have been two large (>20,000 ML/d) unregulated flow peaks in the Edward/Kolety system during August and September in 2021-22, however the observed flow peaks for those two events were considerably lower than expected under modelled natural flows (Figure 4.7). The observed vs modelled natural flows were more similar for three smaller flow peaks in October and December 2021 and January 2022.

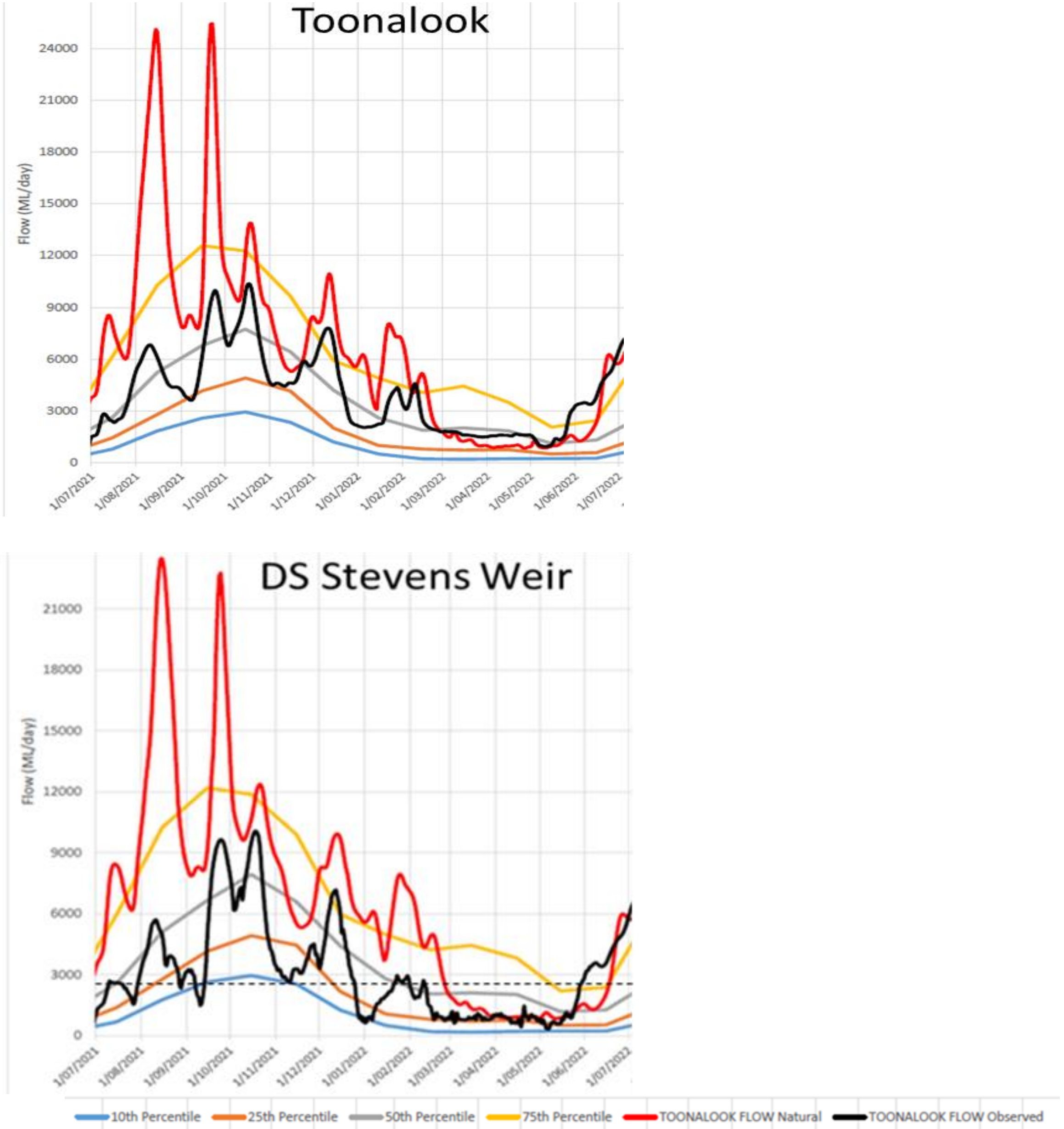


Figure 4.7 Hydrograph showing observed and modelled natural daily discharge in the Edward/Kolety River from 1/6/2021 to 1/7/2022 at the Toonalook and DS Stevens Weir gauges. (Source: MDBA). Flows downstream of Stevens Weir did not reach minor flood level (5.5 m) at any stage during the water year. Black horizontal dashed line on the DS Stevens Weir hydrograph is 2700 ML/d when water commences to flow over Tumudgery regulator into Werai Forest.

Hydrology in 2021-22

In the Edward/Kolety River system downstream of the Edward offtake the discharge was controlled at offtake and held steady for most of the year (Figure 4.8). The flows in the Edward/Kolety River at Toonalook includes return flows from Millewa forest. At Toonalook gauge and all gauges downstream of Stevens Weir the discharge was considerably more variable than at the Edward offtake, and this variability in flows continued down through the Edward/Kolety River to Liewah (Figure 4.8). Unregulated flow downstream of Stevens Weir exceeded 2700 ML/d (Werai regulators open) for extended period in 2021-22. The discharge at Moulamein is lower than at the DS Stevens Weir gauge. This is because some of the water in the Edward/Kolety River entered Werai Forest via Tumudgery Creek and Niemur offtake regulator and Reed Beds regulator.

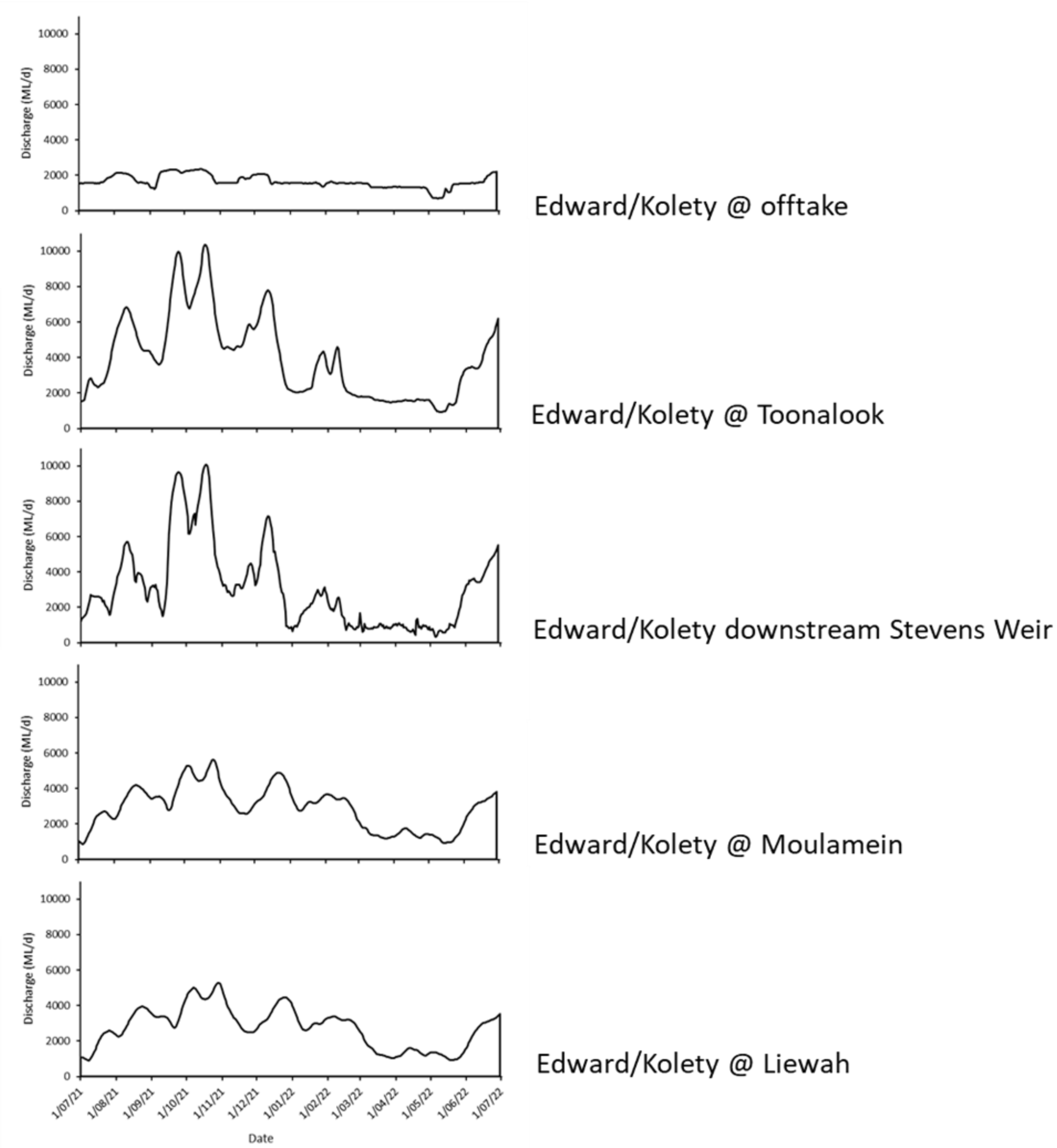


Figure 4.8 Hydrographs for the Edward/Kolety River at the Edward River offtake (gauge 409008), Toonalook (gauge 409047), downstream of Stevens Weir (gauge 409023), Moulamein (gauge 409104) and at Liewah (gauge 409035) from 1 July 2021 to 30 June 2022.

In the Wakool-Yallakool system, unregulated flows occurred in Yallakool Creek and Wakool River during multiple freshes during August to January. (Figure 4.9). The hydrograph in the Wakool River at Barham-Moulamein Rd includes combined flows from Wakool offtake and Yallakool regulator, as well as flows from Wakool escape. The hydrograph for the Wakool River at Stoney crossing has some missing data and the maximum discharge likely to exceed 2300 ML/d as this gauge includes flows from Murray via Merran Creek and other tributaries.

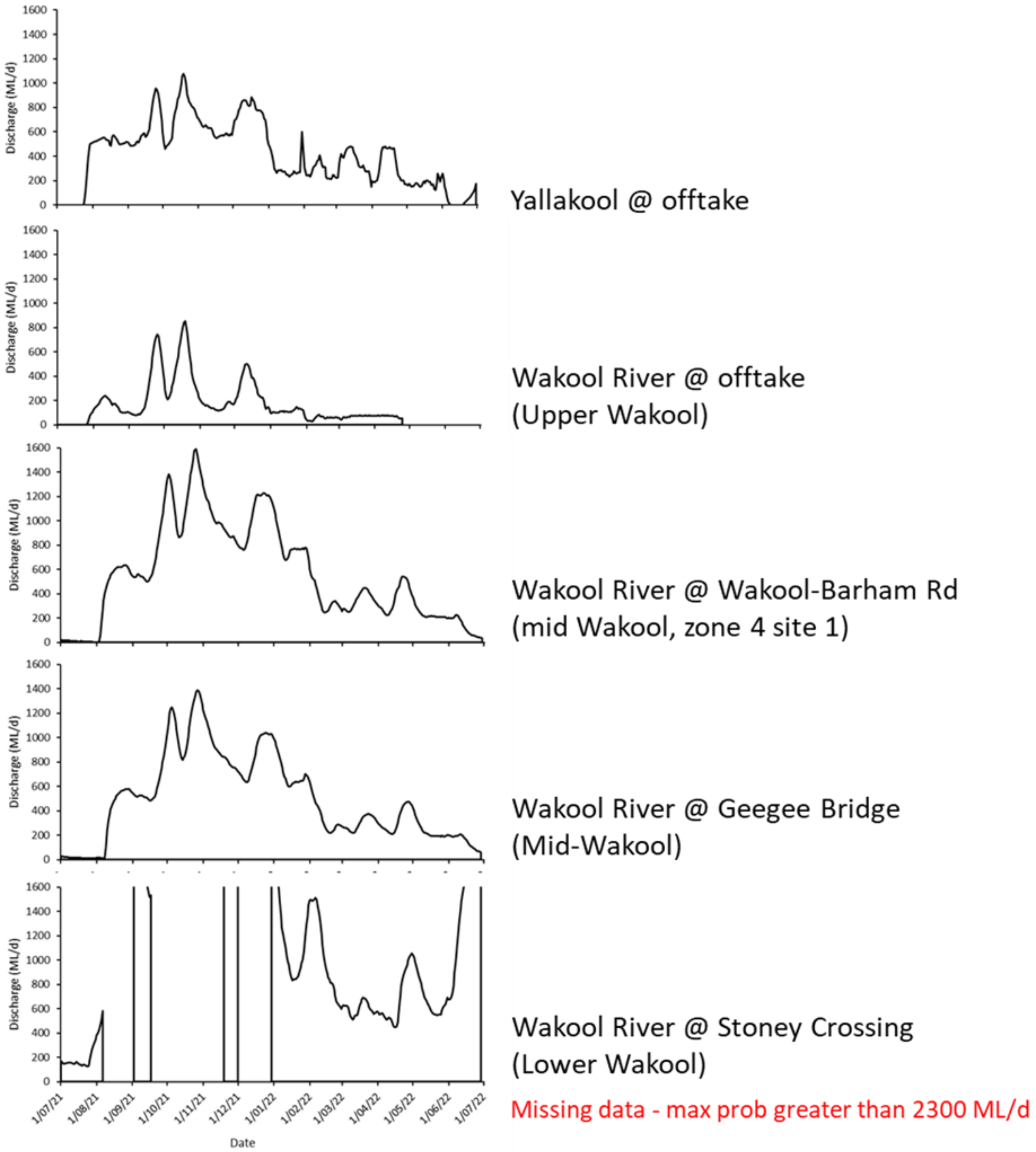


Figure 4.8 Hydrographs for Yallakool Creek (gauge 409020), Wakool River at offtake (gauge 409019), Wakool River at Barham-Moulamein Rd (gauge 409045), Gee Gee Bridge (gauge 409062), and at Stoney Crossing (gauge 409013) from 1 July 2021 to 30 June 2022.

In the Colligen Niemur system there was a similar pattern to the Edward/Kolety system where there was lower variability of flows at the upper reaches, with increased variability further downstream at the Barham-Moulamein Road gauge and Mallan School gauge (Figure 4.9). The inflows into the Niemur River from the Edward/Kolety River via Reed Beds and Niemur regulators has resulted in a more variable hydrograph (Figure 4.9).

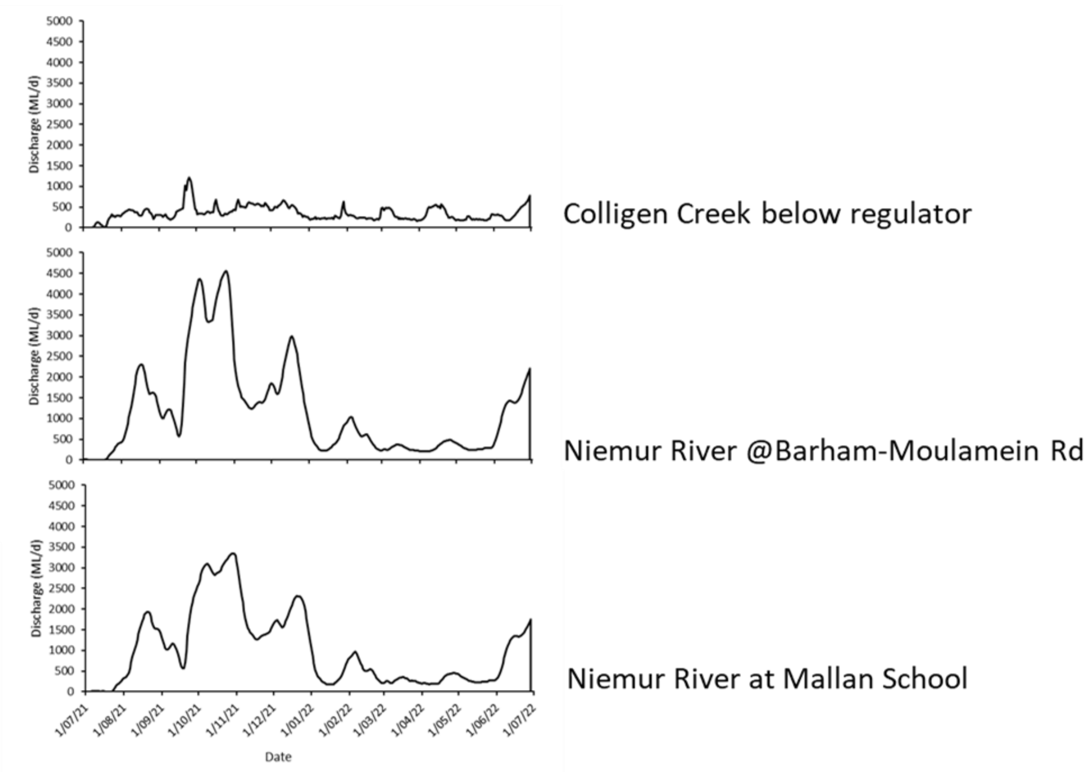


Figure 4.9 Hydrographs for the Colligen-Niemur system at Colligen Creek below regulator (gauge 409024), Niemur at Barham-Moulamein Rd (gauge 409048) and in the Niemur River at Mallan School (gauge 409086) from 1 July 2021 to 30 June 2022.

Environmental Watering actions in 2021-22

The annual hydrographs (1 July 2021 to 30 June 2022) in zones 1 to 4 in the Yallakool-Wakool system shows the contribution of Commonwealth environmental water to the hydrograph (Figures 4.10 to 4.14).

The Commonwealth environmental watering actions from Hume Dam resulting in flows from Millewa Forest to the EKW system contributed a large proportion of the total discharge in zones 1 (Figure 4.10), zone 3 (Figure 4.12), zone 4 (Figure 4.13) and zone 8 Colligen Creek (Figure 4.14), particularly in August to September and November to December 2021. The delivery of environmental water from the Edward escape contributed only a small proportion of the flows to these five hydrological zones over this same period.

In the upper Wakool River (zone 2) the return flows from Millewa Forest contributed less to the overall discharge than in zones 1, 3 and 4 between August 2021 and January 2022 (Figure 4.11). The environmental water delivered from the Wakool escape to the upper Wakool River had a greater influence on the hydrograph in zone 2 (Figure 4.11).

The autumn 2022 environmental watering actions #4 and #5 from the Yallakool offtake and Wakool offtake in April through to early May 2022, made significant contribution to the total discharge in zones 1 to 4. Similarly, the Commonwealth environmental water delivered through the Colligen Creek regulator in Autumn (watering action #6) made significant contributed to the hydrograph in Colligen Creek (Figure 4.12).

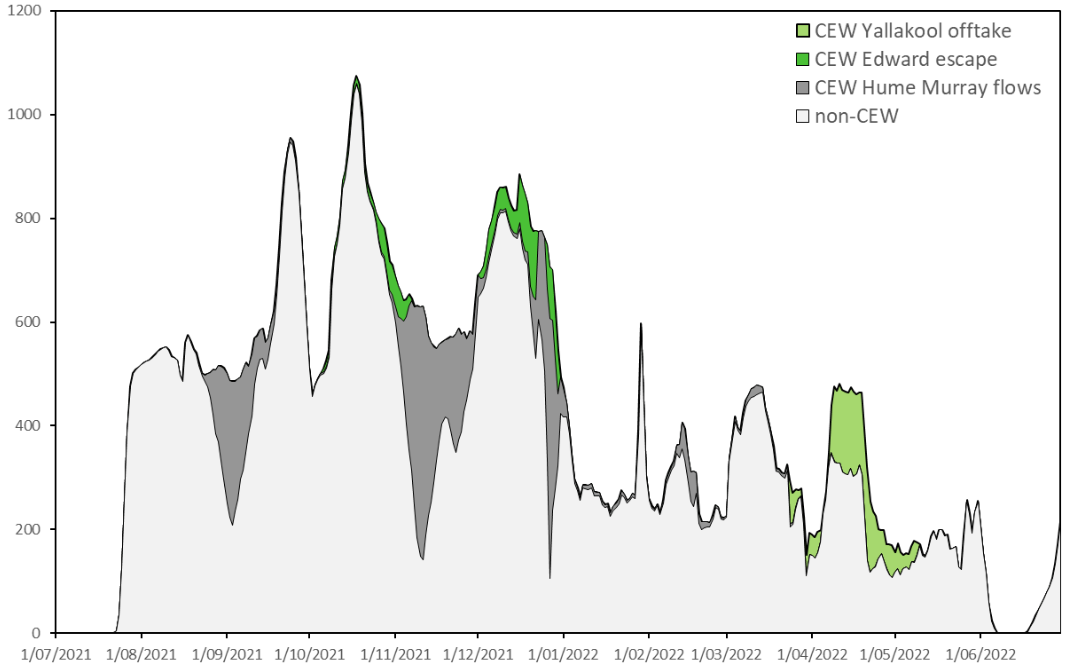


Figure 4.10 Hydrographs of zones 1 Yallakool Creek from 1 July 2021 to 30 June 2022.. The shading indicates the portion of the hydrographs attributed to the delivery of different sources of Commonwealth Environmental Water.

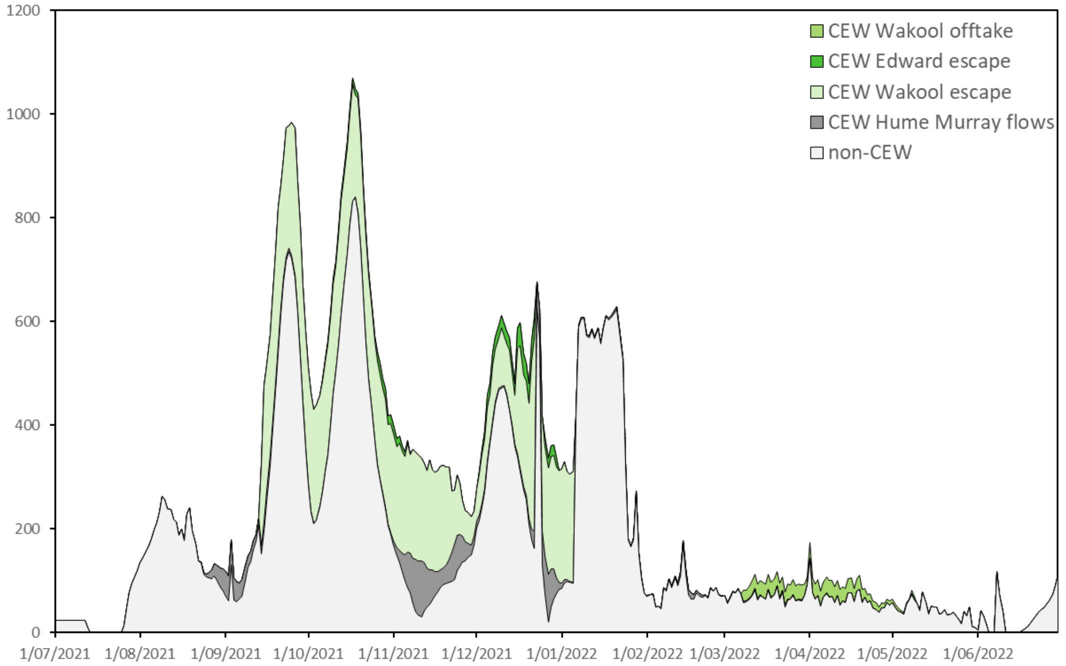


Figure 4.11 Hydrographs at site 4 zone 2 in the upper Wakool River from 1 July 2021 to 30 June 2022. This site includes the contribution of flows from the Wakool escape from Mulwala canal. The shading indicates the portion of the hydrographs attributed to the delivery of different sources of Commonwealth Environmental Water.

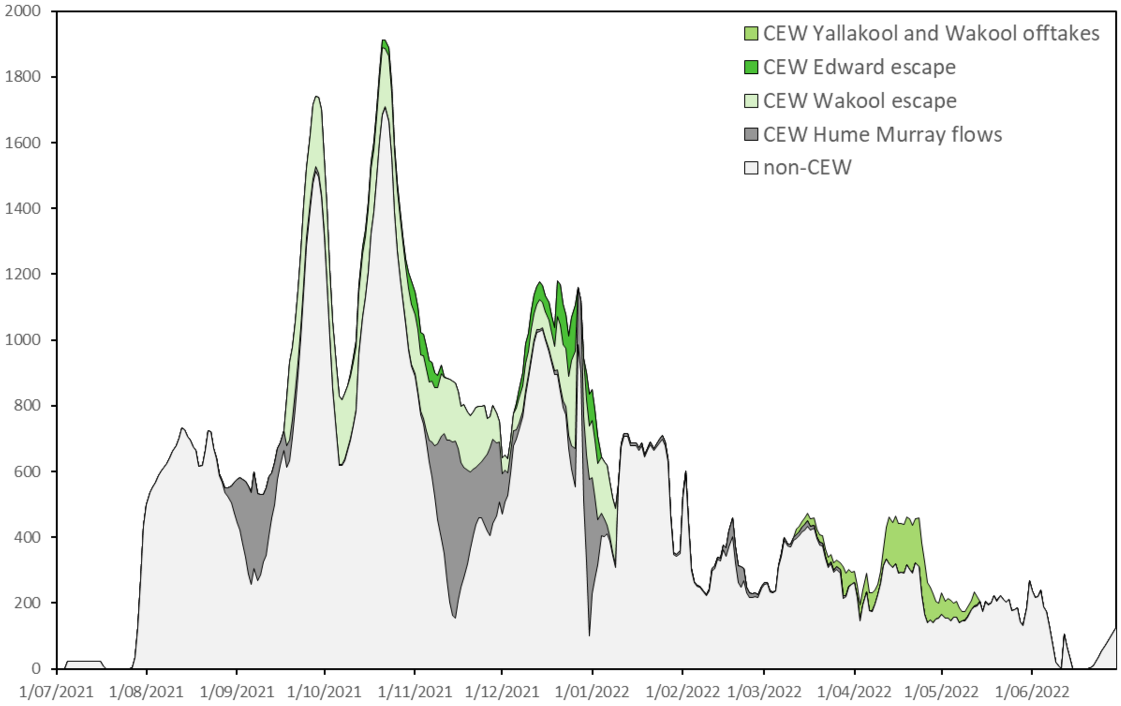


Figure 4.12 Hydrographs at Wakool River zone 3 from 1 July 2021 to 30 June 2022. The shading indicates the portion of the hydrographs attributed to the delivery of different sources of Commonwealth Environmental Water.

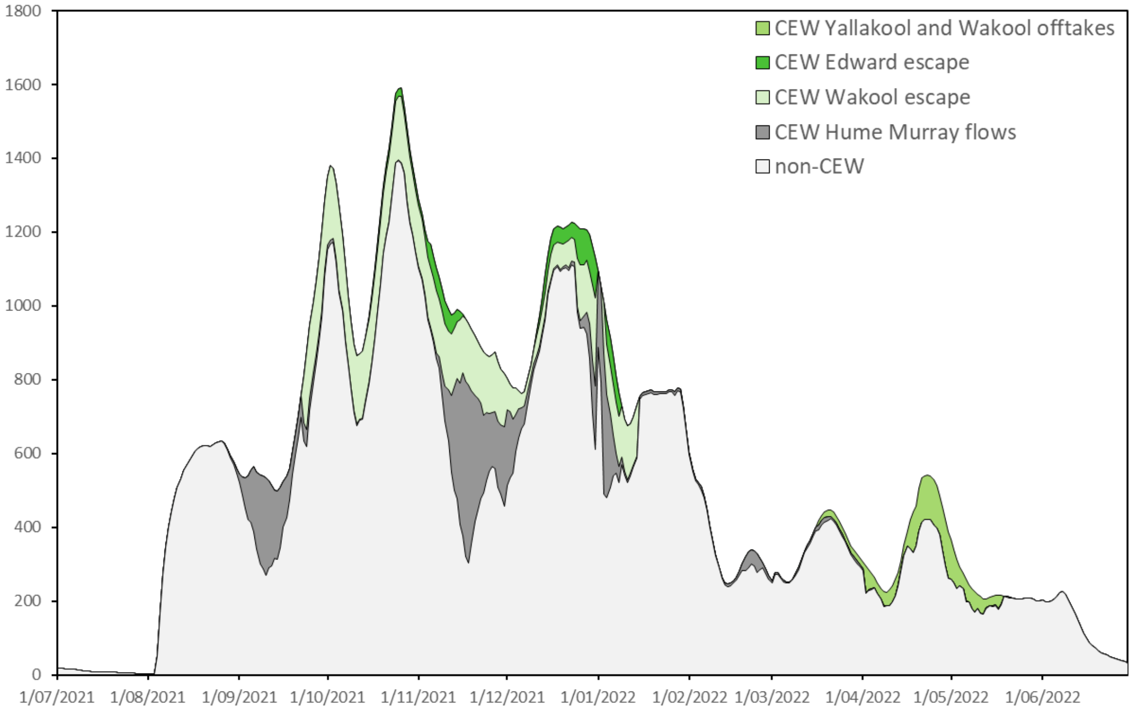


Figure 4.13 Hydrographs at Wakool River zone 4 from 1 July 2021 to 30 June 2022. The shading indicates the portion of the hydrographs attributed to the delivery of different sources of Commonwealth Environmental Water.

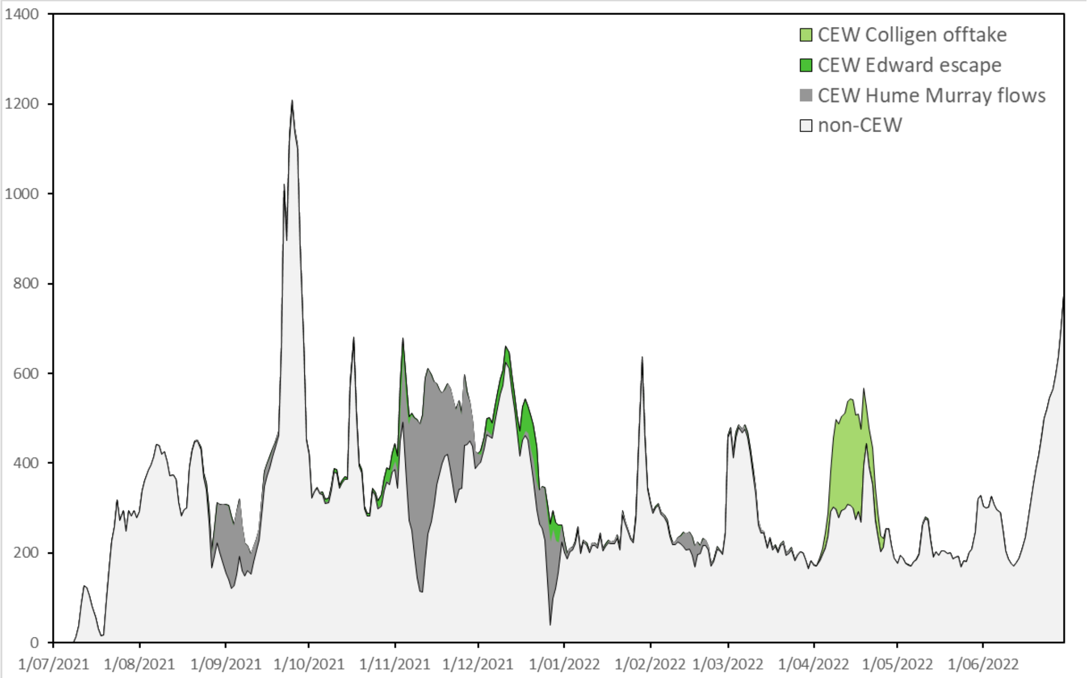


Figure 4.14 Hydrographs at Colligen Creek from 1 July 2021 to 30 June 2022. The shading indicates the portion of the hydrographs attributed to the delivery of different sources of Commonwealth Environmental Water.

Summary hydrological statistics for the 2021-22 water year were calculated for zones 1 (Yallakool Creek), zone 2 (upper Wakool R), zone 3 (mid-Wakool River upstream Thule), zone 4 (mid-Wakool R downstream Thule) and zone 8 (Colligen Creek) (Table 4.5).

- Total annual discharge (ML): Environmental water delivery increased total annual discharge by 14% in zone 1, 30% in zone 2, 20% in zone 3, 17% in zone 4 and 12% in zone 8.
- Minimum daily discharge (ML/d): Environmental water delivery made no difference to minimum discharge, because all zones experienced an operational cease to flow in 2021-22.
- Maximum daily discharge (ML/d): Environmental water delivery increased daily maximum discharge by 2% in zone 1, 21% in zone 2, 11% in zone 3, 12% in zone 4 and 1% in zone 8. The large increase in maximum discharge in zone 2 (upper Wakool River) and zone 3 and 4 was due to CEW released from the Wakool Escape (Figure 4.11). Despite this increase in maximum discharge, the flows remained within channel and did not result in an overbank flood event.
- Mean daily discharge (ML/d): Environmental water delivery increased mean discharge in all five zones. The percent increase was the same as that for total annual discharge.
- Median daily discharge (ML/d): Environmental water delivery increased daily maximum discharge by 27% in zone 1, 29% in zone 2, 27% in zone 3, 23% in zone 4 and 10% in zone 8.
- Coefficient of variation of daily discharge: There was a slight reduction in the coefficient of variation in zone 1 (8%), zone 2 (9%), zone 3 (5%), and zone 8 (6%). This was due to the return flow from Millewa Forest increasing base flows during spring, thus reducing the variation from trough to peak flows during spring/early summer. Delivery of environmental water has also reduced the coefficient of variation in previous water years, such as in 2017-18 (Table 4.5).

When compared to 2017-18 when there was regulated flows for the entire year, the total annual discharge (ML/year) in 2021-22 was increased by 89% in zone 1, 424% in zone 2, 89% in zone 3, 73% in zone 4 and 27% in zone 8 (Table 4.5).

Table 4.5 Summary hydrological statistics for five hydrological zones in the Edward/Kolety-Wakool system for the 2021-22 water year (1 July 2021 to 30 June 2022) and for 2017-18 (1 July 2017 to 30 June 2018) which was a year when the system was regulated flow for the entire water year. Statistics are shown for each zone with and without Commonwealth Environmental Water (CEW). CV = coefficient of variation (standard deviation/mean). There is no data for Colligen Creek for 2017-18 as it was not monitored as part of the project in 2017-18.

Flow variable	**Yallakool Creek**		**Wakool R zone2**		**Wakool R zone 3**		**Wakool R zone 4**		**Colligen Ck zone 8**	
	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW
2021-22 water year (1 July 2021 – 30 June 2022)										
Total discharge (ML)	129,184	149,480	62,691	89,723	168,442	203,588	163,680	204,470	110,380	125,203
Q_{min} (ML/d)	0	0	0	0	1.57	1.57	0	0	0.2	0.2
Q_{max} (ML/d)	1,057	1,074	839	1,069	1,394	1,591	1,707	1,913	1,199	1,209
mean (Q_{mean}) (ML/d)	354	410	172	246	461	558	448	560	302	343
median (Q_{50}) (ML/d)	307	419	82	115	393	507	344	473	274	304
CV	0.69	0.64	1.13	1.03	0.80	0.77	0.72	0.72	0.56	0.53
2017-18 water year (1 July 2017 – 30 June 2018)										
Total discharge (ML)	88,967	111,464	13,310	17,120	84,591	108,464	95,873	117,833		
Q_{min} (ML/d)	0	0	0	0	0	0	4	4	No data	No data
Q_{max} (ML/d)	543	543	158	163	530	530	574	588	No data	No data
mean (Q_{mean}) (ML/d)	244	305	36	47	232	297	263	323	No data	No data
median (Q_{50}) (ML/d)	264	328	36	54	250	304	270	314	No data	No data
CV	0.66	0.50	0.79	0.71	0.63	0.48	0.56	0.44	No data	No data

Analysis of CEW contribution to flows in 2021-22 comparing previous and new approach

In 2021-22 the contribution of CEW in the Edward/Kolety-Wakool system was calculated differently to the seven previous year of the LTIM/Flow-MER Program. In 2021-22 the calculation included the proportion of CEW that had been delivered from Hume Dam to the Murray River and flowed from Millewa Forest to the EKW system.

A comparison of the two methods for the 2021-22 water year, shows that when the return flows from MIllewa were included, there was a consistently higher percentage of CEW across the whole water year in all tributaries (Table 4.6).

- The difference between the two methods was particularly notable in spring/summer period in zone 1 Yallakool creek, where the contribution of CEW using the previous method was only 2%, but using the new method the contribution of CEW was 13.58% (Table 4.6).
- In Yallakool Creek and Colligen Creek there would have been no contribution of CEW in spring when calculated using the previous method, but the contribution of CEW to the total discharge was 17.32% and 18.02% respectively when using the new method (Table 4.6, Figure 4.10, Figure 4.14).
- There was a smaller difference between the two calculation methods in Wakool (zone 2) because in that system the Wakool escape makes up a large proportion of CEW and that component was included in calculations prior to 2021-22. Thus, there was less influence of the CEW return flows from Millewa on the Upper Wakool River hydrograph. (Figure 4.11)

Table 4.6 Comparison of the percent contribution of CEW of the total discharge in monitored river zones in the Edward/Kolety-Wakool (EKW) system calculated a) using CEW delivered specifically for watering actions in the EKW system, and b) CEW delivered from all sources (offtakes, escapes and Hume Dam) for the whole water year (1/07/21 to 30/06/22) and spring summer (different dates in different hydrological zones due to lag in flows).

River	Flow period	Dates	**Previous method:** Contribution CEW delivered the EKW system in 2021-22 as % total discharge over same period	**New method:** Contribution of CEW delivered from all sources in 2021-22 as % total discharge over same period
Yallakool (zone 1)	Whole water year	1/07/21 to 30/06/22	2.41	13.58
	Spring/summer	24/08/21 to 4/01/22	0	17.32
	Autumn fresh (action 5)	24/03/22 to 9/05/22	27.33	27.56
Wakool (zone 2)	Whole water year	1/07/21 to 30/06/22	25.25	30.13
	Spring/summer	26/08/21 to 5/01/22	34.21	40.88
	Autumn baseflow (action 4)	8/03/22 to 9/05/22	25.33	26.00
Wakool (zone 3)	Whole water year	1/07/21 to 30/06/22	11.05	19.95
	Spring/summer	28/08/21 to 9/01/22	13.88	26.79
Wakool (zone 4)	Whole water year	1/07/21 to 30/06/22	7.94	17.26
	Spring/summer	2/09/21 to 14/01/22	12.20	23.45
Colligen Creek	Whole water year	1/07/21 to 30/06/22	2.52	11.84
	Spring/summer	24/08/21 to 2/01/22	0	18.02
	Autumn fresh (action 6)	3/04/22 to 26/04/22	31.54	31.57

Longitudinal connectivity

Even though the unregulated flows in 2021-22 remained within channel and didn't result in an over bank flow, many of the ephemeral and intermittent creeks in the system were connected and/or able to receive environmental water, creating additional longitudinal connectivity that is not usually seen under operational flows (Figure 4.15).

The unregulated flows in spring increased longitudinal connectivity by initiating flows in several runners that connected between the main tributaries in the system (Figure 4.15). For example, during the unregulated flows, Black Dog Creek commenced to flow, connecting the upper Wakool River and Yallakool Creek. The delivery of environmental water from the Wakool escape also extended the recession of the unregulated event from November through to January, thus increasing the duration of this longitudinal connections.

During the unregulated flows in 2021-22 environmental water was able to be delivered to several other intermittent creeks (see water actions in Appendix 1). This included Jimaringle-Cockran-Gwynnes Creek System (WUM10117- 05), Murrain-Yarrien Creek (WUM10117- 06), Thule Creek (WUM10117- 07)(Figure 4.15), Whymoul Creek (WUM10117- 08), Yarrein Creek (WUM10117- 09)(Figure 4.15), and Buccaneit-Cunninyeuk Creek (WUM10117- 15).

The environmental watering actions increased the duration of the recession after flows became regulated (Figures 4.10 to 4.14), and this would have facilitated a longer duration of longitudinal connectivity in parts of the system.

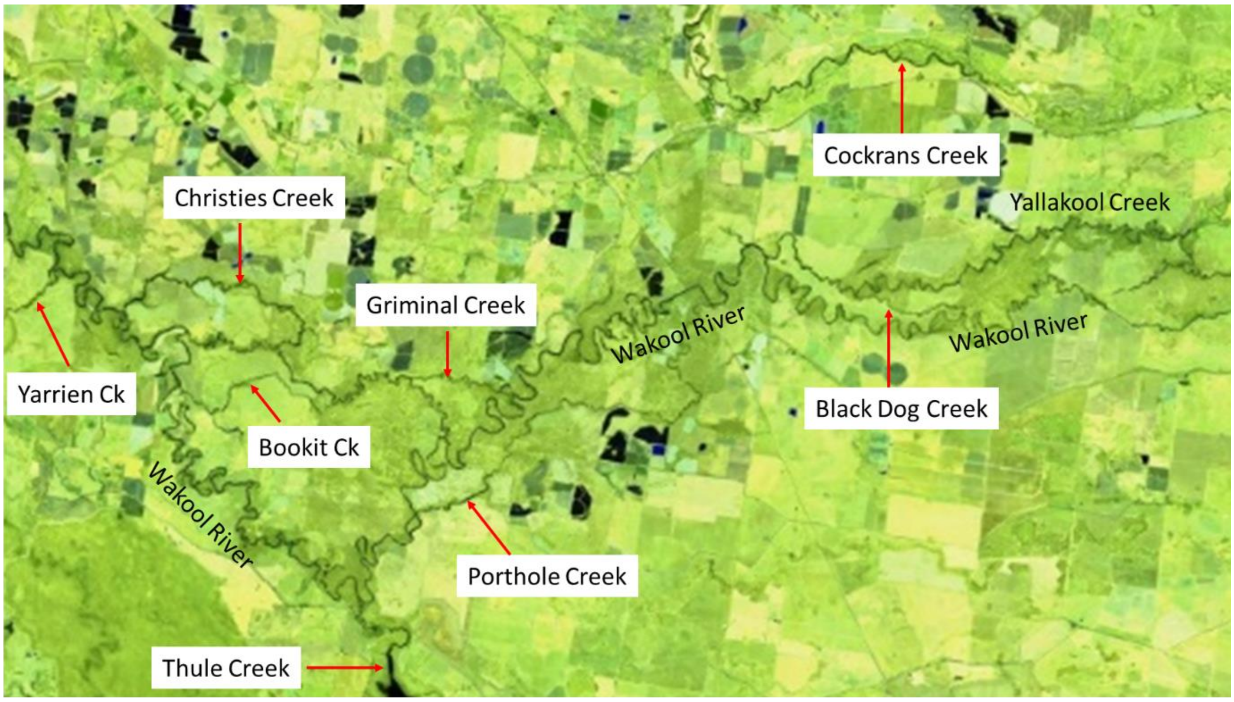


Figure 4.15 Colour enhanced Sentinel-2 satellite image of Barmah-Millewa Forest, taken 22 October 2021 representing nearest cloud-free image to the flood peak 42 days earlier at 45,700ML/d at Yarrawonga), showing extent of floodplain inundation (from Sentinel-hub 2021).

Lateral connectivity

The change in lateral connectivity in response to environmental watering, unregulated flows and operational flows was undertaken using hydraulic modelling outputs previously reported by Watts et al. (2015). For selected study reaches the hydraulic model can be used to estimate modelled inundated area under different flows. Previous research had shown that there is not a linear relationship between the discharge and extent of riverbank inundated under different flows (Watts et al 2015).

In all zones, the larger maximum discharge experienced in 2021-22 than in previous years increased lateral connectivity by inundating low lying wetlands and other in-channel features, increasing the total wetted area of riverbank compared to operational flows. Increasing the extent and duration of lateral connectivity can play an important role in river productivity, increasing dissolved carbon released from the sediment, leaves, and vegetation. Increased inundation of the riverbank can also trigger germination and growth of aquatic and riverbank plants, which provide habitat for invertebrates, frogs and fish.

4.6 Discussion

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

The environmental watering actions, combined with unregulated flows increased the total annual discharge (ML/year) in all reaches. That was particularly notable in zone 2 (upper Wakool River), where the watering actions increased total annual discharge increased by 30 percent. This significant increase contributed to increase in longitudinal connectivity and lateral connectivity in the system, in addition to the additional connectivity from the unregulated flows.

The environmental watering actions had no effect on minimum daily discharge, because there was an operational cease to flow in the system during July-August 2021. Winter environmental watering actions could not be delivered during this period due to maintenance scheduled for Stevens Weir. There are many ecosystem benefits that have previously been documented from winter flow actions (see Watts et al, 2019). To facilitate the benefits of connectivity flows, CEWO should work with river managers and river operators to maximise the opportunities to deliver environmental water to tributaries during winter and eliminate the impact of operational shutdowns in winter.

The environmental watering actions increased the maximum discharge compared to operational flows. In some river zones the increase was minimal (e.g., increase in maximum daily discharge of 2% in zone 1 Yallakool Creek, and 1% in zone 8 Colligen Creek). However, in tributaries influenced by releases from Wakool escape there was a significant increase in maximum discharge (e.g., 21% increase in zone 2 upper Wakool, 11% in zone 3 ad 12% in zone 4 in the mid-Wakool River. The flows remained within channel and did not result in an overbank flood event. However, this increased maximum discharge would have contributed to an increase in longitudinal connectivity and lateral connectivity in the Wakool River system from upper reaches through to lower reaches.

What was the effect of Commonwealth environmental water on flow variability in the Edward/Kolety-Wakool system?

There was a slight reduction in the coefficient of variation across the water year in zone 1 (8%), zone 2 (9%), zone 3 (5%), and zone 8 (6%) in response to environmental watering actions. This was due to the return flow from Millewa Forest increasing base flows during spring, thus reducing the variation from trough to peak flows during spring/early summer. Delivery of environmental water has also reduced the coefficient of variation in previous water years.

This reduced variability was evident in the hydrograph in some tributaries more so than others. In 2021-22 the reduced variability of flows in zone 1 Yallakool Creek, would have resulted in the continual inundation of the riverbank 200 ML/d and 550 ML/d) from August through to the end of December 2021. This extended period of inundation of this part of the riverbank would be detrimental for emergence and survival of amphibious riverbank taxa (see section 7). In contrast, zone 2 upper Wakool River experience more variability over this period from August to December. Because the delivery of water from the Wakool escape was variable, increasing the maximum discharge and also reduced releases from the escape facilitating a short period of lower discharge at the end of November 2021.

What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?

Even though the unregulated flows in 2021-22 remained within channel and didn’t result in an over bank flow, the outcome was that a many of the ephemeral and intermittent creeks and flood runners in the system were connected and/or able to receive environmental water, creating additional longitudinal connectivity that is not usually seen under operational flows. The delivery of environmental water from the Wakool escape to the upper Wakool River and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event from November through to January, thus increasing the duration of this longitudinal connections.

During the unregulated flows in 2021-22 environmental water was also able to be delivered to several intermittent Creeks, including Jimaringle-Cockran-Gwynnes Creek System, Murrain-Yarrien Creek, Thule Creek, Whymoul Creek, Yarrein Creek, and Buccaneit-Cunninyeuk Creek.

There are many ecosystem benefits from the increased longitudinal connectivity, including opportunities for adult and juvenile fish to move, dispersal of fish larvae and dispersal of seeds and other propagules.

What did Commonwealth environmental water contribute to lateral connectivity?

The unregulated flows and environmental watering actions increased the lateral connectivity in the system. The larger maximum discharge experienced in 2021-22 than in previous years inundated low lying wetlands and other in-channel features, increasing the total wetted area of riverbank compared to operational flows. The delivery of environmental water from the Wakool escape to the upper Wakool River and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event from November through to January, thus increasing the duration of this lateral connections. Increasing the extent and duration of lateral connectivity can play an important role in river productivity, increasing dissolved carbon released from the sediment, leaves, and vegetation. Increased inundation of the riverbank can also trigger germination and growth of aquatic and riverbank plants, which provide habitat for invertebrates, frogs and fish. However, there is trade-off between increased inundation and reduced variability of flows that needs to be considered to achieve maximum ecosystem benefits.

5 Water quality and carbon

Authors: Xiaoying Liu, Nicole McCasker, Robyn Watts

Key findings	
Dissolved oxygen concentrations	• In 2021-22 there was a sustained period of unregulated flows and cooler temperatures over late spring/early summer. Widespread hypoxia was not present in the system during the unregulated flows and mostly DO was above the range of concern to fish populations (below 4 mg/L). • From early November to late December 2021 water temperature started to increase. The environmental watering actions in 2021-22 water year helped to maintain dissolved oxygen concentrations and prevented the development of widespread hypoxic blackwater events. However, in the upper reach of Edward/Kolety River with no environmental watering, dissolved oxygen concentration was briefly below 4 mg/L. • Concentrations of dissolved oxygen in the upper Wakool River briefly dropped below 4 mg/L in February 2022 when watering actions 1, 2 and 3 ceased, although these concentrations were within the range normally measured at that time of year in the upper Wakool River. • Autumn watering actions 4, 5 and 6 maintained DO levels in the Wakool-Yallakool system and Colligen-Niemur River. • Watering action 7 in Tuppal Creek helped maintain dissolved oxygen levels in November 2021 and between mid-March and May 2022, but it did not prevent the decline in dissolved oxygen levels (below 2 mg/L) in the system during hot months.
Nutrient concentrations	• Nutrient concentrations remained in the acceptable range in 2021-22. • Only small pulses of nutrients were detected in spring/early summer during the period of unregulated flows. • Watering actions 1, 2 and 3 delivered during the unregulated flows mitigated increases in nutrients. • The increase in nutrient concentrations in January and February 2022 were related to increased water temperature and reduced discharge. • Autumn watering actions 4, 5 and 6 maintained stable nutrients levels in the Wakool-Yallakool system and Colligen-Niemur River system.
Type and amount of dissolved organic matter	• In 2021-22 pulses of dissolved organic carbon were detected in the EKW River system and the organic carbon mix was similar across sites during the period of unregulated flows. Higher fluorescence was observed at all sites with a gradual increase downstream, indicating a combination of aged organic matter and very fresh leachates or algal organic matter introduced by unregulated flows. • Environmental water for the Murray River from Hume Dam increased DOC in the EKW system, whereas watering action 1 delivery of water from Wakool escape mitigated the extent of increases in DOC and nutrients in the Wakool-Yallakool system. • Pulses of dissolved organic carbon detected in January and February 2022 were related to increased water temperature and reduced discharge. • The autumn watering actions 4, 5 and 6 diluted dark coloured water in the Wakool-Yallakool system and the Colligen-Niemur system.

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 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. Many of these parameters used 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. Nutrients and organic matter concentrations are also 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 & Mitchell 2000).

Aquatic environments 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).). 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).

This chapter reports on changes in water quality (nutrients and organic carbon, algal biomass, temperature, and DO) in response to flows from 1 July 2021 to 30 June 2022.

5.2 Environmental watering actions targeting water quality outcomes

Seven Commonwealth environmental watering actions were evaluated in the EKW system in 2021-2022 water year (Table 5.1). The overall objective of these watering actions was to support the recovery of the river system following the hypoxic blackwater event in 2016, and to contribute to connectivity and improve water quality.

High flows throughout mid-summer have the potential to lead to poor water quality, particularly in rivers downstream of extensive areas of floodplain. To avoid these environmental risks in 2021-22, Watering actions 1, 2 and 3 were implemented by CEWO to mitigate the risks from hypoxic blackwater in spring and summer, improve water quality and create localised refuges for fish and other aquatic species (Table 5.1).

Table 5.1 Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2021-22.

Action	System	Type (delivery point)	Dates
1	Wakool-Yallakool	Spring-summer hypoxic blackwater refuge (Wakool escape)	14/09/21 - 05/01/22
2	Edward/ Kolety	Spring-summer hypoxic blackwater refuge (Edward escape)	06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	Spring-summer hypoxic blackwater refuge (Niemur escape)	07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
5	Wakool-Yallakool	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
6	Colligen-Niemur	Autumn fresh (Colligen offtake)	03/04/22 -26/04/22
7	Tuppal Creek	Elevated flows	01/11/21-29/05/22

5.3 Selected Area evaluation questions

To understand the impact of environmental water deliveries to the water quality in the EKW River system, we monitor a number of water quality parameters at 18 'core' sites throughout the Wakool-Yallakool system, Edward/Kolety River, the Colligen-Niemur system and Tuppal Creek. In addition, monitoring was also undertaken in the vicinity of the Neimur Escape, to specifically assess the impact of watering action 3 on the Colligen-Niemur River system.

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 an annual basis.

In 2021-22 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?*
- *What did Commonwealth environmental water contribute to reducing the impact of hypoxic blackwater or other adverse water quality events in the system?*

5.4 Methods

Core Monitoring sites

Core water quality, nutrient and carbon data was collected from 18 sites throughout the Edward/Kolety Wakool system including the length of the Yallakool-Wakool River system, the Edward/Kolety River, Colligen-Niemur River System and Tuppal Creek (Figure 5.1). Monitoring sites were also located on Mulwala Canal and Edward/Kolety River at Stevens Weir to record of Source water contributions entering the rivers. The establishment of monitoring sites throughout the EKW system allows better capture the impact of environmental water in the broader system. For example, sites at Eastman Bridge and Balpool Road sites (Edward/Kolety River) together with sites at Old Morago Road, Moulamein Road and Mallan School (the Colligen-Niemur River system) can be used 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 water quality and organic matter inputs changes during in-stream flows (Table 5.2). Sampling consists of water samples collected from each site on a monthly basis throughout the year.

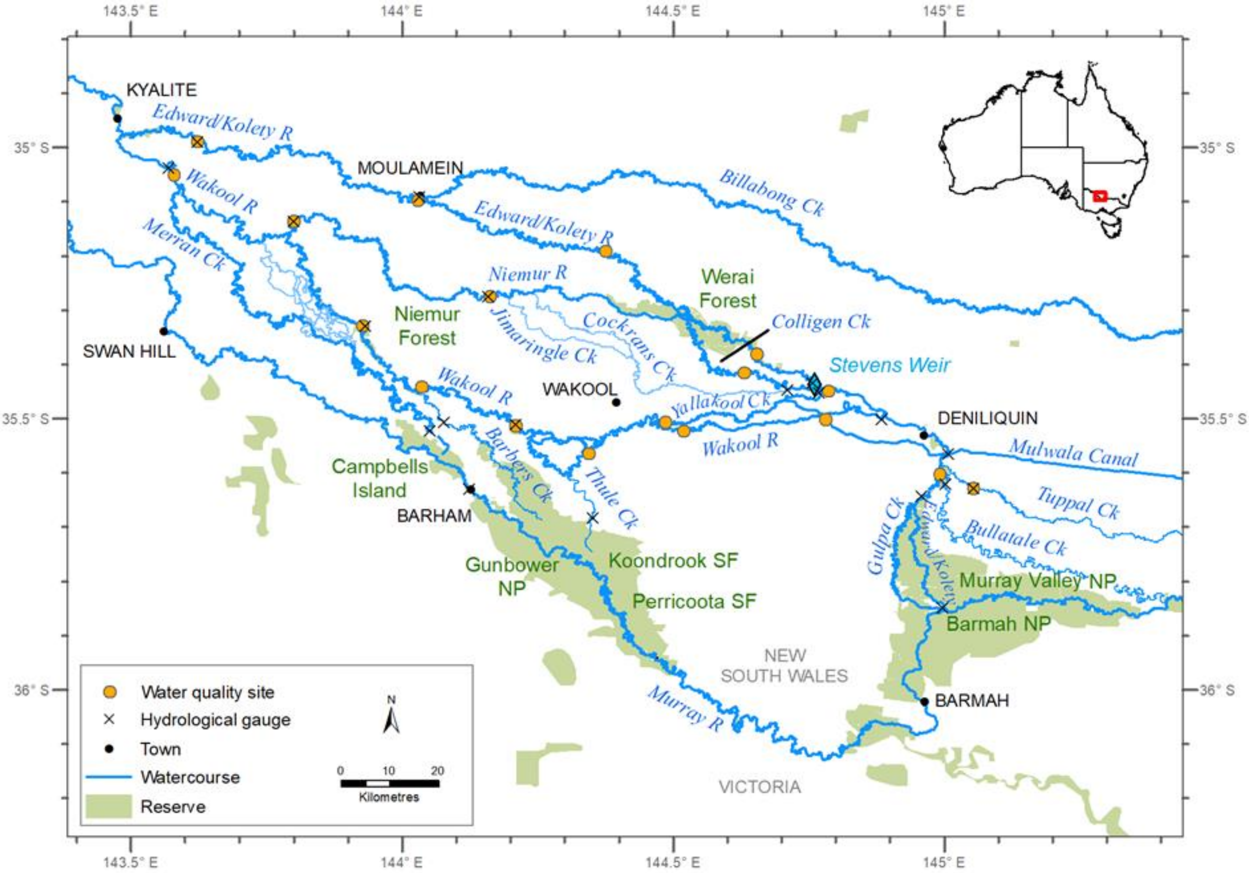


Figure 5.1 Map of the water quality and carbon 18 core monitoring sites (orange dots) in the Edward/Kolety-Wakool Selected Area, and nearby hydrological gauges (crosses).

Table 5.2 Sample site for water quality and carbon core monitoring for the Wakool-Yallakool River system, the Edward/Kolety River system, the Colligen-Niemur River system and Tuppal Creek. Grey shades indicate the parameters that were monitored in 2021-22.

River Section	Site name	Lat/long	Spot pH, Turbidity, EC	Spot Chl a, Nutrients, Carbon	Continuous DO & Temp
Wakool – Yallakool System					
Edward/Kolety River, Stevens Weir	Weir	-35.4486, 144.7865	▨	▨	
Mulwala Canal	Canal	-35.5060, 144.7870	▨	▨	
Yallakool Creek	Zone 1	-35.5060, 144.7528	▨	▨	
Upper Wakool River	Zone 2	-35.5228, 144.5192	▨	▨	▨
Mid. Wakool River us Thule	Zone 3	-35.5641, 144.3449	▨	▨	
Mid. Wakool River ds Thule	Zone 4 upstream	-35.5128, 144.2098	▨	▨	▨
	Zone 4 downstream	-35.4414, 144.0364	▨	▨	
Mid. Wakool River ds Barbers	Zone 5 (@ Gee Gee Bridge)	-35.3293, 143.9275	▨	▨	
Lower Wakool River	Zone 6 (@ Stoney Crossing)	-35.0497,143.5803	▨	▨	▨
Edward/Kolety River					
Upper Edward River	Four posts	-35.6016, 144.9932	▨	▨	▨
Edward River, Stevens Weir	Weir	-35.4486, 144.7865	▨	▨	
Edward River, ds Stevens Weir	Eastman bridge	-35.3802, 144.6542	▨	▨	▨
Mid. Edward River	Balpool road	-35.1916, 144.3762	▨	▨	
Lower Edward River	Moulamein	-35.0970, 144.0318	▨	▨	
Lower Edward River	Liewah	-34.9894, 143.6228	▨	▨	▨
Colligen-Niemur System					
Edward/Kolety River, Stevens Weir	Weir	-35.4486, 144.7865	▨	▨	
Colligen Creek	Old Morago road	-35.4150, 144.6308	▨	▨	▨
Upper Niemur River	Moulamein road bridge	-35.2742, 144.1630	▨	▨	▨
Lower Niemur River	Mallan School	-35.1352, 143.8000	▨	▨	▨
Tuppal Creek					
Tuppal Creek	Aratula road	-35.6281, 145.0545	▨	▨	▨

Niemur Escape refugia flows sites

To monitor the impact of environmental water released from the Niemur Escape, water quality and carbon characterisation data were collected at upstream of Niemur Escape, Northern Branch Canal (source water) and downstream of Niemur Escape (Figure 5.2).

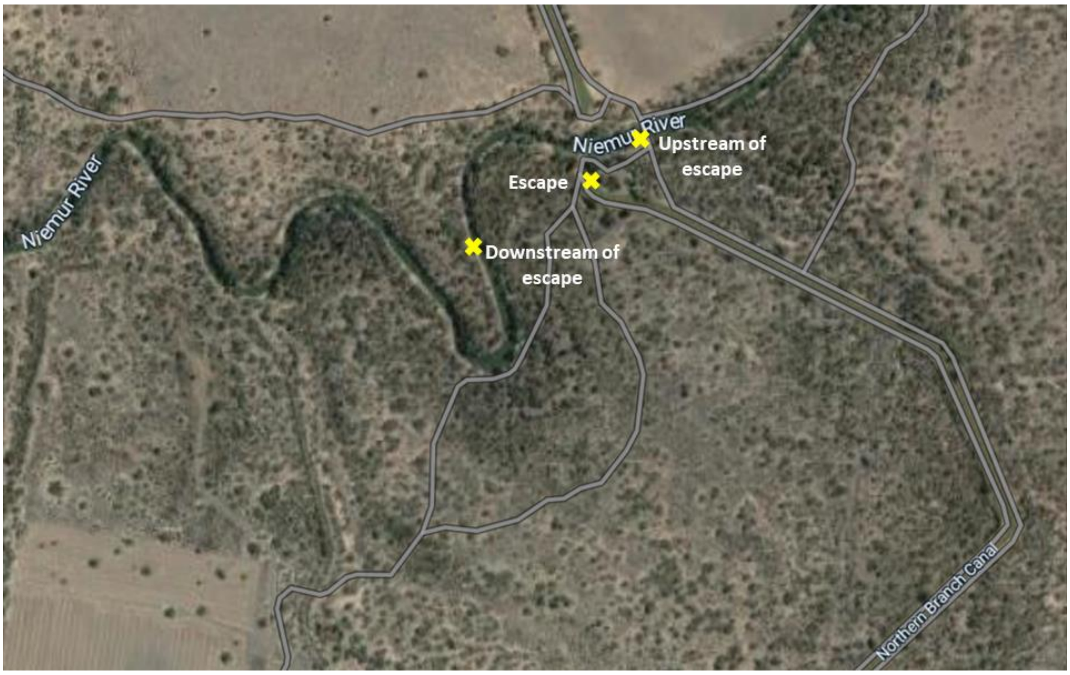


Figure 5.2 Map of the Niemur Escape selected sites showing upstream of escape, escape and downstream of escape (yellow cross).

Field data collection

For the core water quality monitoring, water temperature and dissolved oxygen (DO) concentration were logged every ten minutes at sites in the upper, middle and lower sections of the Wakool-Yallakool River system, Edward/Kolety River, the Colligen Niemur River system and Tuppal Creek (Table 5.2). Data were downloaded and loggers were calibrated approximately once per month depending on access to survey sites (e.g., high rainfall may prevent access). 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 2019 to 30 June 2022.

From July 2019 to June 2022 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) concentration
- Nutrients (total phosphorus (TP), filtered reactive phosphorus (FRP), total nitrogen (TN), dissolved nitrate + nitrite (NO_x) and ammonium (NH_4^+) concentrations)
- Chlorophyll-*a* (Chl *a*) concentrations
- Absorbance and fluorescence spectroscopy for organic matter characterisation.

For Niemur escape refugia flows monitoring, water samples were collected at upstream of Niemur Escape, Northern Branch Canal (source water) and downstream of Niemur Escape fortnightly between 21 October 2021 and 29 March 2022, covering the period of before and after the released water from Northern Branch Canal was mixed with Niemur River. Water samples collected for laboratory processing included DOC, TP and TN, FRP/NOx/ NH_4^+, and Chl *a*.

Laboratory analysis

All water samples (core monitoring and escapes monitoring) for DOC and bioavailable nutrients (FRP, NO_x, NH_3) and organic matter characterisation, 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.

Carbon 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 5.3. The contour plots have the excitation wavelength (light shone into the sample) on the y-axis. On the x-axis is the emission wavelength (light given off by the sample). The intensity of the fluorescence (how much light is given off, corrected for absorbance by the sample) is represented by the colours of the contour plot, with more intense fluorescence represented by the blue end of the scale. The two blue diagonal lines are artefacts of the technique and will be present in all samples- key data is found between these two lines.

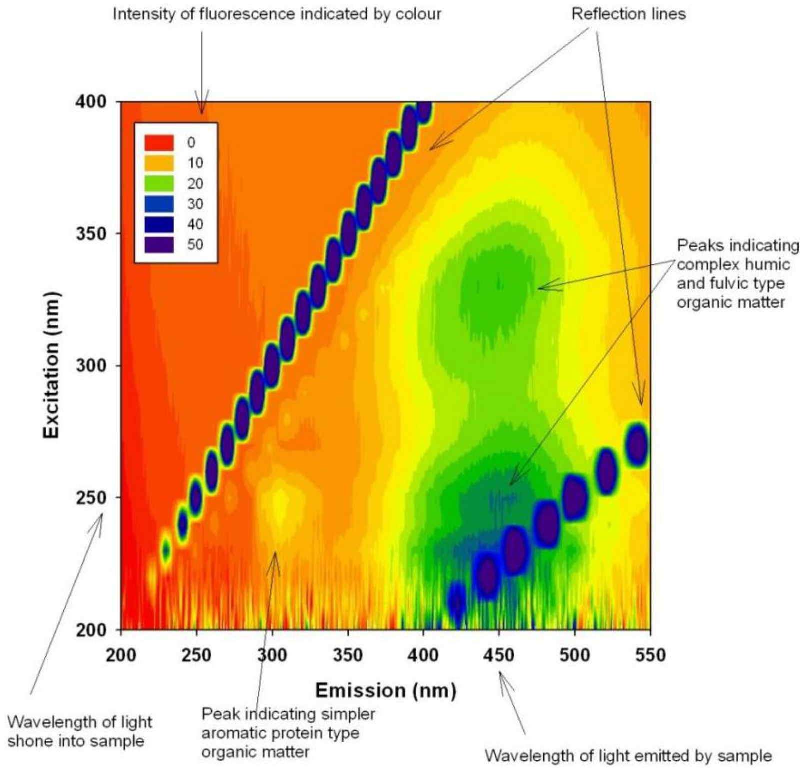


Figure 5.3 Sample excitation emission contour plot indicating key features of the data (Watts et al. 2013).

Data analysis

Water quality, nutrient and carbon concentrations 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 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 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.

The collected water quality and carbon data of 2021-22 water year was grouped based on the major rivers; the Wakool-Yallakool system, the Edward/Kolety River, the Colligen-Niemur River system and Tuppal Creek. 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.

5.5 Results

The hydrology of the study sites in the 2021-22 water year was different to previous years monitored for the LTIM/Flow-MER program (2014-21). In 2021-22 there was a sustained period of unregulated flows and cooler temperatures over late spring/early summer.

The Wakool-Yallakool system

Spot water quality parameters (electrical conductivity (EC), turbidity and pH) remained (see Table 5.3) within the normal range for the Wakool-Yallakool system throughout the study period and were similar to results from the 2014-15, 2017-18, 2018-19, 2019-20 and 2020-21 sampling years in the absence of extensive overbank flows or excessive algae bloom.

Table 5.3 Range and mean values of water physico-chemical parameters for the Wakool-Yallakool system in 2021-22 water year across all core monitoring sites. The order of sampling sites from left to right is present from upstream to downstream of the river system. ANZECC (2000) trigger levels for available water parameters are in bold. pH, Turbidity and EC are spot reading data. DO data were collected from loggers. Chl a, TP, FRP, TN, NH_4^+, NO_x and DOC are from laboratory analysis of water samples. NA not available.

	Edward/ Kolety River	**Mulwala Canal**	**Yallakool Creek**	**Wakool River**				
				Upper	**Middle**			**Lower**
WQ Parameters	weir	canal	zone 1	zone 2	zone 3	zone 4 d/stream	zone 5	zone 6
pH **6.5-8**	6.57-7.82 (7.18)	7.42-9.35 (8.29)	6.54-7.7 (7.14)	6.41-7.45 (6.97)	6.65-7.77 (7.03)	6.83-7.75 (7.25)	6.83-7.68 (7.25)	6.73-8.66 (7.36)
Turbidity (NTU) **50**	21.3-64.6 (35.8)	32.8-95.5 (56.6)	26.6-88.3 (50.6)	30.9-90.5 (57.6)	41.7-112.0 (60.2)	97.0-183 (64.1)	39.2-106 (62.7)	26.0-86.6 (50.0)
EC ($mS\ cm^{-1}$) **0.125**	0.038-0.066 (0.050)	0.037-0.087 (0.054)	0.038-0.068 (0.052)	0.041-0.232 (0.082)	0.044-0.068 (0.056)	0.049-0.081 (0.060)	0.044-0.088 (0.061)	0.067-0.438 (0.122)
DO ($mg\ L^{-1}$)	NA	NA	4.64-10.87 (8.48)	3.45-10.46 (7.42)	5.02-10.6 (8.25)	4.84-11.55 (8.28)	5.01-11.66 (8.46)	0.40-12.20 (7.55)
Chl *a* ($\mu g\ L^{-1}$) **5**	6.64-31.76 (15.37)	5.32-22.29 (12.66)	9.96-41.57 (18.36)	7.81-50.24 (22.20)	10.3-36.59 (19.11)	8.47-39.83 (18.45)	9.3-37.73 (19.75)	16.64-46.57 (22.61)
TP ($mg\ L^{-1}$) **0.05**	0.019-0.051 (0.034)	0.018-0.056 (0.034)	0.027-0.074 (0.041)	0.015-0.072 (0.041)	0.022-0.062 (0.040)	0.025-0.064 (0.044)	0.034-0.06 (0.045)	0.02-0.073 (0.046)
FRP ($mg\ L^{-1}$) **0.02**	0.005-0.008 (0.006)	0.005-0.01 (0.005)	0.005-0.006 (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)	0.005-0.013 (0.006)
TN ($mg\ L^{-1}$) **0.5**	0.315-0.690 (0.487)	0.305-0.87 (0.53)	0.39-1.05 (0.57)	0.315-0.88 (0.558)	0.33-0.74 (0.515)	0.86-0.81 (0.569)	0.475-0.92 (0.615)	0.33-1.1 (0.622)
NH_4^+ ($mg\ L^{-1}$) **0.02**	0.005-0.050 (0.01)	0.005-0.053 (0.01)	0.005-0.031 (0.011)	0.005-0.007 (0.005)	0.005-0.01 (0.006)	0.005-0.008 (0.005)	0.005-0.059 (0.011)	0.005-0.079 (0.013)
NO_x ($mg\ L^{-1}$) **0.04**	0.002-0.049 (0.011)	0.002-0.022 (0.005)	0.002-0.005 (0.004)	0.002-0.009 (0.003)	0.002-0.029 (0.006)	0.002-0.023 (0.005)	0.002-0.08 (0.01)	0.002-0.014 (0.004)
DOC ($mg\ L^{-1}$)	3.6-10.5 (6.7)	3.7-8.4 (5.6)	3.7-15.0 (7.0)	4.0-12.5 (6.6)	3.2-11.3 (6.0)	4.0- 9.9 (6.5)	3.3-9.7 (6.6)	3.6-10.2 (7.2)

pH

pH remained within the trigger values with the exception at Mulwala Canal where high pH values were observed between December 2021 and March 2022. These elevated values may reflect increased algal activity as a result of higher water temperatures and light levels. In July 2021 the pH value in Mulwala canal was collected in a shallow and disconnected pool, and therefore is not of concern (Figure 5.4).

Figure 5.4 Mulwala Canal in March 2022 (left) and July 2021 (right). (Photo: Xiaoying Liu)

Turbidity

Turbidity measurements were generally above the ANZECC (2000) trigger level but within the range commonly observed in this river system.

Electrical conductivity (EC)

At all sites EC remained below the ANZECC (2000) trigger levels on all sampling dates and were slightly lower than those values from the 2019-20 and 2020-21. The increase in EC values sometimes observed in the upper Wakool River was not observed in the 2021-22 water year and the relatively variable regulated and unregulated 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.

Chlorophyll-*a*

Chl *a* values in the Wakool-Yallakool system in 2021-22 had a similar range to those observed in 2019-20 and 2020-21, with exceptions in January and February 2022 (Figures 5.5a, 5.5b and 5.5c). This higher Chl *a* value likely was associated with ceased watering actions with lowered discharge and increased water temperature, corresponding with poor water quality was observed in the system (Figure 5.6). Amber alerts for blue-green algae were declared at lower Wakool (Stoney Crossing) by WaterNSW in January 2022.

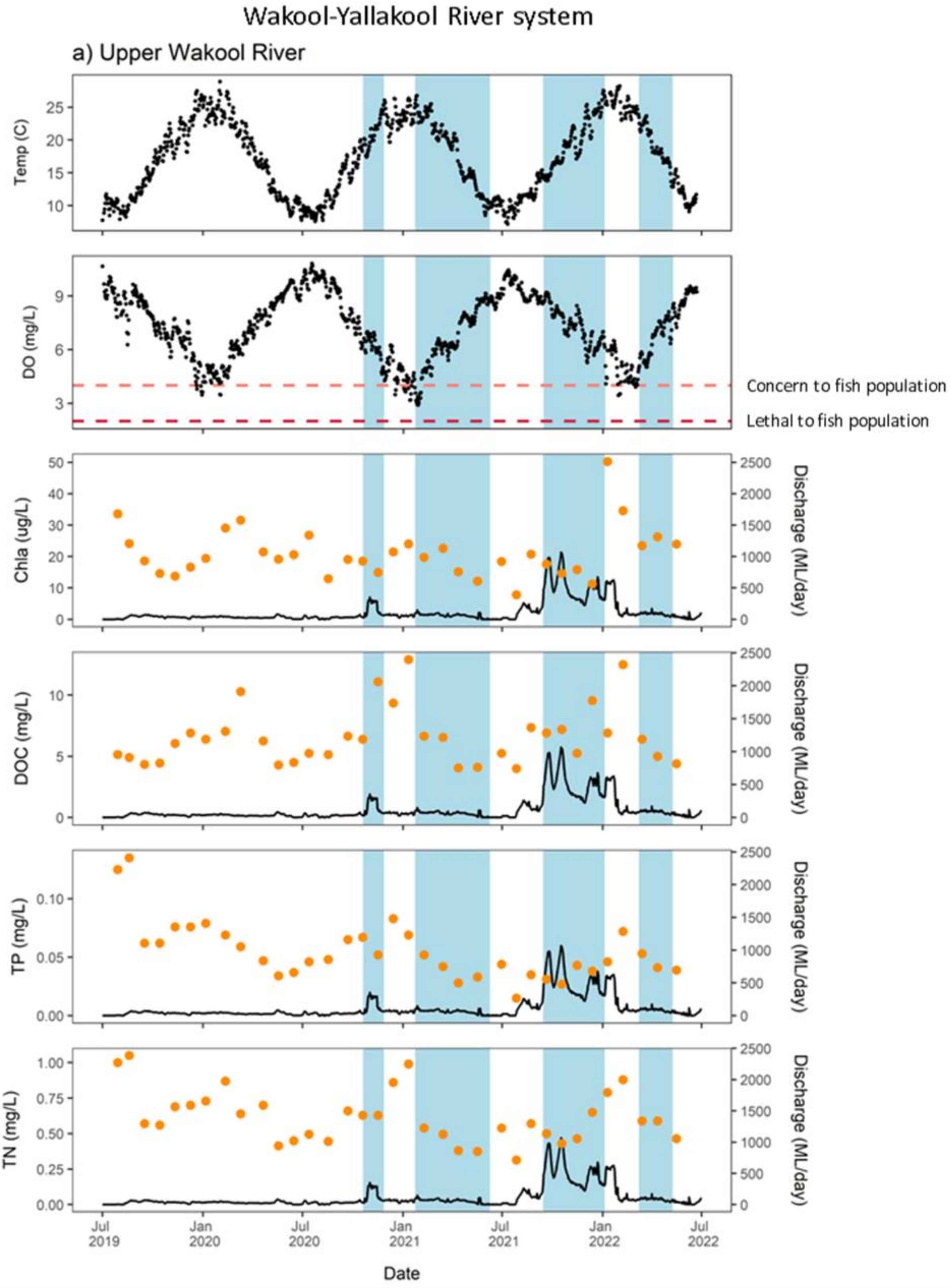


Figure 5.5a Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for upper Wakool River (zone 2) over the 2019-22 watering years. Blue shaded vertical bars indicate watering actions.

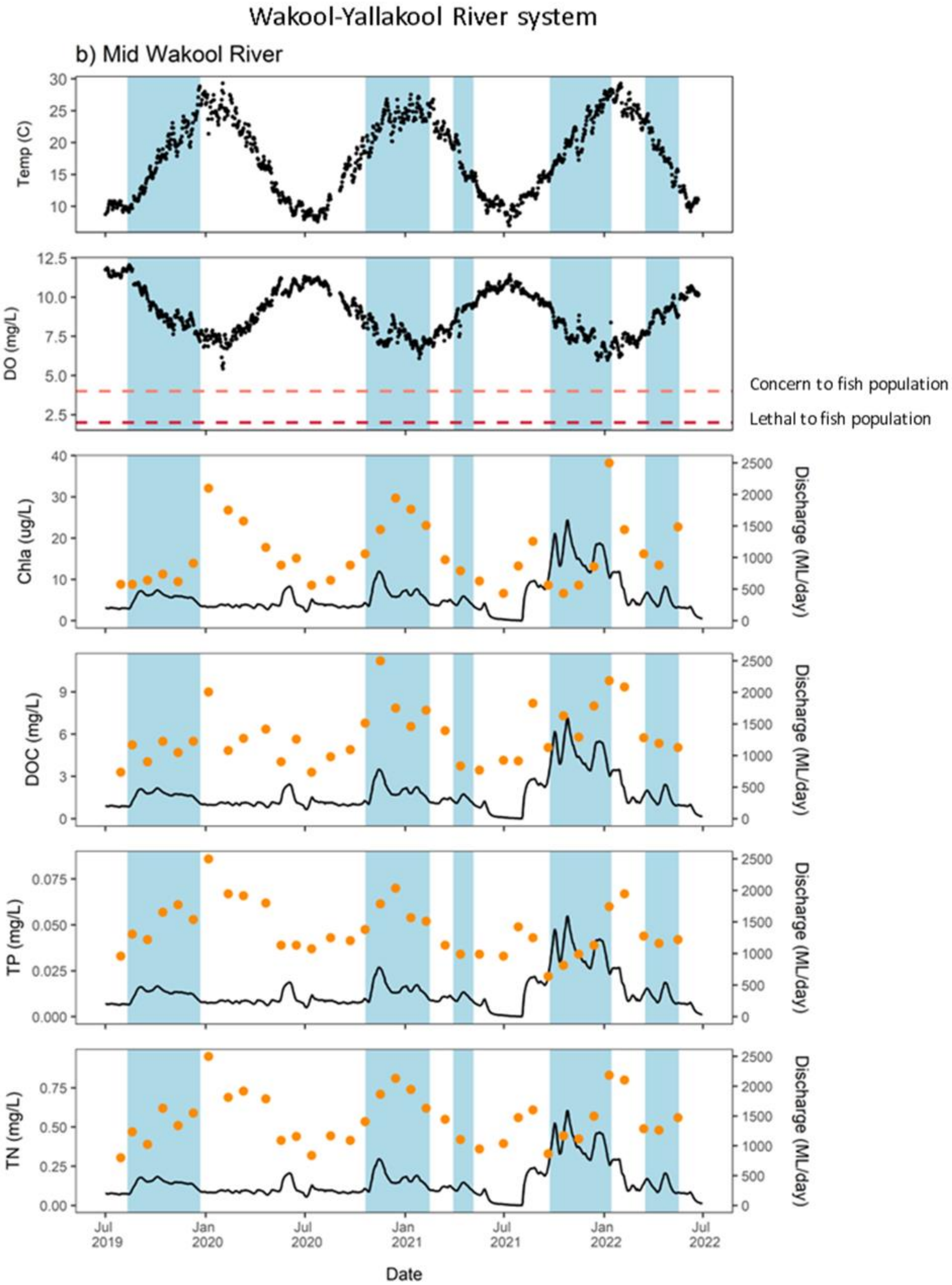


Figure 5.5b Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for mid Wakool River (zone 4) upstream over the 2019-22 watering years. Blue shaded vertical bars indicate watering actions.

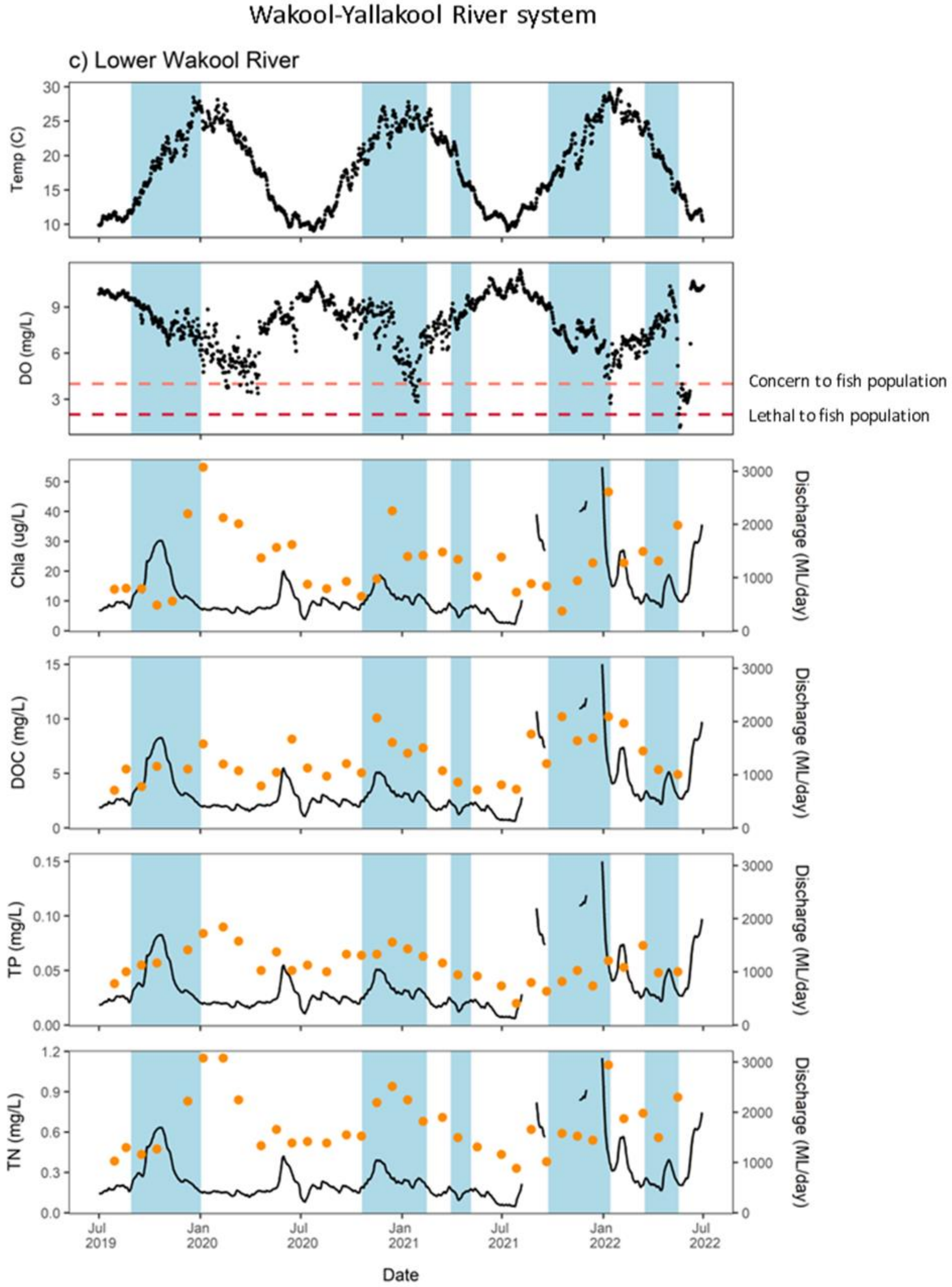


Figure 5.5c Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for Stoney Crossing over the 2019-22 watering years in the lower Wakool-Yallakool system. Blue shaded vertical bars indicate watering actions. Water temp and DO data collected from Water NSW flow gauge (409013).

Figure 5.6 Poor water quality was observed at the upper Wakool River system in January (left) and February (right) 2022.

Nutrients

In general, 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, 2019-20 and 2020-21 sampling years. TP generally increased in 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 Wakool River suggesting slight increases in TP and TN as the water progresses through the system. The filterable reactive phosphorus (FRP) remained below the trigger levels (ANZECC 2000). Most NO_x values remained below the trigger value with the exception on one occasion at Stevens Weir (source water via Edward/Kolety River) in June 2022 which might be associated with the input along Edward/Kolety River.

At Yallakool Creek, most ammonia (NH_4+) values remained below the trigger value with the exception in December 2021 which might be related to the ammonia introduced from the source water corresponding with a higher ammonia level detected at Stevens Weir. High TN, NO_x and NH_4+ concentrations were recorded in Yallakool Creek in July 2021 and likely a result of but are likely an artifact of sediment disturbance while sampling, as there was no discharge in the channel during those sampling periods (see Figure 5.7).

Figure 5.7 Yallakool Creek in July 2021 (left) and June 2022 (right). (Photo: Xiaoying Liu)

Dissolved organic carbon (DOC)

Small pulses of DOC and nutrients were detected in the Wakool-Yallakool system in August, October and December 2021. A larger pulse of DOC and nutrients was also detected in the Wakool-Yallakool system in February 2022. DOC concentration (12.5 mg/L) at upper Wakool in February 2022 almost reached the similar level during 2016-17 flooding year, which corresponds with dark coloured water and floating algae were observed in this part of the system (see Figure 5.5a). It is common for DOC and nutrients levels to be higher in upper Wakool River than the other study sites during summer because discharge is typically much lower than other study reaches.

Water temperature

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. This was consistent with the trend observed in previous years, and observed in the Edward/Kolety River, Colligen-Niemur and Tuppal Creek. As such, we do not report on water temperature here after in the 2021-22 report, unless there is an extraordinary pattern.

Dissolved Oxygen (DO)

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. 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). This was consistent with the trend observed in previous years, and observed in the Edward/Kolety River, Colligen-Niemur and Tuppal Creek. As such we do not report on DO here after in the 2021-22 report, unless DO levels dropped into the range of concern to fish populations (below 4 mg/L) and dropped into the range of lethal to fish populations (below 2 mg/L).

Concentrations of DO in the upper Wakool River briefly dropped into the range of concern to fish populations (below 4 mg/L) in February 2022. DO values at lower reach of Wakool River at Stoney Crossing dropped below 4 mg/L and further declined below 2 mg/L for a very short time in January and May 2022.

Organic carbon absorbance

The absorbance spectra for water samples collected from the Wakool-Yallakool system are shown in Figure 5.8. Absorbance scans indicate that throughout most of the 2021-22 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 abosorbance spectra for samples from the upper Wakool River (Zone 2) resembled the organic matter profile of the source water at Mulwala Canal, and other sites were similar to the organic matter profile of source water at Stevens Weir. There is a slight increase in the absorbance in August 2021 which is consistent with a small pulse of DOC detected due to return flows from the watering action for the Murray River from Hume Dam via the Millewa Forest. The amount and mixture of DOC at all sites during the unregulated flow event are higher, particularly during the initial period of unregulated flows. Absorbance scans show the organic matter of water from Stevens Weir was higher, and the scans for water samples from Yallakool Creek (zone 1) and the middle and lower reaches of Wakool River (zones 3 to 6) were showing similar trends. A slight stronger absorbance is present in January and February 2022. Absorbance generally decreased from autumn through to winter 2022.

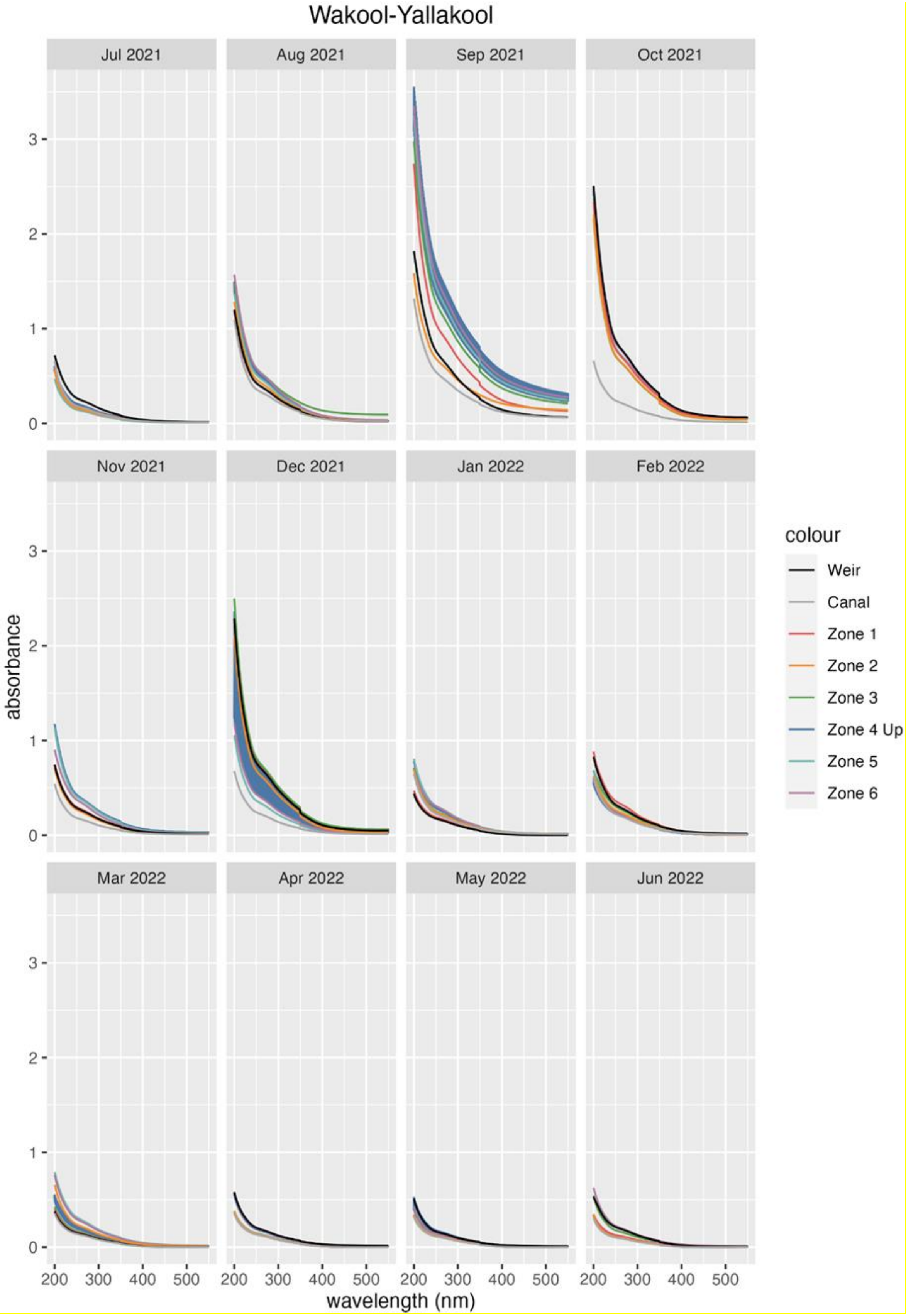


Figure 5.8 Absorbance of water samples at the Wakool-Yallakool River system in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Organic matter carbon

Fluorescence excitation-emission matrices for water samples in the Wakool-Yallakool system indicate that between August and December 2021 higher fluorescence was observed at all sites with a gradual increase downstream, fluorescence of upper Wakool River (Zone 2) was more similar to the signature from Mulwala Canal and other sites were more similar to Stevens Weir, consistent with the absorbance results. In September 2021 Stevens Weir and Yallakool Creek (zone 1) were also showing high fluorescence. 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). In addition, the stronger fluorescence was detected at the middle and lower reaches of Wakool River supporting the conclusion that a pulse with stronger fluorescence transited through the system where larger areas were wetted due to unregulated flows.

A broadly similar and stronger fluorescence was evident in the upper Wakool River in January and February 2022. 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 fluorescence as upper Wakool River. Fluorescence generally decreased from late summer through to winter 2022.

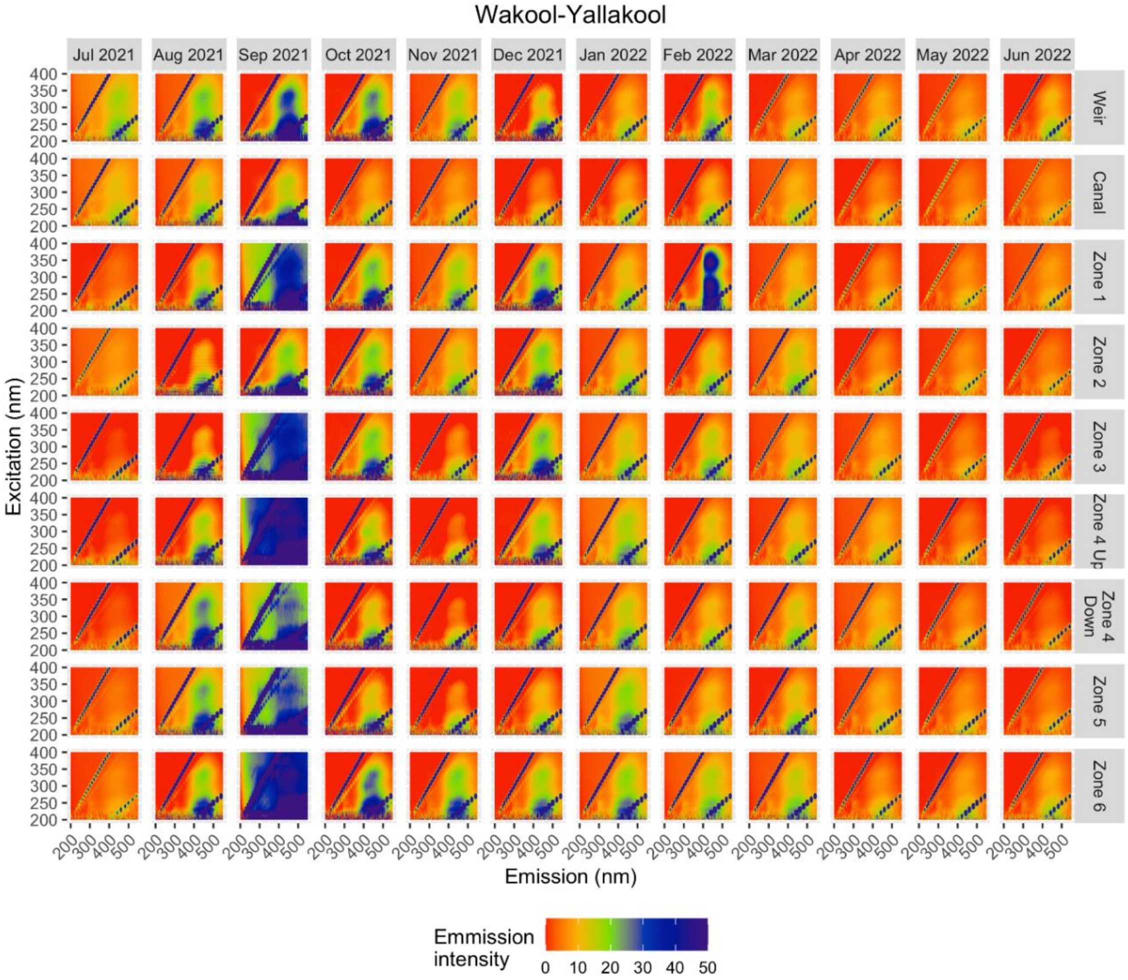


Figure 5.9 Fluorescence scans of water samples from the Wakool-Yallakool system in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Watering actions

Unregulated flows: Spring-early summer

Pulses of nutrients and dissolved organic carbon were detected in the Wakool-Yallakool River system in August 2021 while unregulated flow was not available in the system yet. A higher fluorescence also was observed at all sites in late winter 2021-22, indicating that nutrients and dissolved organic carbon leached from Millewa Forest via return flows by the watering action for the Murray River from Hume Dam were introduced to the system.

A long period of unregulated flows occurred in the Wakool-Yallakool River system from September to December 2021. Pulses of nutrients and dissolved organic carbon were detected in the Wakool-Yallakool River system over the period of unregulated flows, consistent with intensifying absorbance and fluorescence results, suggesting the unregulated flows that moved through the system at this time, where larger areas of floodplain were inundated, both locally and also from Barmah-Millewa Forest.

Watering action 1: Spring-summer hypoxic blackwater refuge (Wakool escape)

Spring-summer hypoxic blackwater refuge flow delivered to the upper Wakool system via the Wakool escape from 14 September 2021 until 5 January 2022 (watering action 1). The delivery of watering action 1 commenced following the unregulated flows to mitigate the risk of hypoxic blackwater events.

Small pulses of DOC and nutrients were detected in the Wakool-Yallakool system over watering action 1 but all were within the acceptable range and similar to the range observed in previous years (Figures 5.5a, 5.5b and 5.5c). A decline in nutrients and dissolved organic carbon concentrations was measured in the Wakool-Yallakool system in November 2021, consistent with slightly weakening absorbance and fluorescence results. Commonwealth environmental water for the Murray River from Hume Dam tended to increase DOC in the system, whereas watering action 1 mitigated the extent of increases in DOC and nutrients in the Wakool-Yallakool system.

Watering actions 4 and 5: Wakool Offtake autumn elevated variable base flow and Yallakool Autumn Fresh

Concentrations of DO in the upper Wakool River briefly dropped into the range of concern to fish populations (below 4 mg/L) in February 2022 when delivery of environmental watering action 1 ceased, accordingly dark-coloured water was also observed with low DO concentration (3.45 mg/L) recorded, although these were within the range normally measured at that time of year. 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 black coloured water and floating algae were observed in upper Wakool River in January and February 2022, broadly similar and stronger fluorescence is present.

DOC and nutrients concentrations in the middle and lower reaches of Wakool River in 2021-22 water year were similar to those observed in 2019-20 and 2020-21. However, higher concentrations of DOC and nutrients were detected at middle and lower reaches of Wakool River in January and February 2022 after the end of watering action 1 (Figures 5.5b and 5.5c). Middle and lower reaches of Wakool River have a similar fluorescence as upper Wakool River, this is consistent with slight increases in

DOC concentrations over that period. At this time DO values dropped below 4 mg/L and further declined below 2 mg/L for a short time at lower reach of Wakool River at Stoney Crossing.

An autumn elevated variable base flow delivered to the upper Wakool system via the Wakool offtake from 8 March until 9 May 2022 (watering action 4). An autumn fresh flow delivered to the Wakool-Yallakool system via Yallakool offtake from 24 March to 9 Many 2022 (watering action 5). The increased flow (watering actions 4 and 5) diluted otherwise green and dark-coloured water and resulted in increased DO concentrations and decreased in DOC concentrations in the Wakool system.

DO values briefly dropped below 4 mg/L and declined below 2 mg/L again in May 2022 at lower reach of Wakool River which might be related to rapid drop in water discharge (ceased watering actions 4 and 5) and slight increase in water temperature and it did not result in any adverse effects.

The Edward/Kolety River

Spot water quality parameters (electrical conductivity (EC), turbidity and pH) remained (see Table 5.4) within the normal range for the Edward/Kolety system throughout the study period and were similar to results from the 2019-20 and 2020-21 (Table 5.4).

Table 5.4 Range and mean values of water physico-chemical parameters for the Edward/Kolety River system in 2021-22 water year. The order of sampling sites from left to right is present from upstream to downstream of the river system. ANZECC (2000) trigger levels for available water parameters are given and bolded. pH, Turbidity and EC are spot reading data. DO data were collected from loggers. Chl a, TP, FRP, TN, NH$_4^+$, NO$_x$ and DOC are from laboratory analysis of water samples. NA not available.

WQ Parameters	**Edward/Kolety River**					
	Upper	**Weir**	**Mid**		**Lower**	
	Four post	Weir	Eastman Bridge	Balpool Road	Moulamein	Liewah
pH **6.5-8**	6.48-7.76 (7.0)	6.57-7.82 (7.18)	6.33-7.91 (7.02)	6.54-7.79 (7.05)	6.91-7.71 (7.26)	6.94-7.55 (7.26)
Turbidity (NTU) **50**	16.3-78.5 (41.5)	21.3-64.6 (35.8)	23-50.1 (35.7)	14-99.6 (42.0)	42.8-89.5 (64.1)	48.1-83.2 (60.7)
EC (mS cm^{-1}) **0.125**	0.035-0.067 (0.049)	0.038-0.066 (0.050)	0.037-0.066 (0.051)	0.039-0.067 (0.053)	0.077-0.174 (0.113)	0.073-0.18 (0.119)
DO (mg L^{-1})	2.49-11.69 (8.15)	NA	4.28-11.13 (8.14)	0-11.13 (7.78)	1.05-11.4 (8.35)	5-11.24 (8.02)
Chl *a* (µg L^{-1}) **5**	7.98-31.58 (14.88)	6.64-32.93 (17.12)	8.95-27.95 (13.76)	10.64-39.39 (18.88)	10.47-45.57 (24.95)	9.96-32.24 (21.48)
TP (mg L^{-1}) **0.05**	0.017-0.062 (0.038)	0.019-0.051 (0.034)	0.016-0.061 (0.036)	0.021-0.054 (0.038)	0.026-0.13 (0.059)	0.028-0.12 (0.062)
FRP (mg L^{-1}) **0.02**	0.005-0.012 (0.007)	0.005-0.008 (0.006)	0.005-0.013 (0.007)	0.005-0.011 (0.007)	0.005-0.042 (0.011)	0.005-0.025 (0.008)
TN (mg L^{-1}) **0.5**	0.31-0.66 (0.47)	0.315-0.69 (0.487)	0.31-0.98 (0.51)	0.4-0.87 (0.52)	0.4-0.97 (0.64)	0.36-1.1 (0.66)
NH$_4^+$ (mg L^{-1}) **0.02**	0.005-0.009 (0.006)	0.005-0.05 (0.01)	0.005-0.016 (0.007)	0.005-0.018 (0.008)	0.005-0.023 (0.007)	0.005-0.008 (0.006)
NO$_x$ (mg L^{-1}) **0.04**	0.002-0.036 (0.008)	0.002-0.049 (0.011)	0.002-0.054 (0.012)	0.002-0.055 (0.014)	0.002-0.036 (0.01)	0.002-0.028 (0.006)
DOC (mg L^{-1})	3.5-12.5 (6.6)	3.6-10.5 (6.7)	3.6-14.8 (7.1)	3.8-15.2 (6.7)	4.7-13.5 (8.5)	4-15.1 (8.6)

pH and turbidity

pH values were within the acceptable range (ANZECC, 2000) throughout the year.

Turbidity measurements fluctuated above and below the ANZECC (2000) trigger level and values were similar between sites. Turbidity values measured at Moulamein and Liewah were higher in 2021-22 than in previous years, which might be associated with the considerably higher inflow from Murrumbidgee Catchment via Billabong Creek (turbidity range 73.3-141 NTU, mean 96.7 NTU) to Edward/Kolety River in 2021-22.

Electrical conductivity (EC)

EC remained stable within the lower end of the ANZECC (2000) range expected for lowland rivers. EC values at the Moulamein and Liewah were higher in 2021-22 sampling year than those observed in previous years which might be associated with the considerably higher inflow from Murrumbidgee Catchment via Billabong Creek [EC range 0.153-0.233 mS/cm (mean 0.200 mS/cm).

Chl *a*

Chl *a* concentrations remained stable in the Edward/Kolety River system and values observed in 2021-22 were similar to those observed in 2019-20 (Figures 5.10a, 5.10b and 5.10c). Increases in Chl *a* concentrations along the Edward/Kolety River between January and March 2022 corresponded with observed excessive algae growth. Chl *a* concentrations then declined from April 2022.

Nutrients

The min-max ranges of nutrients concentrations in the Edward/Kolety River were higher in 2021-22 than those observed in previous years (2019-20 and 2020-21). TP and TN concentrations fluctuated above and below the ANZECC (2000) trigger values and concentrations at Moulamein and Liewah were slightly higher, and attributable to inflows from Billabong Creek. The bioavailable nutrient (FRP, NO_x and ammonia) concentrations did not exceed trigger values (ANZECC 2000).

Dissolved organic carbon (DOC)

The min-max ranges of DOC concentrations in the Edward/Kolety River were higher in 2021-22 than those observed in previous sampling years, and likely associated with the unregulated events and increased Billabong Creek inflows occurred in this water year where larger areas were wetted.

Water temperature

Water temperature was influenced by seasonal rather than site-specific factors with all sites in Edward/Kolety River displaying the same seasonal variation and influence of weather patterns. Compared to previous years (2019-20 and 2020-21) water temperatures were elevated in summer/early autumn of 2021-22 in the Edward/Kolety River. This might be attributable to the warmer return flows coming out of Barmah-Millewa Forest where water would have spread across the flood plain and warmed before re-entering the Edward/Kolety River.

Dissolved oxygen (DO)

In 2021-22 water year, no DO values below 4 mg/L (the range of concern to fish populations) were recorded in the middle and lower reaches of Edward/Kolety River However from early November to late December 2021 and from early to late February 2022 at upper reach of Edward/Kolety River system (Four Posts), low DO concentrations briefly below 4 mg/L were detected.

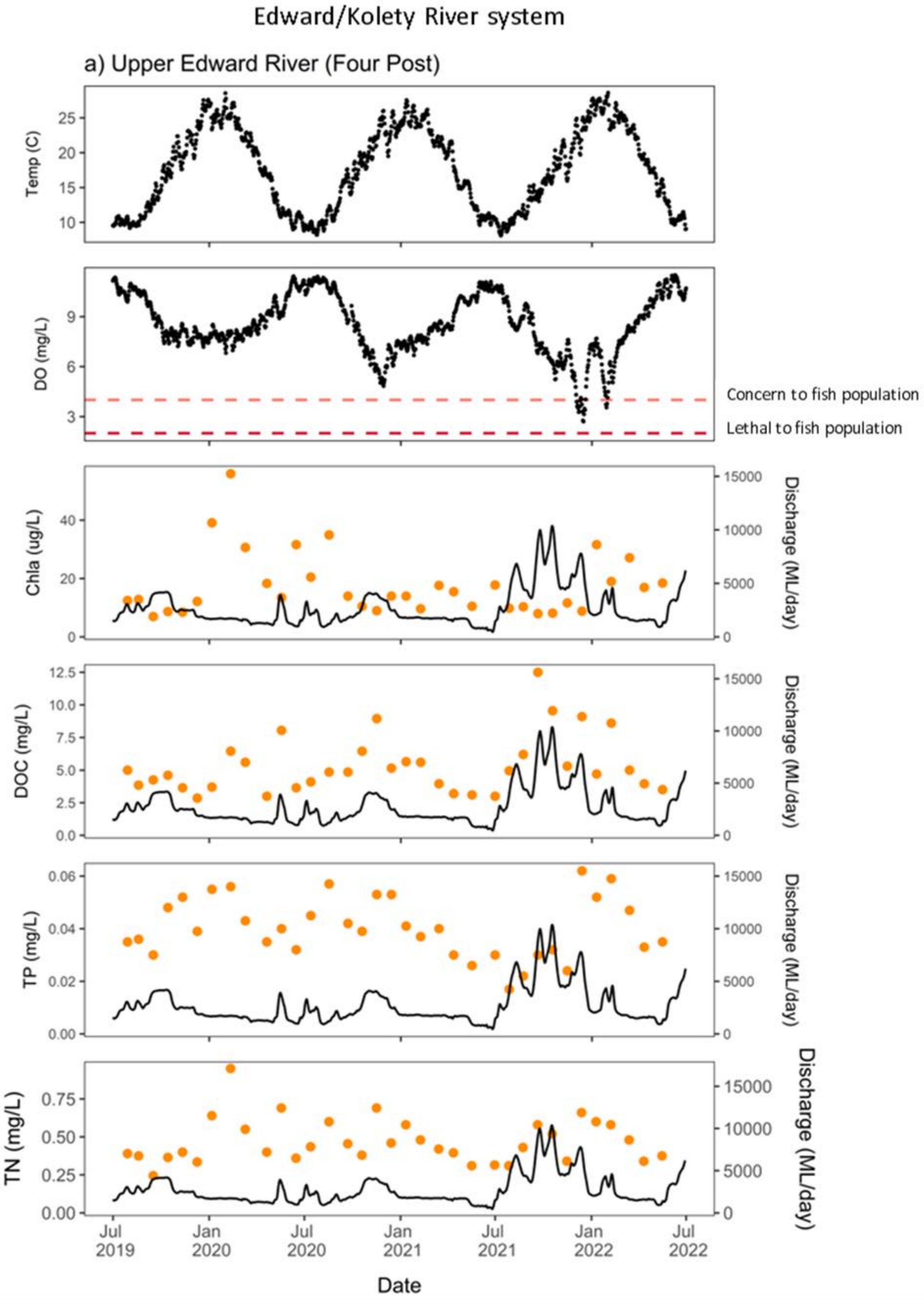


Figure 5.10a Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) values for Four Posts in the upper Edward/Kolety River from 2019-2022. Blue shaded vertical bars indicate watering actions.

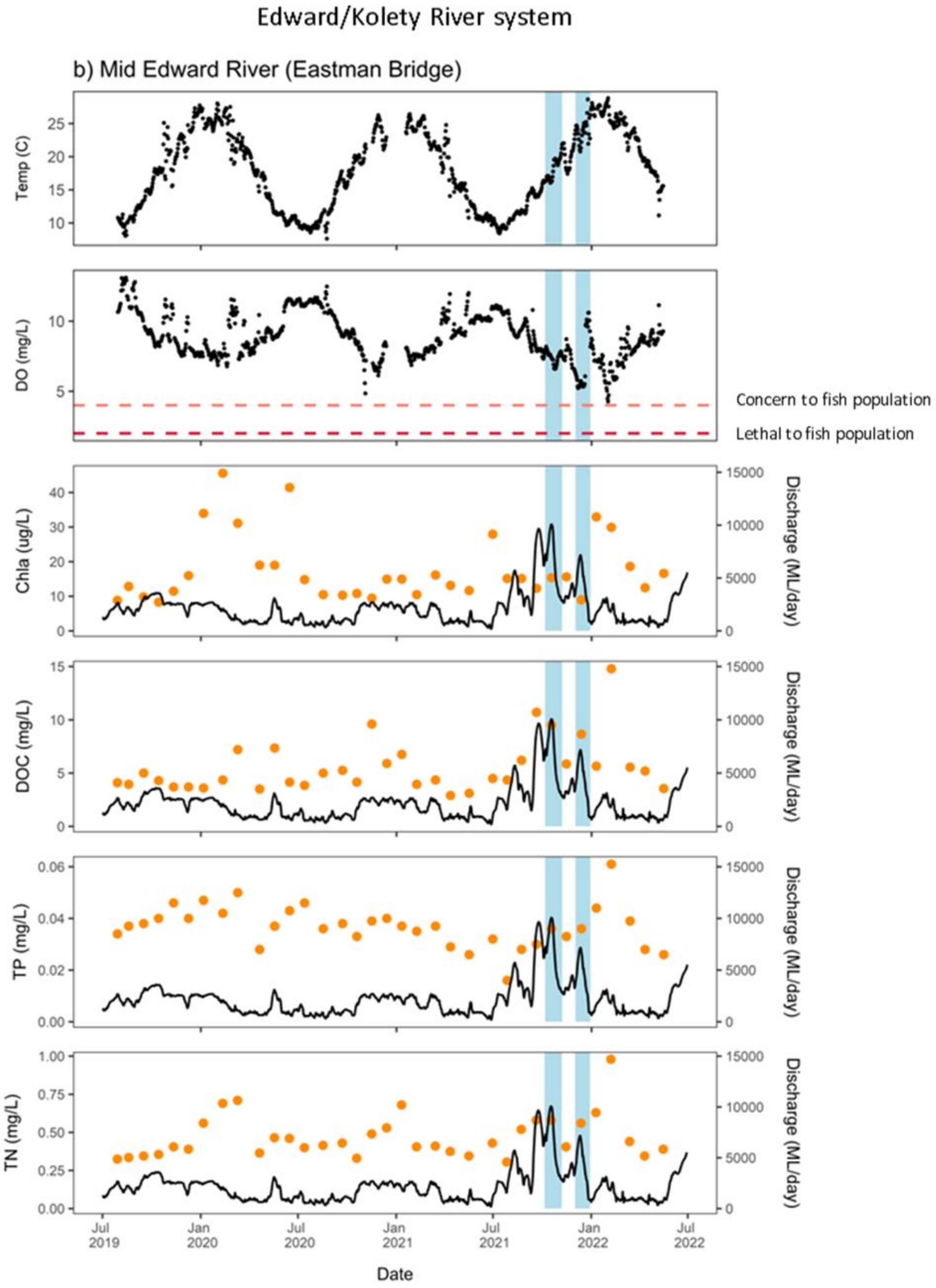


Figure 5.10b Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) values for Eastman Bridge in the mid Edward/Kolety River from 2019-2022. Blue shaded vertical bars indicate watering actions.

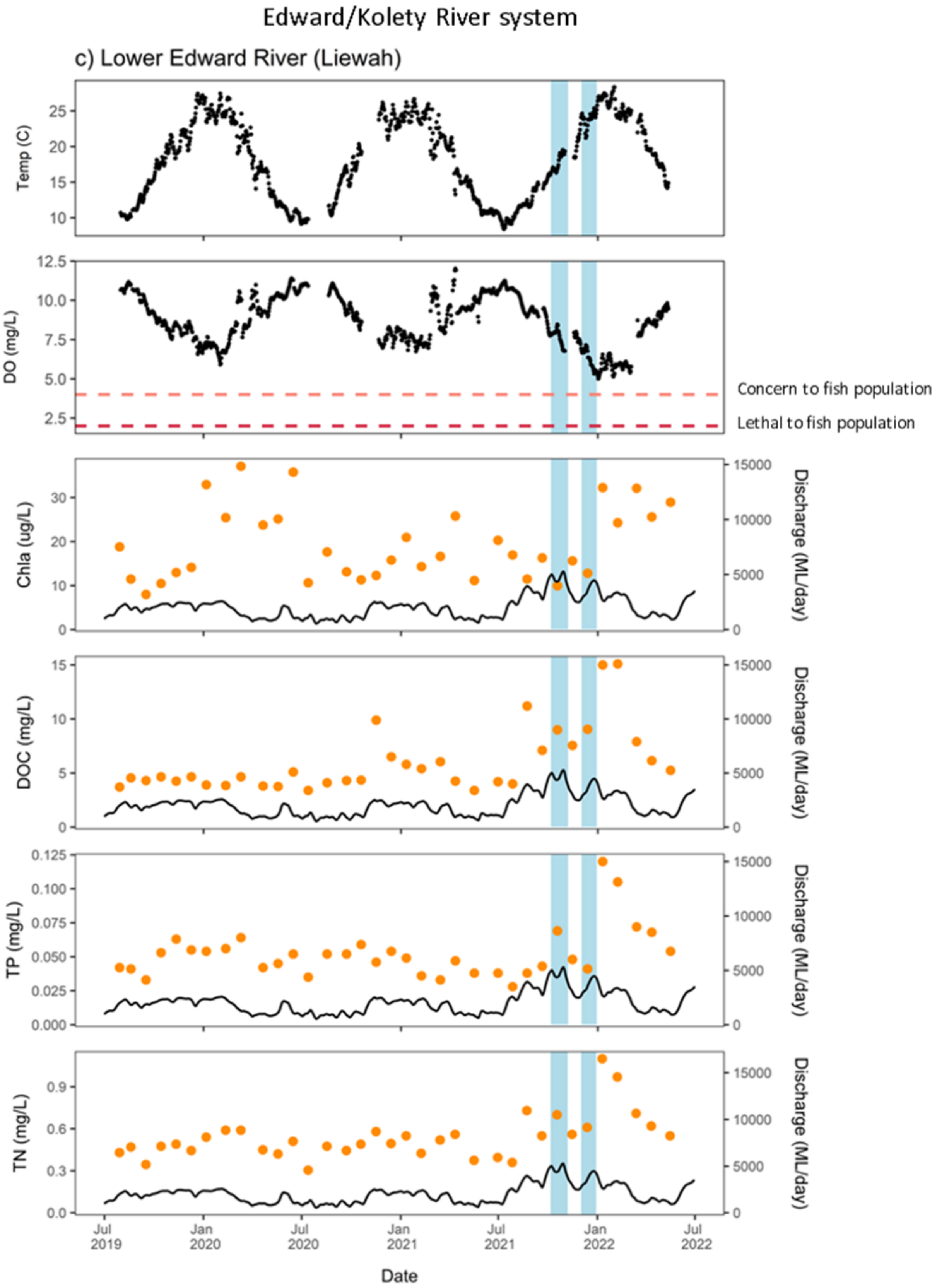


Figure 5.10c Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) values for Liewah in the lower Edward/Kolety River from 2019-2022. Blue shaded vertical bars indicate watering actions.

Organic carbon absorbance

Absorbance scans (Figure 5.11) 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 the Edward/Kolety River. There is a slight increase in the absorbance in August 2021 which is consistent with a small pulse of DOC detected as the increased return flows from the watering action for the Murray River from Hume Dam via the Millewa Forest. Both the amount and mixture of DOC at all sites during the unregulated flows were stronger, particularly during the initial period of unregulated flows. The absorbance scans show the organic matter of water from Four Posts via Barmah-Millewa Forest was higher. The middle and lower reaches of Edward/Kolety River have a higher absorbance as the pulse transited through the system.

In January and February 2022 there is an obvious trend towards increasing organic matter absorbance at lower reach of Edward/Kolety River, Moulamein and Liewah sites, consistent with detected pulses of DOC due to the higher discharge from Billabong Creek to the system.

By March 2022 the absorbance spectra for all sites were very similar and through the autumn to winter 2022 the sites remain similar.

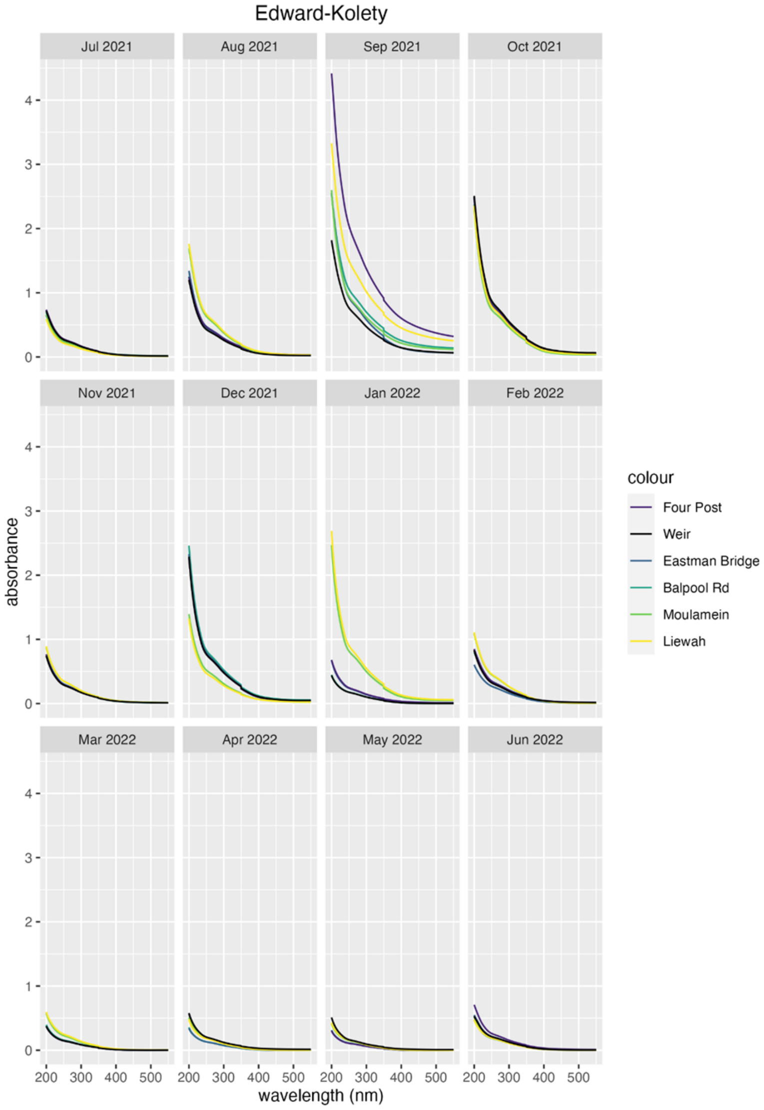


Figure 5.11 Absorbance of water samples at the Edward/Kolety River system in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Organic carbon fluorescence

Fluorescence excitation-emission matrices for water samples at the Edward/Kolety River through the 2021-22 water year are shown in Figure 5.12. Between August and December 2021, the higher fluorescence was observed at all sites which was progressed downstream over time, consistent with the absorbance results. Broadly similar fluorescence was 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 unregulated flows (sourced from organic material in channel or from return flows from Murray via Barmah-Millewa Forest from newly wetted forests, wetlands, and anabranches).

In January and February 2022, a slightly strong fluorescence was observed in the upper Edward/Kolety River which could be organic matter introduced by return flows from Hume Dam via the Edward and Gulpa offtakes and Millewa Forest flowing into the Edward/Kolety-Wakool system. In addition, the middle and lower reaches of Edward/Kolety River were showing high fluorescence in January and February 2022, that could be due to the increased inflows from Billabong Creek introducing additional organic matter.

Fluorescence generally decreased from late summer through to winter 2022 consistent with decreases in DOC and Chl *a*.

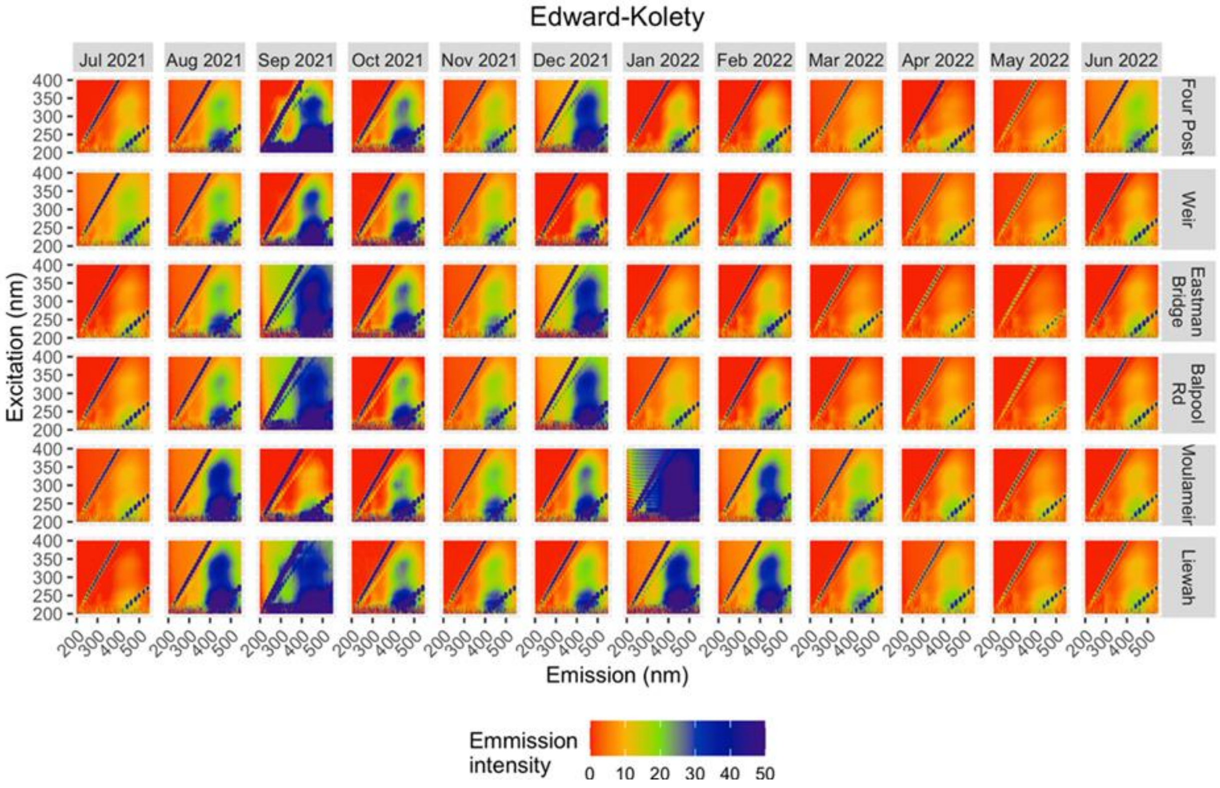


Figure 5.12 Fluorescence scans of water samples from the Edward/Kolety River system in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Watering actions

Unregulated flows: Spring-early summer

Pulses of DOC and nutrients were detected in the Edward/Kolety River in August 2021 prior to the unregulated flow, and a higher fluorescence also was observed at all sites in the system, indicating that nutrients and dissolved organic carbon leached from Millewa Forest via return flows by the watering action for the Murray River from Hume Dam were introduced to the Edward/Kolety River.

From September to December 2021, pulses of DOC and nutrients were detected in the Edward/Kolety River over the period of unregulated flow events and a stronger fluorescence was observed at all sites in the system. It may also be sourced from increased return flows via Millewa Forest from newly wetted forests, wetlands, and anabranches. Low DO concentrations (briefly below 4 mg/L) were detected in the upper reach of the Edward/Kolety River from early November to late December 2021 at Four Posts when temperature started to warm up. TN and TP concentrations increased in the Edward/Kolety River and also corresponded with higher discharges which might have been associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column).

Watering action 2: Spring-summer hypoxic blackwater refuge (Edward escape)

A spring-summer hypoxic blackwater refuge flow was delivered to the upper Edward/Kolety system via the Edward offtake from 6 October to 7 November 2021 and from 2 December to 30 December 2021 (watering action 2). The delivery of watering action 2 commenced following the unregulated flows to mitigate the risk of hypoxic blackwater events in the Edward/Kolety system.

Extensive overbank natural flooding can result in export and decomposition of carbon from the floodplain and subsequent hypoxia due to microorganisms consuming DOC and using up oxygen in the water column. The oxygen consumption by microbial activity is often faster than the oxygen can be replenished from the atmosphere (Howitt et al. 2007; King et al. 2012; Whitworth and Baldwin 2016). The occurrence of hypoxic can potentially lead to death of aquatic organisms.

Watering action 2 commenced following the unregulated flows decreased the concentrations of DOC and nutrients across all sites downstream of Edward escape in the Edward/Kolety River, comparing to data collected in September 2021 (Figures 5.10b and 5.10c). Lower concentrations of nutrients and dissolved organic carbon were also measured in the Edward/Kolety River in November 2021, consistent with slightly weakening fluorescence absorbance results. Watering action 2 and Commonwealth environmental water for the Murray River from Hume Dam mitigated the extent of increases in DOC and nutrients and then reduced the occurrence of hypoxic events in the Edward/Kolety River.

After the end of watering action 2, critical DO concentrations (briefly below 4 mg/L) occurred in the upper reach of the Edward/Kolety River in February 2022 which is likely due to the elevated water temperature. DOC values were outside the normal range observed in the middle and lower reaches of Edward/Kolety River in February 2022, this corresponded with dark coloured water observed in these parts of the system (Figure 5.13), suggesting the increased discharge from Billabong Creek introduced DOC and nutrients to the Edward/Kolety River system.

Figure 5.13 Poor water quality was observed at the upper (left) and mid (right) reaches of Edward/Kolety River system in February 2022. (Photo: Xiaoying Liu)

The Colligen-Niemur system

Spot water quality parameters (electrical conductivity (EC), turbidity and pH) (Table 5.5) remained within the normal range for the Colligen-Niemur system throughout the study period and were similar to results from 2019-20 and 2020-21. pH, turbidity and EC collected from the Colligen-Niemur system were similar to the values of Edward/Kolety River. In January and February 2022 there was poor water quality water observed in the system (Figure 5.14).

Table 5.5 Range and mean values of water physico-chemical parameters for the Colligen-Niemur system in 2021-22 water year. The order of sampling sites from left to right is present from upstream to downstream of the river system. ANZECC (2000) trigger levels for available water parameters are given and bolded. pH, Turbidity and EC are spot reading data. DO data were collected from loggers. Chl a, TP, FRP, TN, NH_4^+, NO_x and DOC are from laboratory analysis of water samples. NA not available.

WQ Parameters	**Edward/Kolety River**	**Colligen Creek**	**Niemur River**	
			Upper	**Lower**
	weir	Old Morago Road	Moulamein road	Mallan School
pH **6.5-8**	6.57-7.82 (7.18)	6.18-7.7 (7.0)	6.68-7.49 (7.1)	6.71-7.71 (7.18)
Turbidity (NTU) **50**	21.3-64.6 (35.8)	23.8-77.8 (44.8)	7.5-89.9 (38.4)	17.8-79.3 (49.5)
EC (mS cm^{-1}) **0.125**	0.038-0.066 (0.050)	0.038-0.067 (0.050)	0.04-0.07 (0.055)	0.05-0.072 (0.059)
DO (mg L^{-1})	NA	4.77-11.67 (8.24)	3.80-11.22 (7.70)	3.89-11.67 (8.33)
Chl *a* (µg L^{-1}) **5**	6.64-31.76 (15.37)	9.96-33.1 (18.51)	6.64-126.45 (27.48)	6.64-87.83 (28.45)
TP (mg L^{-1}) **0.05**	0.019-0.051 (0.034)	0.019-0.065 (0.034)	0.023-0.105 (0.049)	0.032-0.093 (0.052)
FRP (mg L^{-1}) **0.02**	0.005-0.008 (0.006)	0.005-0.006 (0.005)	0.005-0.013 (0.007)	0.005-0.024 (0.008)
TN (mg L^{-1}) **0.5**	0.315-0.69 (0.49)	0.36-1.05 (0.51)	0.39-1.65 (0.63)	0.43-1.45 (0.67)
NH_4^+ (mg L^{-1}) **0.02**	0.005-0.05 (0.01)	0.005-0.047 (0.009)	0.005-0.015 (0.007)	0.005-0.009 (0.006)
NO_x (mg L^{-1}) **0.04**	0.002-0.049 (0.011)	0.002-0.047 (0.009)	0.002-0.007 (0.003)	0.002-0.004 (0.003)
DOC (mg L^{-1})	3.6-10.5 (6.7)	3.9-12.5 (7.1)	4.4-11.1 (7.4)	3.3-10.9 (7.6)

Figure 5.14 Poor water quality was observed at Colligen Creek at Old Morago Road (left) and Niemur River at Mallan School (right) in January 2022. (Photo: Xiaoying Liu)

pH

pH values were within the ANZECC (2000) trigger range.

Turbidity

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.

Electrical conductivity (EC)

EC remained stable within the lower end of the range expected for lowland rivers (ANZECC 2000). In general, the range of Chl *a*, DOC and nutrients concentrations in the Colligen-Niemur system was higher in 2021-22 (Figures 5.15a and 5.15b) than observed in previous sampling years and was in similar range as measured in the Edward/Kolety River.

Chlorophyll-*a*

Increases in Chl *a* level at sampling sites in the Colligen-Niemur system in January and February 2022 corresponding with poor water quality water observed in the system (Figures 5.15a and 5.15b), suggesting increases in photosynthesis which is quite common during the summer months with high water temperatures and light levels. Chlorophyll-*a* was lower during the watering actions.

Nutrients

The range of nutrients concentrations in the Colligen-Niemur system was similar as that measured in source water from the Edward/Kolety River system in 2021-22 water year remaining in the acceptable range. While TP and TN concentrations fluctuated above and below the ANZECC (2000) trigger values the bioavailable nutrient concentrations remained stable and did not exceed trigger values (ANZECC 2000).

Dissolved organic carbon (DOC)

The range of DOC concentrations in the Colligen-Niemur system was similar as that measured in source water from the Edward/Kolety River system in 2021-22 water year and slightly higher than DOC values observed in 2019-20 and 2020-21.

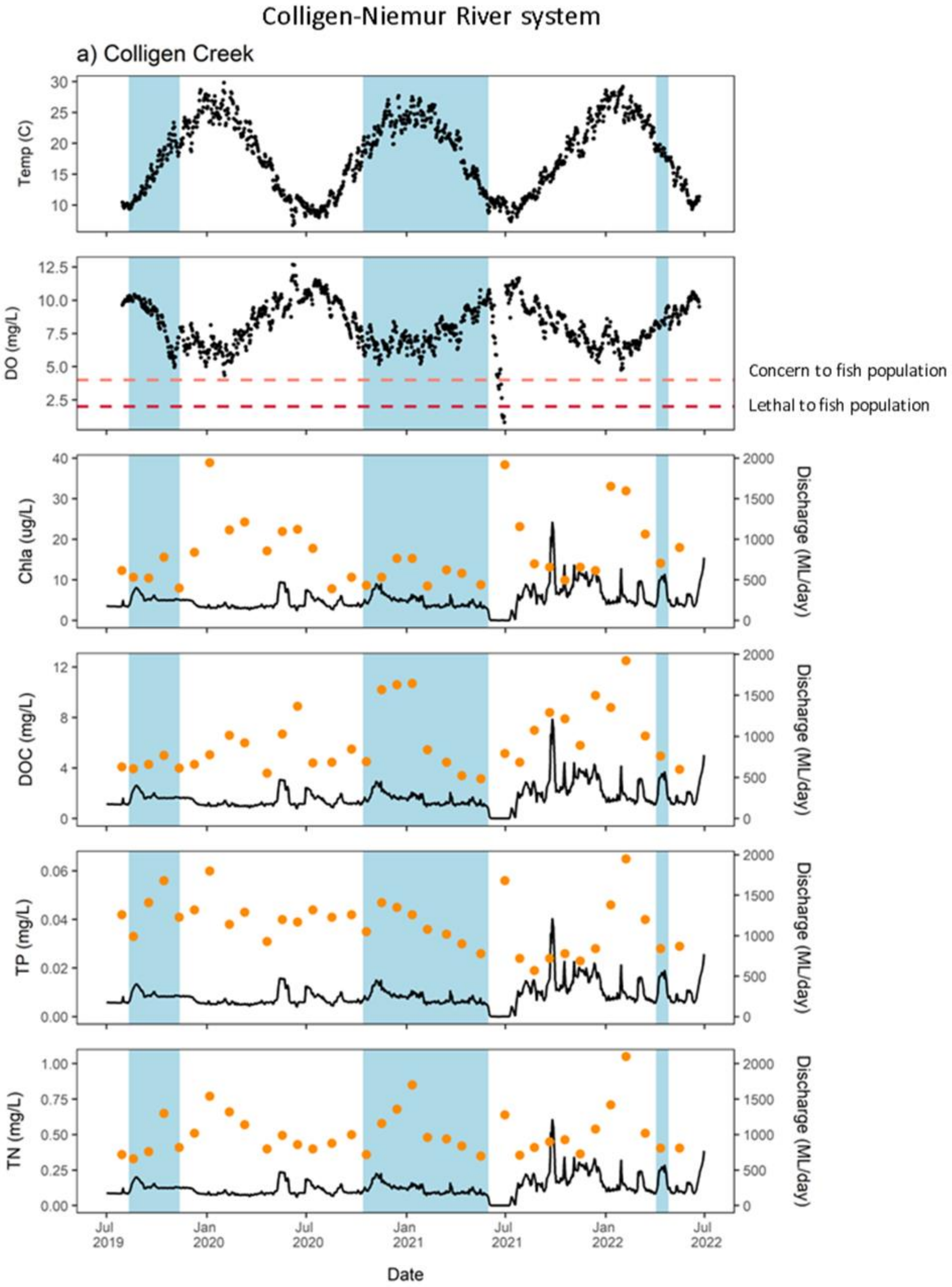


Figure 5.15a Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for Colligen Creek at Old Morago Rd over the 2019-22 watering years in the upper Colligen-Niemur system. Blue shaded vertical bars indicate watering actions.

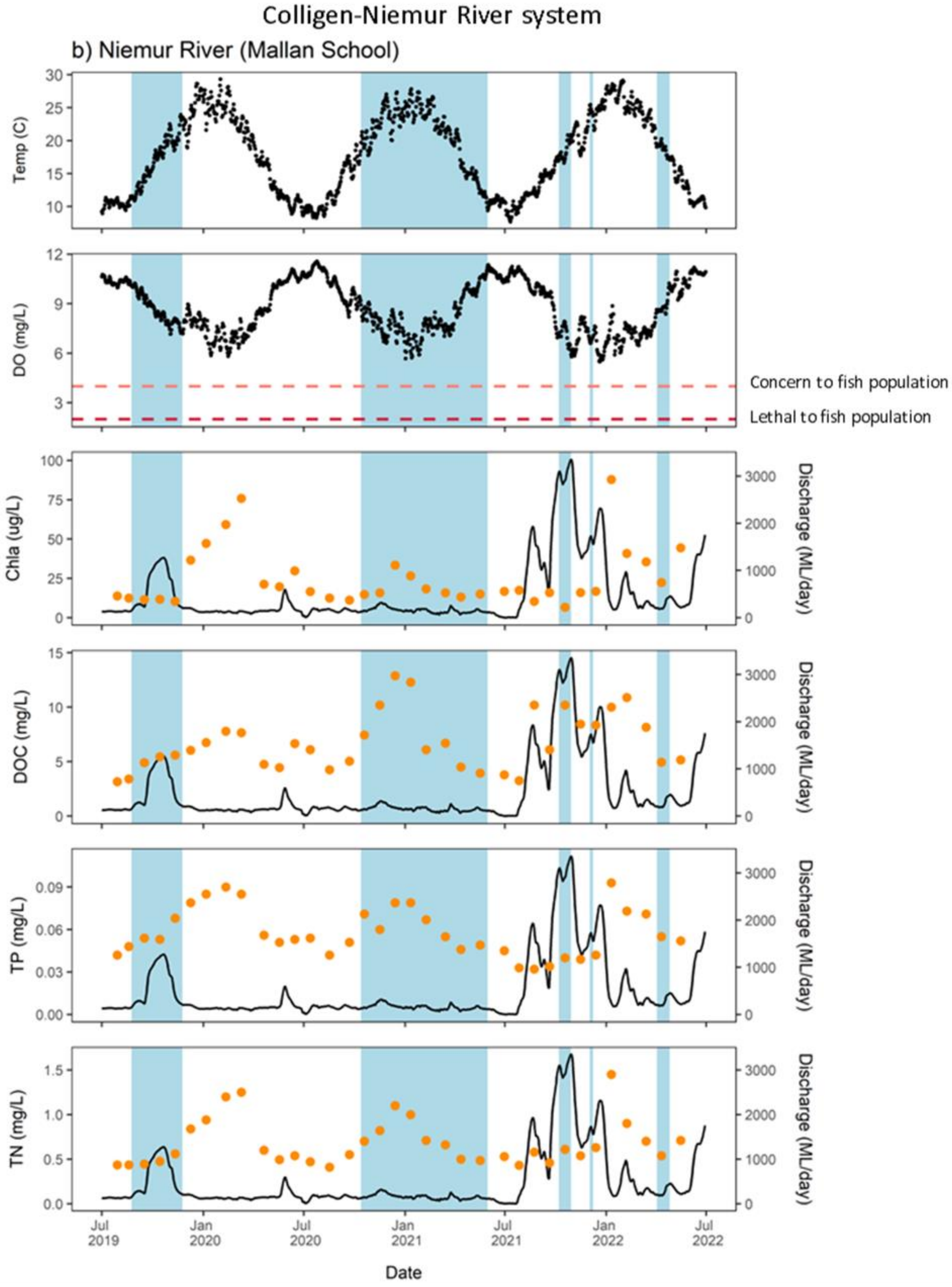


Figure 5.15b Water temperature, discharge, dissolved oxygen (DO), chlorophyll *a* (Chl *a*), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for Niemur River at Mallan School over the 2019-22 watering years in the lower Colligen-Niemur system. Blue shaded vertical bars indicate watering actions. Water temp and DO data collected from Water NSW flow gauge (409086).

Organic carbon absorbance

Absorbance scans (Figure 5.16) 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 in the Colligen-Niemur River system. A slight increase in the absorbance in August 2021 was observed which is consistent with a small pulse of DOC detected as the increased return flows from Millewa Forest due to the watering action for the Murray River from Hume Dam. A slight trend towards increasing organic matter absorbance at all sites occurred in January and February 2022. By March 2022 the absorbance spectra for all sites were very similar and through the autumn to winter 2022 the sites remain similar.

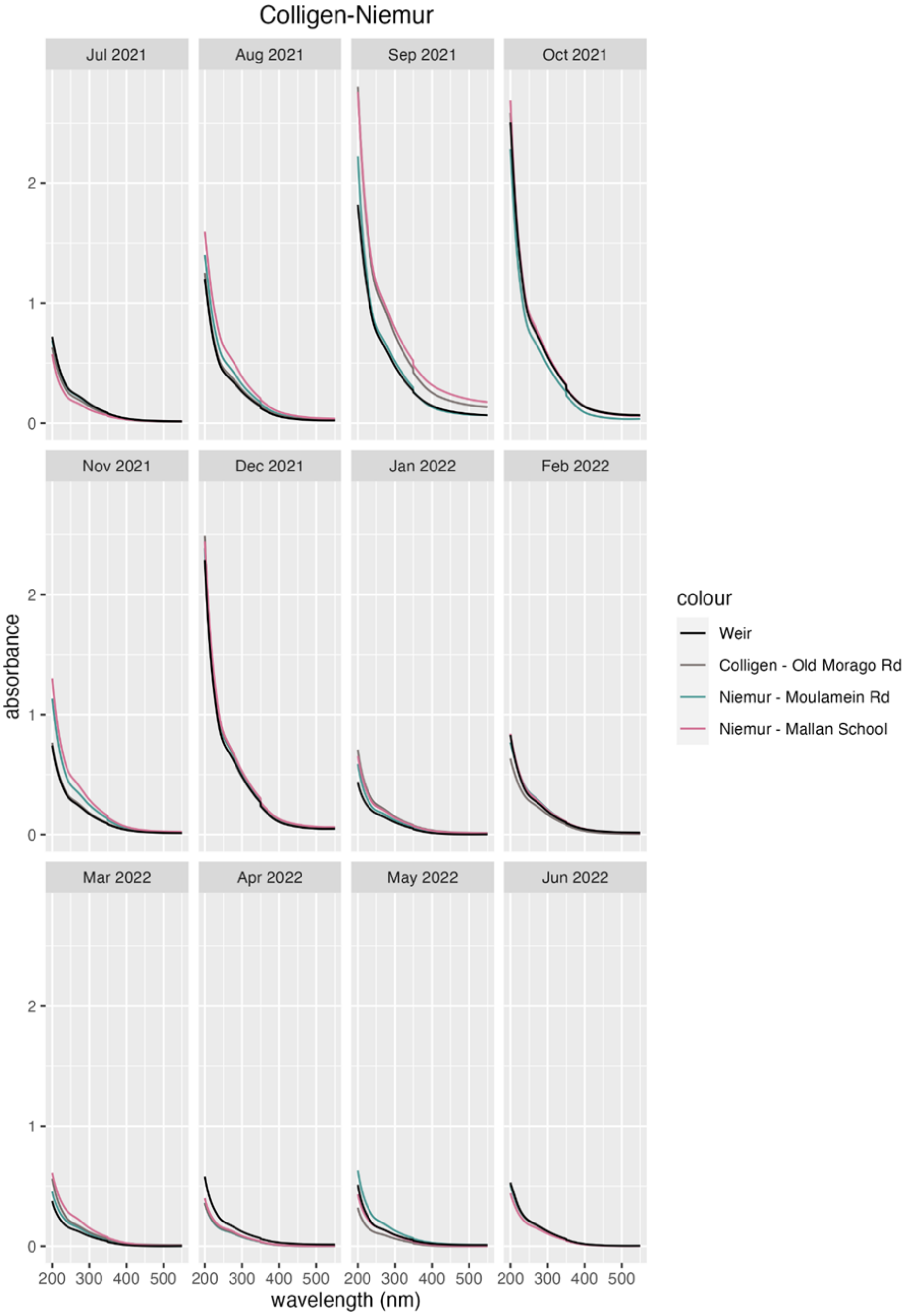


Figure 5.16 Absorbance of water samples at the Colligen-Niemur River system in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Organic carbon fluorescence

Fluorescence excitation-emission matrices at all sites through the sampling period (Figure 5.17) indicate that the organic matter mixture was similar across sites at the Colligen-Niemur River system in the 2021-22 water year. Between August and December 2021 an obvious fluorescence with a stronger humic and fulvic signature was observed at all sites of the Colligen-Niemur River progressed downstream over time with a very gradual increase at downstream sites, consistent with the absorbance results. This is indicative that the humic and fulvic component of dissolved organic matter might be terrestrially derived on lowland rivers or from return flows from Murray via Barmah-Millewa Forest from newly wetted forests, wetlands, and anabranches by unregulated flows.

A high fluorescence was observed in January and February 2022 at sites of the system this is consistent with slight increases in DOC and Chl *a* concentrations over that period with the black coloured water and floating algae were observed in the system. Fluorescence generally decreased from late summer through to winter 2022 consistent with decreases in DOC and Chl *a*.

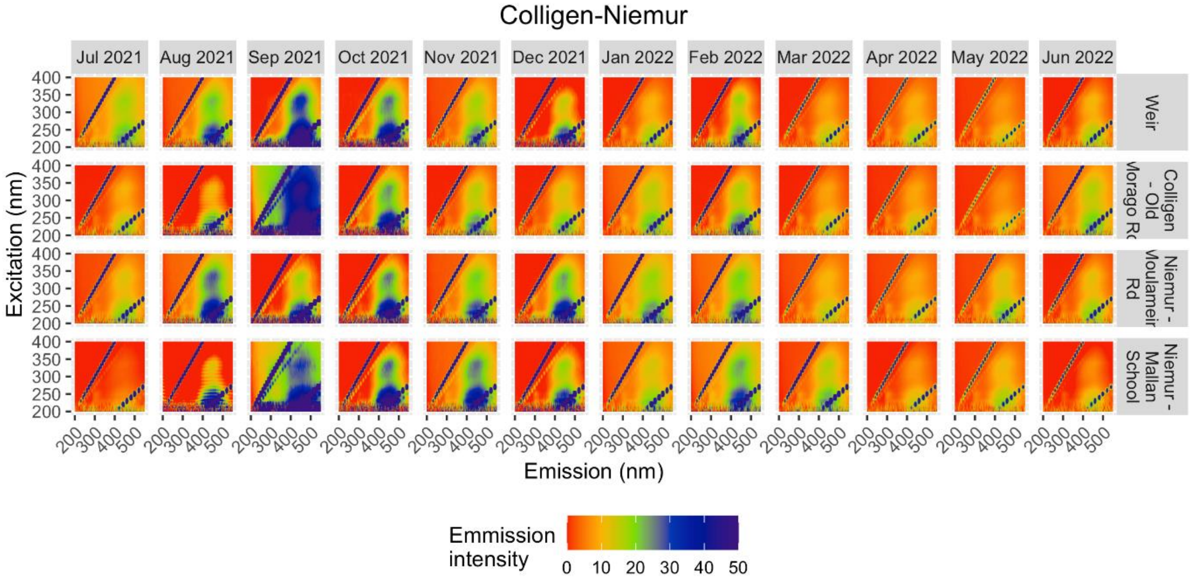


Figure 5.17 Fluorescence scans of water samples from the Colligen-Niemur River system in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Watering actions

Unregulated flows: Spring-early summer

Pulses of DOC and nutrients were also detected in the Colligen-Niemur River system in August 2021 prior to the unregulated flows, and a higher fluorescence also was observed at all sites in the system, indicating that nutrients and dissolved organic carbon leached from Millewa Forest via return flows by the watering action for the Murray River from Hume Dam were introduced to the system.

Slightly larger and steady pulses of DOC occurred between September and December 2021 in the Colligen-Niemur River system indicates greater carbon inputs associated with the unregulated flow events where larger low-lying areas are wetted and/or introduced from source water at Edward/Kolety River. Between August and December 2021 an obvious fluorescence was observed at all sites of the Colligen-Niemur River. There were generally higher concentrations in the lower reach of Niemur River (Mallan School) than upstream in Colligen Creek (Old Morago Rd) suggesting slight increases in DOC and nutrients as the water progresses through the system.

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).

Watering action 3: Spring-summer hypoxic blackwater refuge (Niemur escape)

A spring-summer hypoxic blackwater refuge flow was delivered via Niemur escape to Niemur River from 7 October to 29 October and from 2 December to 8 December 2021 (watering action 3). The spring-summer flow (watering action 3) maintained the nutrients and DOC concentrations at lower reach of Niemur River (Mallan School), reduced the Chl *a* concentrations, and contributed to keeping DO level above 4 mg/L and preventing fish kills over the period of unregulated flows (see Figure 5.15b).

Watering action 6: Colligen Offtake autumn fresh flow

Concentration of DOC and nutrients in the Coligen-Niemur River system elevated in January and February 2022 during summer period probably resulted from receiving less amount of discharge in hot months (see Figures 5.15a and 5.15b), consistent with a high fluorescence observed in the system. This corresponded with dark coloured water observed in selected sites of the system (Figure 5.18). Soil microbial decomposition activity is facilitated and accumulation of soil available nutrients is accelerated with increasing temperature, which leads to a higher soil organic carbon output and soil nutrients availability.

An Autumn fresh flow delivered to the upper Colligen-Niemur River system via the Colligen offtake from 3 March until 26 May 2022 (watering action 6). The increased flow (watering action 6) diluted otherwise dark-coloured water and resulted in decreases in Chl *a*, nutrients and DOC concentrations in the Colligen-Niemur River system, reflecting dilution as a consequence of higher discharges of flow events.

Figure 5.18 Dark-coloured water was observed at Colligen Creek at Old Morago Road (left) and Niemur River at Mallan School (right) in February 2022. (Photo: Xiaoying Liu)

Tuppal Creek

Most water quality spot readings in Tuppal Creek remained within the acceptable range throughout the study period of 2021-22 and were very similar to 2019-20 and 2020-21 (Table 5.6).

Table 5.6 Range and mean values of water physico-chemical parameters for Tuppal Creek in 2021-22 water year. ANZECC (2000) trigger levels for available water parameters are given and bolded. pH, Turbidity and EC are spot reading data. DO is collected from loggers. Chl a, TP, FRP, TN, NH_4^+, NO_x and DOC are from laboratory analysis of water samples.

Sampling site	pH **6.5-8**	Turbidity NTU **50**	EC mS cm^{-1} **0.125**	Chl *a* µg L^{-1} **5**	DO (mg L^{-1})		TP mg L^{-1} **0.05**	FRP mg L^{-1} **0.02**	TN mg L^{-1} **0.5**	NH_4^+ mg L^{-1} **0.02**	NO_x mg L^{-1} **0.04**	DOC mg L^{-1}
Aratula Road	6.2-7.3 (6.8)	17.7-98.6 (57.7)	0.067-0.259 (0.144)	9.96-75.18 (25.48)	0-7.88 (3.51)		0.053-1.1 (0.2)	0.005-1.05 (0.1)	0.68-6.3 (1.7)	0.005-4.5 (0.62)	0.002-0.84 (0.087)	5.7-21.2 (10.9)

pH

pH values were within the ANZECC (2000) trigger range.

Turbidity

Turbidity measurements fluctuated above and below the ANZECC (2000) trigger level. pH values were within the acceptable range throughout the year.

Electrical conductivity (EC)

EC remained stable in Tuppal Creek within the lower end of the range expected for lowland rivers indicating in ANZECC (2000). EC values were slightly higher than those values in the previous years, with lower discharge during this period which may have increased the impact or amount of groundwater seeping into the system.

Chlorophyll *a*

Chl *a* level remained stable in Tuppal Creek over 2021-22 sampling year which might be associated with several small and steady water pulses occurred in the channel (Figure 5.19).

Nutrients

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 and 2020-21, TP and TN concentrations consistently exceeded the ANZECC (2000) trigger values of 0.05 mg/L and 0.5 mg/L respectively. Most FRP, NO_x and ammonia values in Tuppal Creek remained below the trigger levels (ANZECC, 2000).

The higher nutrients levels in Tuppal Creek in August 2021 were detected that could possibly be due to nutrients and carbon introduced from a disturbance upstream as the channel had not been discharged since mid-May 2021 or disturbance of the sediments while sampling.

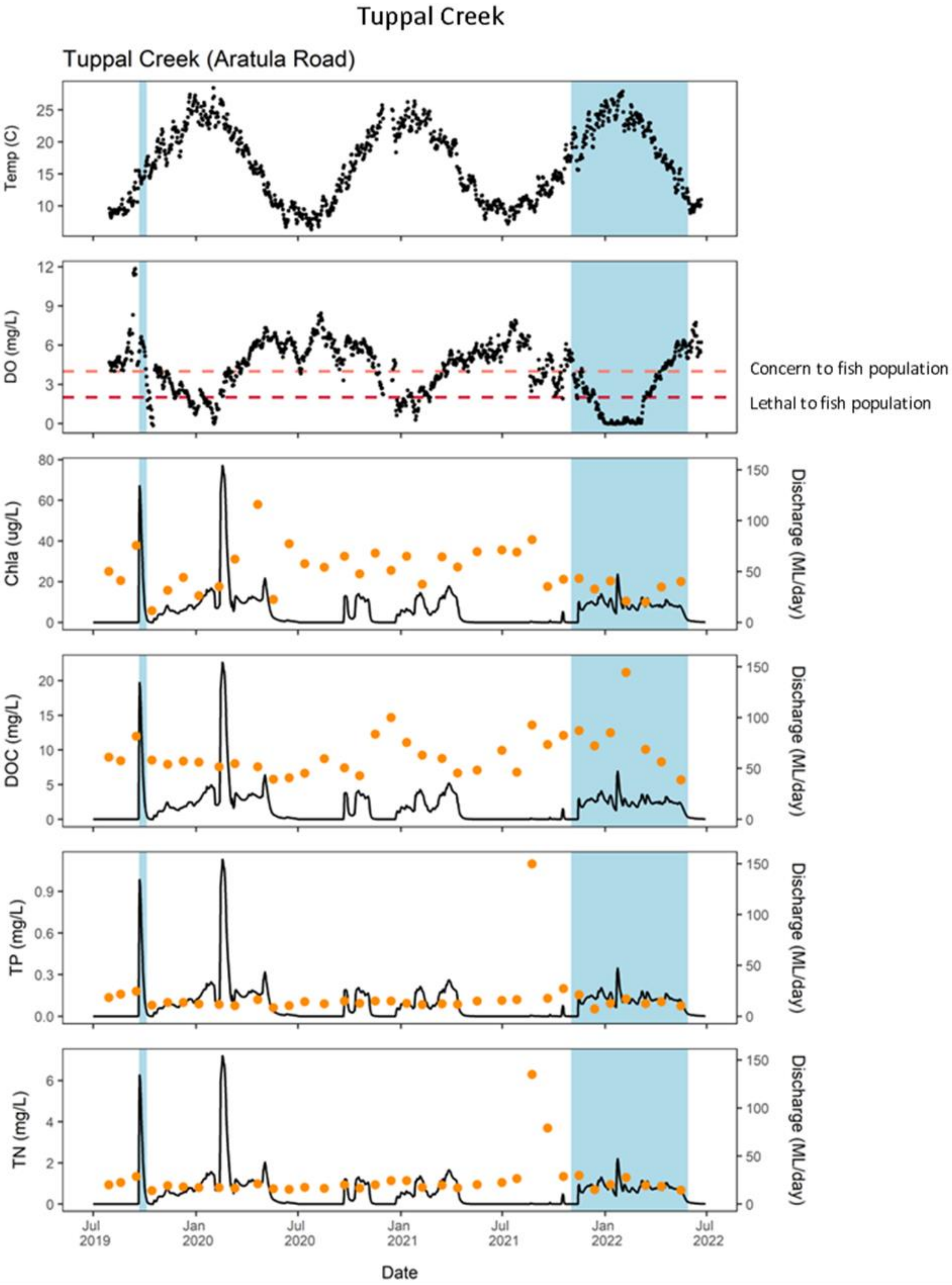


Figure 5.19 Water temperature, discharge, dissolved oxygen (DO), chlorophyll a (Chl a), dissolved organic carbon (DOC), total phosphorus (TP) and total nitrogen (TN) for Tuppal Creek over the 2019-22 watering years. Blue shaded vertical bars indicate watering actions.

Dissolved organic carbon (DOC)

Most DOC values at Tuppal Creek in 2021-22 were within the range that observed in the system as in 2020-21 which also received very low base flows. The higher DOC levels in Tuppal Creek in spring 2021/22 were detected that could possibly be concentrated local sources of carbon as the channel had not been discharged since mid-May 2021.

DOC values in summer period remained stabilised in Tuppal Creek. An outlier of DOC value in Tuppal Creek occurred in February 2022 could possibly be due to carbon introduced from a disturbance upstream as the channel received a higher discharge pulse during that period of time, suggesting there may be local sources of DOC, possibly due to water that was in backwaters or on low lying benches started to flow down the system.

Dissolved oxygen (DO)

Concentrations of DO in Tuppal Creek dropped into the range of concern to fish populations (below 4 mg/L) between August 2021 and mid-December 2021 and between mid-March 2022 and early April 2022 and dropped into the range of lethal to fish populations (below 2 mg/L) from mid-December 2021 to mid-March 2022, this corresponds with dark coloured water was observed in the system (Figure 5.20).

Figure 5.20 Dark-coloured water observed at Tuppal Creek in January (left) and February (right) 2022. (Photo: Xiaoying Liu)

Organic carbon absorbance

Absorbance scans (Figure 5.21) indicate that the mixture of organic compounds making up the DOC was consistent in Tuppal Creek throughout most of the 2021-22 water year. Increases in absorbance were detected between August and December 2021, suggesting slightly increased discharge could possibly source from return flows by the watering action for the Murray River from Hume Dam via the Millewa Forest and unregulated flows.

In summer months in 2021/22, there is a slight increase in absorbance, but the pattern is maintained.

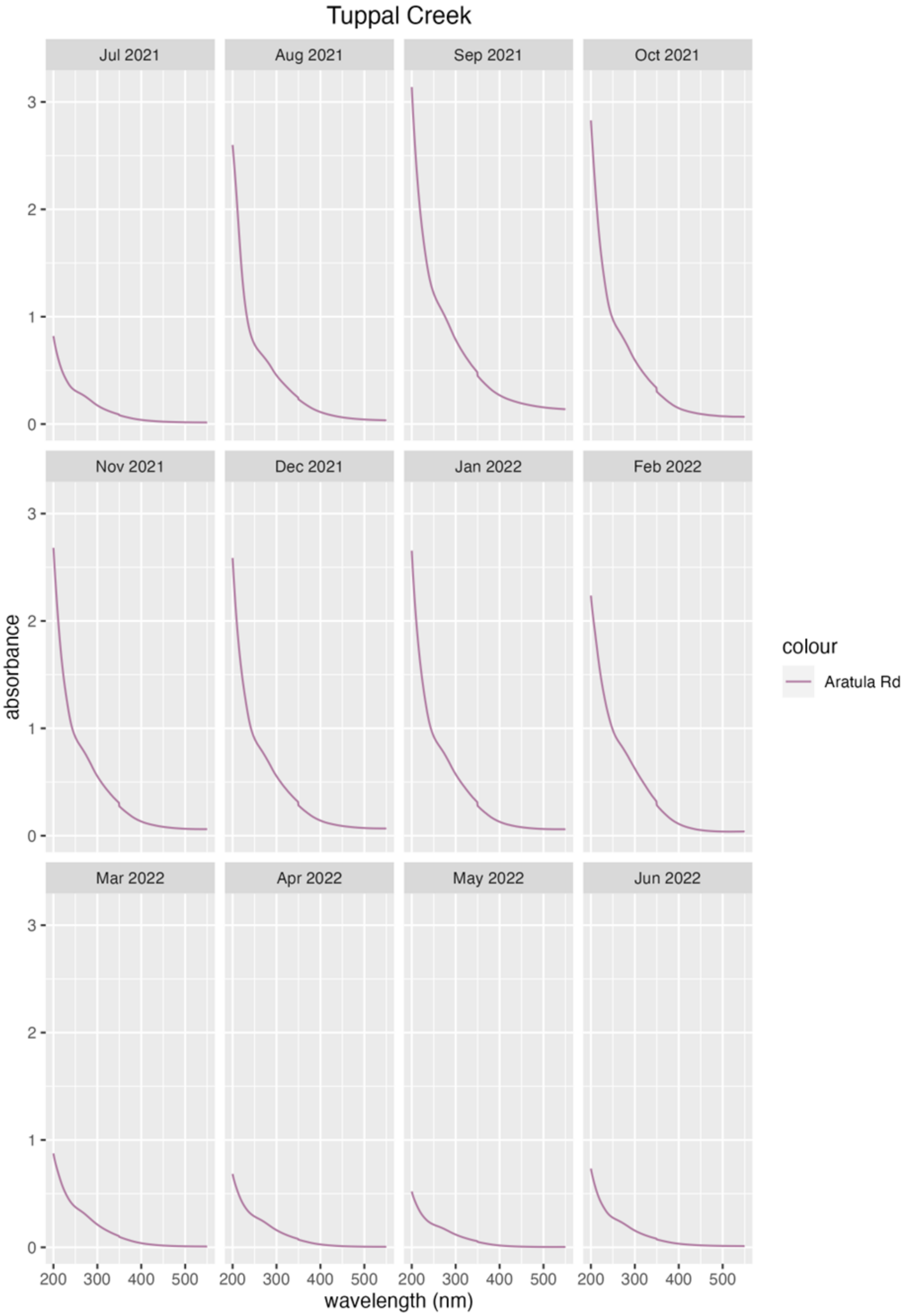


Figure 5.21 Absorbance of water samples at Tuppal Creek in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Organic carbon fluorescence

At Tuppal Creek fluorescence excitation-emission matrices for water samples through the sampling period (Figure 5.22) indicate that the organic matter mix was similar at the system with stronger humic and fulvic signatures. In February 2022, stronger humic and fulvic signature was identified which is consistent with observed poor water quality and a rapid 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.

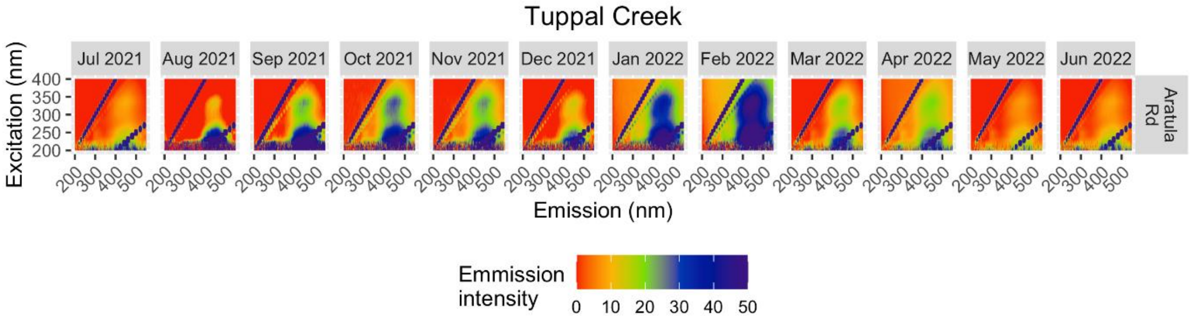


Figure 5.22 Fluorescence scans of water samples from Tuppal Creek in 2021-22. The water samples for the assessment of organic matter inputs were collected from July 2021 to June 2022.

Watering action 7

A late spring-autumn elevated flow was delivered to Tuppal Creek starting 1 November 2021 and ending 29 May 2022 (watering action 7). The late spring-autumn elevated flow maintained the Chl *a*, nutrients and DOC concentrations at Tuppal Creek. However, DO concentrations in Tuppal Creek were below 4 mg/L most of the time during watering action 7, particularly in summer months (Figure 5.19).

The nutrients and DOC concentrations in Tuppal Creek were generally higher than the concentrations recorded in the Edward/Kolety-Wakool system in 2021-22 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 is connected to the main river channel.

Niemur Escape monitoring

Reinstating flows from Northern Branch Canal and escaped into Niemur River was expected to improve water quality in the system as weather was warming up in 2021-22. The water released from Northern Branch Canal to the Niemur River system was implemented to create local oxygen refuges via release of water with higher DO and lower DOC from the irrigation canal system into the river system.

Watering actions

Watering action 3: Spring-summer hypoxic blackwater refuge (Niemur escape)

Dark-colour water of Niemur River was mixing with turbid water of Northern Branch Canal at the junction of Niemur Escape after the escape was turned on (Figure 5.23). As shown in Figure 5.24 at the very beginning of water release, the DO value in Northern Branch Canal measured on 30 November 2021 was slightly lower (7.76 mg/L) than DO value in the upstream of Niemur Escape (8.65 mg/L). It should be noted that the water was sitting in Northern Branch Canal for a while as weather was warming up before it was released into Niemur River. The DO at the downstream site of Niemur Escape was 5.35 mg/L, which may be because of the escape was turned on almost at the same time as the sampling time, so the lower DO value at downstream of Niemur escape might be because the escape water had not flowed downstream and reached that site yet.

Figure 5.23 Junction of Northern Branch Canal and Niemur River on 30 November (left) and 15 December (right) 2021. (Photo: Xiaoying Liu)

The discharge from Niemur Escape was limited, and did not exceed 10 % of the overall flow in 2021-22 water year. Thus there was limited capacity for the watering action from the Niemur Escape to improve river water quality of river water downstream of the escape (Figure 5.24). However, there is evidence that water released from Northern Branch Canal to Niemur River facilitate the slight increase in DO levels and lowered the DOC and nutrients concentrations at downstream site of Niemur Escape. For example, at the sampling trip on 12th January 2022 the volume of canal water caused a slight dilution effect (< 10%). There was a very small difference in DO levels at upstream (7.14 mg/L) and downstream (7.20 mg/L) of Niemur Escape which indicated that a small amount of water release from Northern Branch Canal with higher DO (9.14 mg/L) could possibly increase DO levels in Niemur River. The discharge from the canal (DOC concentration was 6.40 mg/L) mitigated the DOC concentrations at the downstream of Niemur Escape (5.10 mg/L), comparing to its upstream of Niemur Escape with 8.50 mg/L.

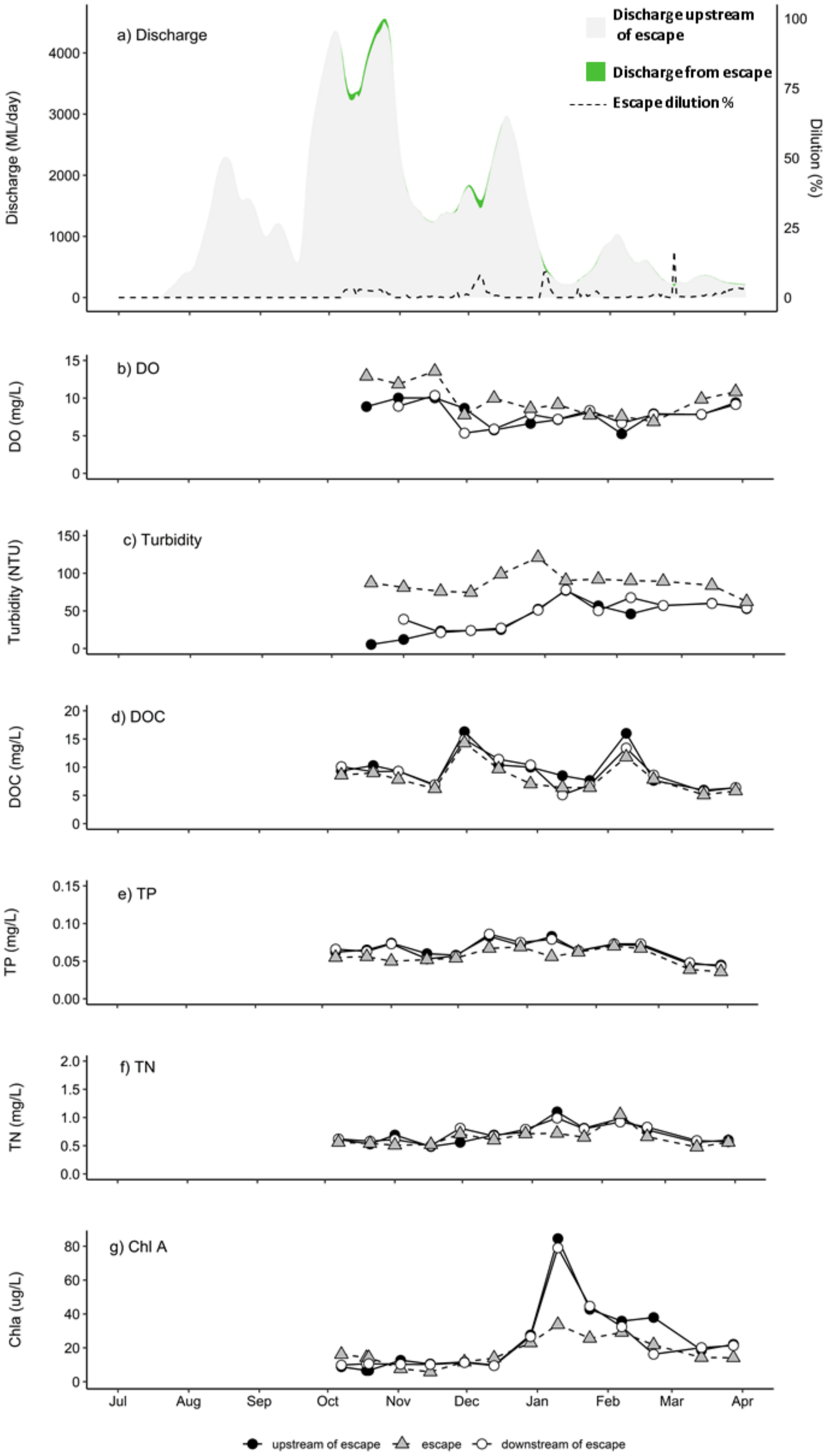


Figure 5.24 Dissolved oxygen (DO), turbidity, dissolved organic carbon (DOC), total phosphorus (TP), total nitrogen (TN) and chlorophyll a (Chl *a*) at Niemur Escape over the 2021-22 watering action. Dotted grey line indicates the percent contribution of environmental water to total discharge downstream of the escape. Discharge data are from Barham-Moulamein road gauge.

Organic carbon absorbance

Absorbance scans (Figure 5.25) indicate 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 Niemur Escape sites.

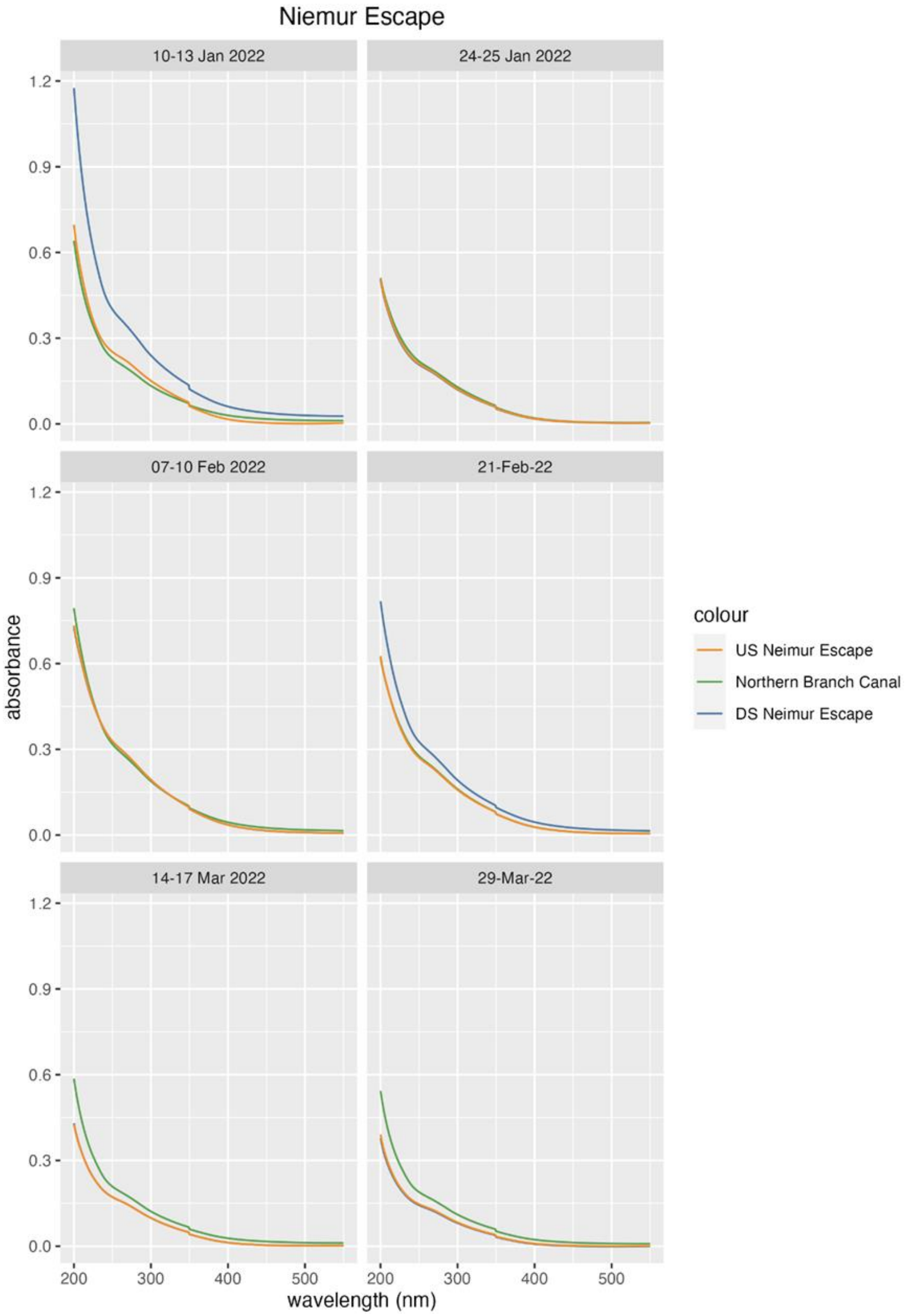


Figure 5.25 Absorbance of water samples of sites at Niemur Escape in 2021-22. The water samples for the assessment of organic matter inputs were collected fortnightly between January and March 2022.

Organic carbon fluorescence

The Niemur Escape fluorescence excitation-emission matrices for water samples through the sampling period (Figure 5.26) indicate that the organic matter mix was similar with strong humic and fulvic signatures. In February 2022, stronger humic and fulvic signature was identified, which is consistent with observed poor water quality and a rapid increase in DOC concentration in the system. It is possibly a combination of aged organic matter and very fresh leachates or algal organic matter which is consistent with receiving no discharge from Niemur Escape during that hot period.

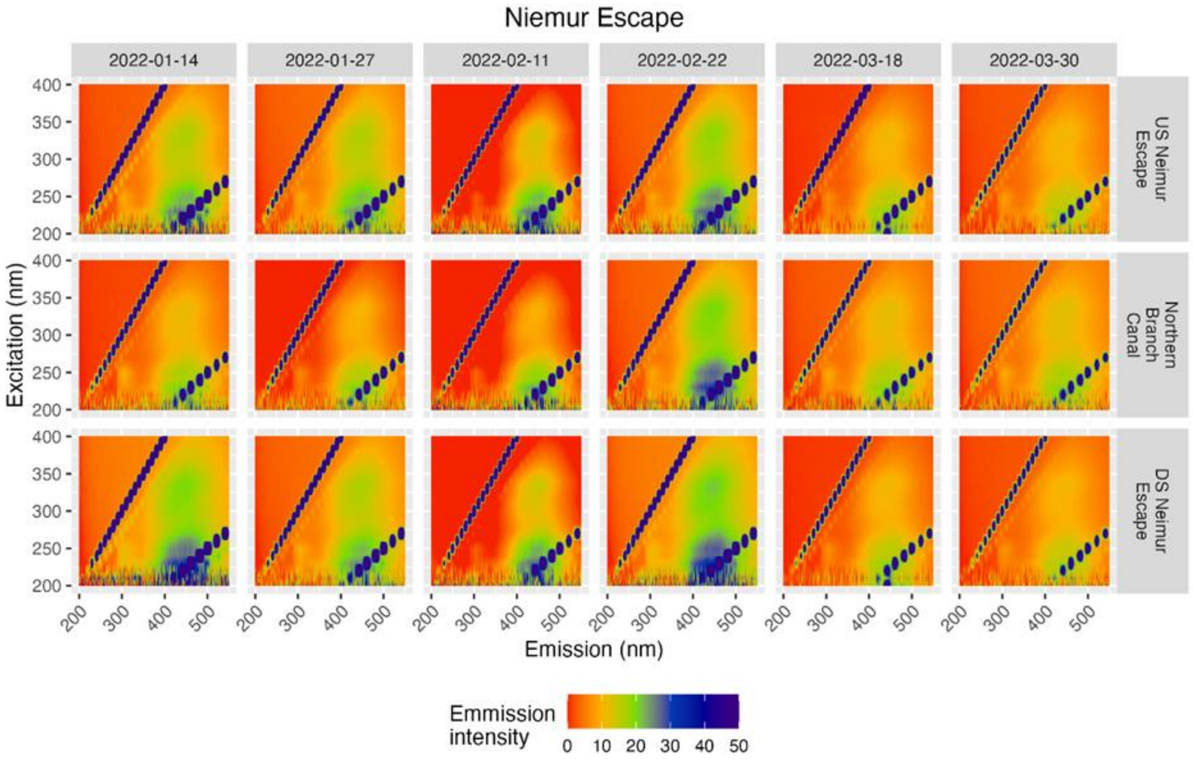


Figure 5.26 Fluorescence scans of water samples of sites at Niemur Escape in 2021-22. The water samples for the assessment of organic matter inputs were collected fortnightly between January and March 2022.

5.6 Discussion

Short and long-term evaluation questions for core monitoring

Seven watering actions were delivered by the CEWO Central Delivery team specifically for the Edward/Kolety system in the 2021-22 water year.

Overall, the characteristics of water quality in the EKW Selected Area during the 2021-22 water year were different from 2019-20 and 2020-21, in particular during the period of unregulated flows.

In 2021-22 the key questions relating to the CEW actions were:

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

In general, the watering actions in 2021-22 water year demonstrate that using Commonwealth environmental water can improve water quality (preventing potential hypoxic water events) in the Edward/Kolety-Wakool River system.

The planned sequence of freshes in spring/early summer for the Wakool-Yallakool system and the Colligen-Niemur system were not required to be delivered because there were already freshes in these river systems due to unregulated flows and water flowing into the Edward/Kolety River from Millewa Forest following the Murray Spring River flowing pulse.

Unregulated flows occurred in the Edward/Kolety-Wakool River system from September to December 2021. To mitigate the risks from hypoxic blackwater in spring/summer 2021-22, four watering actions delivered by the CEWO Central Delivery team specifically for the Edward/Kolety system in the 2021-22 water year, including to the Wakool-Yallakool system from Wakool Escape (watering action 1), to the Edward/Kolety system via Edward Escape (watering action 2), to the Colligen-Niemur system via Niemur Escape (watering action 3) and to Tuppal Creek (watering action 7) that commenced following the unregulated flows. The southern spring flow delivered to the Murray River from Hume Dam also contributed environmental water to the Edward/Kolety-Wakool system via return flows from Millewa Forest in 2021-22 water year. As such, the spring/early summer environmental watering actions, combined with unregulated flows and the southern spring flows in the Murray River, occurred in spring/early summer 2021/22 in the Edward/Kolety-Wakool River system.

For the Wakool-Yallakool system, unregulated flows in spring/early summer 2021-22 water year did not result in occurrence of critical dissolved oxygen levels in the system as watering actions 1 commenced at the same time helped to mitigate the occurrence of hypoxic blackwater events. Dissolved oxygen concentrations remained above the critical levels for fish population during the period of implement of watering action 1 (spring/mid-summer) in the Wakool-Yallakool system in 2021-22 water year. It is common for dissolved oxygen to be lower in the upper Wakool River than other sites in the system during hot months when discharge is much lower and the risk of temperature induced hypoxia during heatwaves is greater in this part of the system. However dissolved oxygen below 4 mg/L did not occur in the upper Wakool in the early and mid-summer 2021-22 compared with previous water years 2019-20 and 2020-21, suggesting the delivery of environmental water from the Wakool escape to the upper Wakool River and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event from November through to January and helped to mitigate the occurrence of hypoxic blackwater in the upper Wakool River.

Watering action 4 (an autumn elevated variable base flow delivered to the upper Wakool system via the Wakool offtake) and water watering action 5 (an autumn fresh delivered to Yallakool Creek via the Yallakool offtake) from March until early May 2022 increased dissolved oxygen levels in the middle and lower reaches of Wakool. In addition, increased flow of watering action 4 diluted greenish and dark coloured water and dissolved oxygen levels increased in the upper Wakool River.

Concentrations of DO in the middle and lower reaches of Edward/Kolety River system were above the range of concern to fish populations (below 4 mg/L) over the study season in 2021-22. From early November to late December 2021 (water temperature started to warm up) at upper reach of

Edward/Kolety River system at Four Posts (upstream of Edward Escape) with no environmental watering, dissolved oxygen concentrations below 4 mg/L were detected. The Commonwealth environmental watering action 2 via the Edward Escape and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event and helped mitigate the occurrence of hypoxic blackwater downstream of the Edward Escape site at Eastman Bridge (mid Edward/Kolety River) compared to upstream of the Edward Escape at Four Posts (upper Edward/Kolety River) that did not receive the environmental water.

Concentrations of DO in the Colligen-Niemur River system were generally above the range of concern to fish populations over 2021-22, except DO briefly dropped to 4 mg/L in the upper Colligen-Niemur system (Colligen) in February 2022. Commonwealth environmental watering actions 3 and 6 in the Colligen-Niemur system may have only minorly assisted in the maintenance of dissolved oxygen concentrations in the lower reach of the system (Niemur Mallan School) that received the additional flows during the period of watering actions.

Watering action 7 in Tuppal Creek helped maintained dissolved oxygen levels in November 2021 and between mid-March and May 2022, but it did not stop the further decline in dissolved oxygen levels (below 2 mg/L) in the system during hot months, this corresponds with presence of dark coloured water. Additionally, the water temperature in Tuppal Creek was slightly higher in summer 2021-22 than observed in 2019-20 and 2020-21. It suggests the magnitude of delivering environmental water to Tuppal Creek was not sufficient to improve dissolved oxygen condition and mitigate the occurrence of hypoxic blackwater events under the hotter weather. Limited counterfactual data exists to show what would have happened if the escape flows had been managed differently. It is important that the interaction between dissolved oxygen and water temperature needs to be taken into account.

As in 2020-21 water year CEW delivered to the upper reach of Wakool River during January to June 2021 resulted in higher discharge than previous years, and the variable base flows supported dissolved oxygen concentrations in this river reach. This demonstrates that using Commonwealth environmental water in the upper Wakool that usually has very low flow in hot months could provide a proactive, longer-term approach to improve water quality and prevent potential hypoxic water events. Decision making about using Commonwealth environmental water as a response plan could be improved by considering Bureau of Meteorology forecasting of air temperature combined with dissolved oxygen levels as the trigger for watering action to commence.

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

Nutrient concentrations remained within the acceptable range throughout the EKW River system during the 2021-22 water year. 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.

The unregulated flow event in spring/early-summer 2021-22 with higher discharges resulted in increased TP, TN and Chl *a* in the Wakool-Yallakool system, Edward/Kolety River system and the Colligen-Niemur system, also sourced from increased return flows from River Murray via Millewa

Forest from newly wetted forests, wetlands, and anabranches (with leached nutrients from the forest). It was also associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column).

In general, nutrients concentrations are higher in the upper reach of Wakool River when it receives minor to no amount environmental water. However nutrient concentrations in the upper Wakool remained within slightly lower range during the period of watering action 1 in 2021-22 than observed in 2019-20 and 2020-21. In addition, only small pulses of nutrients were detected in the Edward/Kolety River system, the Colligen-Niemur system and Tuppal Creek in spring/early summer. This suggests that the delivery of environmental water from the Escapes to the Edward/Kolety-Wakool River system (including Wakool-Yallakool system from Wakool Escape (watering action 1), the Edward/Kolety system (watering action 2) via Edward Escape and the Colligen-Niemur system via Niemur Escape (watering action 3)) and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event and helped mitigate the concentration of nutrients in the system in spring/early summer.

As Commonwealth environmental watering actions ceased in early summer, nutrients concentrations rapidly increased in the EKW River system in January and February 2022. This may be related to increased water temperature with ceased environmental watering actions with reduced discharges during that time.

The environmental watering actions in 2021-22 water year demonstrates Commonwealth environmental water can assist in the maintenance of stable nutrients levels over the spring/early summer period.

- ***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?***

Hypoxic blackwater events occur when large quantities of organic matter dissolve into water resulting in a dark tea colour 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 EKW 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.

In 2021-22 increases in DOC concentrations occurred in the Wakool-Yallakool system, Edward/Kolety River system and the Colligen-Niemur system due to unregulated flows resulting from larger areas wetted and also sourced from increased return flows from Barmah-Millewa Forest (with leached DOC from the forest) might introduce pulses of carbon into the whole system. However only small pulses of DOC were detected in these systems in spring/early summer 2021-22, which might be associated with Commonwealth environmental watering actions 1, 2 and 3 commenced following the unregulated flows in the Edward/Kolety-Wakool River system in spring/early summer 2021-22 mitigated the extent of increases in DOC.

For the Wakool-Yallakool system, DOC concentrations in Yallakool Creek (zone 1) that did not receive environmental water in spring/early summer 2021/22 were increased, resulting in a higher DOC concentration observed in the system than in 2019-20 and 2020-21 water years. In comparison, DOC concentrations were maintained stable or lower than normally observed in the upper Wakool during the commencing of watering actions 1 at the same period as unregulated flows, suggesting the delivery of environmental water from the Wakool escape to the upper Wakool River and the return flows of CEW delivered to Millewa Forest helped mitigate the increases in DOC concentrations in Wakool River.

Concentrations of DOC downstream of the Edward Escape site at Eastman Bridge (mid Edward/Kolety River) were slightly lower than upstream Edward Escape at Four Posts (upper Edward/Kolety River) during the watering action 2 targeting the Edward/Kolety River system. This demonstrates that the delivery of environmental water from the Edward escape to the mid Edward/Kolety River and the return flows of CEW delivered to Millewa Forest extended the recession of the unregulated event and helped mitigate the accumulation of DOC concentrations.

The Colligen-Niemur system had the same trend. The monitoring site downstream of the Niemur Escape at Mallan School during watering action 3 had slightly lower DOC concentration in December 2021 that upstream Niemur Escape at Colligen Creek that did not receive environmental water.

Watering action 7 helped maintain DOC concentrations at Tuppal Creek over summer months 2021-22, DOC concentrations were slightly lower than observed in summer 2020-21 without receiving environmental water.

Fluorescence excitation-emission matrices for water samples at the EKW system through the sampling period indicate that the organic matter mix was similar across sites across most of the 2020-21 water year. Between September and December 2021 higher fluorescence was observed at all sites with a gradual increase downstream consistent with the absorbance results, indicating a combination of aged organic matter and very fresh leachates or algal organic matter introduced by unregulated flows (sourced from organic material in channel or from return flows from Murray via Barmah-Millewa Forest from newly wetted forests, wetlands, and anabranches).

As soon as the delivery of Commonwealth environmental water via escapes ceased, obvious pulses of DOC were detected in the Edward/Kolety-Wakool system in January and February 2022 which might be related to increased water temperature in hot months with ceased environmental watering actions during hot period. The pulses of DOC could have been due to return flows for the Murray River from Hume Dam via the Edward and Gulpa offtakes and Millewa Forest over that period (see Figure 2.6). The black-coloured water and floating algae were also observed in the system, a broadly similar fluorescence was present. In particular DOC concentration at upper Wakool in February 2022 almost reached a similar level to that observed during the 2016-17 flood year. It is common for DOC and nutrients levels to be higher in upper Wakool than the other study sites during summer when discharge is much lower at this reach.

The variable Autumn base/fresh flows (watering actions 4, 5 and 6) made dark coloured water diluted and DOC concentration decreased in the Wakool-Yallakool system and the Colligen-Niemur system. Fluorescence generally decreased from late summer through to winter 2022.

Widespread hypoxia was not present in the Edward/Kolety-Wakool River system in 2021-22 water year and the organic matter was likely to stimulate productivity which can become available as food for aquatic organisms such as fish.

Influences of watering actions for the Murray River from Hume Dam in 2021–22 to the Edward/Kolety-Wakool system

It is a quite different response of organic matter inputs to the EKW River system in 2021-22 water year comparing to 2019-20 and 2020-21 water years.

In addition to the three environmental watering actions that were specifically targeted for the Edward/Kolety-Wakool system in spring/mid-summer 2021-22, water delivered from Hume Dam to the Murray River indirectly affected the entire Edward/Kolety-Wakool system downstream of Millewa Forest. This has been included in reporting for the 2021-22 water year. Environmental water delivered to the Murray River flows into Millewa Forest and exits the forest through several regulators, creeks and flood runners and contributes to flows into the Edward/Kolety River. The environmental watering actions from Hume Dam contributed a large proportion of the total discharge in the whole system, particularly in August to September and November to December 2021 (Figures 4.10 to 4.14).

In terms of water quality for the EKW system, the environmental objective of the environmental water delivery from Hume Dam was to transport of nutrients and carbon to create small productivity input for aquatic biota in late winter/early spring. In late spring/summer the environmental outcome of the delivery was expected to flush of nutrients and carbon increased with warmer water temperature in order to reduce the occurrence of hypoxic blackwater and algal bloom events.

Nutrients and dissolved organic carbon concentrations were lower through winter/early spring consistent with weakening in fluorescence scans, as shown in 2019-20 and 2020-21 water years (Figures 5.27 to 5.29). However small pulses of nutrients and dissolved organic carbon were detected in the EKW system in August 2021 prior to the unregulated flows. As shown in Figures 5.27, 5.28 and 5.29, the higher fluorescence was observed at all sites in late winter 2021-22 which is a quite different response to other water years, with a gradual increase downstream consistent with the absorbance results, indicating a combination of aged organic matter and very fresh leachates or algal organic matter sourced from organic material in channel or from return flows from newly wetted forests, wetlands, and anabranches. It indicates that nutrients and dissolved organic carbon leached from Millewa Forest via return flows by the watering action for the Murray River from Hume Dam were introduced to the system. During this period hypoxia was not present in the system and inputs of nutrients and carbon can have a positive influence on river systems through the stimulation of productivity and increased food availability for downstream.

The 2021-22 water year was different to 2019-20 and 2020-21 water years, there was a long period of unregulated flows over spring/early summer. Higher fluorescence was observed at all sites over spring/early summer 2021-22 which is a sequence of the long period of unregulated flow events occurred in the system.

Increasing the water release in mid-summer has the potential to lead to poor water quality (hypoxic events) downstream of Millewa Forest, especially with higher water temperature. To avoid these environmental risks, environmental water released in spring/early summer 2021/22 was redirected through Mulwala Canal and via MIL escapes into the Edward/Kolety River, Wakool River and Murray further downstream which was expected to help improve water quality in these systems.

A decline in nutrients and dissolved organic carbon concentrations was measured in the EKW system in November 2021, consistent with slightly weakening fluorescence absorbance results. Environmental water delivery from Hume Dam along with other watering actions commenced when temperature started to warm up mitigated the extent of increases in DOC and nutrients and the risks from hypoxic blackwater and algal bloom events.

In October 2019 and November 2020, pulses of DOC and nutrients from Millewa Forest were introduced to the EKW system through the Southern Spring Flow watering actions in Murray River, with higher fluorescence observed. It is likely we have underestimated the influence of environmental water delivered via return flows from MIllewa Forest that contributed to flows in EKW system in previous years.

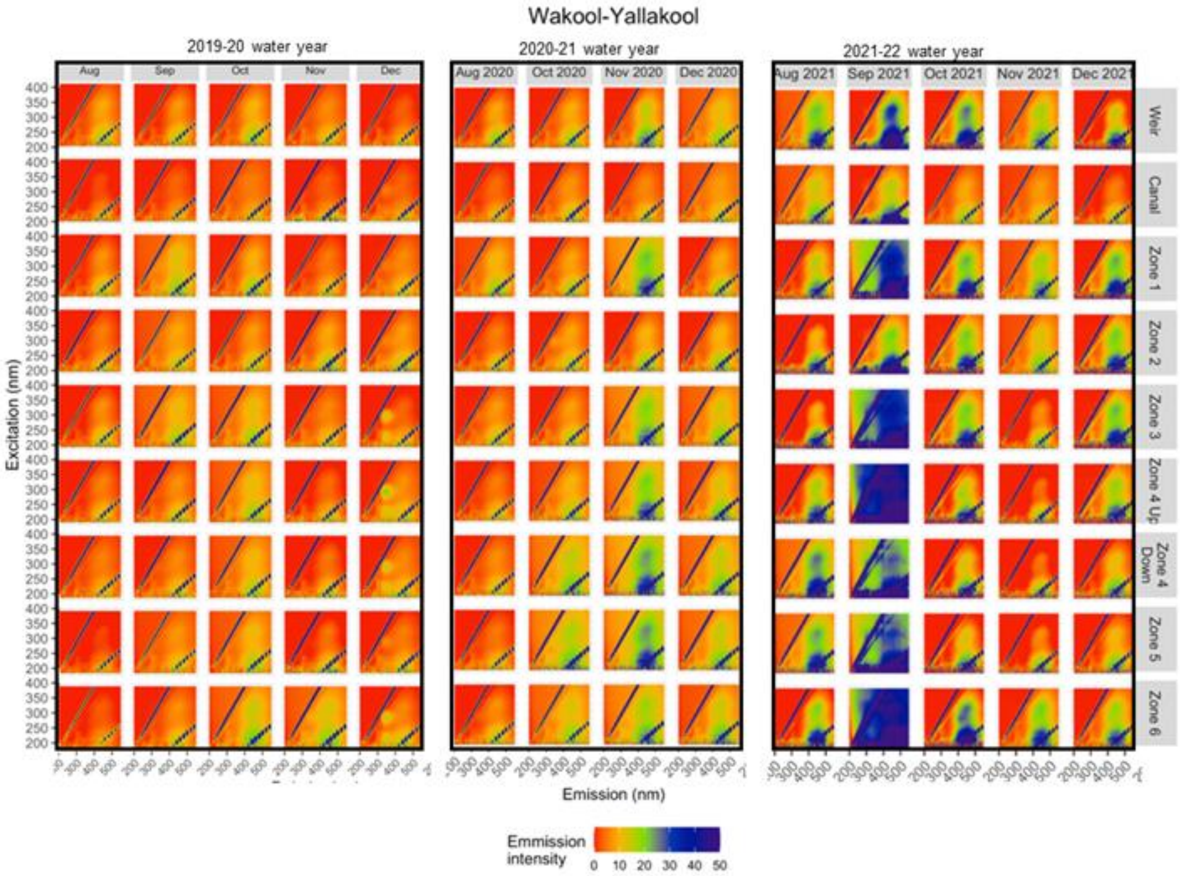


Figure 5.27 Fluorescence scans of water samples from the Wakool River-Yallakool Creek system between August and December in 2019-20, 2020-21 and 2021-22 water years. Please note the data are not available for September 2020 due to instrument failure.

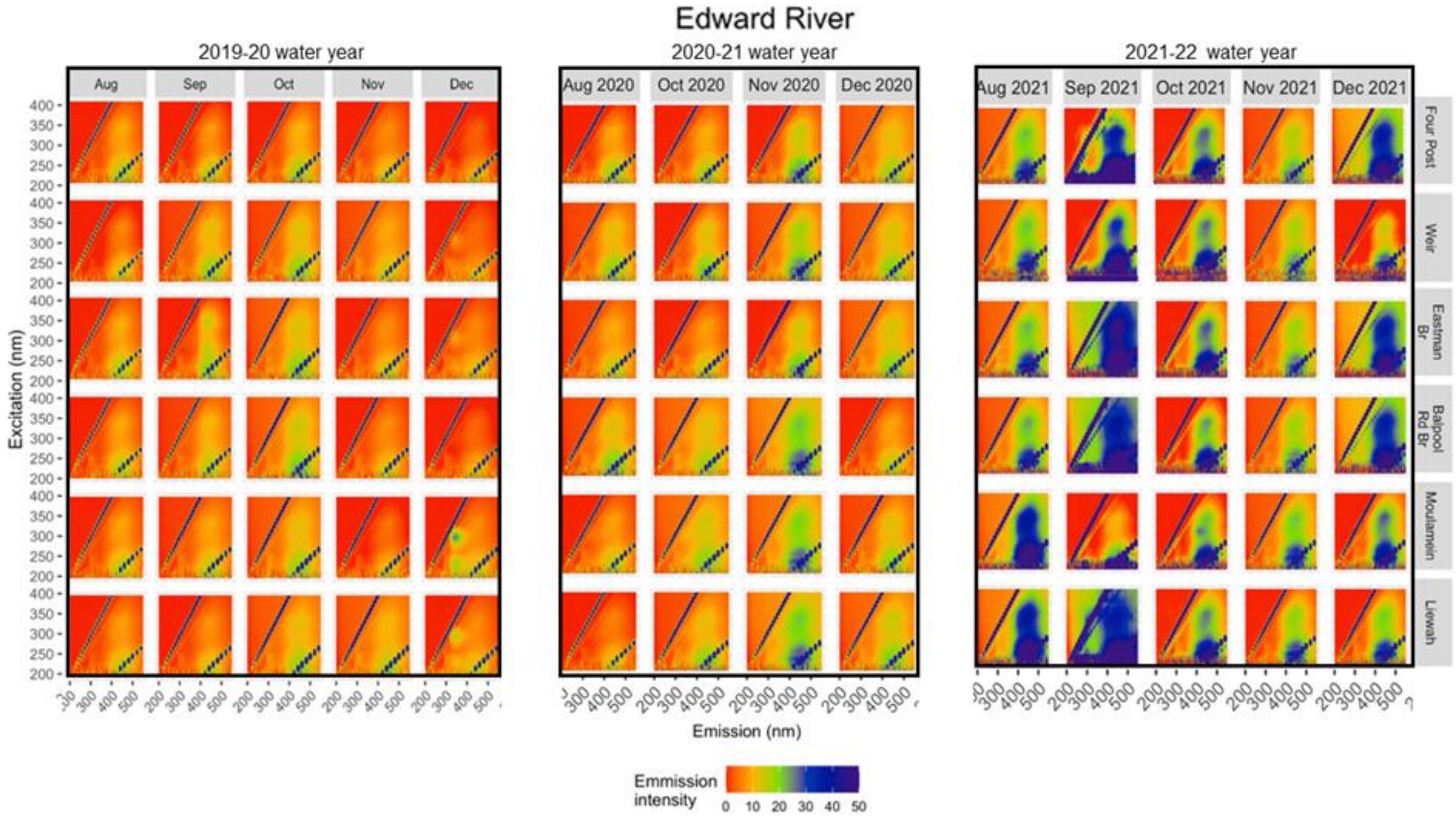


Figure 5.28 Fluorescence scans of water samples from the Edward/Kolety River between August and December in 2019-20, 2020-21 and 2021-22 water years. Please note the data are not available for September 2020 due to instrument failure.

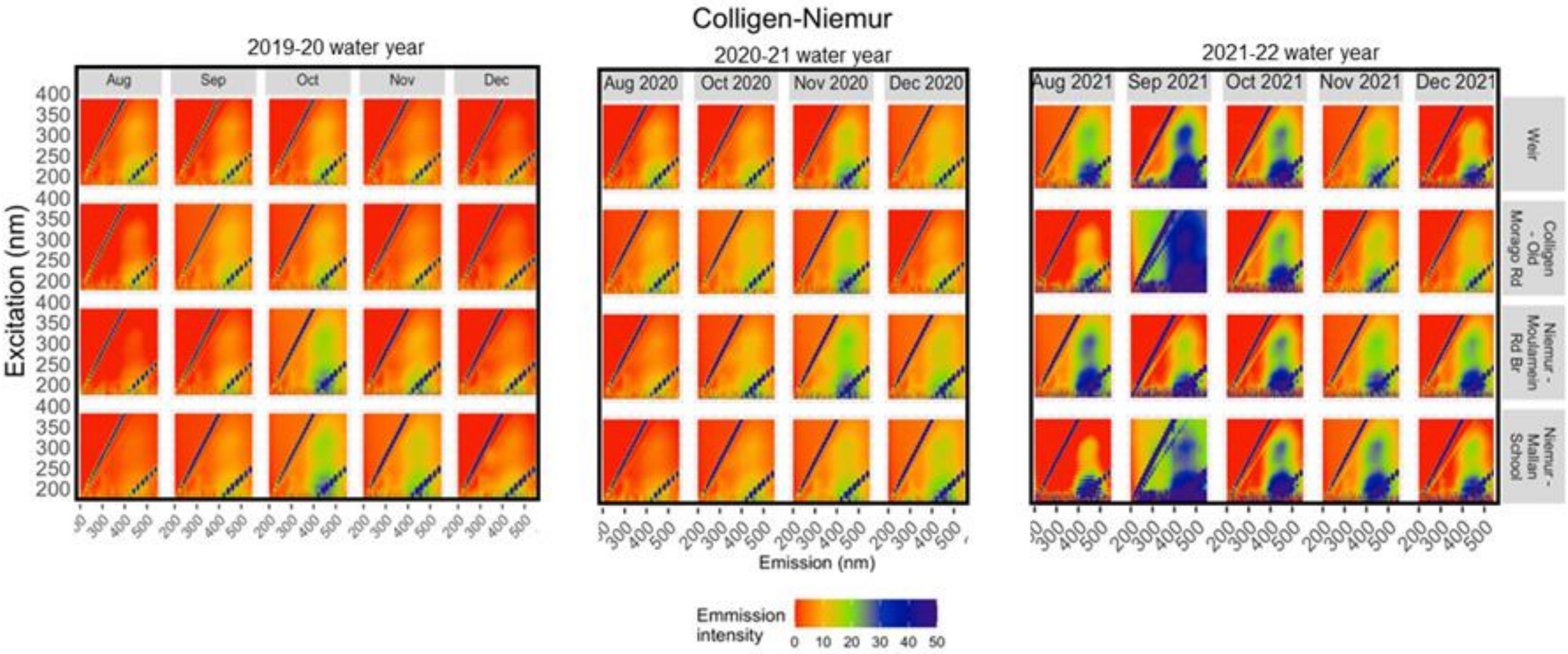


Figure 5.29 Fluorescence scans of water samples from the Colligen-Niemur River between August and December in 2019-20, 2020-21 and 2021-22 water years. Please note the data are not available for September 2020 due to instrument failure.

Influence of Billabong inflows in 2021–22 to the Edward/Kolety River

In 2019-20 and 2020-21 the inflows from Billabong Creek were small relative to discharge in the Edward/Kolety River. In contrast, 2021-22 inflows from Billabong Creek (measured at Darlot WaterNSW gauge #410134) to the Edward/Kolety River was considerably higher than previous years due to wet conditions in the Murrumbidgee catchment (Figure 5.30).

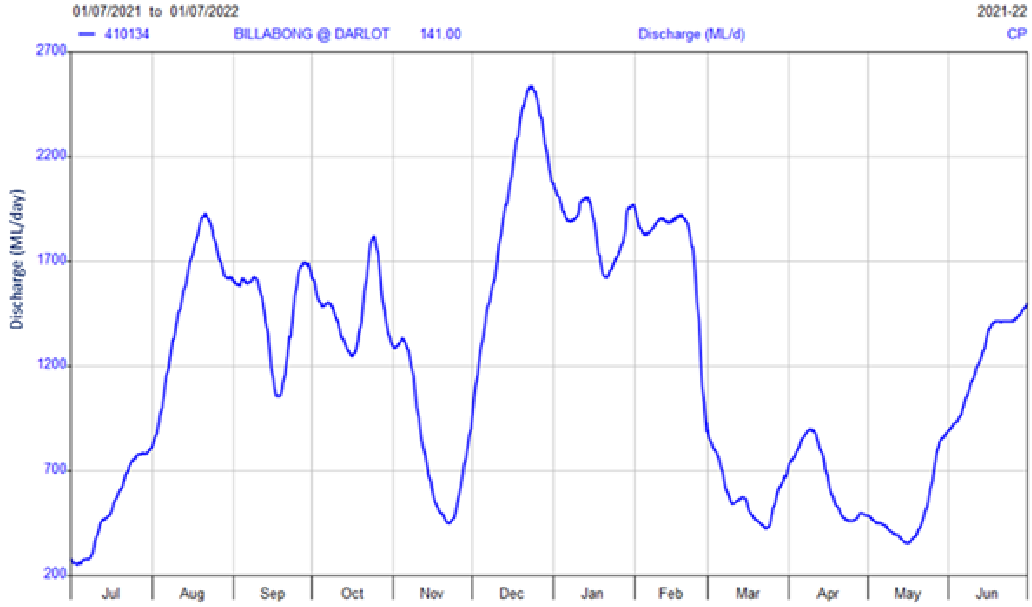


Figure 5.30 Discharge of Billabong Creek measured at Darlot (WaterNSW gauge #410134) from July 2021 to June 2022.

In 2021-22 Billabong Creek inflows influenced the hydrology and water quality of sites in the Edward/Kolety River downstream at Moulamein and Liewah. Slightly higher concentrations of DOC and nutrients were detected at these sites in 2021-22 water year (see Figure 5.10), consistent with the higher fluorescence observed (Figure 5.31). A noticeable increase in DOC was detected at Moulamein and Liewah in August 2021 when Billabong inflows started flowing into the Edward/Kolety River, which is consistent with the higher fluorescence observed at this time. 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 Billabong Creek inflows.

Although we did not collect water samples in Billabong Creek, spot water quality readings were recorded at Moulamein (immediate downstream of Billabong Creek confluence) and Billabong Creek at a similar time on the same day. The data provides a clear indication of the influence of Billabong inflows to the Edward/Kolety River downstream at the time of sampling.

After the initial flush of DOC and nutrients by inflows from Billabong Creek in August 2021, Billabong Creek inflows reduced DOC and nutrients levels and weakened fluorescence in the Edward/Kolety downstream over the period of unregulated flows. Spot dissolved oxygen readings at Moulamein and Billabong Creek were similar between September and December 2021. Billabong inflows concurrent with the unregulated flows in the Edward/Kolety River system when temperature started to warm up mitigated the extent of increases in DOC and nutrients and the risks from hypoxic blackwater and algal bloom events in sites in the Edward/Kolety River downstream.

Higher concentrations of DOC and nutrients were detected at Moulamein and Liewah in January and February 2022, consistent with higher observed carbon fluorescence. Lower spot dissolved oxygen readings were measured at Billabong Creek than at Moulamein, immediate downstream of Billabong Creek confluence. It indicates the inputs of DOC and nutrients might be associated with a higher discharge of Billabong Creek, where areas were wetted in hot months and DOC and nutrients being introduced from Billabong Creek to the Edward/Kolety River.

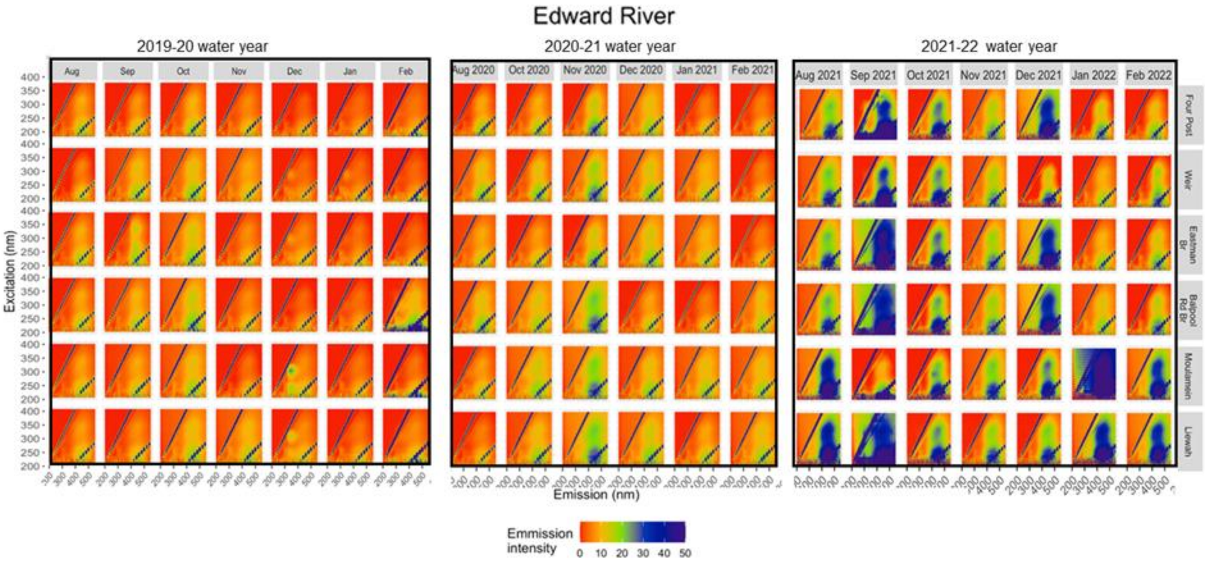


Figure 5.31 Fluorescence scans of water samples from the Edward/Kolety River system between August and February in 2019-20, 2020-21 and 2021-22 water years. Please note the data are not available for September 2020 due to instrument failure.

Evaluation questions for contingency monitoring at Niemur escape

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

Temperature induced hypoxia is likely to result from an increase in the rate of metabolism of the microbial community with normal loadings of DOC and nutrients, combined with lower dissolved oxygen solubility. Increased flow can improve re-aeration to counteract this effect and may also provide some dilution.

Watering action 3 was focused on the creation of localised refuges for aquatic organisms around the Niemur irrigation escape. However, the capacity (size and duration) for Commonwealth environmental water to be used to make widespread improvements in water quality was limited in the Niemur River system in hot weather. The Niemur escape watering action had negligible observed effect in the Niemur River system with CEW never exceeding 10 % of the total flow. Also releases from the escape were quite short duration over summer months. This result concurs with observations from the 2016/2017 monitoring (Watts et al., 2017) where the CEW capacity for widespread improvements in water quality and dilution downstream (low dilution < 7.5%) had minimal effect in having a diluting effect on the water. However, the use of escape flows may have been effective in creating a small 'plume' where fish can obtain refuge.

What did Commonwealth environmental water contribute to dissolved oxygen concentrations?

Commonwealth environmental water appeared to contribute to a slight increase in dissolved oxygen immediately adjacent to the irrigation escape site in late December 2021. CEW never exceeded 10 % of the total volume in the Niemur River system and also the CEW releases were repeatedly being turned on and off during the hot weather. The study design did not allow for the assessment of how far downstream this effect persisted. In future additional sites could be added to determine how far downstream of the escape the plume provides refuge.

What did Commonwealth environmental water contribute to nutrient concentrations?

The irrigation canal water was generally low in nutrients. CEW delivered from the escape generally contributed to a decrease in nutrient concentrations, where sufficient water was added for a dilution effect to be observed. However, the capacity of CEW to be used via Niemur Escape to make some improvements in water quality was limited, thus there was minimal change in nutrients at the site downstream of the escape. Compared with the 2020-21 water year, the algal carbon that occurred in the Colligen-Niemur system during the hot months in 2021-22 water year could be associated with the limited capacity (magnitude and duration) of watering action 3.

6 Stream metabolism

Authors: Andre Siebers, Nick Bond, Nicole McCasker

Key Findings	
Gross Primary Production (GPP)	When GPP was calculated as the amount of organic carbon produced per day (kg C/day) then all environmental water had a beneficial effect on increasing organic carbon production. The largest gross contribution of CEW occurred during the high flows period from 19/10/21 – 05/01/22). The size of the beneficial impact was largely related to the proportion of total flow that came from environmental water, with greater proportional effects of environmental water in lower-flow periods. Carbon production was enhanced by 2-151% by environmental water, with a median across all sites and time periods of 27% more carbon produced during delivery of CEW compared to no CEW. Environmental water delivery did not substantially affect areal rates of gross primary productivity (mg O_2/m^2/day), which largely followed seasonal trends.
Ecosystem Respiration (ER)	When ER was calculated as the amount of organic carbon consumed per day (kg C/day), then all environmental water had a beneficial effect on increasing carbon consumption. 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 2% and 145% by environmental water, with a median across all sites and time periods of 27% more carbon consumed during delivery of Commonwealth environmental water compared to no Commonwealth environmental water. As with GPP, areal rates of ecosystem respiration (mg O_2/m^2/day) were largely driven by seasonal trends.

6.1 Background

Whole stream metabolism measures the production and consumption of dissolved oxygen (DO), which occurs as a result of the key ecological processes of photosynthesis and respiration (Odum 1956). 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.

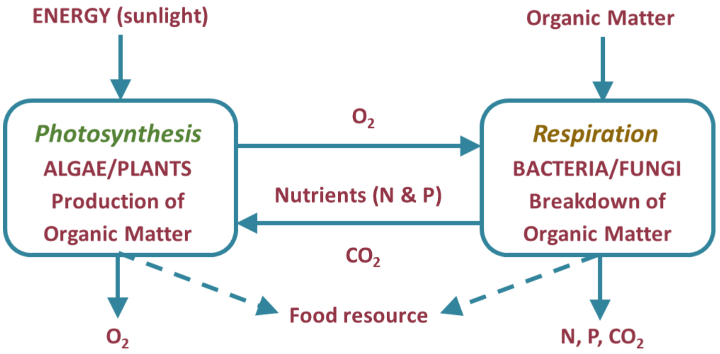


Figure 6.1 Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

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 (GPP) and ecosystem respiration (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 metabolism process rates are too low, this will limit the amount of food resources (bacteria, algae and water plants) for consumers. This limitation can 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 nutrient 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 EKW system.

This chapter reports on stream metabolism in response to flows in the 2021-22 water year and will consider changes in GPP and ER in the system.

6.2 Environmental watering actions in 2021-22

The 2021-22 water year represented substantially different hydrological conditions to the previous years. Unregulated flows and water flowing into the Edward/Kolety River from Millewa Forest following the Murray Southern Spring Flow resulted in high in-channel freshes in spring/early summer 2021. However, some of the environmental water delivered during 2021-22 occurred when these naturally high flows had subsided, and can be assessed as in previous years' monitoring. The response of stream metabolism to watering actions 4, 5 and 6 (autumn fresh) were evaluated (Table 6.1). Given that actions 4 and 5 overlapped temporally in the same systems, these watering actions were evaluated as a block. In addition, the effect of environmental water was also assessed during the naturally high flows, which also contained water released upstream from Hume Dam and irrigation escapes. The 2021-22 metabolism report thus also focuses on these high flow periods (Table 6.1), which have been split between winter-spring periods (period "A"), when CEW made up a smaller proportion of total discharge; and spring-summer periods (period "B"), where CEW contributed to maintenance of high flows.

Table 6.1 High flow periods and environmental watering actions assessed for ecosystem metabolism in the Edward/Kolety-Wakool system in 2021-22.

Flow type	No.	System	Type	Dates
High flow period	A	Wakool-Yallakool Edward/Kolety Colligen-Niemur	Naturally high flows, combined with watering actions from Hume Dam and irrigation escapes	09/08/21 – 18/10/21
	B	Wakool-Yallakool Edward/Kolety Colligen-Niemur	Naturally high flows, combined with watering actions from Hume Dam and irrigation escapes	19/10/21 – 05/01/22
Environmental watering action	4	Wakool-Yallakool	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
	5	Wakool-Yallakool	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
	6	Colligen-Niemur	Autumn fresh (Colligen offtake)	03/04/22 -26/04/22
	7	Tuppal Creek	Elevated base flow	01/11/21-29/05/22

6.3 Selected Area questions

The 2021-22 EKW Flow-MER report follows previous years evaluations of stream metabolism responses to Commonwealth environmental water delivery, with the addition of examining how GPP and ER in 2021-22 compare to previous years' data. 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 gross primary production (GPP), ecosystem respiration (ER), and net primary production (NPP)? • What did Commonwealth environmental water contribute to total GPP, ER, and NPP? • Which aspect of Commonwealth environmental water delivery contributed most to productivity outcomes? • Did 2021-22 represent a markedly different water year with respect to GPP, ER, and productivity outcomes?

6.4 Methods

Data collection

Flow-MER stream metabolism measurements were performed in accordance with the Long Term Intervention Monitoring (LTIM) Standard Operating Procedure (Hale et al. 2014). As in 2019-2020 and 2020-21, water temperature and dissolved oxygen were logged every ten minutes with at least one logger placed in each of five study zones (Yallakool River (zone 1), Upper Wakool River (zone 2), mid Wakool River upstream of Thule Creek (zone 3), mid Wakool River downstream of Thule Creek (zone 4) and Colligen Creek (zone 8) (Figure 6.2). Two loggers were placed at the upstream and downstream end of zone 4, to allow for the possibility of conducting two-station metabolism estimates as a cross-check on single-station results (Grace et al. 2015). In addition, in 2020-21 and 2021-22, water temperature and dissolved oxygen were also logged at Liewah in the lower Edward 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.

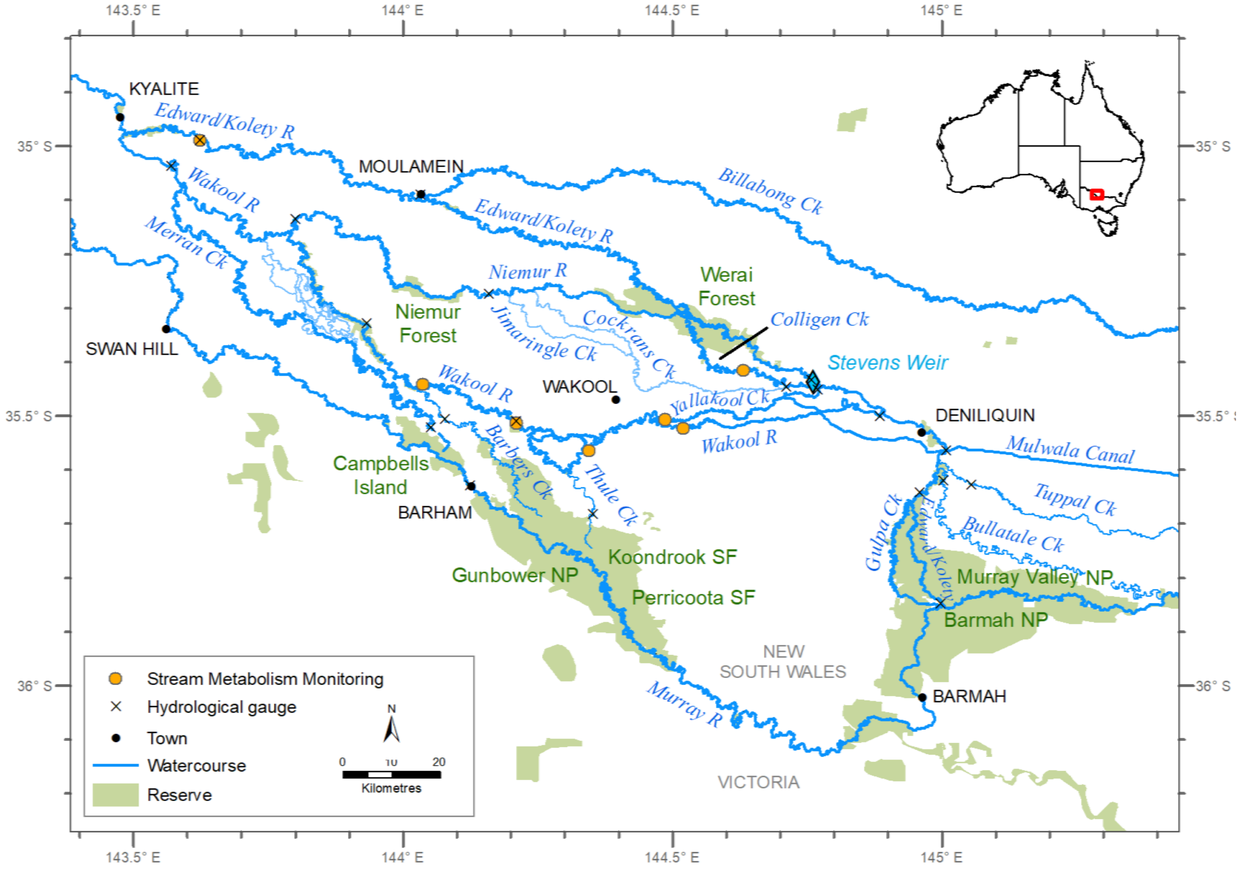


Figure 6.2: Map of the seven stream metabolism monitoring sites in the Edward/Kolety-Wakool River System.

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 2019-21, 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 five 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.

Further, during the flow pulses there were various sources of environmental water, rather than a single source as in previous years. The potential effect of these different sources was estimated by splitting each proportion of discharge associated with Hume Dam, and various offtakes, into distinct fractions (i.e., to represent the two most distinct groupings within discharge associated with CEW). The daily estimates of CEW-attributable production and consumption were predicted individually for each fraction, following the steps above, in addition to the contribution of overall CEW.

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 28.0% of all days with data available for lower Edward/Kolety River to a high of 73.0% in the upper Wakool River (zone 2) (Table 6.3). These values have a higher minimum but equivalent maximum to those for 2020-2021 (8 to 73%) (Watts et al., 2021).

Table 6.3 Summary of data availability for the seven data logger sites, July 2021 – July 2022.

River Zone	Zone No.	Logger location in zone	Total days	Days with acceptable data	% Acceptable data days
Yallakool Creek	zone 1	downstream	321	227	70.72
Upper Wakool River	zone 2	downstream	333	243	72.97
Mid Wakool River upstream Thule Creek	zone 3	downstream	304	111	36.51
Mid Wakool River downstream Thule Creek	zone 4	upstream	336	194	57.74
	zone 4	downstream	338	223	65.98
Colligen Creek	zone 8	downstream	334	157	47.01
Lower Edward/Kolety River@Liewah	*na*	downstream	271	76	28.04

Median GPP values for all seven sites fell within a narrow range of 1.17 to 2.57 mg O_2/L/day, with a greater minimum and maximum than the range in 2020-21 (0.8 to 1.9 mg O_2/L/day) (Watts et al., 2021). When converted to areal rates, the median GPP values had a similarly narrow range (from 1.5 to 1.9 g O_2/m^2/day) (Table 6.4) comparable with that from 2020-21 (1.1 to 1.8 g O_2/m^2/day) (Watts et al., 2021).

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 2021 – June 2022. 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, n = 227)			
	Median	Mean	Min	Max
GPP (g O_2/m^2/day)	1.74	1.84	0.15	9.31
ER (g O_2/m^2/day)	3.04	3.58	0.37	14.15
GPP / ER	0.57	0.59	0.05	1.76

	Upper Wakool River (zone 2, n = 243)			
	Median	Mean	Min	Max
GPP (g O_2/m^2/day)	1.54	1.74	0.34	6.95
ER (g O_2/m^2/day)	5.95	6.18	1.09	18.15
GPP / ER	0.29	0.31	0.05	0.72

	Mid Wakool River upstream Thule Creek (zone 3, n = 111)			
	Median	Mean	Min	Max
GPP (g O_2/m^2/day)	1.56	2.41	0.14	10.57
ER (g O_2/m^2/day)	3.89	4.46	0.31	27.33
GPP / ER	0.51	0.58	0.05	1.48

	Mid Wakool River downstream Thule Creek (zone 4, upstream, n = 194)				**Mid Wakool River downstream Thule Creek (zone 4 downstream, n = 223)**			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (g O_2/m^2/day)	1.88	2.23	0.40	9.44	1.90	2.36	0.48	9.72
ER (g O_2/m^2/day)	3.21	4.51	0.54	22.34	4.14	5.10	0.50	20.13
GPP / ER	0.59	0.58	0.07	1.20	0.50	0.53	0.07	1.44

	Colligen Creek (zone 8, n = 157)			
	Median	Mean	Min	Max
GPP (g O_2/m^2/day)	1.63	2.19	0.34	10.97
ER (g O_2/m^2/day)	4.06	4.66	0.18	16.01
GPP / ER	0.45	0.49	0.10	1.87

	Lower Edward/Kolety River@Liewah (n = 76)			
	Median	Mean	Min	Max
GPP (g O_2/m^2/day)	1.55	1.69	0.25	10.73
ER (g O_2/m^2/day)	3.15	4.40	1.01	17.66
GPP / ER	0.42	0.43	0.03	0.88

There was a seasonal increase in GPP from spring into summer in zones 1 – 4 (Yallakool Creek and Wakool River), and a subsequent decrease from the end of summer into autumn, although useable data in zone 3 (mid Wakool upstream of Thule Creek) constrained conclusions around consistent patterns through autumn. Despite the constrained range of median values, all zones also exhibited short pulses of very high GPP (> 5 mg $O_2/m^2/d$) in late December 2021/early January 2022. As with the 2020/21 data, warmer days and more hours and higher intensity of sunshine during summer are the most likely driver of these patterns (Watts et al., 2021). ER also showed a seasonal trend in zones 1 – 4, and pulses of respiration were largely correlated with those of GPP. These pulses coincided with the end of flow pulses in late December, but follow the seasonal patterns of summer peaks from previous years' monitoring in which flow pulses did not occur (Watts et al., 2019, 2020, 2021), and may thus be driven by similar climatic conditions rather than flow patterns (Figure 6.2). Areal rates of GPP and ER were thus largely unaffected by flow conditions. GPP GPP and ER in Colligen Creek followed a similar seasonal pattern to that in Zones 1 – 4, although pulses were also recorded into autumn. GPP data in the lower Edward/Kolety River at Liewah were too scarce to assign seasonal patterns in 2021/22 (Figure 6.3).

For most of the time each hydrological zone was strongly heterotrophic (GPP < ER), even during early-summer GPP peaks (Figure 6.2, Figure 6.3). The exceptions were sporadic days, particularly within the flow pulse or watering action periods, when GPP briefly exceeded ER in zones 1 (Yallakool Cree), 3 and 4 (Mid Wakool River), and Colligen Creek. 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 adjacent riparian ecosystems. Unlike previous years, flows were high enough during the 2021-22 period to connect anabranches and low-lying floodplains, i.e., shallow wetted habitat where primary productivity can often reach very high areal rates. However, NEP and GPP:ER did not appear to be consistently affected by the 2021 flow pulses, so the most likely source of this additional carbon is transport from upstream reaches regardless of connectivity with off-channel areas.

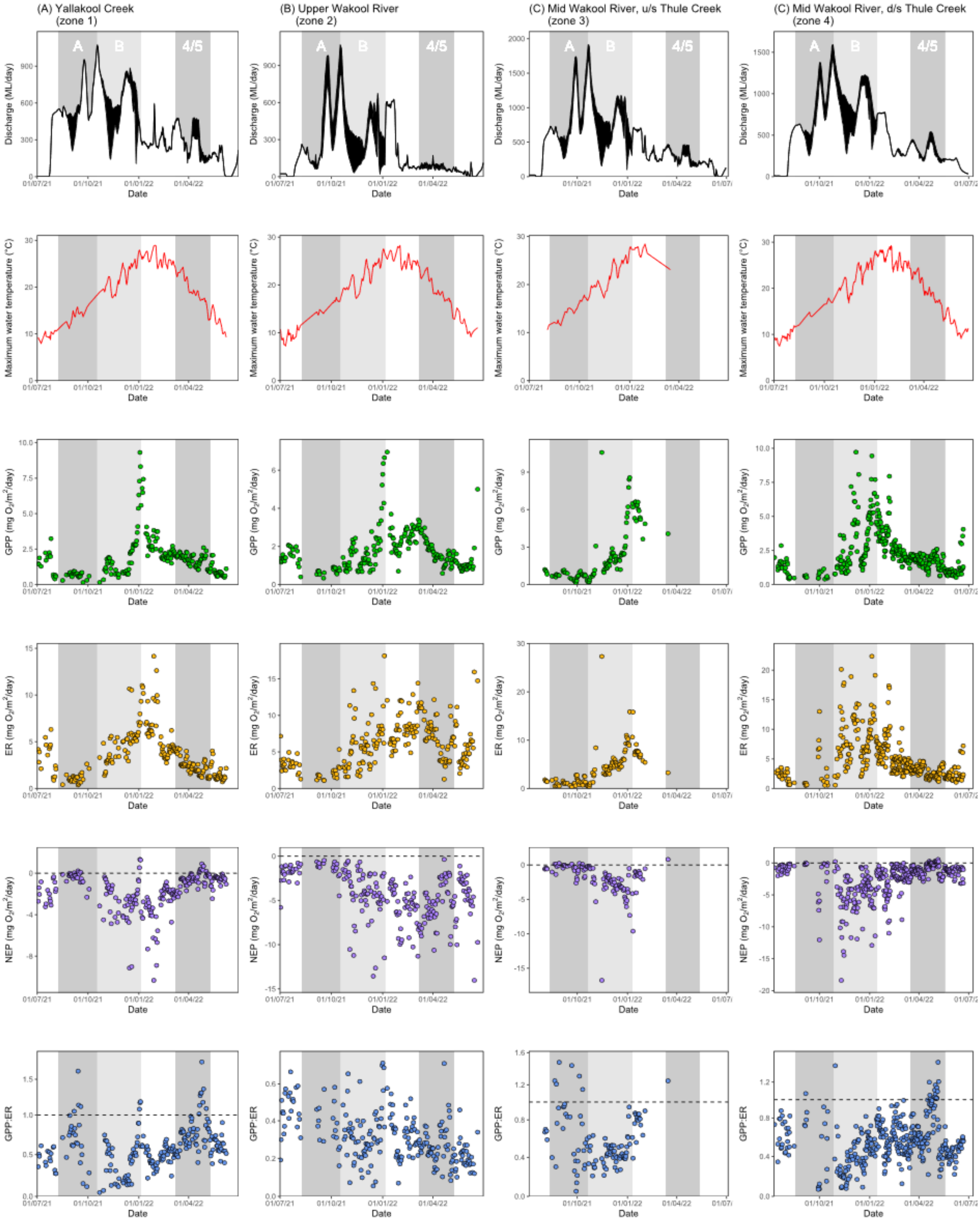


Figure 6.2 Plots of discharge, maximum water temperature, oxygen production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GPP:ER) over all sites in the four hydrological zones from Yalllakool Creek and the Wakool River in 2021-22. High flow periods in which environmental water was delivered (A and B) and watering actions (4 and 5, combined) are indicated by shaded bars. Shaded bars are adjusted for travel time for zones 3 (4 days) and 4 (9 days).

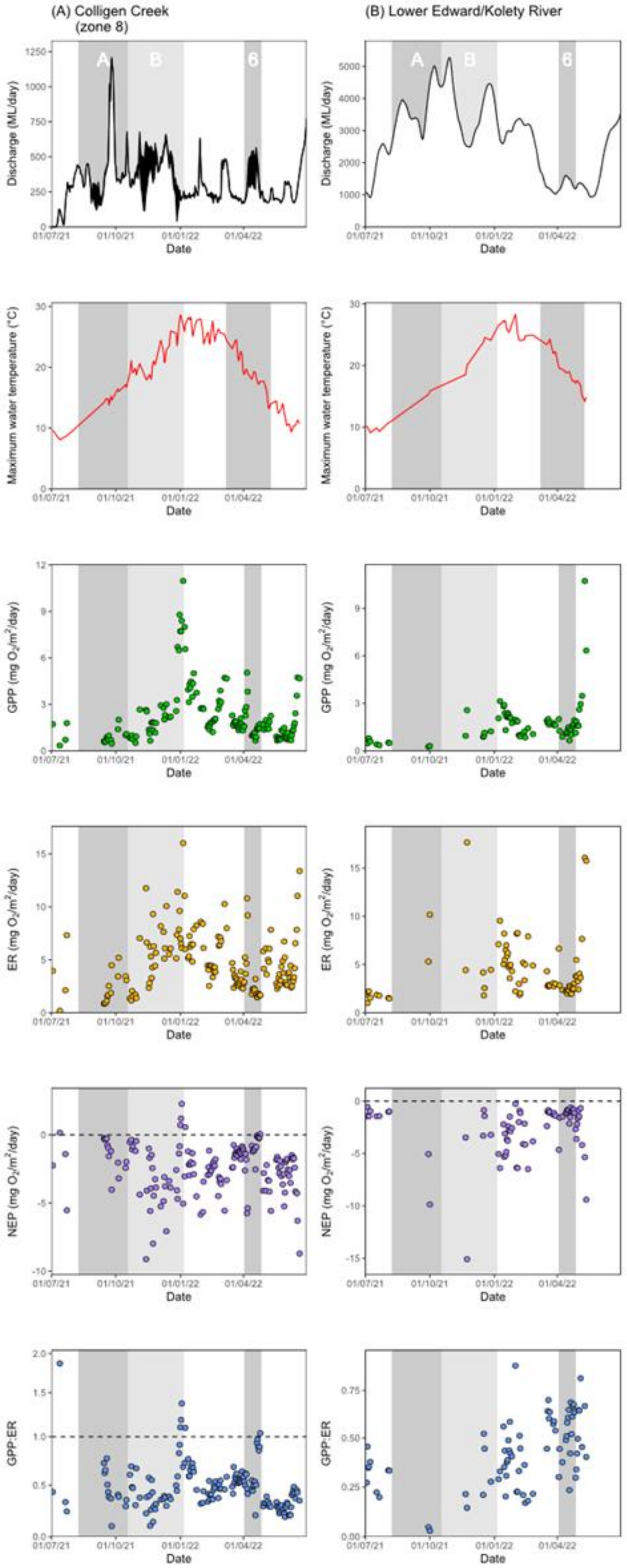


Figure 6.3 Plots of discharge, maximum water temperature, oxygen production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GPP:ER) in the Colligen Creek and Liewah sites in 2021-22. High flow periods in which environmental water was delivered (A and B) and watering actions (6) are indicated by shaded bars. There is no data on environmental water actions for the Liewah site.

Response of stream metabolism to Commonwealth environmental watering actions

High flow period A (09/08/21 – 18/10/21): GPP rates mostly fell within a narrow range (0.5 to 1.0 g O_2/m^2/day) across all sites during the first high flow period. ER rates varied largely between 1 and 5 g O_2/m^2/day, with Zone 4 (Mid Wakool d/s Thule) exhibiting a number of days with higher values. All zones were largely heterotrophic during the flow pulse (Figure 6.4).

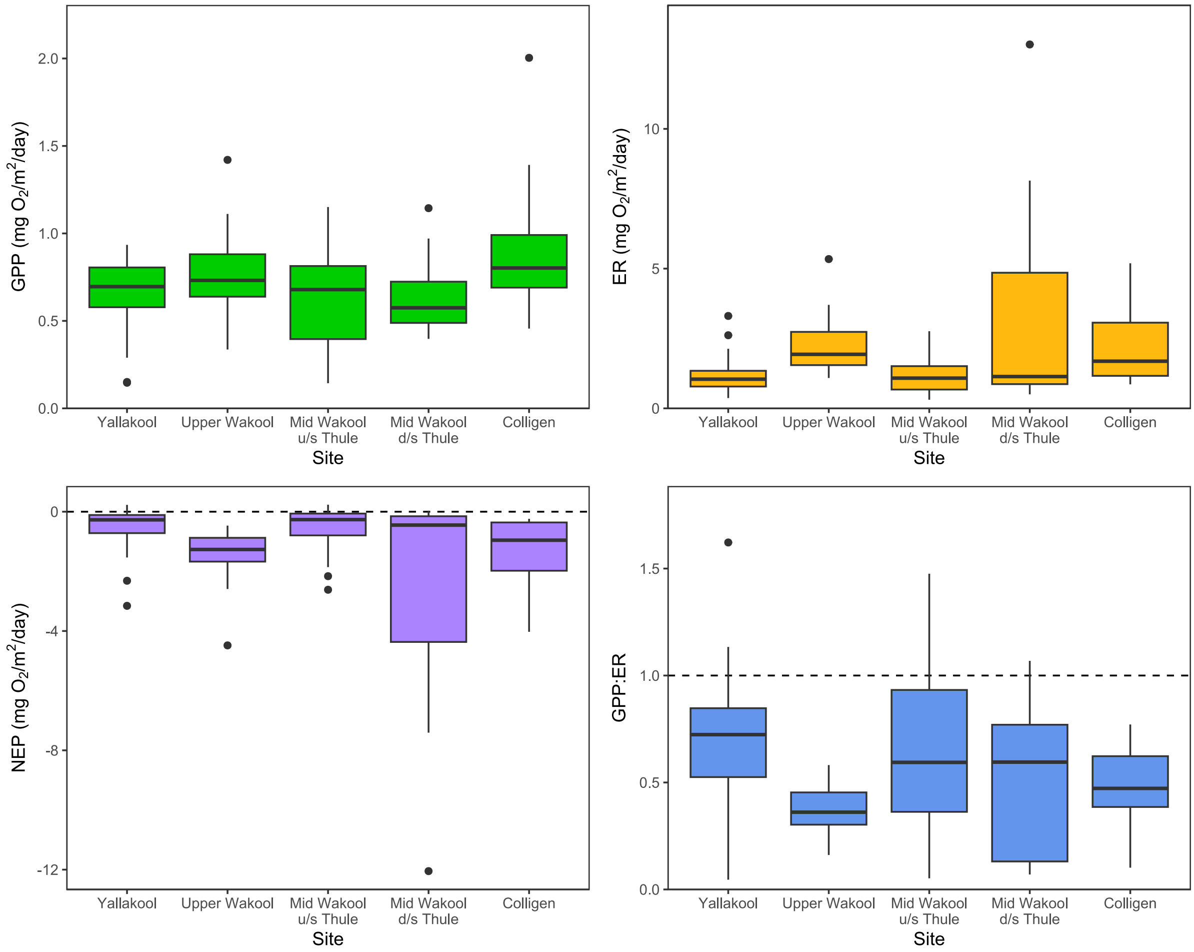


Figure 6.4 High flow period A (09/08/21 – 18/10/21), Yallakool Creek, Wakool River and Colligen Creek. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

Delivery of environmental water resulted in increased production and consumption of carbon at all Zones (Figure 6.5). The effect of CEW was more difficult to predict at Colligen Creek due to lower amounts of useable data (i.e., BASEv2 model results did not meet acceptance criteria), but the data available suggests that there was an increase in carbon produced with delivery of environmental water.

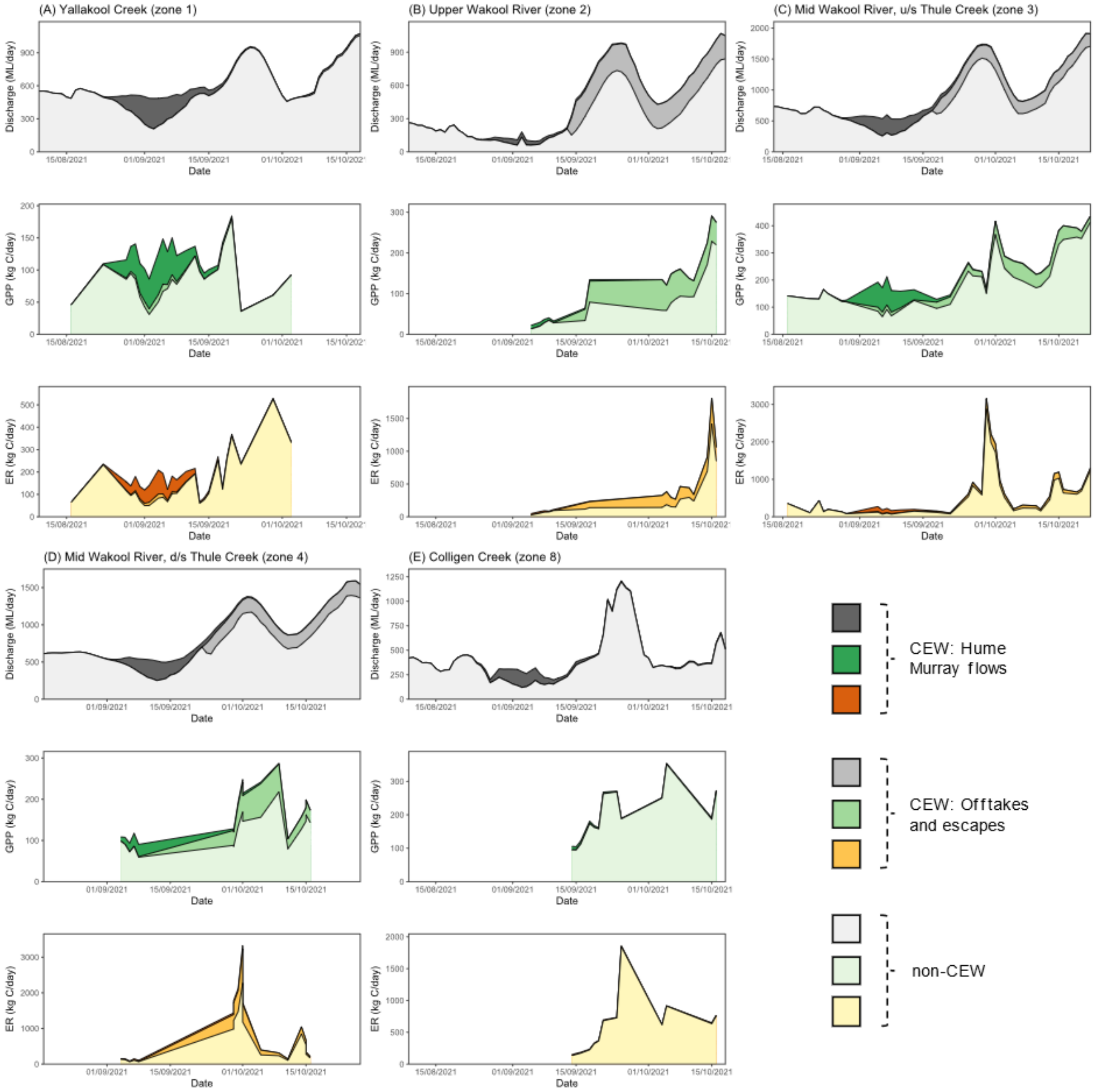


Figure 6.5 Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during high flow period A (09/08/21 – 18/10/21), Yallakool Creek, Wakool River and Colligen Creek, showing the component attributed to Commonwealth environmental water. Dates for zone 3 and zone 4 are 4 and 9 days later than the other areas to allow for differences in travel time.

High flow period B (19/10/21 – 05/01/22): As with the first high flow period, GPP rates mostly fell within a narrow range (1.5 to 4.0 g O_2/m^2/day) across all sites, although this was higher than in the first high flow period. This reflects the early summer pulses of GPP and ER that occurred across all areas during the period (Figure 6.2). All areas were still largely net heterotrophic during the second high flows period (Figure 6.6).

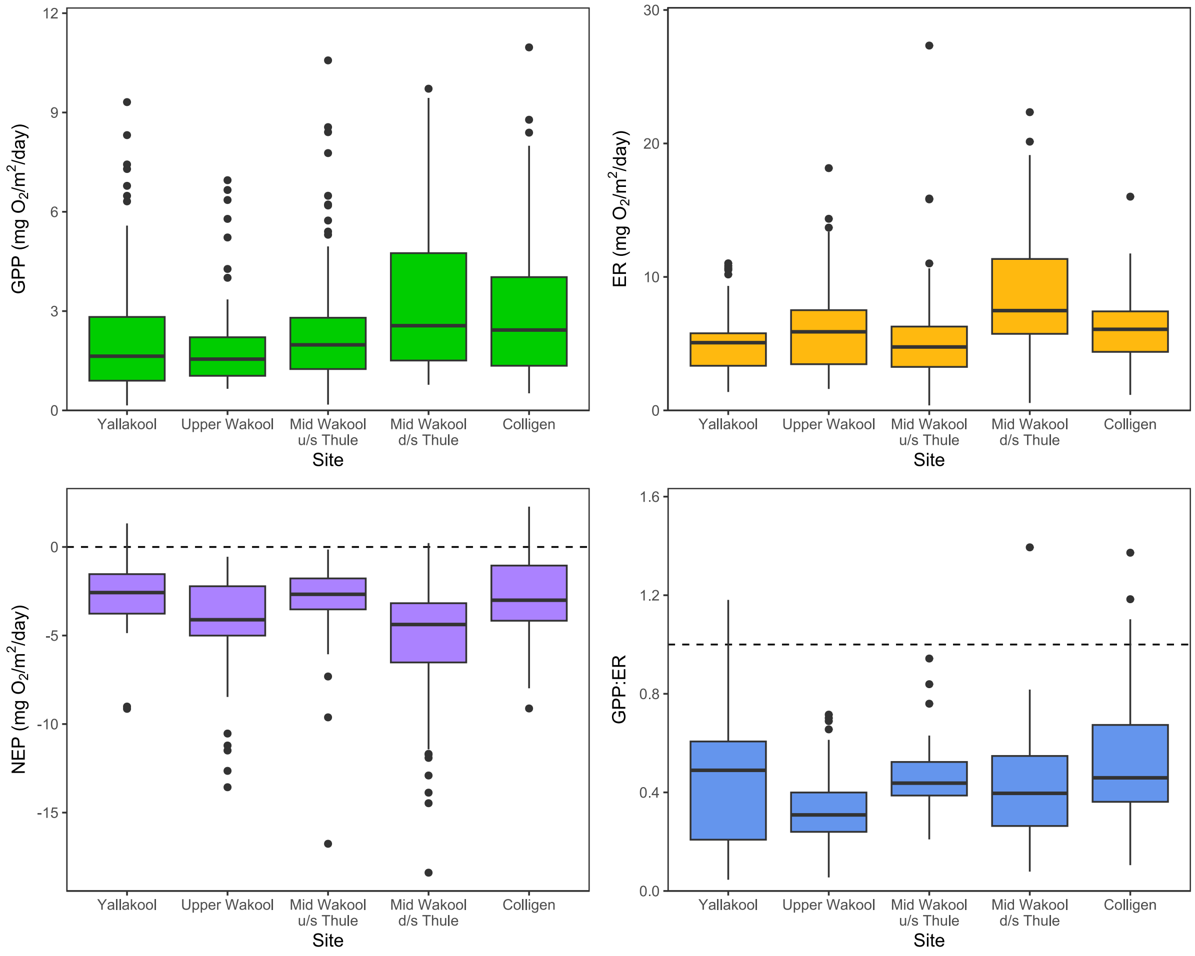


Figure 6.6 High flow period B (19/10/21 – 05/01/22), Yallakool Creek, Wakool River and Colligen Creek. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

During the second high flows period, delivery of environmental water resulted in increased production and consumption of carbon in all hydrological zones (Figure 6.7).

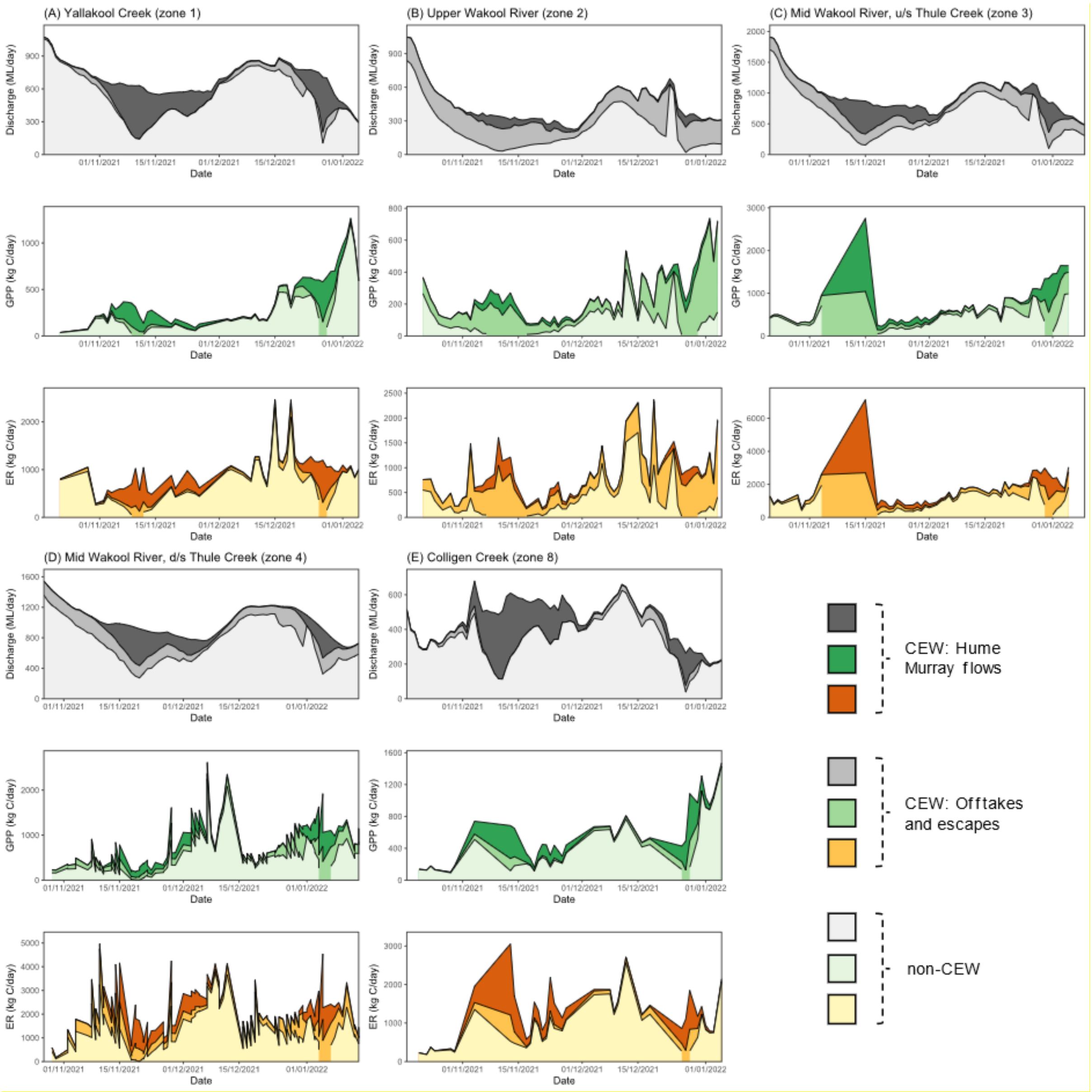


Figure 6.7 Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during high flow period B (19/10/21 – 05/01/22), Yallakool Creek, Wakool River and Colligen Creek, showing the component attributed to Commonwealth environmental water. Dates for Zone 3 and Zone 4 are 4 and 9 days later than the other areas to allow for differences in travel time.

Watering actions 4/5 (24/03/22 - 09/05/22) and 6 (03/04/22 -26/04/22): During the autumn elevated base flows and freshes, rates of both GPP (1.5 to 2 g O_2/m^2/day) were largely consistent through time, although ER (2 to 8 g O_2/m^2/day) showed greater variability across sites (Figure 6.8). All zones were largely heterotrophic during the watering action, although a lack of useable data at zone 3 did not allow determination of trophic status (Figure 6.8).

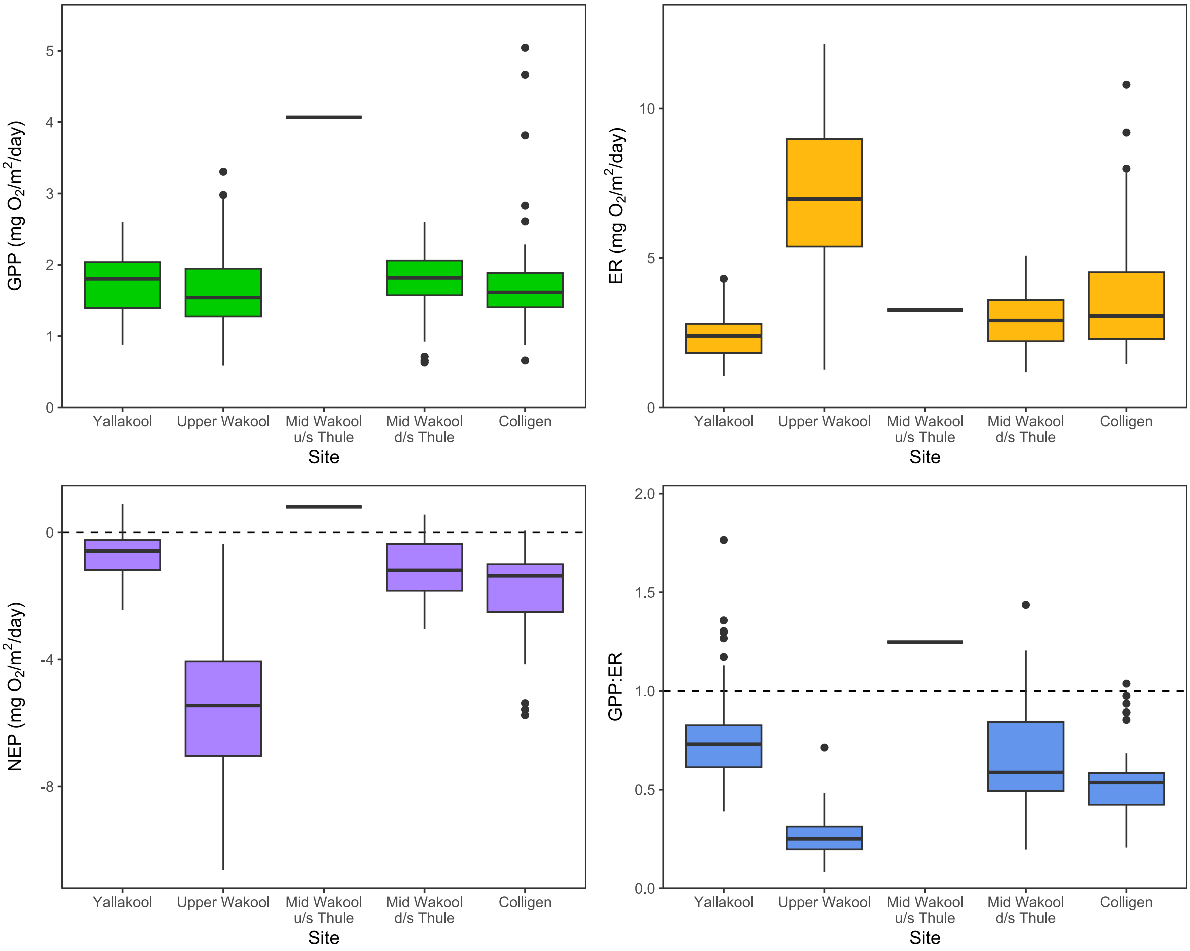


Figure 6.8 Autumn watering actions 4/5 (24/03/22 - 09/05/22) and 6 (03/04/22 -26/04/22), Yallakool Creek, Wakool River and Colligen Creek. Variation in daily rates for organic carbon production (GPP), consumption (ER), net production (NEP) and production: consumption ratio (GGP:ER) are shown.

The autumn watering actions resulted in increased production and consumption of carbon at all zones, although the lack of useable data at zone 3 precluded estimation of C fluxes (Figure 6.9).

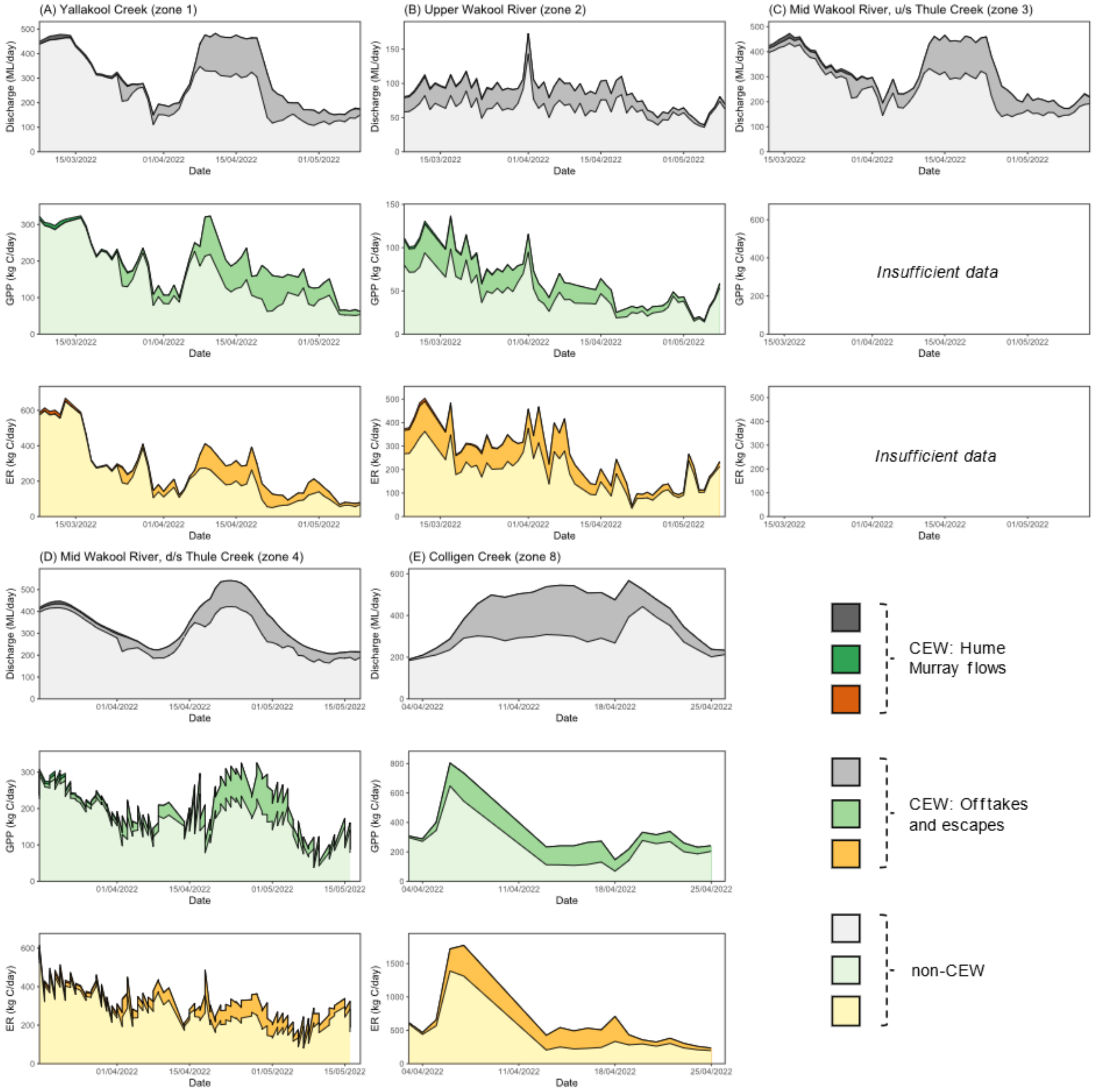


Figure 6.9 Plots of discharge (ML/day) and carbon production (GPP, kg C/day) and consumption (ER, kg C/day) during watering actions 4/5 (24/03/22 - 09/05/22) and 6 (03/04/22 -26/04/22), Yallakool Creek, Wakool River and Colligen Creek, showing the component attributed to Commonwealth environmental water. Dates for zone 3 and Zone 4 are 4 and 9 days later than the other areas to allow for differences in travel time. Note no timeseries was able to be derived for Zone 3 (only one useable data day); note different x axis scale for Colligen Creek (different dates of watering action 6 compared to 4 and 5).

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 period (high flows and watering actions) to determine the average daily additional production and consumption for each period, and the total additional carbon production and consumption attributable to environmental water.

All environmental water delivery resulted in increased production (Figure 6.10) and consumption of carbon (Figure 6.11). The largest gross contribution of CEW to both mean and overall C production and consumption occurred during the second high flows period. This 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 across all measured areas.

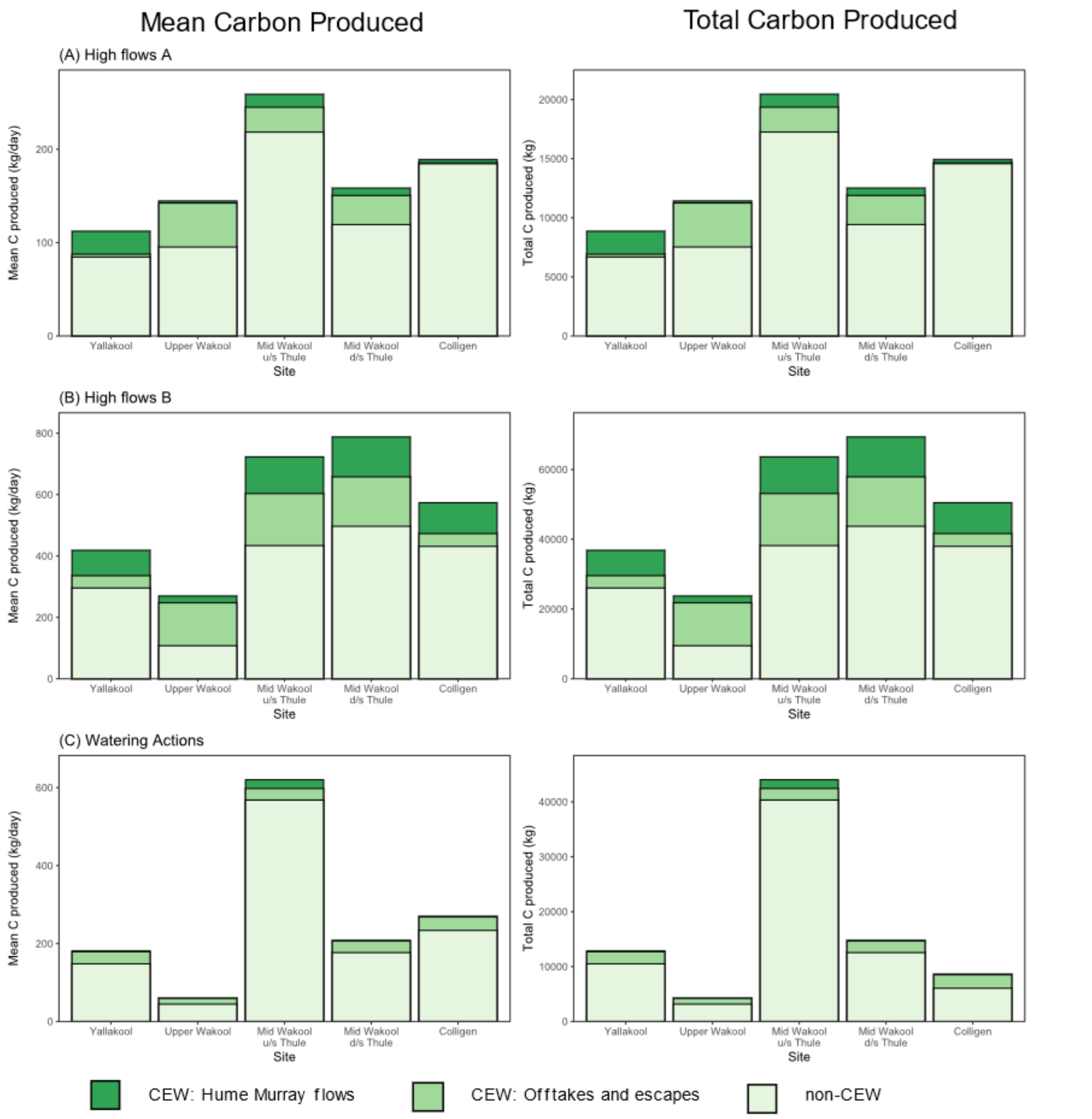


Figure 6.10 Left: The average daily additional production of carbon (kg C/day) during the high flow and environmental watering action periods. Right: The total additional production of carbon (kg) during the high flow and environmental watering action periods.

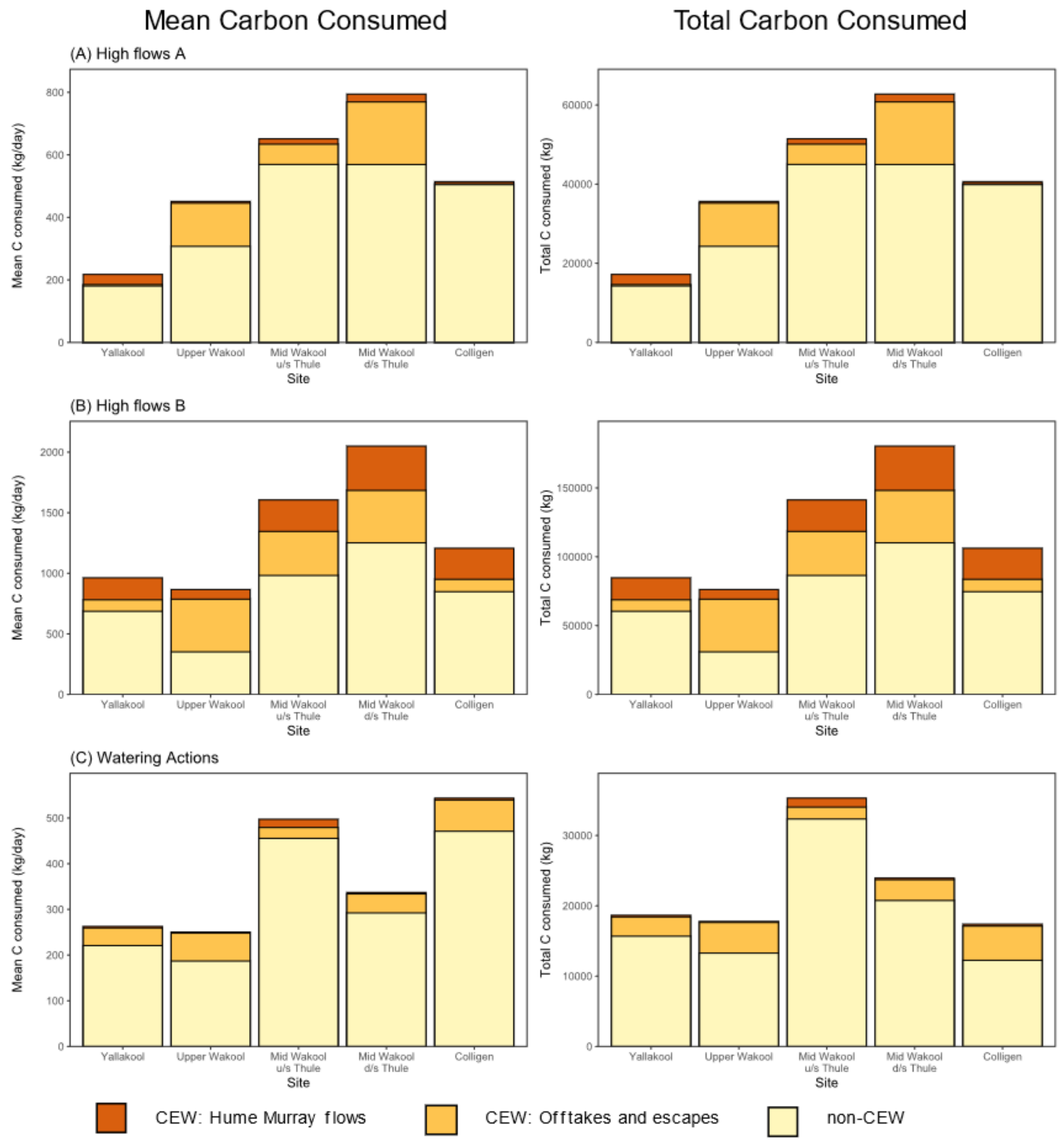
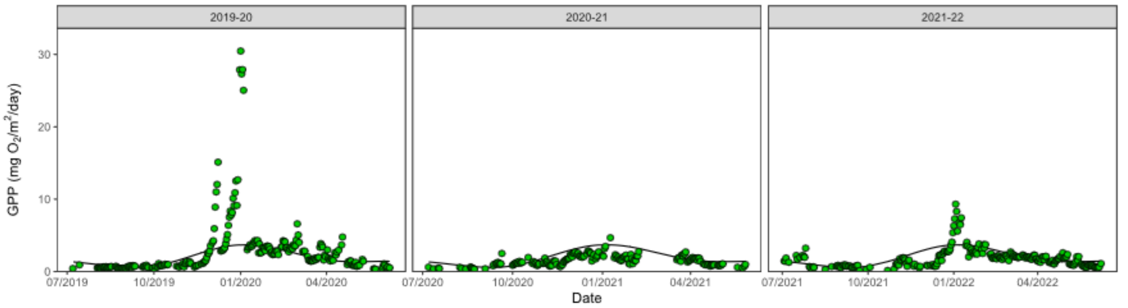


Figure 6.11 Left: The average daily additional production of carbon (kg C/day) during the high flow and environmental watering action periods. Right: The total additional production of carbon (kg) during the high flow and environmental watering action periods.

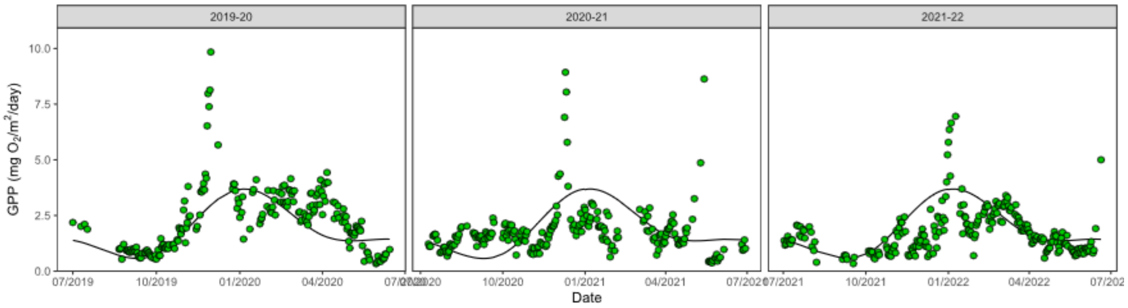
Differences in metabolism between 2021-22 and other water years

Areal rates of both GPP and ER had similar overall magnitude and followed very similar seasonal patterns in 2021-22 to those of the previous two water years, though with a slightly lower magnitude of peak events in zones 1, 2, and 4 (Figure 6.12, Figure 6.13). There was not enough data from previous years to assess whether GPP and ER pulses were exceptional in 2021-22 for the Mid Wakool d/s Thule and Colligen Creek. Production and consumption of carbon were notably higher in 2021-22, with higher overall contributions from CEW in 2021-22 (76 tonnes GPP; 188 tonnes ER) than in 2020-21 (61 tonnes GPP; 117 tonnes ER) or 2019-20 (16 tonnes GPP; 24 tonnes ER) (Figure 6.14). However, the proportional contribution of CEW to overall GPP and ER was lower in 2021-22 (21.0 and 22.7 %) than in 2020-21 (40.2 and 39.8 %), but greater than in 2019-20 (11.3 and 11.6 %).

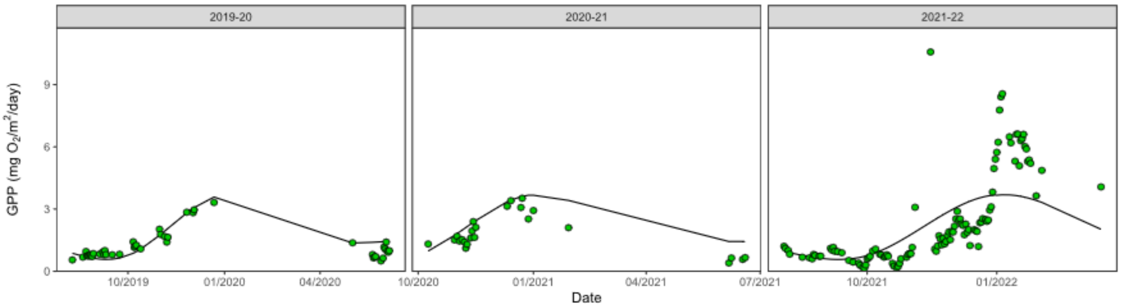
(A) Yallakool Creek (zone 1)



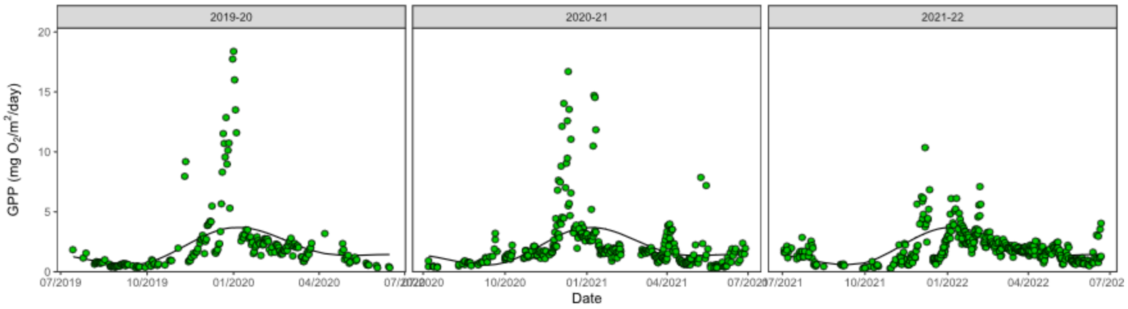
(B) Upper Wakool River (zone 2)



(C) Mid Wakool River, u/s Thule Creek (zone 3)



(D) Mid Wakool River, d/s Thule Creek (zone 4)



(E) Colligen Creek (zone 8)

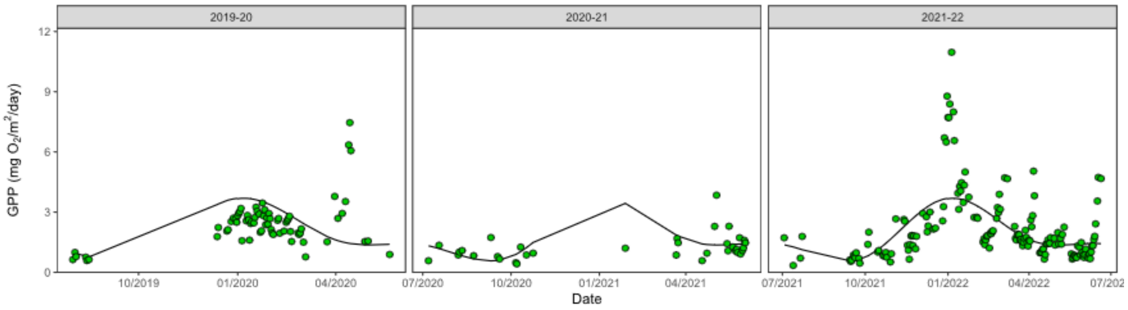
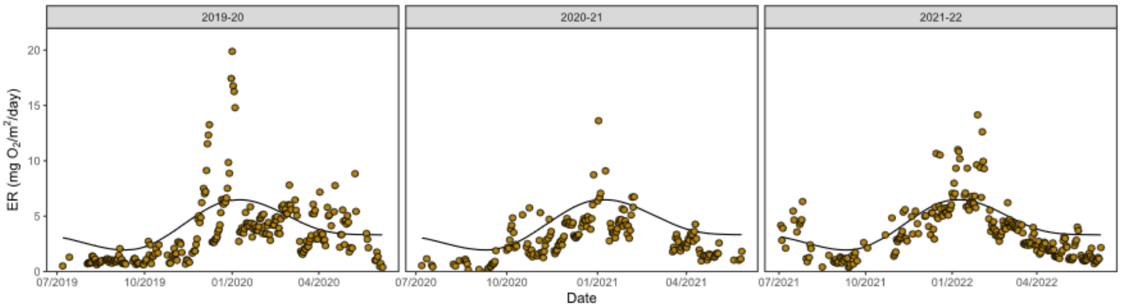
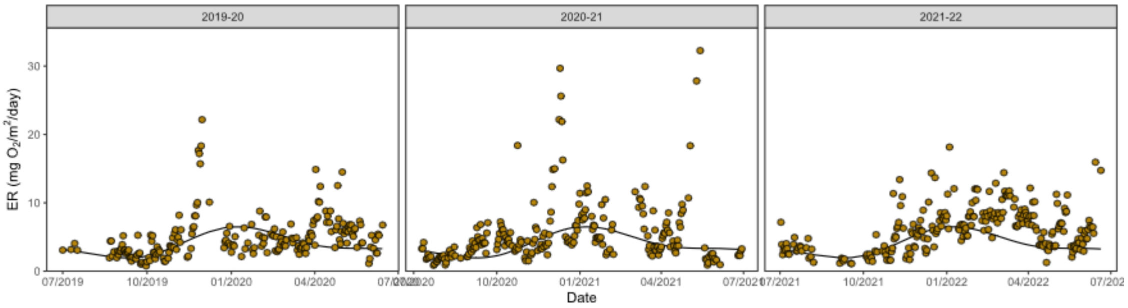


Figure 6.12 Plots of oxygen production (GPP) over all sites in the four hydrological zones from Yalllakool Creek and the Wakool River, plus Colligen Creek, across the current and two previous water years (water year indicated above each individual plot). The black line represents predicted values from a generalised additive mixed-effects model predicting GPP by date, with water year as a random effect (intercept-only).

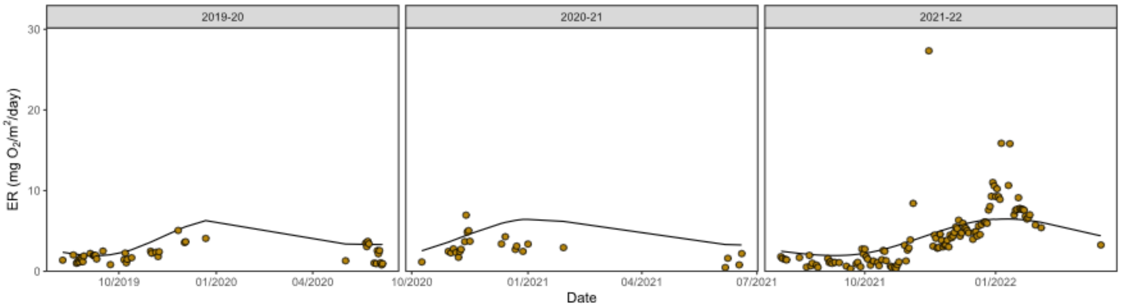
(A) Yallakool Creek (zone 1)



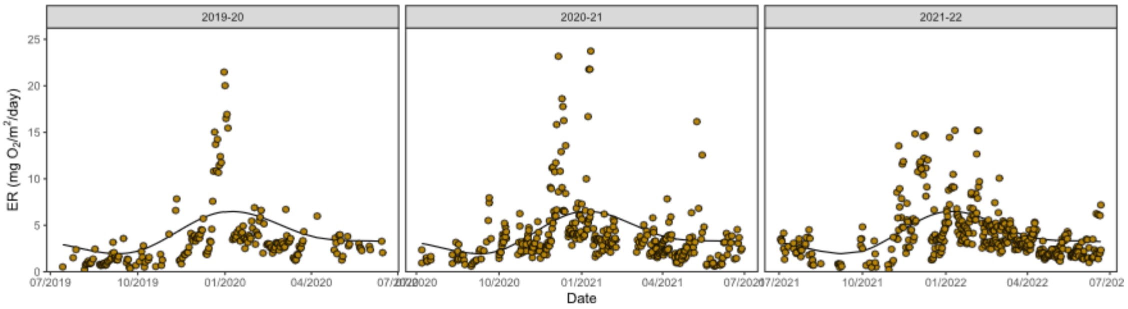
(B) Upper Wakool River (zone 2)



(C) Mid Wakool River, u/s Thule Creek (zone 3)



(D) Mid Wakool River, d/s Thule Creek (zone 4)



(E) Colligen Creek (zone 8)

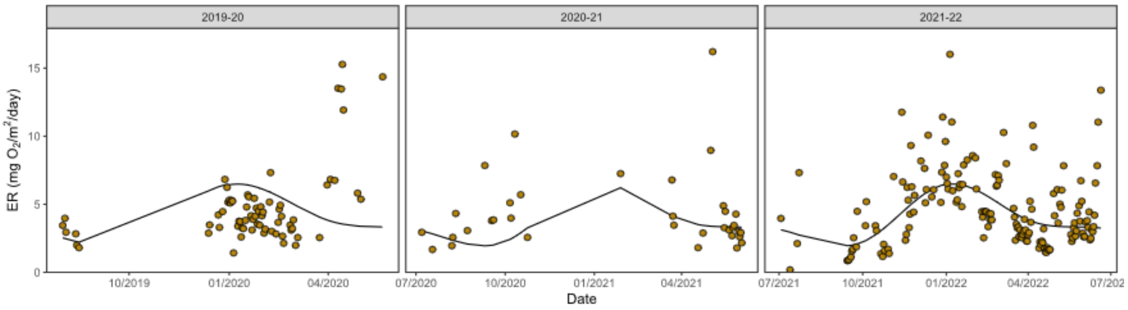


Figure 6.13 Plots of oxygen consumption (ER) over all sites in the four hydrological zones from Yalllakool Creek and the Wakool River, plus Colligen Creek, across the current and two previous water years (water year indicated above each individual plot). The black line represents predicted values from a generalised additive mixed-effects model predicting GPP by date, with water year as a random effect (intercept-only).

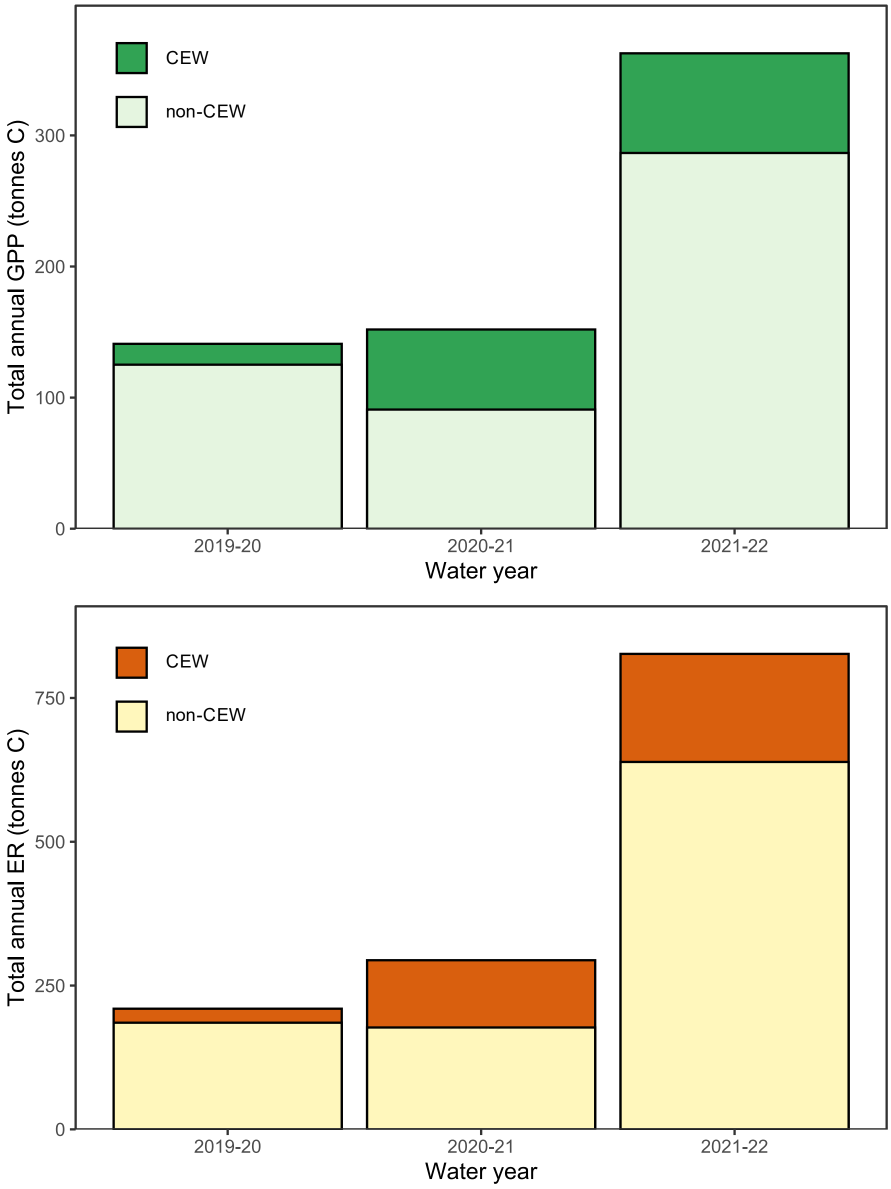


Figure 6.14 The total production (GPP) and consumption (ER) of carbon (tonnes) attributable to environmental water delivery, relative to total annual production, during the current and two previous water years.

6.6 Discussion

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

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 EKW 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 in response to delivery of Commonwealth environmental water and a strong seasonal trend in rates of GPP and ER became apparent. In particular, areal rates of GPP were higher and pulses appear more frequently during warmer summer months, indicating that temperature and light are major drivers of GPP rates within the EKW system. Consequently, increases and decreases in flow likely had little effect on where production and consumption of carbon is occurring within the EKW river channels.

Except in conditions of major phytoplankton growth (e.g., an algal bloom), much of the metabolism in the EKW river channels 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. In previous years, it was hypothesised that substantial increases in areal rates of GPP with increased flows would likely only occur when discharge is high enough for low-lying anabranches, backwaters and floodplain to become inundated and connected to the river channel. These off-channel inundation events should 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. The results in 2021-2022, when flows were high enough to inundate off-channel areas, suggest that this is not the case, as metabolism did not deviate from regular seasonal cycles. However, it must be stressed that rates of off-channel production were measured directly (i.e., within off-channel environments such as temporary wetlands and flood runners in Werai Forest) during the second flow pulse and found to be substantially greater than those in the river channel (Watts et al. 2022). This greater off-channel productivity does not appear to be reflected in patterns of GPP and ER in the main channel monitoring sites, suggesting that much of the production and consumption of carbon associated with inundation of off-channel areas did not influence metabolism in the river channels and was not picked up by the regular monitoring network.

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.

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 channels, and is thus also a strong influence on total carbon production and consumption. However, as stated above, the production occurring in off-channel areas during the high flow periods does not appear to be noticeably transferred or consumed within the river channel environments of the Edward/Kolety -Wakool System. We therefore cannot assess the true contribution of Commonwealth environmental water to total GPP, ER, and NPP across the entire river system, as a substantial proportion of this production and consumption likely occurs on the wider, inundated off-channel areas which were not measured as part of the core monitoring program (Watts et al. 2022). The contribution of this off-channel ecosystem metabolism to whole-system trophic dynamics thus represents an important knowledge gap and area of future research.

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

The median total contribution of Commonwealth environmental water to carbon production was greatest during the second high flow period (14,257 kg) than the first (3,091 kg), or the autumn watering actions (2,342 kg). These results reflect the higher overall rates of GPP during summer. During the second high flows period, the delivery of environmental water derived from Hume Dam resulted in a lower median total production (8,851 kg) than that of water not attributed to CEW (12,307 kg). However, these results reflect the timing of water delivery, where pulsed GPP events in the second half of the high flows period coincided with a majority of environmental water being derived from sources other than Hume Dam. Consequently, the effect of CEW on productivity outcomes was most greatly affected by the timing of delivery. It must be stressed, however, that provision of environmental water at other times of the year can have a greater proportional effect, particularly during otherwise low flows (such as the provision of winter base flows).

Did 2021-22 represent a markedly different water year with respect to GPP, ER, and productivity outcomes?

Areal rates of GPP and ER did not appear to deviate from regular, seasonal patterns and magnitudes of pulses (i.e., days with disproportionately higher rates) in 2021-22 when compared with the two previous water years, which suggest that higher flows in 2021-22 did not affect how carbon is produced and consumed in the river channels. However, the overall production and consumption of carbon was much greater on an annual scale. High flows likely increased overall carbon production and consumption simply through a greater volume of water, providing more aquatic environment in which GPP or ER could take place (e.g., through phytoplankton growth and metabolism); a greater volume of water, including greater volumes of CEW, therefore resulted in a proportionally greater increase in total production and consumption.

However, the percentage contribution of CEW to total production was greater in the previous water year (2020-21), when annual discharge was lower than in 2021-22 (Watts et al., 2020). These patterns reflect that Commonwealth environmental water has a substantial proportional effect during low-flow periods (i.e., GPP and ER are 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 also very important to note that although environmental watering actions increased production of carbon in the riverine ecosystem, it has now been shown that reconnection of off-channel wetlands, ephemeral channels, and the floodplain to the river channel results in substantial production within these off-channel areas in the EKW system (Watts et al. 2022). This off-channel production was not reflected in the main drivers of GPP and ER, or the overall effect of environmental water, in the main river channel environments. This result may be due to the overall moderate nature of the high flows in relation to previous high flows which have resulted in blackwater events (e.g., 2016). However, the effect of many other factors, such as the timing of flows, inter-flood intervals, and the scale and trophic dynamics of aquatic production on the floodplain remain key knowledge gaps in this respect. It is recommended that quantification of off-channel production and its potential incorporation into the aquatic ecosystems of the EKW systems, as well as any potential variation in these processes driven by the delivery of environmental water, be made a priority in future years where flows which inundate the floodplain are likely to occur.

7 Riverbank and aquatic vegetation

Authors: Robyn Watts, Sascha Healy, Nicole McCasker

Key findings	
Total species richness	The total number of taxa in zones 2, 3, 4 and 8 increased in 2021-22. There was a significant increase in the number of plant taxa in zone 2 in 2021-22, being the equal largest number of taxa recorded since the program commenced in 2014-15. In zone 4, the number of plant taxa were recorded in 2021-22 (n=29) was the largest since the program commenced. The mean total richness in each of the five monitored zones has increased 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 flood. The relationship between total annual discharge and total number of taxa of amphibious taxa showed a polynomial relationship in zones 2 and 4. Data from eight years of the LTIM/Flow-MER Program suggest that species diversity in these two zones is maximized when ecological disturbance is neither low (e.g., constant regulated flows) nor too frequent (e.g., large unregulated flood such as in 2016). The higher than regulated flows that were experienced in 2021-22 increased species richness in these two zones relative to highly regulated lower dicharge years, and also compared to higher discharge unregulated flood year.
Richness and percent cover of functional groups	Following the 2016 flood there was a reduction in the richness and percent cover of riverbank and aquatic plant functional groups. The patterns varied within functional groups. After the 2016 flood all submerged taxa were absent from monitored river zones. Since the flood, submerged taxa have recovered in all zones, but the total richness has not yet reached levels observed prior to 2016. In 2021-22 *Chara* was present in all zones, with strong increase in percent cover in zone 2. The relationship between total annual discharge and number of taxa of submerged taxa was not consistent among hydrological zones. However, in all of the zones during the flood year the number of submerged taxa reduced to zero. 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 floating pondweed was previously the dominant amphibious taxa in zone 3 prior to the flood but significantly reduced in cover or was killed by the flood in 2016. In 2021-22 there was a significant increase in percent cover of floating pondweed in zones 3 and 4 but has not yet reached the same cover as prior to the 2016 flood.
Other responses	The inundation of riverbanks from to the watering actions combined with unregulated flows and return flows from Millewa Forest supported riverbank and aquatic plant germination.

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 EKW 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 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 plants 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 EKW system is to maintain riparian and in channel vegetation condition and increase periods of growth for non-woody 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 2021-22 will be influenced by the condition and diversity of plants at the start of the watering year. The unregulated flood in 2016 reduced the cover and richness of riverbank and aquatic vegetation in all zones (Watts et al. 2017b). Between 2017 and 2021 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 has continued to be lower than prior to the 2016 flood (Watts et al. 2019, 2020). This chapter reports on the response of riverbank and aquatic vegetation to flows in the EKW system in 2021-22 and describes the trajectory of recovery for riverbank and aquatic plants since the 2016 flood.

7.2 Environmental watering actions for vegetation outcomes

River Murray objectives for environmental watering in the River Murray Valley (CEWO 2021) were 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 2021, Table RM1).

Seven Commonwealth environmental watering actions were delivered in the EKW system in 2021-22 (Table 7.1). Those actions that included objectives that are related to aquatic and riverbank vegetation are shaded in Table 7.1.

Watering actions 1 to 3 were delivered from MIL irrigation escapes to improve water quality and provision of habitat for fish. The environmental water delivered to achieve these objectives also added variability into the hydrograph and increased the maximum discharge (section 4), changes that could potentially influence riverbank and aquatic plants. Watering actions 4 to 6 had the objective to "maintain riparian and aquatic vegetation condition" (Table 7.1). The variable base flow in the upper Wakool River (watering action 4) added variability and increased maximum discharge Section 4). Watering actions 5 and 6 (autumn fresh) created a peak flow that would have wetted part of the lower riverbank and could have potentially benefitted riverbank plants. These three watering actions will be evaluated from that perspective. Watering action 7 did not have a vegetation objective.

Responses to these watering actions will be evaluated in this section against the main key objectives, taking into account antecedent conditions over previous watering years. In 2021-22 the southern spring flow delivered to the Murray River from Hume Dam contributed water to the EKW system via return flows from Millewa Forest. The response to the unregulated flows and returns from Millewa Forest will also be evaluated.

Table 7.1 Commonwealth environmental watering actions in 2021-22 in the Edward/Kolety-Wakool River system. Objectives (from CEWO Water plans) are listed with those targeting vegetation outcomes highlighted in blue.

Action	System	Type (delivery point)	Objectives (from CEWO 2021)	Dates
1	Wakool-Yallakool	Spring-summer hypoxic blackwater refuge (Wakool escape)	- **Habitat flows** - Water quality - Provision of refuges for native fish	14/09/21 - 05/01/22
2	Edward/ Kolety	Spring-summer hypoxic blackwater refuge (Edward escape)		06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	Spring-summer hypoxic blackwater refuge (Niemur escape)		07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	Autumn elevated variable base flow (Wakool offtake)	Primary - assist with habitat recovery after 2016 flood and hypoxic event. - **maintain riparian and aquatic vegetation condition.** - maintain habitat and support breeding for native fish. Secondary - maintain connectivity	08/03/22 -09/05/22
5	Wakool-Yallakool	Autumn fresh (Yallakool offtake		24/03/22 - 09/05/22
6	Colligen-Niemur	Autumn fresh (Colligen offtake)		03/04/22 -26/04/22
7	Tuppal Creek	Elevated base flows	Maintain connectivity	01/11/21-29/05/22

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 in 2021-22 (Figure 7.1). Sites were 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 August 2021 to May 2022, with the exceptions of September 2021 and March 2022 when there were travel and access issues due to the Covid-19 pandemic.

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 star pickets that had been installed at a known height on the riverbank. The taxa that was present 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.

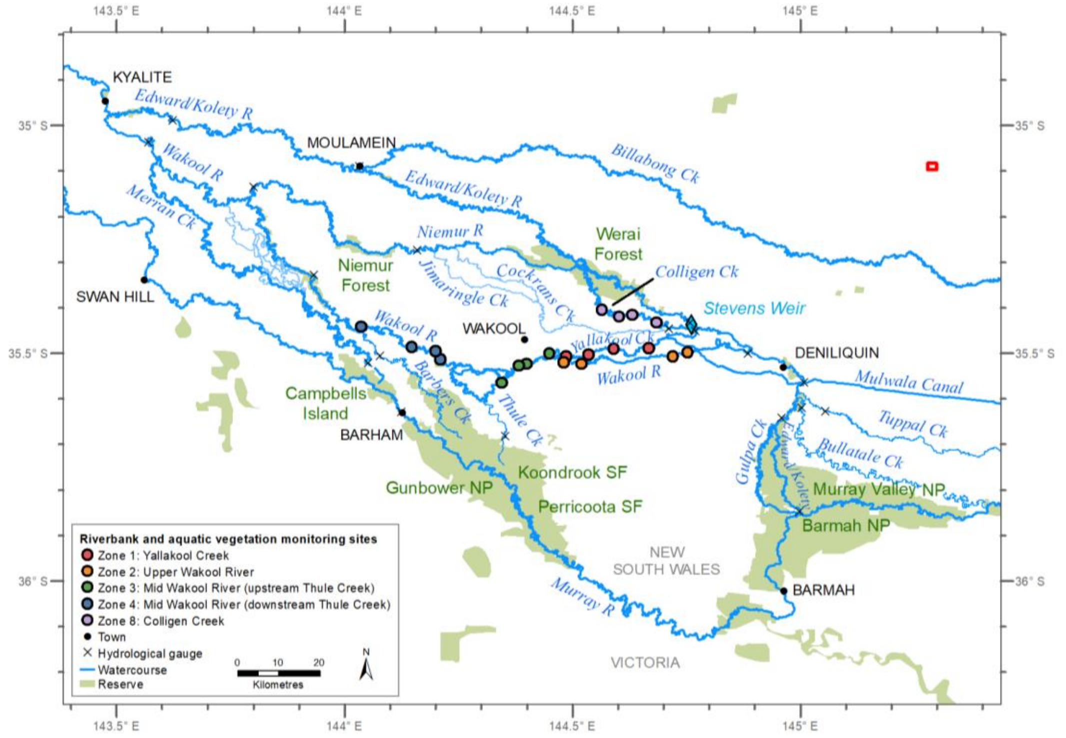


Figure 7.1 Map of the Edward/Kolety-Wakool Selected Area showing existing LTIM/Flow-MER sites where riverbank and aquatic vegetation are surveyed.

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. The five functional categories were:

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.

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).

For the 2021-22 data, 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 eight 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. This period was selected because it is the main growing season for these plants. Percent cover was plotted for the common taxa in each of the five functional categories.

Data collected over the eight years of the LTIM/Flow-MER program were used to examine the relationship between number of taxa and total annual discharge (ML/year) for each hydrological zone. The relationship between average maximum percent cover and total annual discharge (ML/year) were also examined for each hydrological zone.

7.5 Results

Total richness

The unregulated flood in 2016 reduced the total richness riverbank and aquatic plants in all five hydrological zones (Table 7.2). The recovery of riverbank and aquatic plants in the EKW system has been assisted by unregulated flows and environmental watering actions.

In zone 1 Yallakool Creek the smallest number of taxa were recorded during the flood year in 2016-17 (Table 7.2). The total richness did not improve in 2021-22 and remains lower than it was prior to the 2016 flood. The variation in flows in Yallakool Creek in 2021-22 was lower than in the other four study zones, due to i) the return flows from Millewa forest extending the duration of riverbank being inundated, and ii) not receiving benefit of environmental water from Wakool escape.

In 2021-22 the total richness in zone 2 (upper Wakool River) increased significantly, and to be higher than has previously recorded in this river system over the eight years of the LTIM/Flow-MER monitoring program (Table 7.2). Zone 2 received a larger increase in total discharge and the discharge has a larger percentage of environmental water in 2021-22 than the other four zones (see hydrology section 4).

The total richness in zones 3 and 4 (mid-Wakool River downstream of Thule Creek) increased slightly in 2021-22 (Table 7.2). These systems both received benefit from the environmental watering from Wakool escape, increasing the maximum discharge in these zones. The total richness in zone 3 has not yet recovered to the same levels as prior to the flood. The richness in zone 4 is now higher than has previously recorded in this river system over the eight years of the LTIM/Flow-MER monitoring program. In 2021-22 Zone 4 received the benefit of unregulated flows, environmental watering action from Wakool escape, plus inflows from several ephemeral creeks (e.g., Thule Creek and Yarrein Creek).

The total richness of riverbank and aquatic plants in Colligen Creek has gradually increased over the years since the 2016 flood. It now has the same total richness as recorded prior to the 2016 flood. This river system does not benefit from the environmental watering from the Wakool escape, that increased the maximum discharge in zones 2,3 and 4.

Table 7.2 Total richness of riverbank and aquatic plants in five hydrological zones in the Edward/Kolety-Wakool River system. No surveys were undertaken in Colligen Creek in the 2014-15 water year.

	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Zone 1: Yallakool Creek	22	31	10	15	19	22	19	17
Zone 2: Upper Wakool River	18	20	13	18	24	17	12	24
Zone 3: Mid-Wakool upstream Thule	21	29	17	16	14	22	15	18
Zone 4: Mid-Wakool downstream Thule	24	26	21	27	20	25	26	29
Zone 8: Colligen Creek	NA	18	12	20	15	15	17	18

The relationship between total annual discharge and total number of taxa varied between hydrological zones (Figure 7.2). Over the eight years of the LTIM/Flow-MER Program there has not been enough variation in flows to fully understand these relationships, but 2021-22 having higher flows than six of the years with regulated flows, means there is an opportunity to start to explore general relationships with flow.

- In zone 1 Yallakool Creek, the patterns suggest a decrease with high flood flows. There was little difference and total taxa and total discharge among the other seven years of the program to discern a clear pattern at lower and mdium total dicharge.
- In the upper Wakool River zone 2, the total number of taxa was higher in 2021-22 than in all other years of the LTIM/Flow-MER Program, with a polynomial relationship (Figure 7.2) that supports the intermediate disturbance hypothesis. The hypothesis states that species diversity is maximized when ecological disturbance is neither too rare nor too frequent. Zone 2 previously experienced the lowest discharge of all four hydrological zones, and the flows in 2021-22 were notably larger than previous years with regulated flow.
- There is no strong pattern of relationhip between total annual discharge and number of taxa in zones 3 and 4. Medium flows have not yet been experienced in this system to fully understand the relationship between flows and richness.

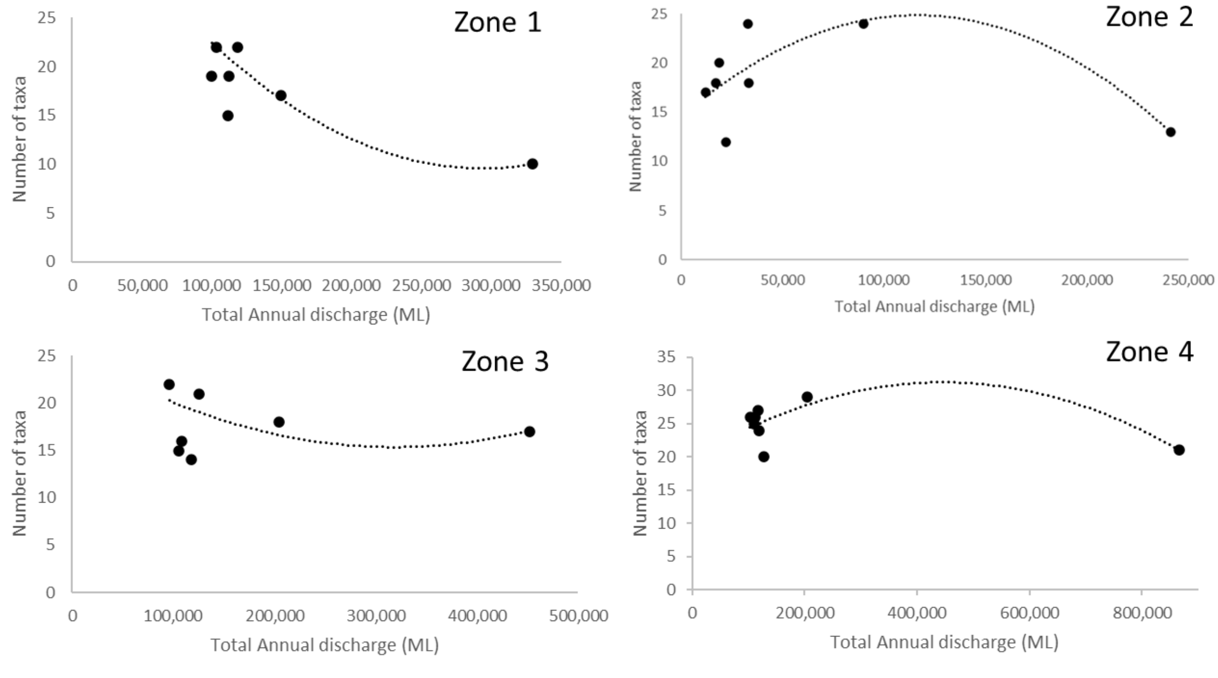


Figure 7.2 Relationship between total annual discharge (ML/year) and total number of taxa in zone 1 (Yallakool Creek), zone 2 (upper Wakool River), zone 3 (mid-Walool river upstream of Thule Creek), and zone 4 (mid-Wakool River downstream of Thule Creek).

The relationship between total annual discharge and number of taxa of submerged and amphibious taxa was similar to that for total taxa. However, there is a clear pattern that in all of the zones during the flood year the number of submerged taxa reduced to zero (Figure 7.3).

- In zone 1 the smallest number of amphibious and submerged taxa were recorded during the flood year in 2016-17 (Figure 7.3).
- In the upper Wakool River zone 2, there was a polynomial relationship between total annual discharge and total amphibious taxa and submerged taxa (Figure 7.3) supporting the intermediate diturbance hypothesis. There was a notable increase in the number of amphibious taxa during 2021-22, with intermediate total discharge
- There is no strong pattern of relationhip between total annual discharge and number of taxa in zone 3 or zone 4. This zone is a long deep permanent section of the Wakool river, and possibly experiences less variation in riverbank inundation than the other zones.

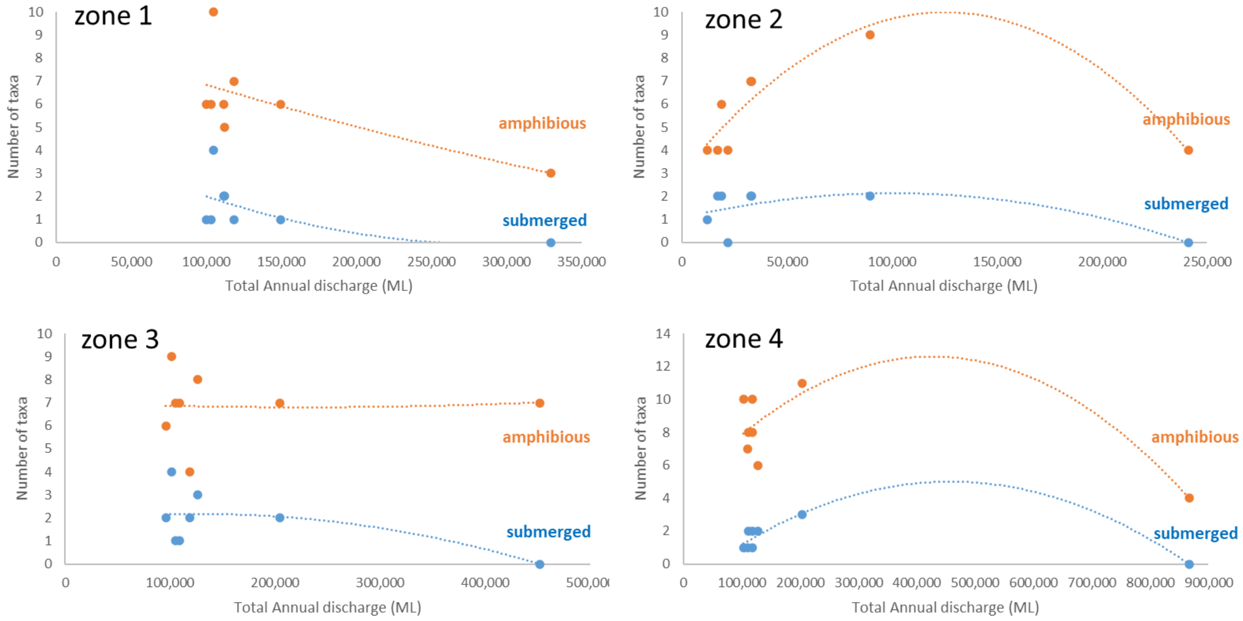


Figure 7.3 Relationship between total annual discharge (ML/year) and total number of amphibious and submerged taxa in zone 1 (Yallakool Creek), zone 2 (upper Wakool River), zone 3 (mid-WaKool river upstream of Thule Creek), and zone 4 (mid-Wakool River downstream of Thule Creek).

Total mean species richness and cover

The unregulated flood in 2016 resulted in a decrease in total mean species richness in all study zones in 2016-17 (Figure 7.4). In zones 1, 3 and 4 the mean species richness has not yet recovered to the same levels as prior to the flood. In general, the environmental watering actions in 202-21 maintained total species richness of riverbank and aquatic plants in zones 1, 3, 4 and 8. From 2014 to 2021 the mean total number of taxa in zone 2 was consistently lower than the other zones, however, in 2021-22 there was a significant increase in number of taxa in zone 2.

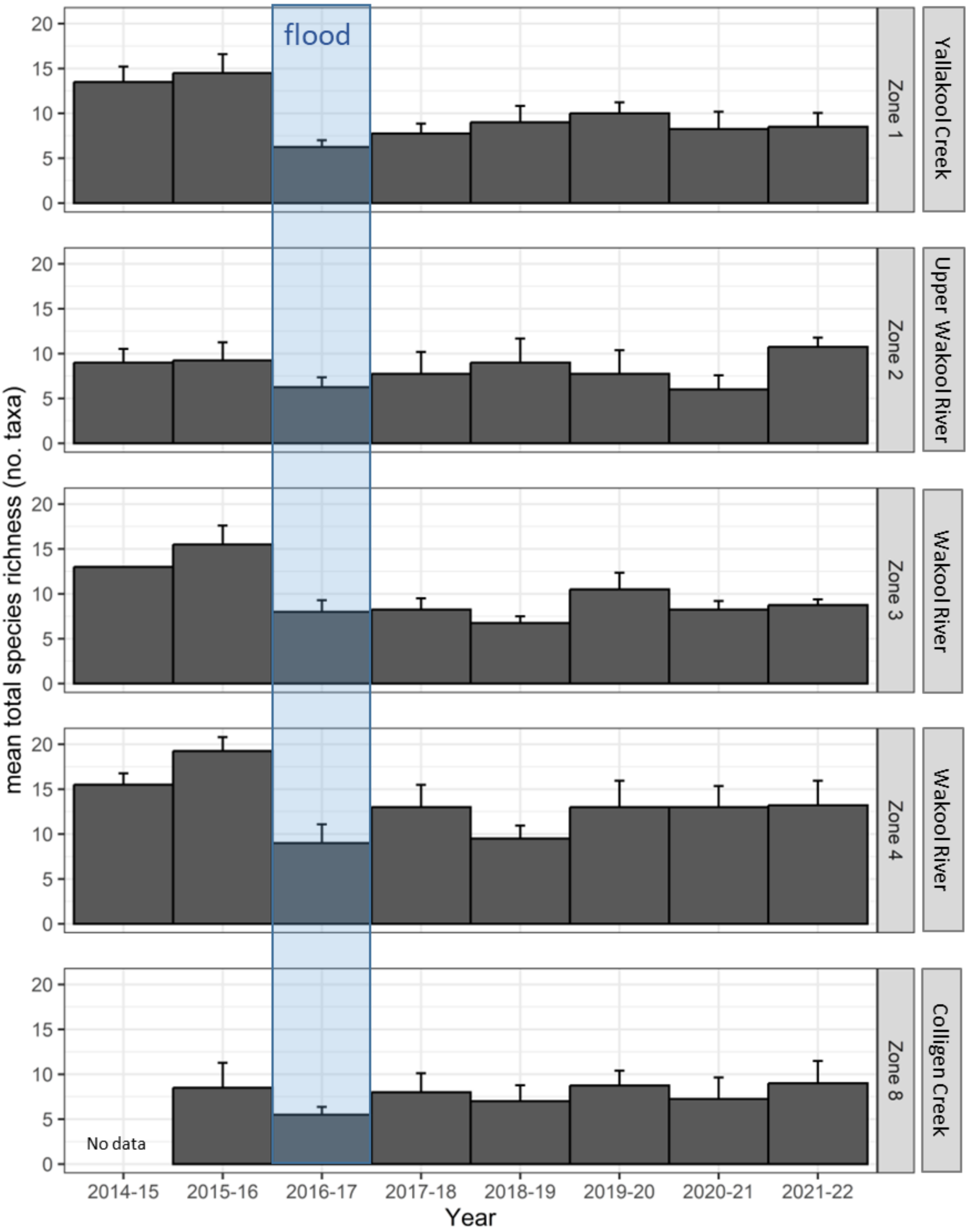


Figure 7.4 Mean total richness of vegetation taxa monitored monthly in five zones in the Edward/Kolety-Wakool system between 2014 and 2022. Blue shading indicates the unregulated flood in 2016-17 water year.

A large percentage of taxa across the five hydrological zones were native taxa (Figure 7.5). A greater proportion of native taxa were negatively impacted by the 2016 flood, particularly in zones 1, 3 and 4. The relative proportion of native and exotic taxa were maintained in 2021-22. In zone 2, the number of native taxa increased in 2021-22.

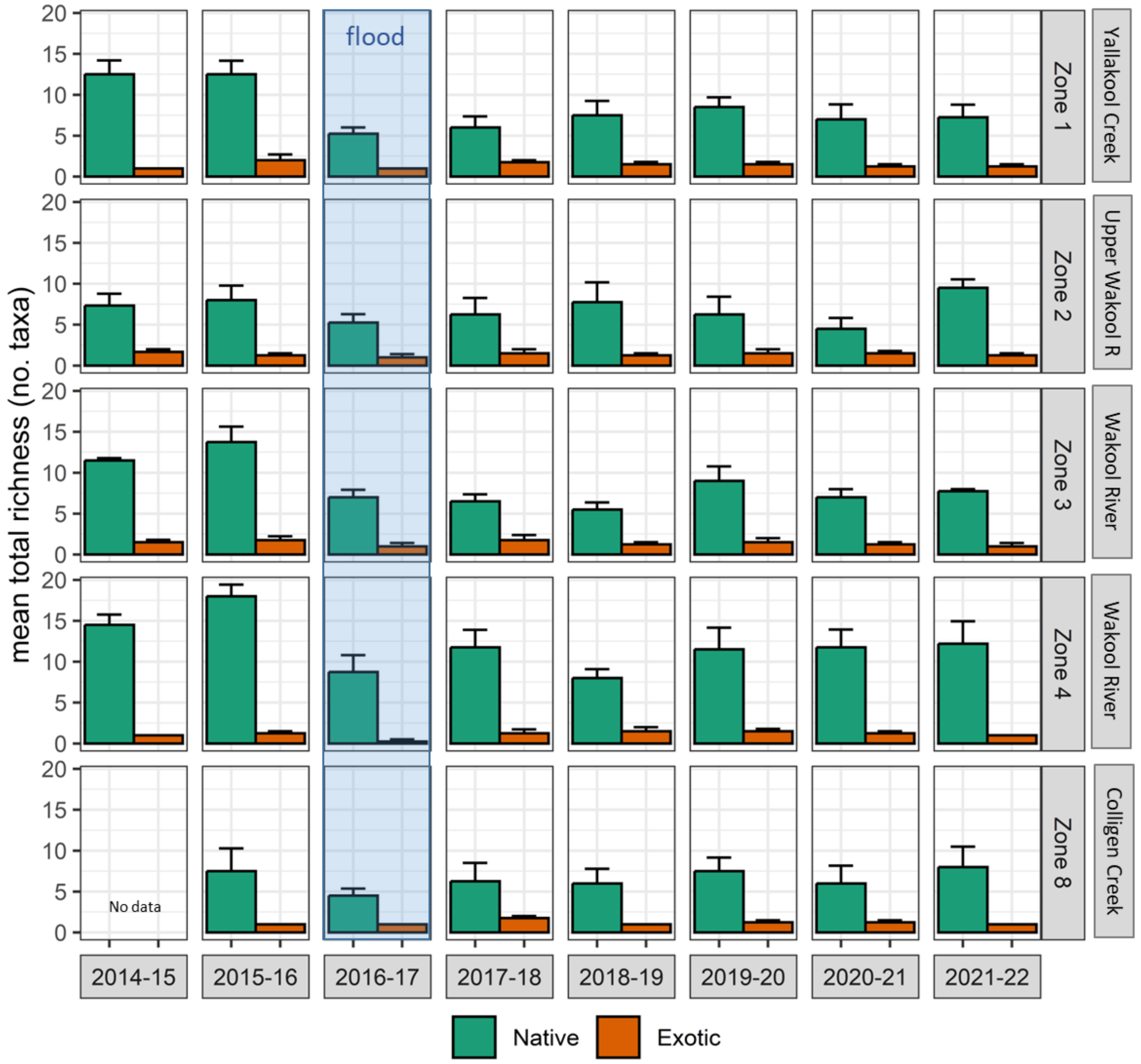


Figure 7.4 Mean richness of native and exotic vegetation taxa monitored monthly in five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Blue shading indicates the unregulated flood in 2016-17 water year.

Mean 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 (Figure 7.6). In all zones, all of the submerged taxa were absent after the flood and number of amphibious taxa was greatly reduced in all zones, but particularly in zones 1, 3 and 4. There has been an increase in aquatic and amphibious taxa over time since the flood.

Similarly, since the flood there has been a reduction in the percentage cover of functional groups (Figure 7.7). However, the patterns are varied within functional groups.

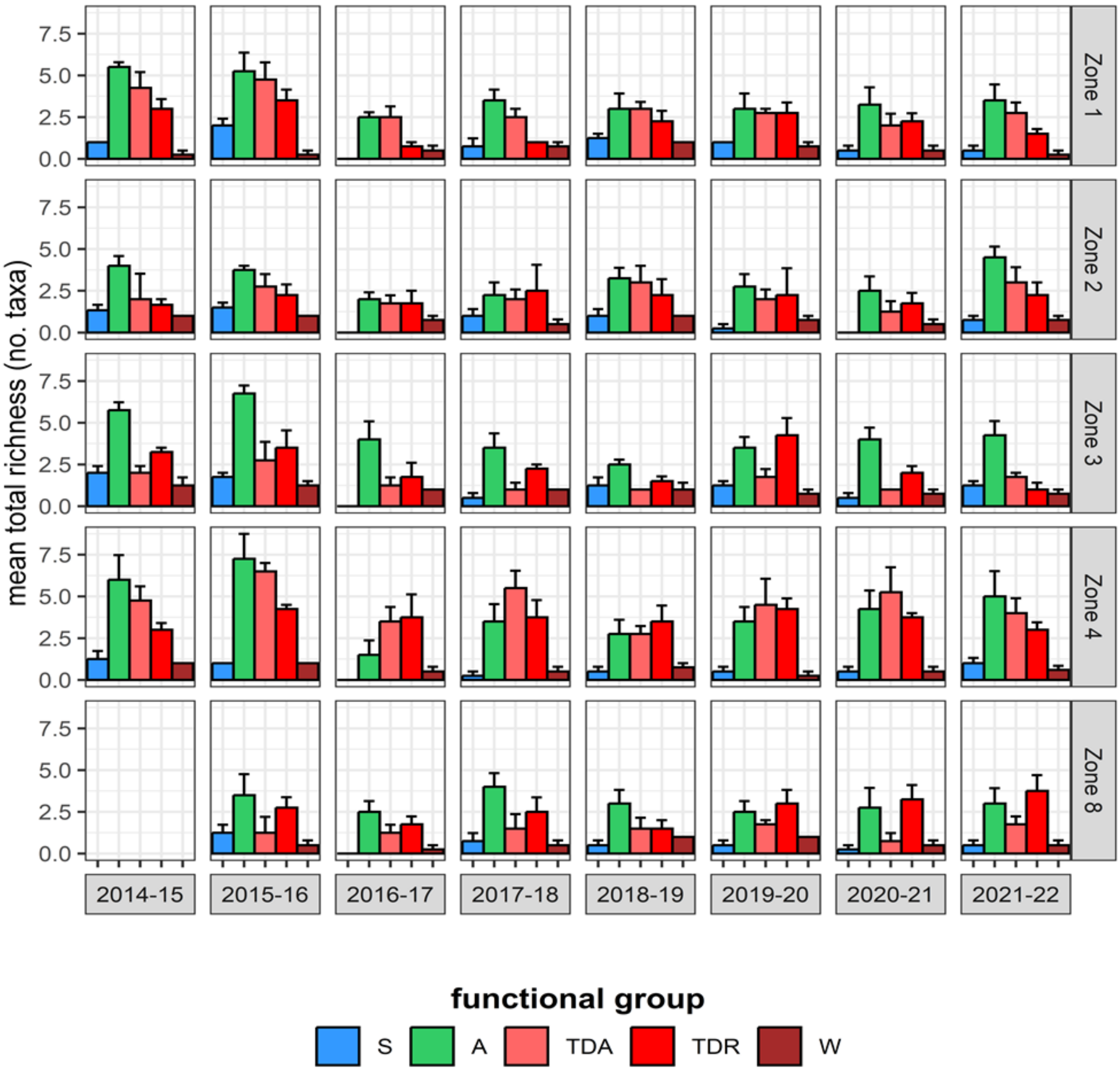


Figure 7.6 Mean total richness of vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Taxa were classified as submerged, amphibious, terrestrial damp, terrestrial dry, and woody. Blue shading indicates the unregulated flood in 2016-17. S= submerged, A = amphibious, TDA = terrestrial damp, TDR= terrestrial dry, W= woody.

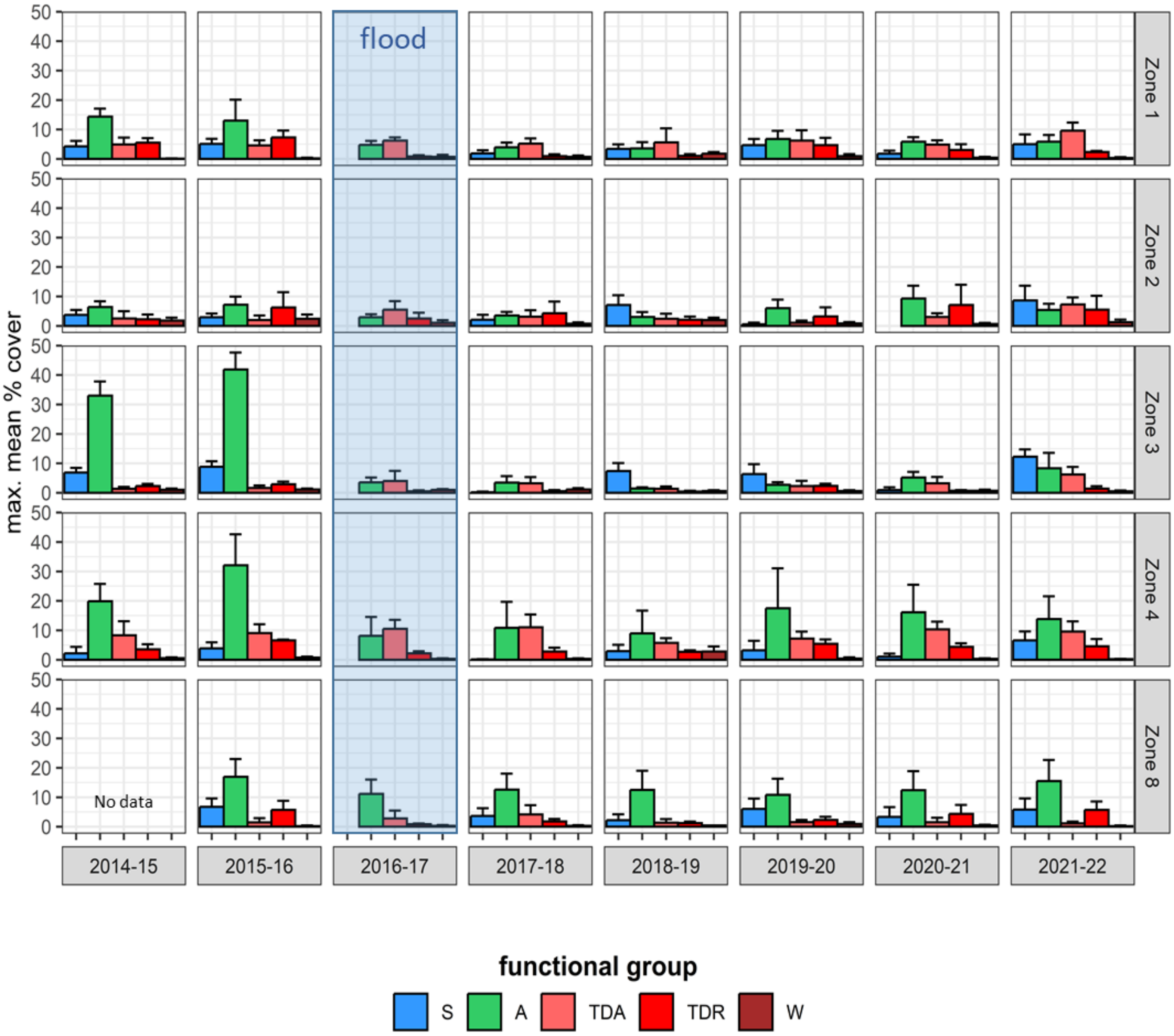


Figure 7.7 Mean percent cover of vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Taxa were classified as submerged, amphibious, terrestrial damp, terrestrial dry, and woody. Blue shading indicates the unregulated flood in 2016-17. S= submerged, A = amphibious, TDA = terrestrial damp, TDR= terrestrial dry, W= woody.

Mean 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 7.8), but by 2020-21 the total richness has not yet reached levels observed prior to the flood. In 2021-22 the total number of submerged taxa increased in zone 2, 3 and 4s. This was particularly notable in zone 2, where in 2021-22 there had previously been no submerged plant species present.

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 (Figure 7.9). In 2018-19 Chara was present in all five study zones following environmental watering actions, but the percent cover of this taxa was low. However, in 2019-20 and 2020-21 *Chara* was absent from zone 2 (Figures 7.8), that received less environmental water than the other zones (Figure 4.8). In 2021-22 the maximum mean percent cover of submerged taxa increased in all zones.

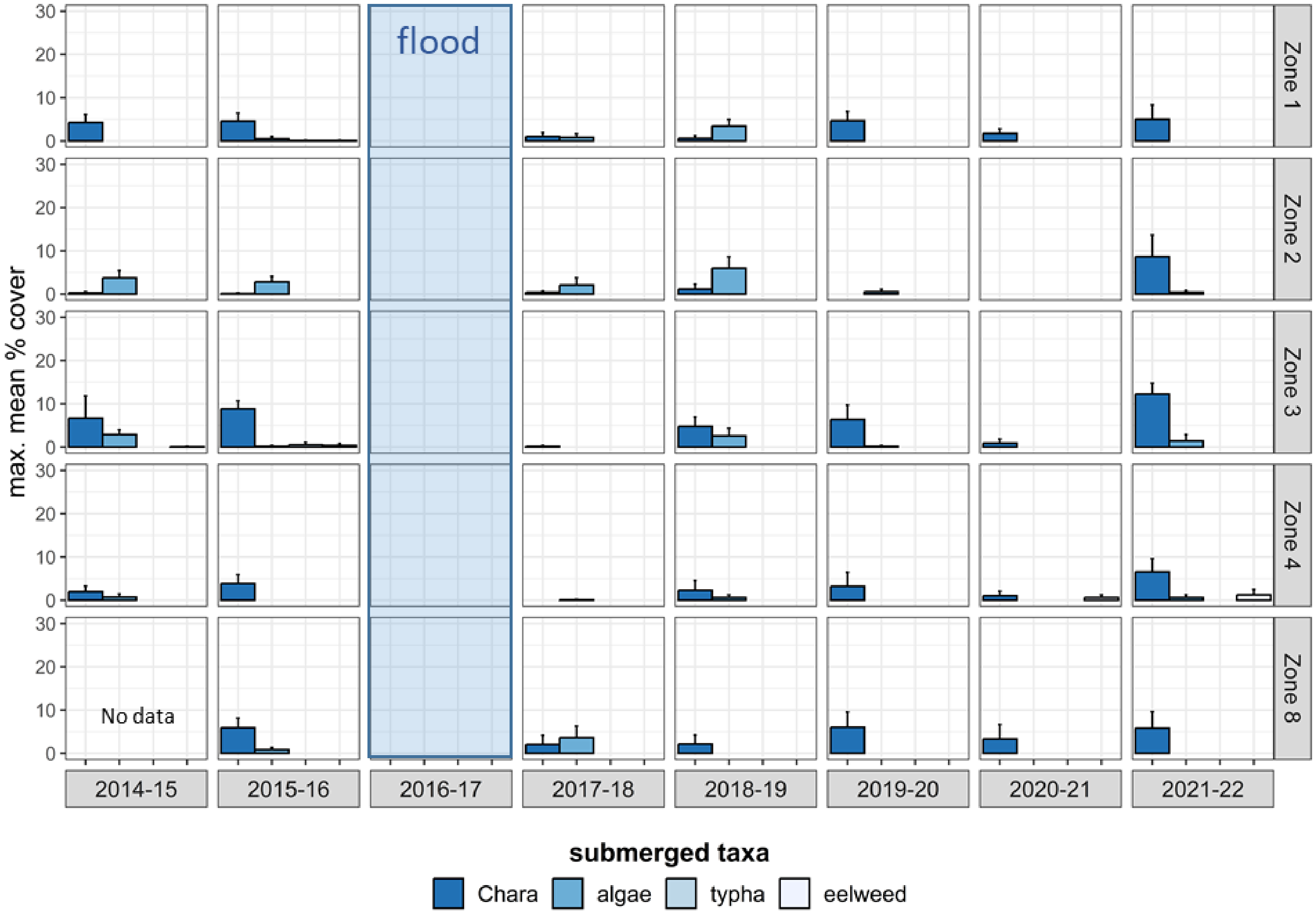


Figure 7.8 Mean percent cover of four submerged vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and 2020-21 when it received variable base flows.

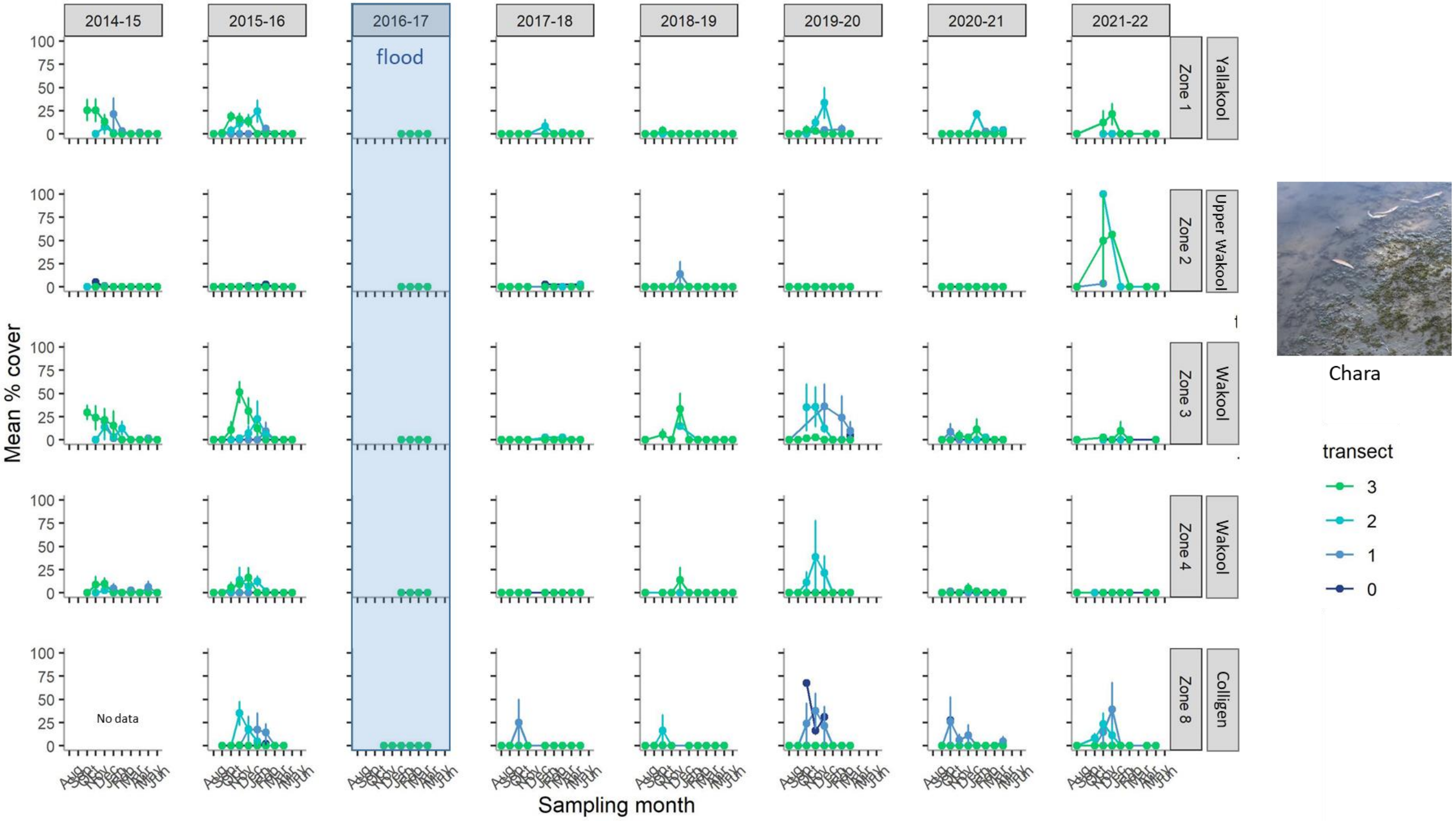


Figure 7.9 Mean percent cover of *Chara* monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Green shading indicates that 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 when it received variable base flows

Mean richness and cover of amphibious taxa

Amphibious taxa are classified as responder and tolerator taxa. Following the flood in 2016 there was a reduction in mean total richness and percent cover of amphibious taxa in all zones (Figures 7.6, 7.7). 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 7.7). However, total richness has not recovered to that observed prior to the flood.

Amphibious responders

Amphibious responder taxa have responded variably to the flood disturbance in 2016 (Figure 7.10).

The flood in 2016 had minimal impact on the percent cover of amphibious responder spiny mudgrass (*Pseudoraphis spinescens)* (Figures 7.10 and 7.11). 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. This species has recovered well since the flood and increased in percent cover in zones 2 and 4 such that it currently has a higher percent cover in all zones than was recorded prior to the flood (Figures 7.10, 7.11).

Floating pondweed was previously the dominant amphibious taxa in zone 3 prior to the flood (Figure 7.10) but significantly reduced in cover or was killed by the flood in 2016 (Figure 7.12). 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 and in 2021-22 showed a significant increase in percent cover in zones 3 and 4 (Figure 7.12), but has not yet reached the same cover as prior to the 2016 flood.

Other amphibious responders azolla, milfoil and water primrose were all negatively impacted by the flood in 2016 (Figure 7.10), 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. In 2021-22 water primrose re-established in Zone 2 and milfoil re-established in zone 4 (Figure 7.13).

Amphibious tolerators

Amphibious tolerator taxa responded differently to the flood disturbance in 2016 (Figure 7.14). The number of amphibious tolerator taxa in zones 1, 3, and 8 in 2021-22 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 7.14) with no strong relationship to watering regime. Spikerush was also present in zones 3 and 4 prior to the 2016 flood and while there was slight reduction in percent cover in zone 3 after the flood, it continues to be present in these zones.

The rush (*Juncus sp*.) was also an abundant species and had high percent cover in all zones prior to the flood (Figure 7.14). 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.

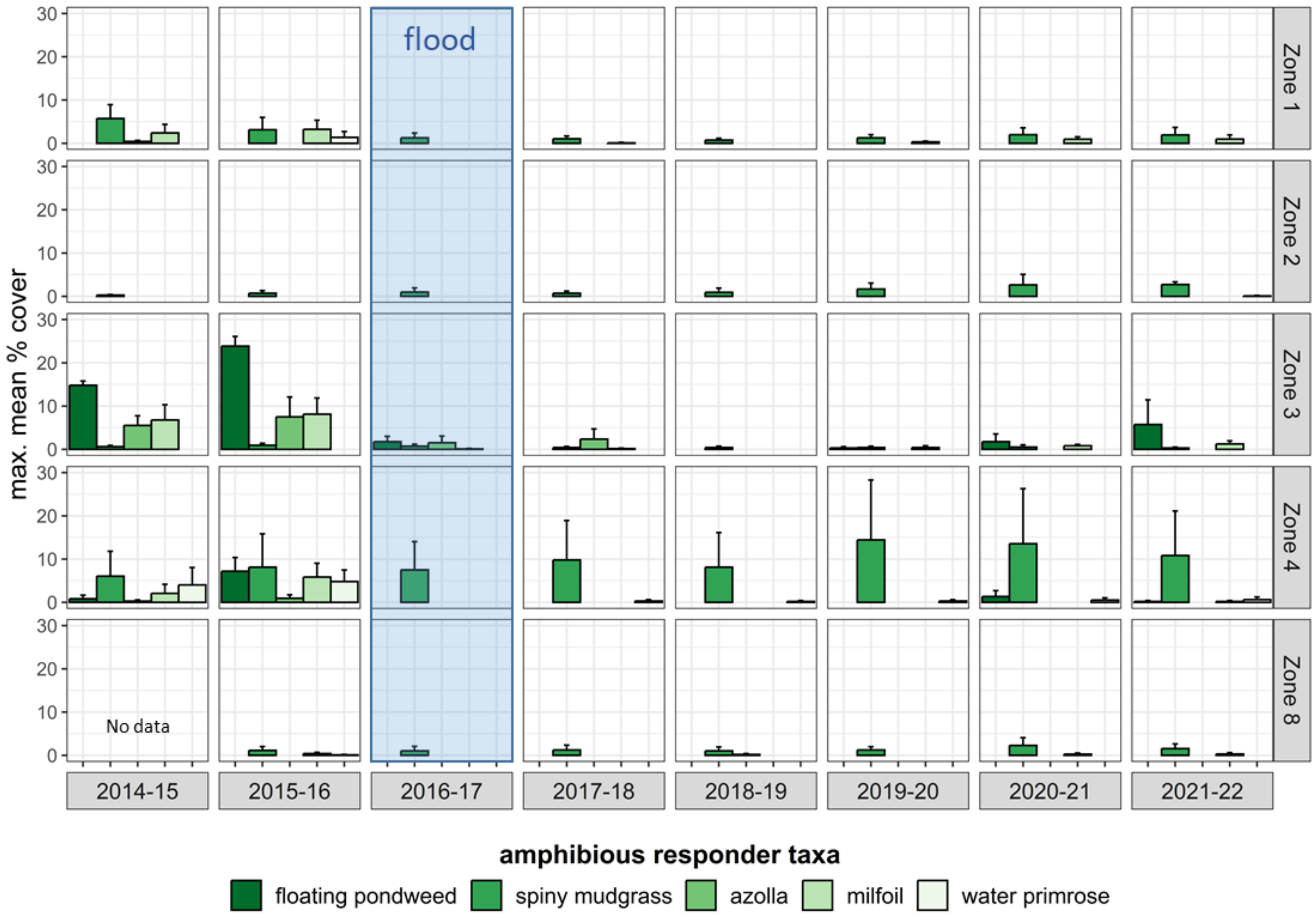


Figure 7.10 Mean percent cover of the five most abundant amphibious responder vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

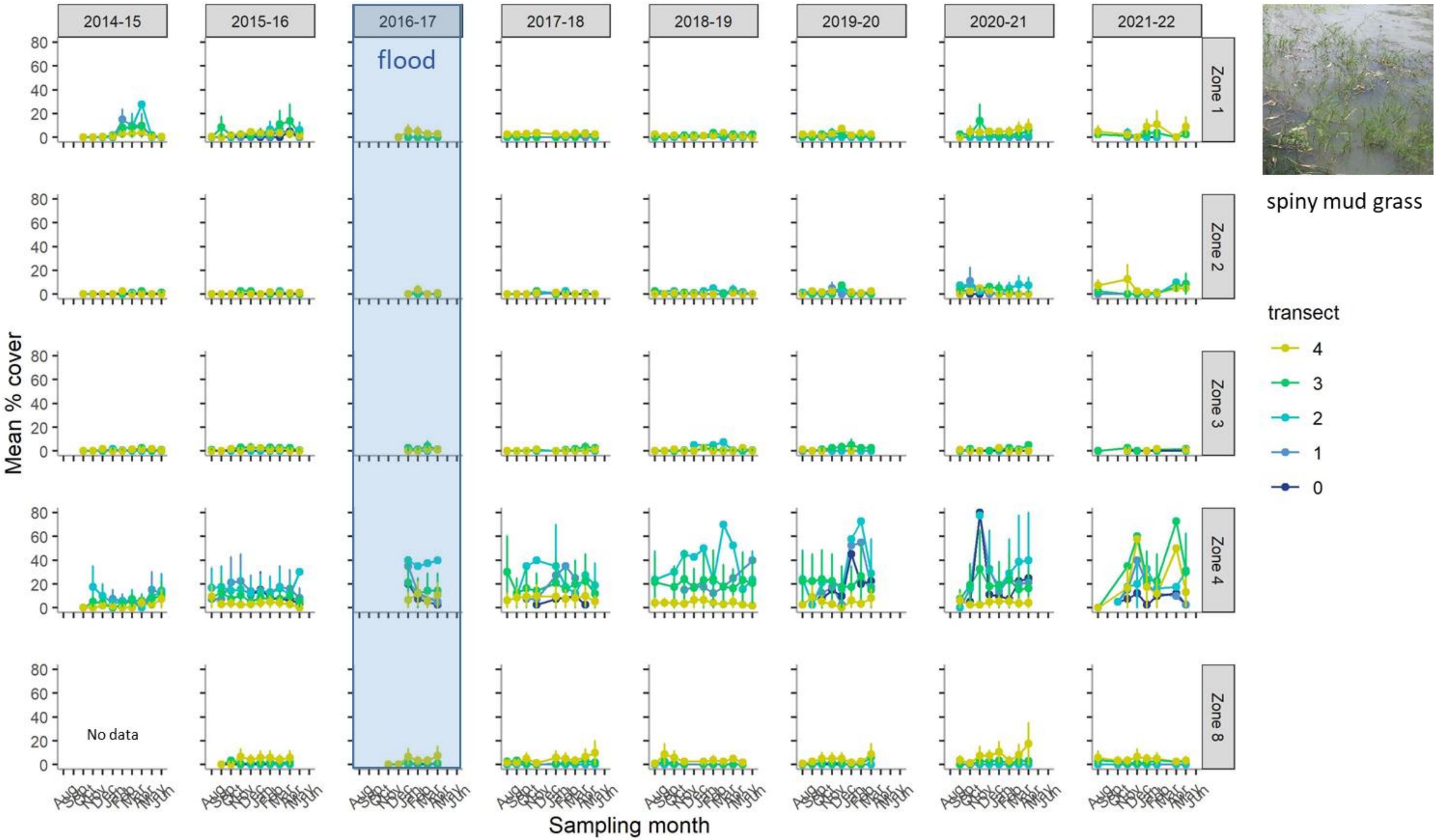


Figure 7.11 Mean percent cover of spiny mud grass (*Pseudoraphis spinescens*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

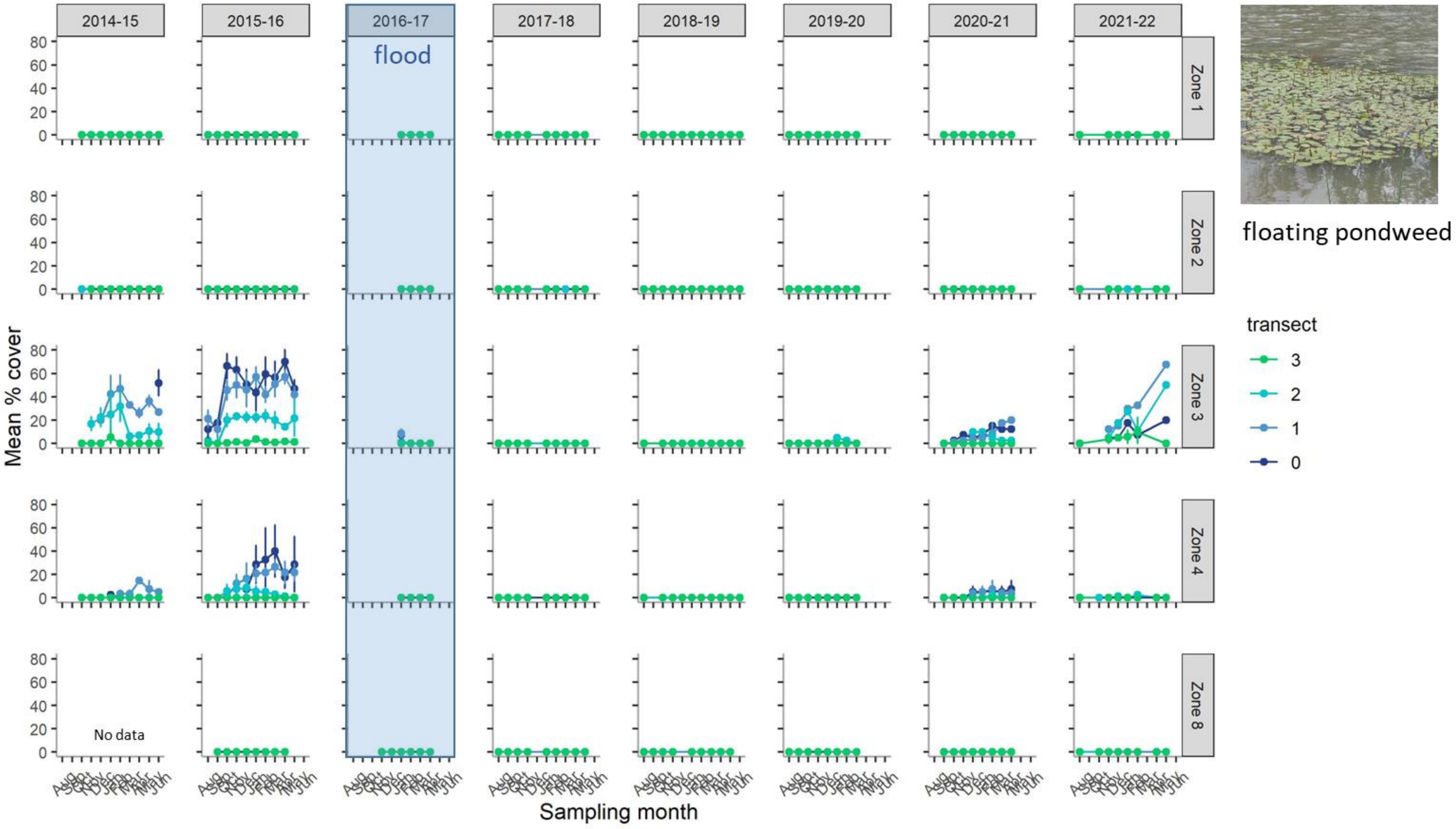


Figure 7.12 Mean percent cover of floating pondweed (*Potamogeton tricarinatus*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

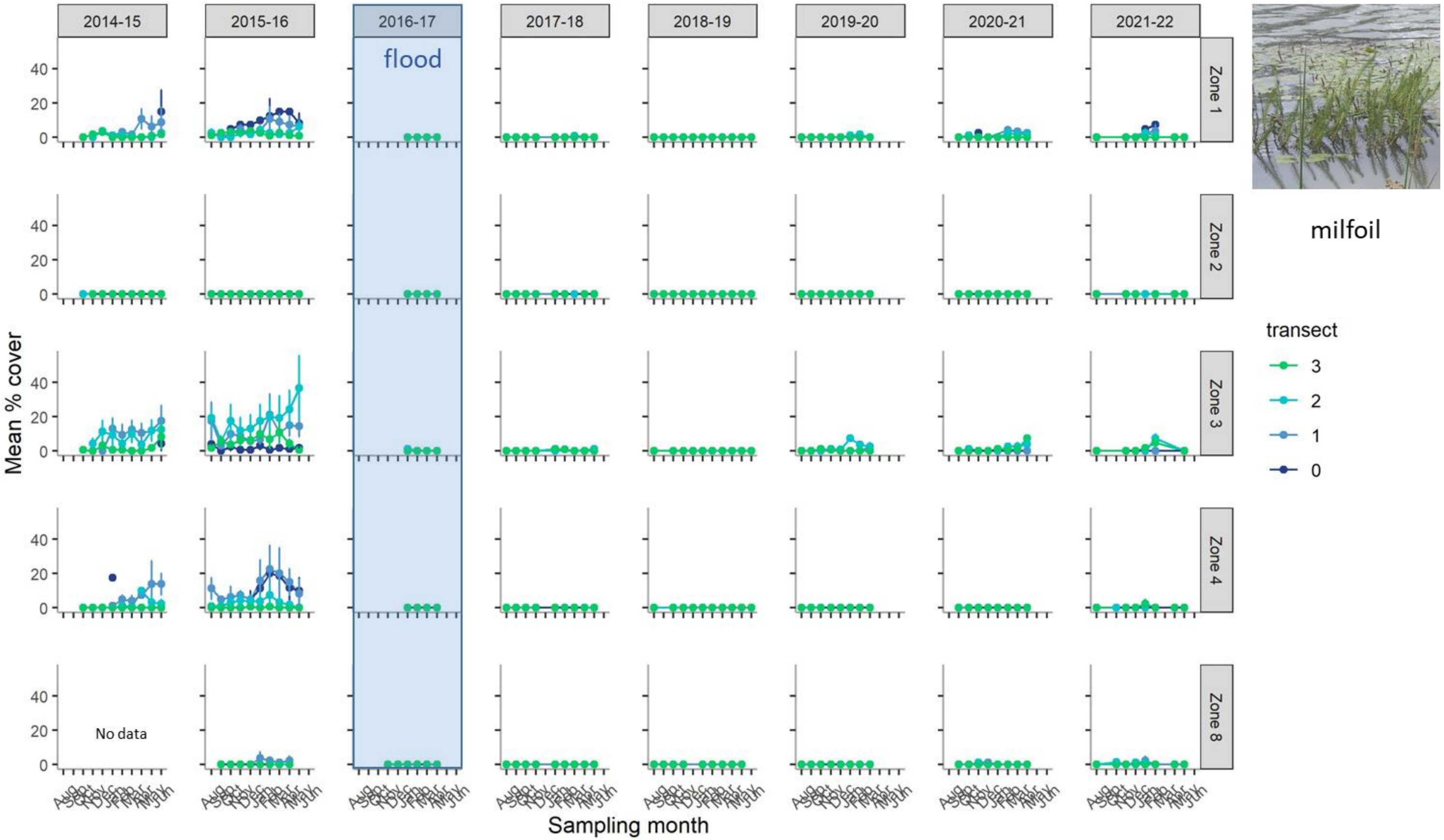


Figure 7.13 Mean percent cover of milfoil (*Myriophyllum spp*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. 2 received minimal no environmental water, with the exception being in 2018-19, and received variable base flows in 2020-21

Figure 7.14 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 2022. 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..

Mean richness and cover of terrestrial taxa

Terrestrial taxa are classified as i) terrestrial damp, ii) terrestrial dry, and iii) woody taxa. Following the flood in 2016 there was a reduction in the mean total richness of terrestrial taxa in all zones (Figures 7.7), but the change in cover was variable. Indeed, in some zones there was an increase in percent cover of terrestrial damp taxa (Figure 7.7).

Terrestrial damp taxa

The total number of taxa of terrestrial damp species did not change following the 2016 flood (Figure 7.15). The terrestrial damp common sneezeweed (*Centipeda cunninghamii)* (Figure 7.16) increased in cover after the flood, especially at transects higher up on the bank (Figure 7.16) that are not usually inundated during operational flows or environmental actions. Most other terrestrial damp taxa have shown very little change over time.

The terrestrial damp species *Alternanthera sp* (joyweed) increased notably in 2021-22, particularly in zones 1,2 and 4 (Figure 7.17). This species had been present at low percent cover since the 2016 flood.

Terrestrial dry taxa

The number and cover of taxa of terrestrial dry species reduced following the 2016 flood (Figure 7.18). However, the year following the flood most taxa had returned. There has been an increase in the percent cover of grasses in all zones over the past 2 years, possibly due to the higher rainfall and average temperatures.

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 7.19). Tangled lignum is more prevalent on the floodplain than on the riverbanks within the channel, so is not impacted by environmental watering actions.

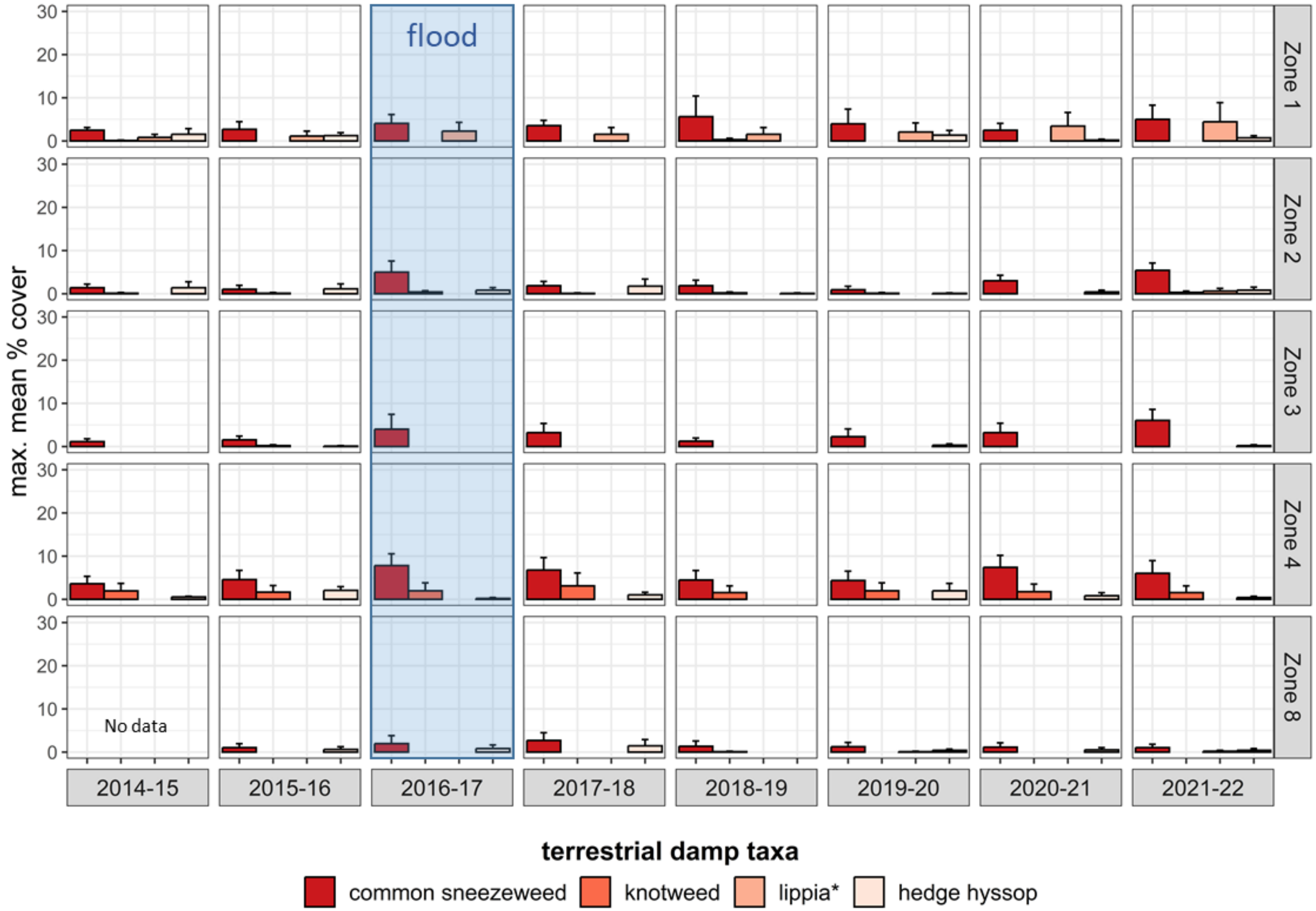


Figure 7.15 Mean percent cover of the four most abundant terrestrial damp vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

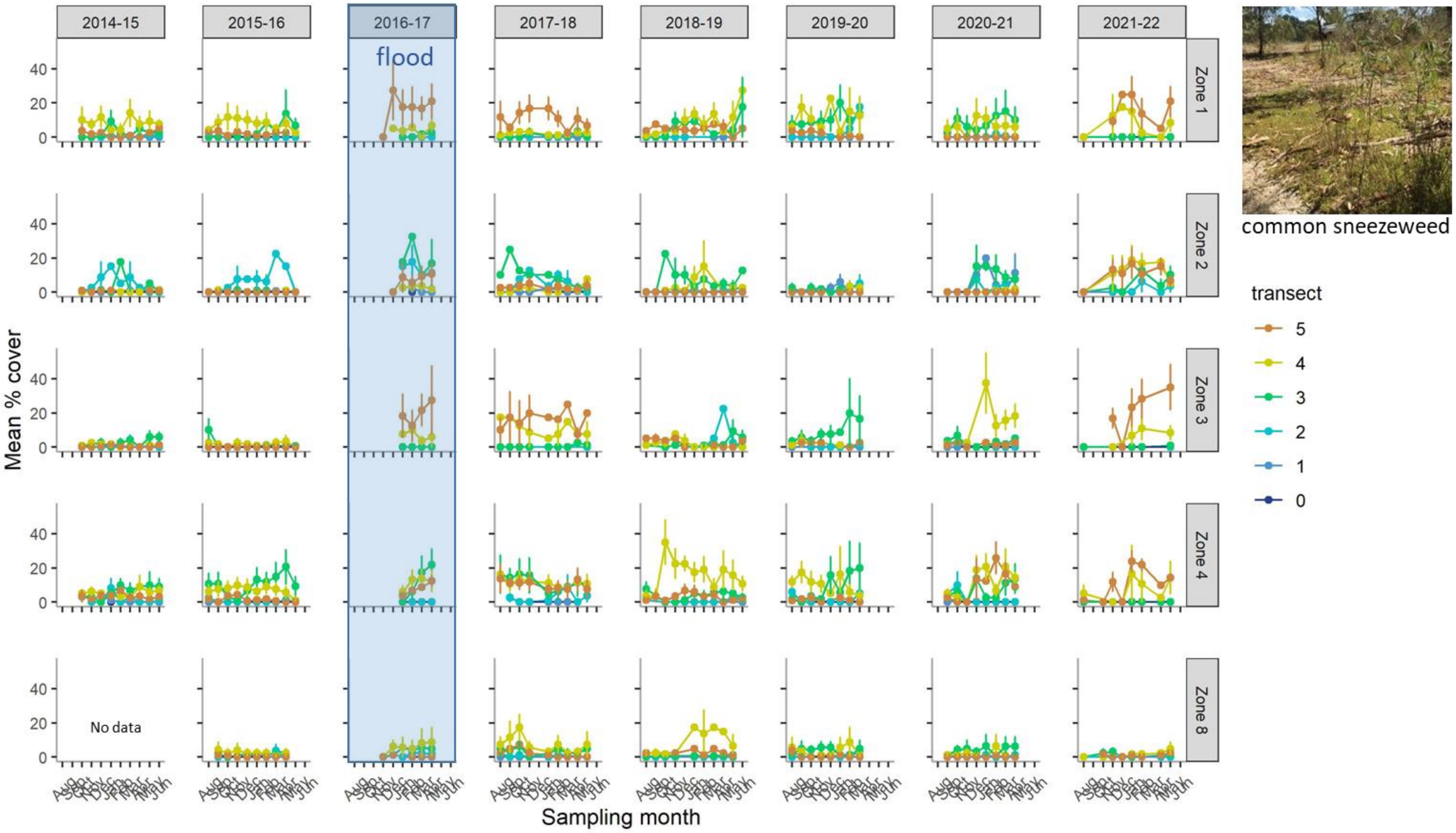


Figure 7.16 Mean percent cover of common sneeze weed (*Centipeda cunninghamii*) monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the riverbank. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

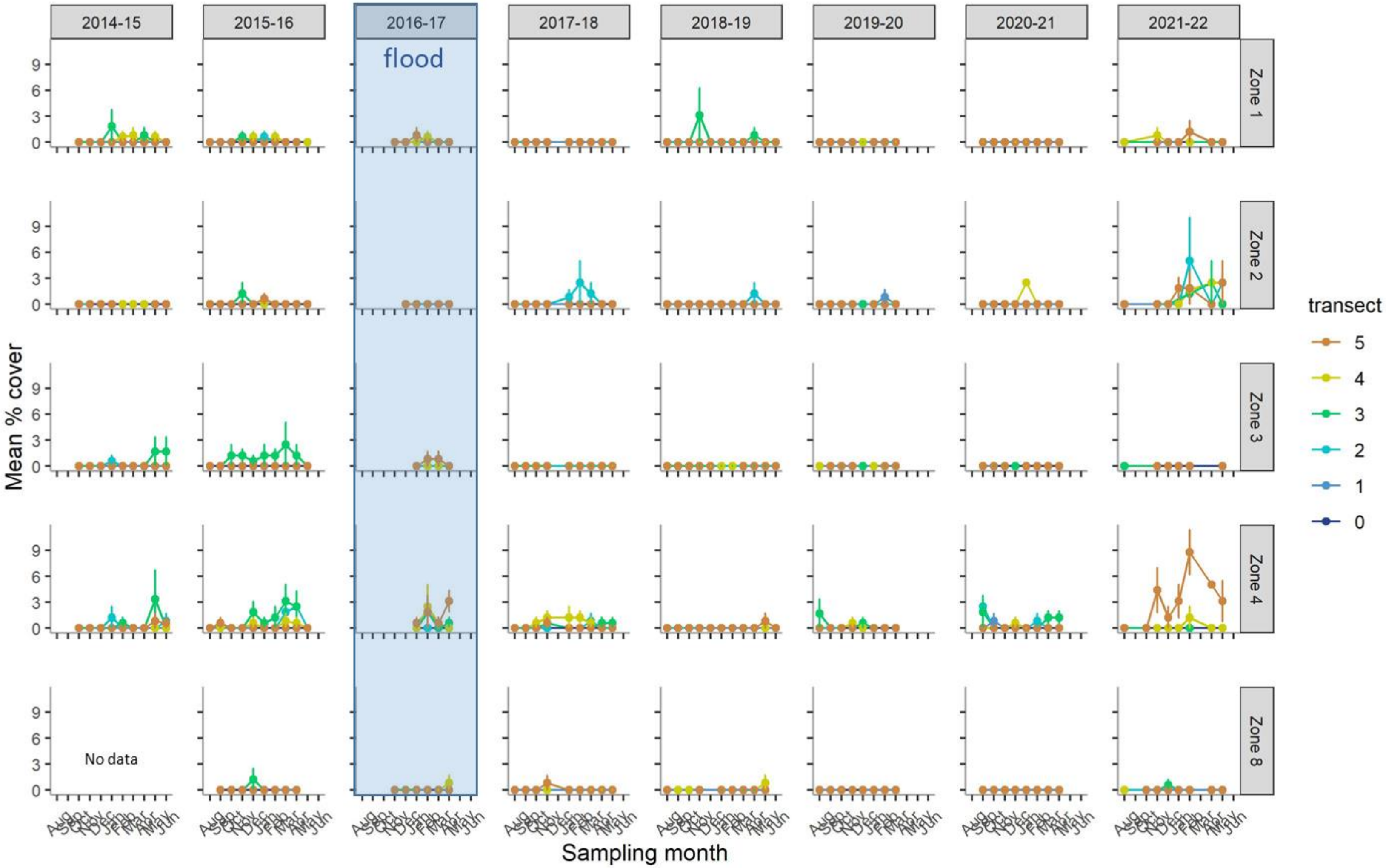


Figure 7.17 Mean percent cover of *Alternathera* monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the rive bank

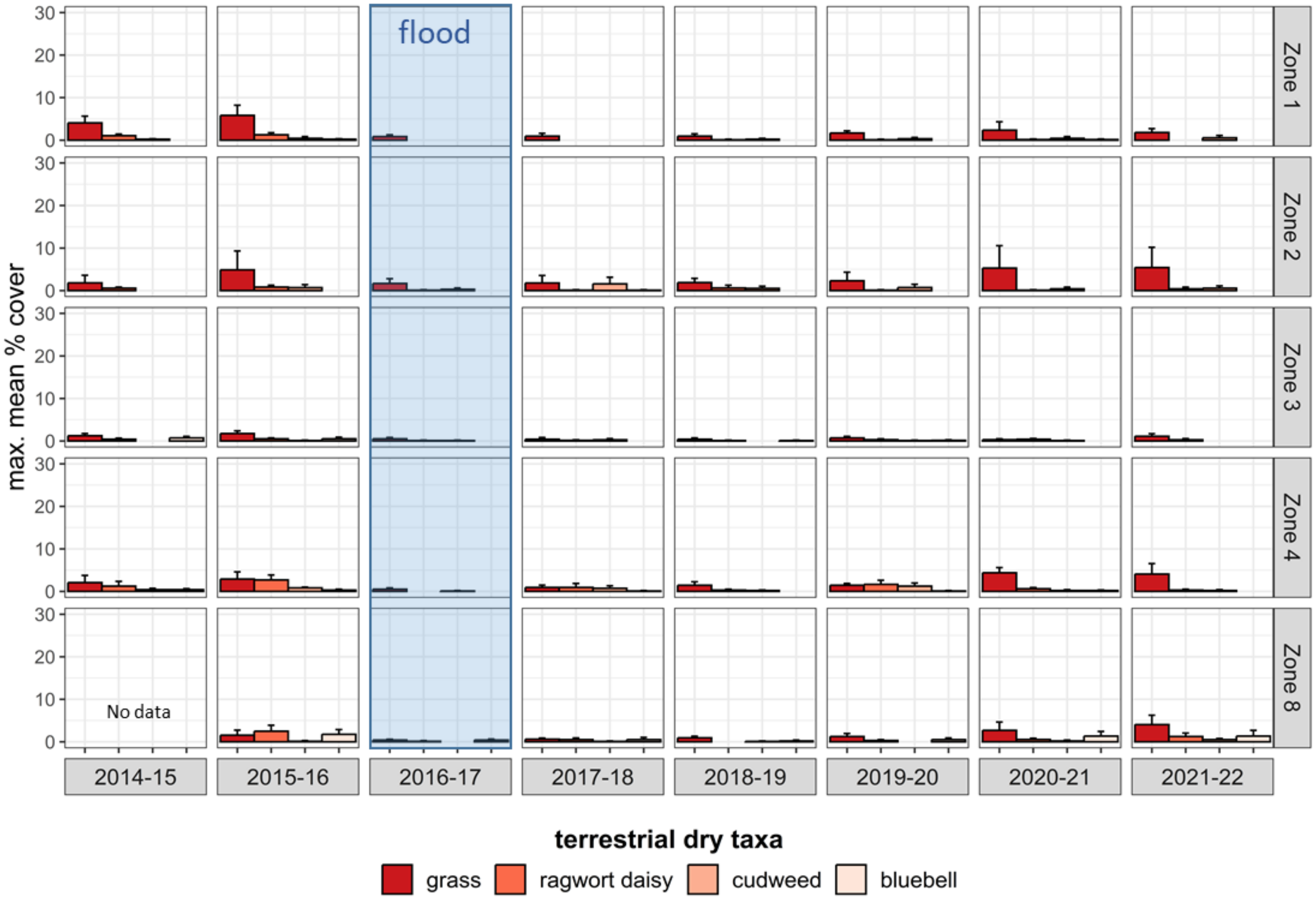


Figure 7.18 Mean percent cover of the four most abundant terrestrial dry vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

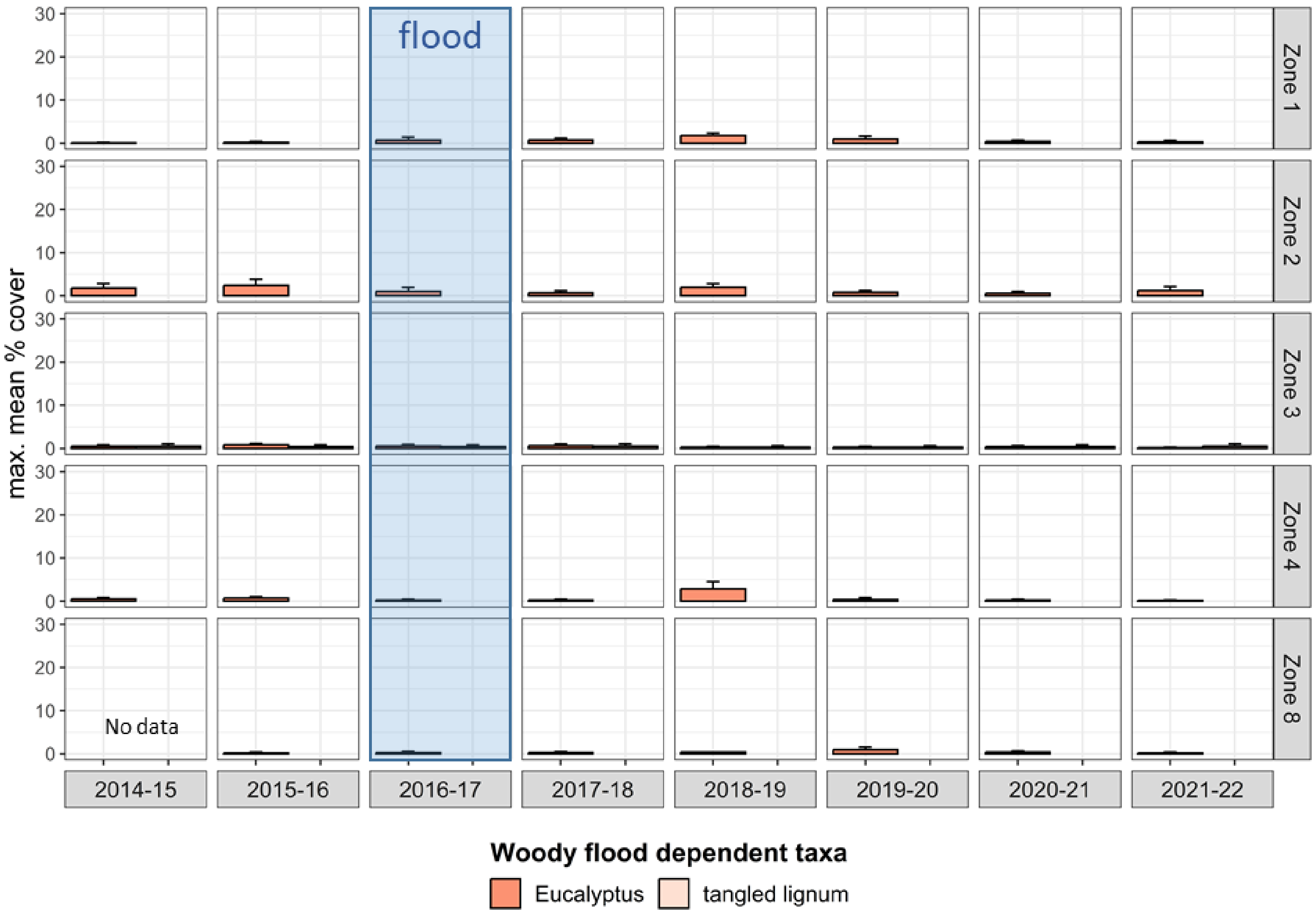


Figure 7.19 Mean percent cover of the two most abundant terrestrial woody vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2021. Green shading indicates that zones 1, 3, 4 and 8 received environmental water each year. Zone 2 received minimal no environmental water, with the exception being in 2018-19 and variable base flows in 2020-21.

7.6 Discussion

Riverbank and aquatic plants in the EKW 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 2021-22 there was further evidence of signs of recovery such as an increase in the number of amphibious taxa.

The potential for environmental water to promote recovery of vegetation is evident by examining the response of taxa in zone 2. This zone (upper Wakool River) received none or very minimal environmental water in 2014-15, 2015-16 and 2017-18. This zone has recorded consistently lower taxa richness than other zones. 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 2020-21 zone 2 received variable base flows, but not a large spring fresh as did the other zones. In 2021-22 zone 2 received large unregulated flows and additional environmental water from the Wakool escape. The response in zone 2 to this additional water has been significant, with increased number of taxa and percentage cover of riverbank and submerged plants. Much of the increase in peak flow was due to unregulated water, however the environmental water from the Wakool escape further increased the peak flow (see section 4). Thus, the environmental water would have contributed to some of the benefits to riverbank vegetation due to increasing the extent of riverbank inundation.

These observations of responses of riverbank plants to environmental watering actions 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 EKW 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 EKW 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.

In 2021-22 the slower recovery of riverbank amphibious plants in zone 1 (Yallakool Creek) compared to zone 2 (Upper Wakool River), may be because zone 1 experienced a reduced in variability in flows due to return flows from Millewa Forest, yet zone 2 (and to a lesser extent zones 3 and 4) experienced higher variability of flows due to the environmental water from the Wakool escape. The increase in riverbank inundation in zone 2 due to environmental flows from the Wakool escape was modest, however it would have contributed to the increased wetting of the riverbank and improved riverbank vegetation outcomes in the Wakool River.

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?

There is evidence that Commonwealth environmental watering actions have contributed to the recovery of riverbank plants since the flood in 2016. 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 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. The environmental watering action in the upper Wakool from the MIL escape has confirmed this relationship between increased peak flows/high variability of flows and increased number of riverbank plant taxa.

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 negatively impacted during flood in 2016 and were reduced in cover or were killed. In 2021-22, five years after the flood, there are signs that these taxa are beginning to recover. Plants of these species were observed in 2021-22 and percent cover has increased. The recovery of these species can be supported by environmental watering.

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 have had positive outcomes on the germination of riverbank vegetation. Following the recession of flows, the damp banks provide 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 outcome is when there are subsequent freshes (environmental actions or operational flows) that re-wet these areas and 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 as in 2020-21 supports growth of the seedlings.

In 2021-22 the unregulated flows combined with environmental watering actions have confirmed that there is an adequate seedbank on the riverbanks, and there is an opportunity to see a vegetation response and increase in number of taxa and percent cover when a larger part of the riverbank is inundated. The exception is a large flood year, like 2016, when long periods of inundation reduce the number of taxa and cover.

8 Fish

Authors: Nicole McCasker, John Trethewie, Jason Thiem, Laura Michie

Key Findings		
spawning	Flow-dependent spawners (golden perch, silver perch, carp)	• Despite the high spring/summer in-channel freshes that characterized the 2021-22 water year, there was no evidence of local golden or silver perch spawning in the Wakool River or Yallakool Creek. This was further supported the absence of YOY golden and silver perch caught in the targeted recruitment surveys. • While low numbers of carp larvae were detected in 2021-22, results of adult population surveys indicate that carp recruitment was widespread throughout the Selected Area, and a likely response to the high spring/summer in-channel freshes.
	Small bodied species	• Evidence of spawning was observed in 2021-22 for four of the six small-bodied native fish species known to the Edward/Kolety Wakool River system. • Abundance of flathead gudgeon larvae were highest on record in 2021-22 and has been steadily increasing every year since 2018-19.
recruitment	Murray cod, silver perch and golden perch recruitment	• Murray cod YOY abundance and growth rates were highest in 2021-22 than in previous two years. • Highest catch rates of 1+ silver perch were recorded in 2021-22 since monitoring commenced in 2015, with juveniles widespread throughout the Yallakool Creek and Wakool River study sites. • Two juvenile (1+) golden perch were caught in the Yallakool and Wakool River study sites for the first time since monitoring commenced in 2015. • The increase in juvenile golden and silver perch (species not known to spawn regularly in the Edward/Kolety Wakool System) may have been due to fish immigration into the system in response to the high unregulated flows and the Southern Connected Spring Flow.
adults	Adult fish populations	*Broad-scale surveys across the Edward/Kolety Wakool System (Cat 3)* • Catch rates of adult fish across the broader Edward/Kolety River system wide surveys were twice as high in 2022 than in previous surveys conducted in 2015 and 2019. The 2022 surveys also indicated high recruitment responses for small-bodied fish species, including Australian smelt, carp gudgeon, unspecked hardyhead and Murray Darling Rainbowfish as well as bony herring. Carp and goldfish also displayed strong recruitment in 2021-22 compared to 2015 and 2019. *Annual surveys of Mid Wakool River upstream Thule Creek (Cat 1)* • Native bony herring abundance and biomass in Mid-Wakool River upstream of Thule Creek in 2022 was higher than all previous years. Few of these fish were recruits, and may have been due to immigration into the system in response to the high unregulated flows and Southern Connected Spring Flow.

8.1 Background

The EKW 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 EKW system. Historically, the EKW 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.

The overarching principle that underpins the monitoring and evaluation project for the EKW Selected Area is that we are taking an ecosystem approach to evaluate Commonwealth environmental watering. A suite of questions and indicators have been selected that all have clear linkages to other components of the Monitoring, Evaluation and Research Plan (Figure 8.1). The EKW 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 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 EKW 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 EKW system (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 EKW 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 EKW system responded to watering events and 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 indicate that 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 2014-21
Native species – recorded		
Australian smelt	*Retropinna semoni*	*
carp gudgeon	*Hypseleotris* spp.	*
flathead gudgeon	*Philypnodon grandiceps*	*
Murray cod	*Maccullochella peelii*	*
Murray Darling 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	*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*	

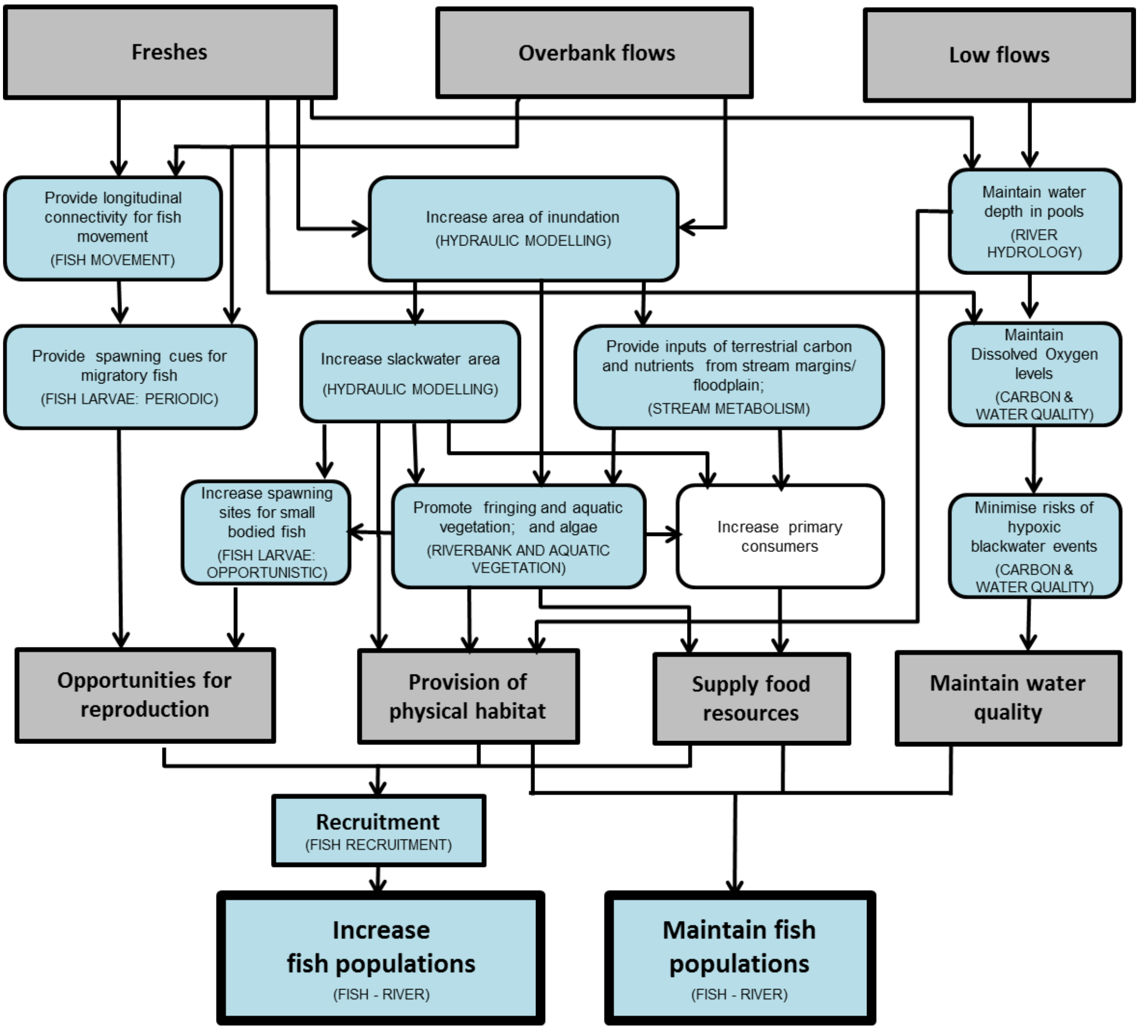


Figure 8.1 Conceptual diagram illustrating the linkages between different types of environmental watering (freshes, overbank flows, low flows) to fish populations via key ecological processes. Key ecological processes that are being monitored as part of the Edward/Kolety-Wakool Monitoring, Evaluation 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 spawned and identify the abiotic (hydraulic and temperature) conditions that contributed to this. This information will enable the development and refinement of ecologically meaningful flow-spawning relationships for the EKW 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 EKW 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 EKW 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 EKW 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 has been undertaken this year in 2021-22 (year three) for the Flow-MER program. 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 EKW 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). In 2021-22, environmental watering actions had been planned by CEWO for the Yallakool-Wakool Rivers which included specific fish objectives, including:

- Maintenance of native fish habitat and instream aquatic vegetation
- Longitudinal connectivity
- Fish spawning, recruitment, and movement
- Nutrient cycling
- Water quality

However, the planned sequence of environmental water freshes in spring/early summer for the Wakool-Yallakool System were delivered because they were already freshes in these river systems. Instead, the watering actions that were delivered were designed to provide pre-emptive spring-summer hypoxic blackwater refuge flows were delivered through Wakool escape, Edward Escape and Niemur Escape, and autumn base flows and freshes (Table 8.2, for details see Chapter 2).

Table 8.2 Commonwealth environmental watering actions in 2021-22 in the Edward/Kolety-Wakool River system that had objectives targeting native fish outcomes. Watering actions assessed by the Flow-MER monitoring program are highlighted in grey.

Action	System	Type (delivery point)	Dates
1	Wakool-Yallakool	Spring-summer hypoxic blackwater refuge (Wakool escape)	14/09/21 - 05/01/22
2	Edward/ Kolety	Spring-summer hypoxic blackwater refuge (Edward escape)	06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	Spring-summer hypoxic blackwater refuge (Niemur escape)	07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
5	Wakool-Yallakool	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
6	Colligen-Niemur	Autumn elevated variable base flow (Colligen offtake)	03/04/22 -26/04/22

8.3 Selected Area evaluation questions

Data from the EKW 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 University of Canberra/CSIRO and evaluated in a separate report.

2021-22 is the third watering year being reported for the Flow-MER monitoring project. 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 EKW 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 at the end of the Flow-MER program in 2024.

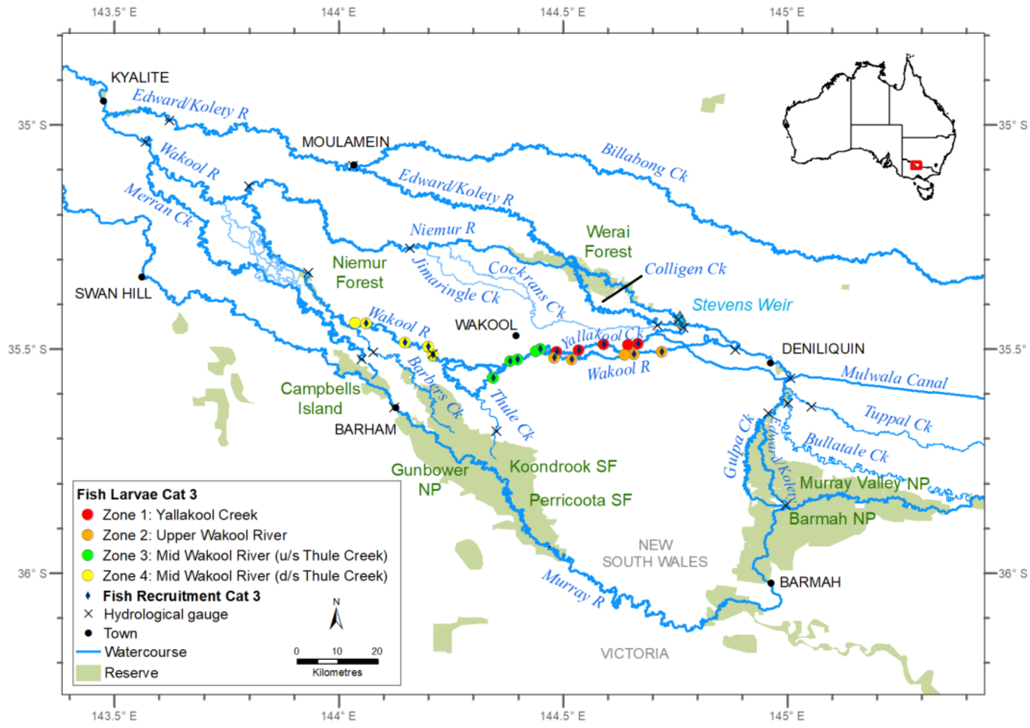
Table 8.3 Selected Area evaluation questions relating to the effect of Commonwealth environmental water on EKW fish populations relevant to this report.

Monitoring component	Selected Area-scale short term evaluation questions
Fish spawning and reproduction	• What did CEW water contribute to the spawning of 'opportunistic' species? • 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? • 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 EKW river system? • Does CEW contribute to the recovery of fish communities following negative conditions within the EKW river system

8.4 Methods

Monitoring sites

a) eggs/larvae and recruitment survey sites



b) adult fish survey sites

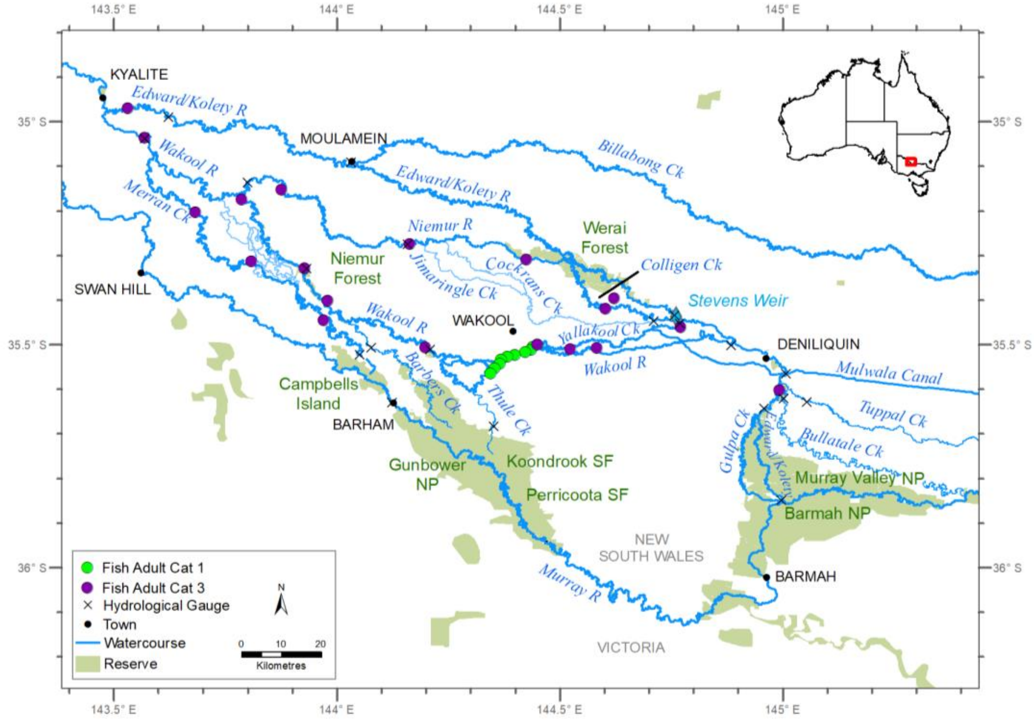


Figure 8.2 Location of Flow-MER monitoring sites used to survey fish a) eggs/larvae and recruits, and b) adult fish. Adult fish populations are surveyed annually in the Mid-Wakool River upstream of Thule Creek (zone 3, category 1) for Basin-scale evaluation (green sites). In addition, every three years (including 2021-22), broad-scale surveys are conducted throughout the Edward/Kolety-Wakool River System for Selected-Area scale evaluation (purple sites, category 3 sampling).

Fish spawning

Fish larvae and eggs were sampled within the EKW Selected Area from 13 September 2021 – 10 March 2022. 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).

For the Selected Area (Category 3) 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 13 September 2021 and finished 10 March 2022 (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 the Selected Area analysis. Drift nets are used in addition to the light traps as they are more effective in detecting drifting 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 4 October – 23 December 2021. 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 (50 cm diameter, 500 µm mesh) 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 scale monitoring, drift net samples were also collected for Category 1 Basin-scale evaluation, however this data is not reported on here. Basin-scale sampling involved setting three drift nets at three sites in Wakool River upstream of Thule (Zone 3), fortnightly, from the 4 October – 23 December 2021 (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. 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 presented in the report.

To aid in visualisation of 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 2021-22 (largest in-channel spring/summer 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 2021-22) 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. 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).

Fish recruitment

Four sites were sampled in each of four river zones within the EKW 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 eight annual sampling events between 2014-15 - 2021-22.

Three sampling methods were undertaken: electrofishing (boat or backpack depending on site depth), standardised angling and baited setlines to sample recruits of Murray cod, golden perch and silver perch at each of the 16 sites. A sub-sample of less than 25 Murray cod and golden perch 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.

All 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 setlines, 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 1+ recruits and daily age of YOY for Murray cod and golden perch, sagittal otoliths were extracted, embedded in a polyester resin and sectioned in the transverse plane to approximately 100 µm thick and mounted on a microscope slide. Final age estimates were based on samples with matching age readings from three reads.

To determine the age of silver perch an age-length key was constructed from silver perch captured an aged in this survey from 2014-2019 (Ogle 2016).

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, setlines 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.

Adult fish community

System-wide fish community surveys of the EKW River system were undertaken as part of Flow-MER in year 1 (2014-15), year 5 (2018-19) and year 8 (2021-22) of the program at 20 sites (Watts et al. 2014). As part of the continuation of this monitoring in Flow-MER, we present a comparison of the three system-wide fish community surveys (Category 3) conducted in years 1, 5 & 8. As well, we provide Category 1 fish community standardised survey data from the mid Wakool River - zone 3 as a continuous comparison from all years of the Flow-MER program (2014/15 – 2021/22).

Category 1 standardised sampling was undertaken from March – May 2022, whereas Category 3 sampling was conducted from May - July 2022. Category 1 sampling involved sampling each site 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). Category 3 surveys involve boat-electrofishing (n=12 operations, each consisting of 90 seconds 'on-time') and unbaited bait traps (n=10). Decapods were also surveyed in both the Category 1 surveys 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 fish 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".

For analysis of the Category 1 and 3 surveys, 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 1). 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 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 8.1 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. These size limits are used across Basin-scale and all other Selected Area reporting.

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
unspecked 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

8.5 Results

Fish spawning

A total of 1,312 fish larvae from species were collected in the 2021-22 monitoring year from a combination of light traps (n=1,294) and drift nets (n=18) (Table 8.5). Seven of the nine fish species detected to have spawned were native. Unlike 2020-21 when the total catch of larvae in 2020-21 was dominated numerically by carp larvae (76% of the total catch), in 2021-22 native fish numerically dominated the larval catch (84% of the total catch).

The diversity of native fish found to have spawned in 2021-22 (n=7) was higher than in 2021-22 (n=5), and comparable with the earlier years of LTIM and Flow-MER monitoring (2014-15: n=7, 2015-16: n=8, 2016-17: n=7; 2017-18: n=11, 2018-19: n=10, 2019-20 n=8). Large-bodied native species detected to have spawned were Murray cod (*Maccullochella peelii)* and river blackfish (*Gadopsis marmoratus*). Small-bodied native species detected to have spawned were Australian smelt (*Retropinna semoni)*, carp gudgeon (*Hypseleotris* spp.), flathead gudgeon (*Philypnodon grandiceps*), Murray Darling rainbowfish (*Melanotaenia fluviatilis*) and unspecked hardyhead (*Craterocephalus stercusmascarum fulvus*)

Australian smelt and carp gudgeon larvae were the most numerically abundant and widespread larvae collected from light traps (Table 8.5). While present in all four focal zones, carp gudgeon larvae were most abundant in the Mid -Wakool River (Zone 3 and 4 respectively) and Australian smelt most abundance in Yallakool Creek. Flathead gudgeon (n=128, 9.7% of LT catch) and Murray cod (*Maccullochella peelii*, n=36, 2.7% of LT catch) larvae were the next most abundant species. Both were detected in each of the four study zones (Table 8.5). River blackfish larvae were recorded in the upper Wakool River (zone 2, n=7) and Mid. Wakool River upstream of Thule Creek (zone 3, n =2) between 11 Oct – 9 November 2022. They were recorded at the greatest number of survey sites in 2021-22 than any other year prior, and found at all five sites in the Upper Wakool River (zone 2), and two sites in the Mid. Wakool River upstream Thule Creek (zone 3). These results confirm our previous observations of a range expansion for this species.

Native fish species that have been recorded as larvae in the EKW Selected Area study zones, albeit in low numbers, but were not caught in 2021-22 include: obscure galaxias (*Galaxias oliros*), bony herring (*Nematolosa erebi*), and freshwater catfish (*Tandanus tandanus,* noting it has only been recorded once over the past 8 years of sampling) and silver perch (*Bidyanus bidyanus*) (Table 8.5).

Silver perch (*Bidyanus bidyanus*) and golden perch (*Macquaria ambigua*) are regularly found as adults in the EKW River System but rarely detected as eggs or larvae. No silver or golden perch larvae or eggs were detected in 2021-22. To date, silver perch have only been detected as eggs or larvae three out of eight years of monitoring. No golden perch eggs or larvae have been detected in the Edward/Kolety – Wakool River System.

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 2021-22. Fish species listed are those known to occur in the Edward/Kolety-Wakool River System. Trout cod have not been detected in the four study zones, but 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 us Thule Ck (Zone 3)**		**Mid. Wakool River ds Thule Ck (Zone 4)**		**Total**	
	LT	DN	LT	DN	LT	DN	LT	DN	LT	DN
Native fish										
Australian smelt	317	-	5	-	62	-	36	-	420	-
carp gudgeon	28	-	55	-	204	1	205	3	492	4
flathead gudgeon	2	-	12	-	96	-	18	1	128	1
dwarf flathead gudgeon	-	-	-	-	-	-	-	-	-	-
unspecked hardyhead	-	-	-	-	-	-	-	-	-	-
Murray Darling rainbowfish	1	-	-	-	-	-	-	-	1	-
obscure galaxias	-	-	-	-	-	-	-	-	-	-
bony herring	-	-	-	-	-	-	-	-	-	-
silver perch	-	-	-	-	-	-	-	-	-	-
golden perch	-	-	-	-	-	-	-	-	-	-
freshwater catfish	-	-	-	-	-	-	-	-	-	-
river blackfish	-	-	7	-	2	-	-	-	9	-
trout cod	-	-	-	-	-	-	-	-	-	-
Murray cod	4	-	8	8	18	4	5	1	35	13
Introduced fish										
gambusia	1	-	-	-	-	-	-	-	1	-
oriental weatherloach	-	-	-	-	-	-	-	-	-	-
redfin perch	-	-	-	-	-	-	-	-	-	-
carp	-	2	4	-	2	-	202	3	208	5
goldfish	-	-	-	-	-	-	-	-	-	-

Spawning responses to the 2021-22 large in-channel freshes

While there were no watering actions that targeted spawning outcomes in the 2021-22 watering year, the EKW River System experienced the highest and most sustained in-channel freshes during spring and summer than has previously occurred since 2014-15 (excluding the overbank floods in 2016-17). As a result, we took this opportunity compare larval catch across years for the four most abundance species, Australian smelt, carp gudgeon, flathead gudgeon and Murray cod.

Varied responses to smaller in-channel freshes had been previously observed in 2020-21 across these four species, with flathead gudgeon the only species that recorded significantly greater numbers of larvae in 2020-21 compared to the previous years (2017-18 and 2018-19). Abundance of flathead gudgeon larval catch has increased consistently every year since 2018-19, and this was observed again in 2021-22 (Figure 8.4). Similarly to 2020-21, in 2021-22 flathead gudgeon larvae were present in Yallakool Creek Zone 1, Upper Wakool River Zone 2, and Mid Wakool upstream of Thule Creek Zone 3 and Mid Wakool downstream of Thule Creek Zone 4, but notably with a greater presence in Zone 3 (Figure 8.3d). Across the full data set from 2014-22, Year and Zone had significant effects on total flathead gudgeon larval abundance (Year: $F_{6,132}$=4.169, p<0.0007; Zone: $F_{3,129}$= 5.4640, p=0.0014), with flathead gudgeon was found in greater numbers in the Mid Wakool River Zone3 and 4 than Yallakool Creek Zone 1 and Upper Wakool River 2 (Figure 8.4).

Australian smelt commence spawning in the EKW system in early spring, the appearance of larvae is typically occurring between September-November when water temperature ranges between 15-22°C (Figure 8.3a). Across the full data set from 2014-22, Year and Zone had a significant effect on total catch of Australian smelt (Year: $F_{6,132}$= 14.236, p<0.0001; Zone: $F_{3,129}$= 4.587, p=0.0001). Despite the uncharacteristic high flows in the Upper Wakool River in 2021-22, catch rates of Australian smelt in this zone remained low. While a significant increase in Australian smelt were observed in 2021-22 compared to 2020-21, the catch rate was similar to 4 of the 6 years prior (Figure 8.4).

Similar to previous years, Murray cod larvae were detected in the EKW Selected Area mid-October to mid-December (Figure 8.3c). While cod larvae were detected in each of the four study zones in the 2021-22, indicating spawning throughout Wakool River study reaches and Yallakool Creek, catch rates were low. Across the full data set from 2014-22, Year and Zone had a significant effect on Murray cod larval abundance: with Year ($F_{6,132}$= 7.620, p<0.0001), explaining larger amount of variance than Zone (Zone: $F_{3,129}$= 3.558, p=0.0162). Since 2017-18 there has been a consistent decline in the number of Murray cod larvae caught each year, and in 2021-22 was the lowest catch since monitoring commenced in 2014-15 (Figure 8.4).

One of the most abundant small-bodied native fish in the EKW 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) and extending through to March. Across the full data set from 2014-22, Year and Zone had a significant effect on the total abundance of carp gudgeon larvae ($F_{6,132}$= 5.818, p<0.0001; Zone: $F_{3,129}$= 26.8656, 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). There was no evidence to indicate carp gudgeon spawning benefited from the large in-channel freshes that moved through Yallakool Creek, and the Wakool River study zones in 2021-22. In fact, carp gudgeon larval catch was the lowest catch of the 7 years of monitoring since 2014 (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 EKW carp larval abundance data, formal statistical analyses were not run. However, unlike in 2021-22 when an in-channel spring fresh resulted in high numbers of carp larvae, particularly in Yallakool Creek (Figure 8.3e), the larger instream spring/summer freshes in 2021-22 did not result in high numbers of carp larvae captured.

Drift net sampling, aimed at detecting a response of golden and silver perch spawning took place from September-December 2021. While the spring/summer in-channel fresh resulted in flows of up to 1000 ML/day in both the Yallakool Creek and Upper Wakool River, and 2000 ML/day in Mid Wakool River upstream of Thule Creek, neither silver perch or golden perch eggs were detected.

Overall, we did not detect a major response in spawning by the EKW fish assemblage to the high in-channel spring-summer freshes in 2021-22. Follow up adult fish surveys conducted in Autumn 2022, presented in Section 8.5.3, allow us to see if the catch rates of recruits are consistent with these findings.

a) Australian smelt

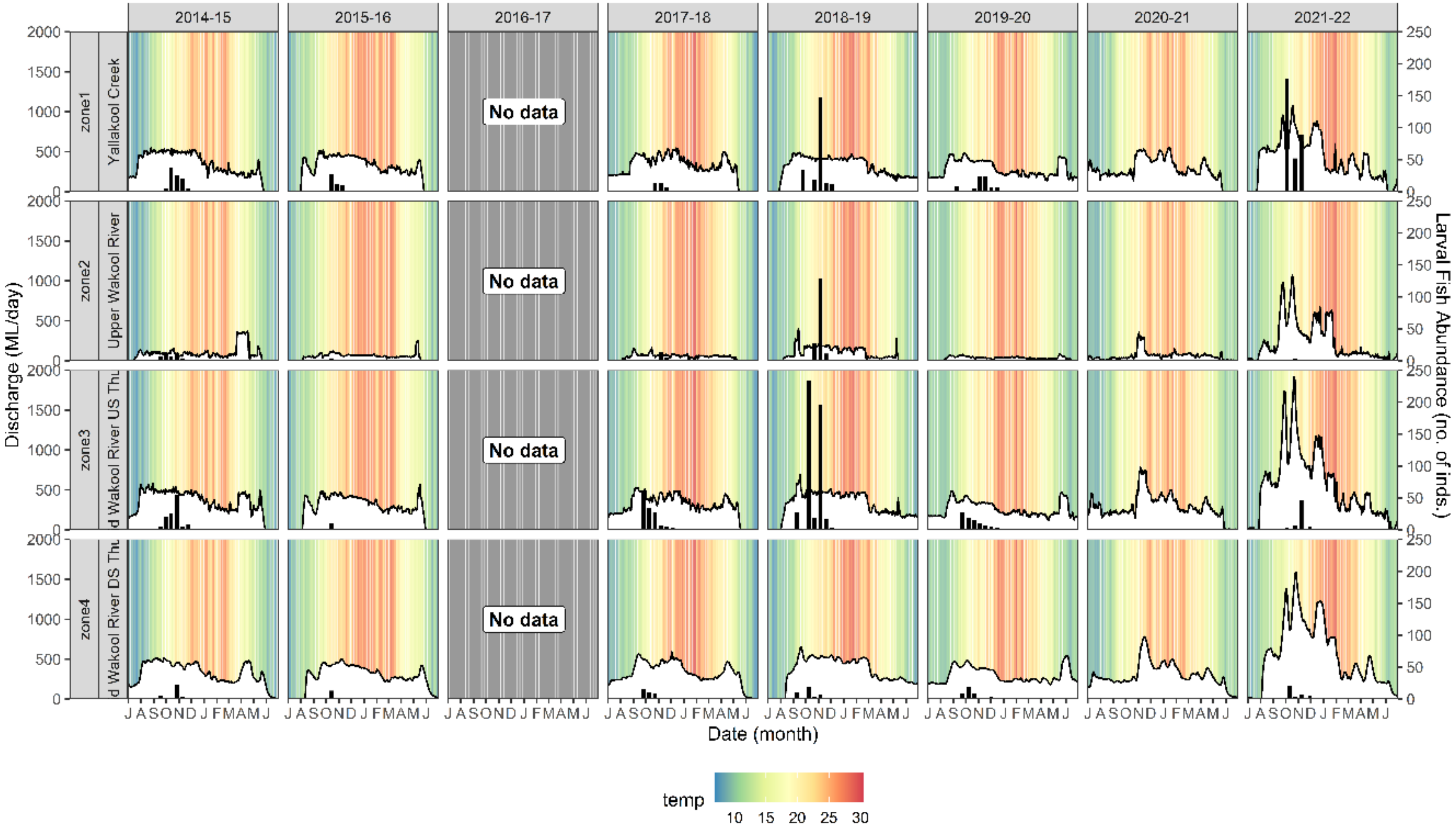


Figure 8.3a Discharge, water temperature and abundance and timing of *a)* Australian smelt larvae in each of the four study zones, from 2014-15 to 2020-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year 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

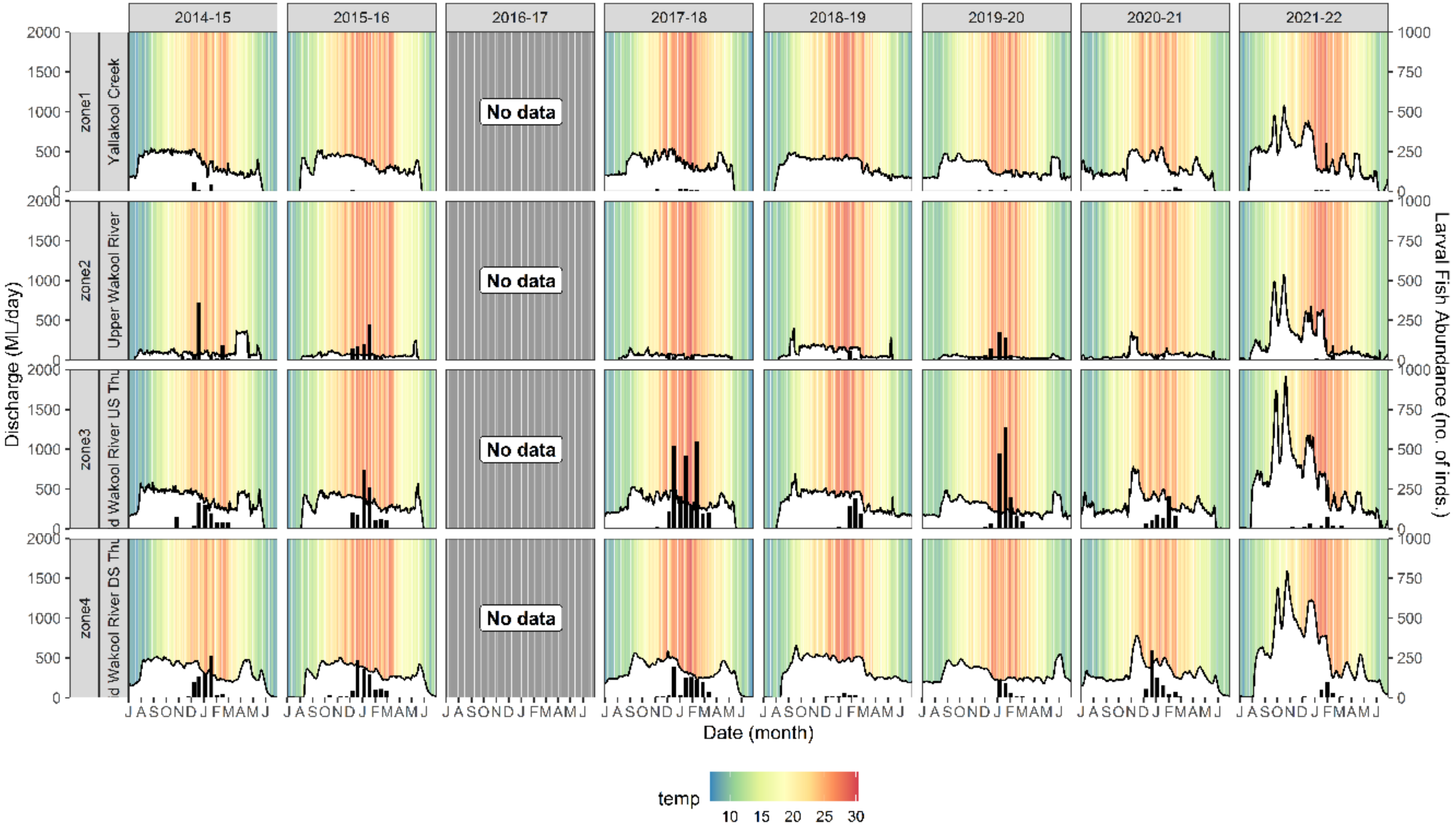


Figure 8.3b Discharge, water temperature and abundance and timing of carp gudgeon larvae in each of the four study zones, from 2014-15 to 2020-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light traps Size of bars for each species determined by max number of individuals caught on one trip (Max no. caught on one trip: =637). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

c) Murray cod

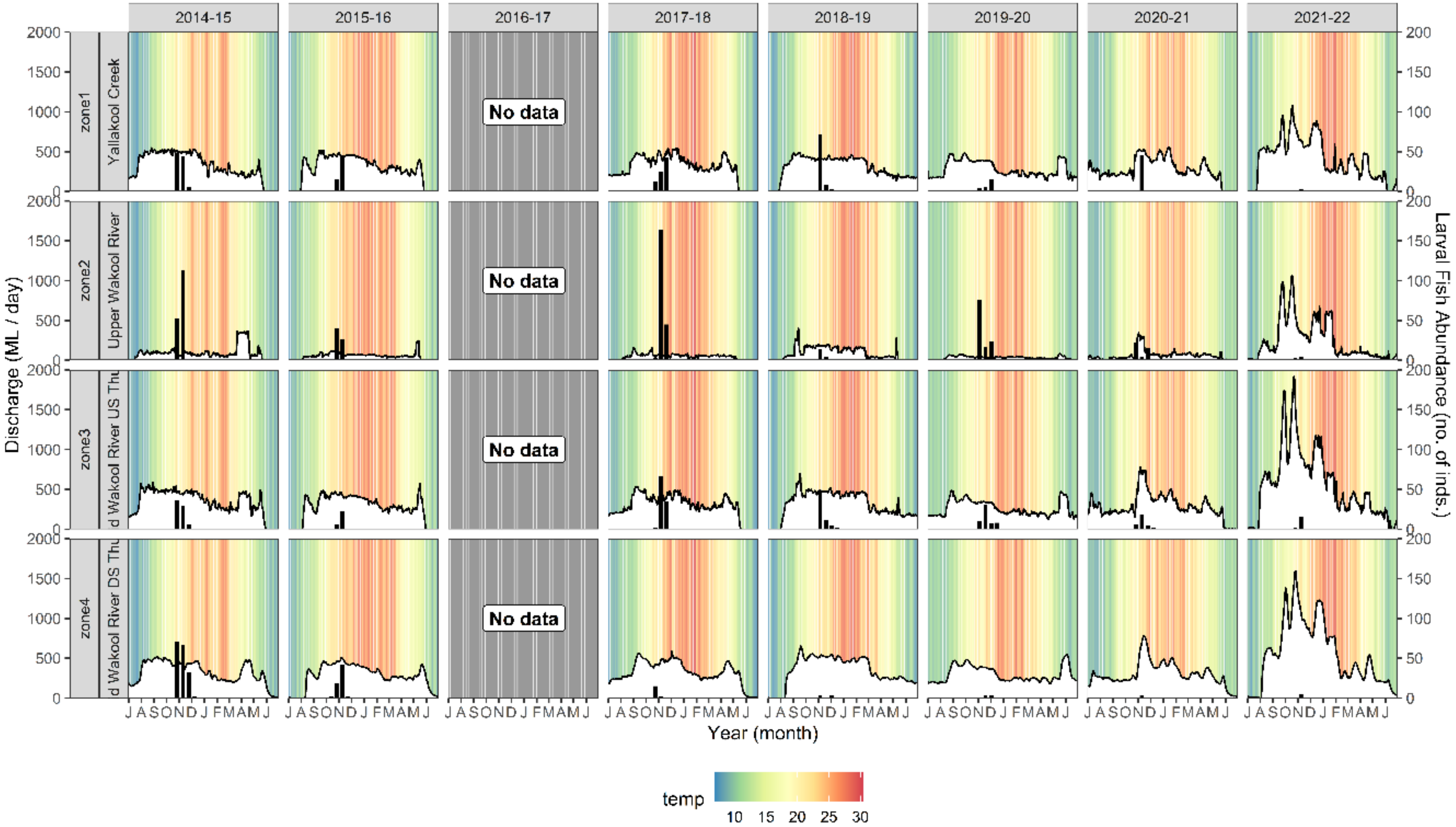


Figure 8.3c Discharge, water temperature and abundance and timing of Murray cod larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent abundance of larvae collected fortnightly from Sep-Mar each year from light traps. Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip:, Murray cod = 164). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued…*

d) flathead gudgeon

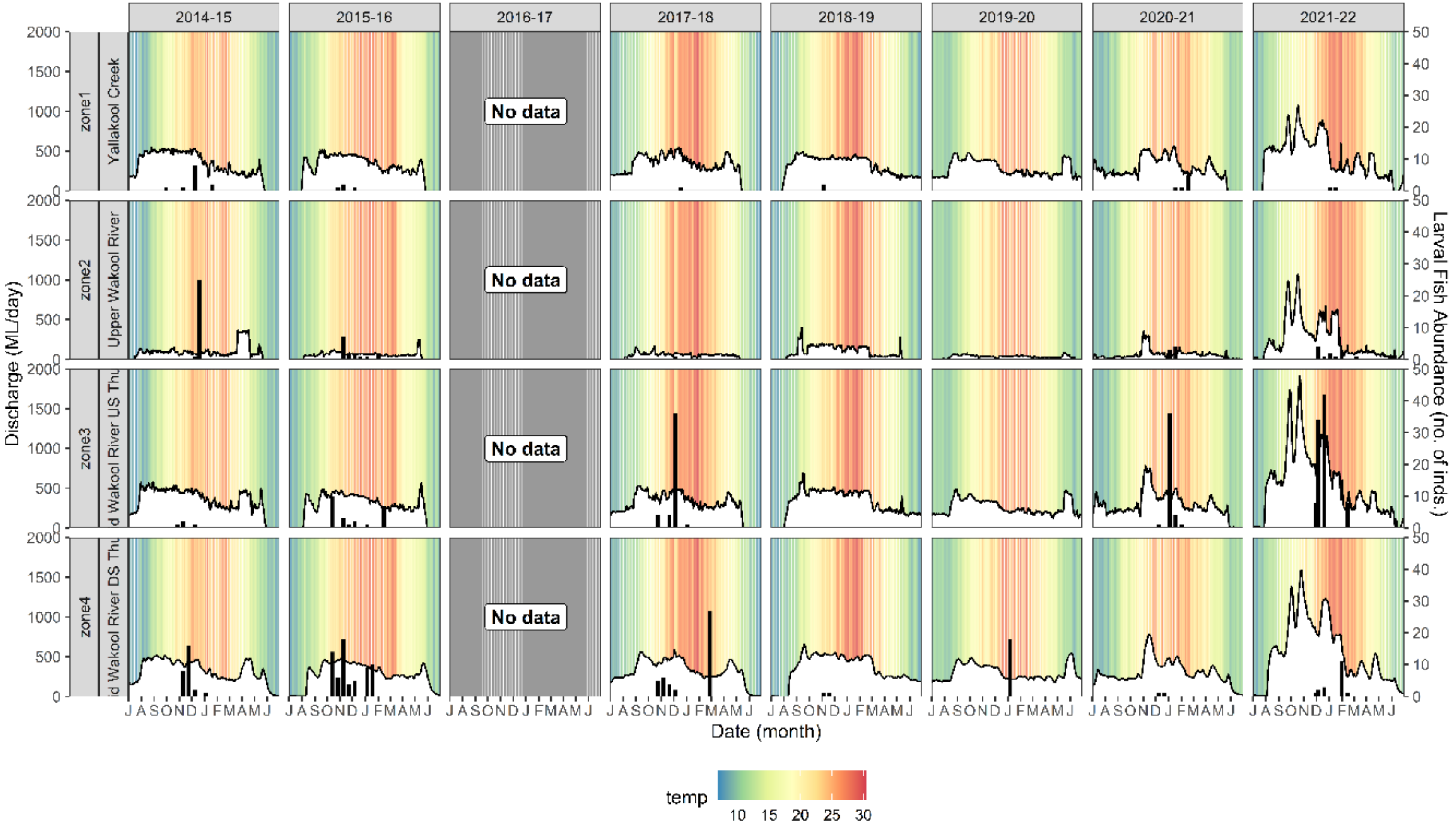


Figure 8.3d Discharge, water temperature and abundance and timing of flathead gudgeon larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent abundance of larvae collected fortnightly from Sep-Mar each year from light 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). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued.*

e) carp

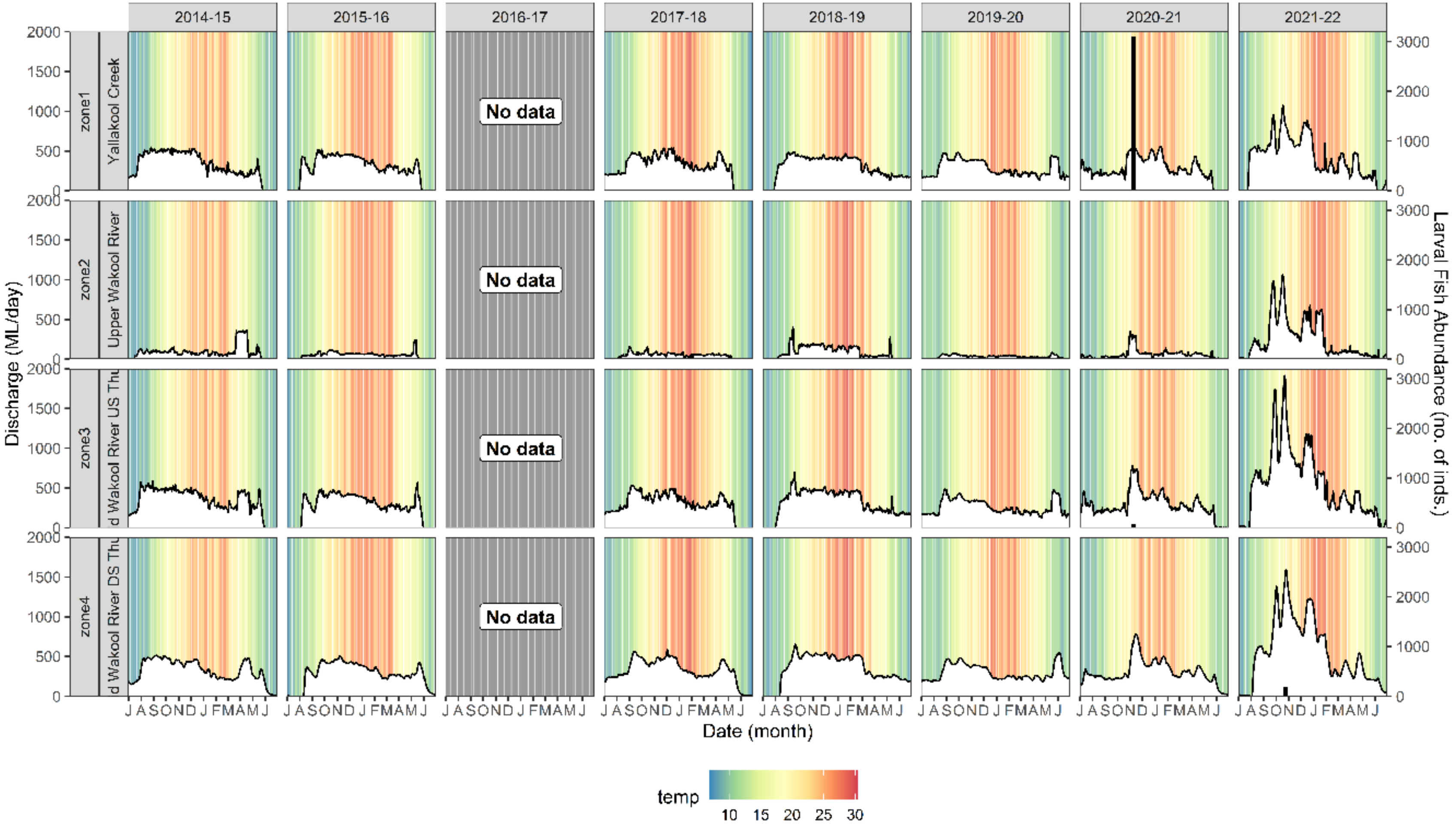


Figure 8.3e Discharge, water temperature and abundance and timing of carp larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent abundance of larvae collected fortnightly from Sep-Mar each year from light traps. Size of bars for each species determined by max number of individuals caught on one trip. (Max no. caught on one trip: carp = 3106). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

f) bony herring

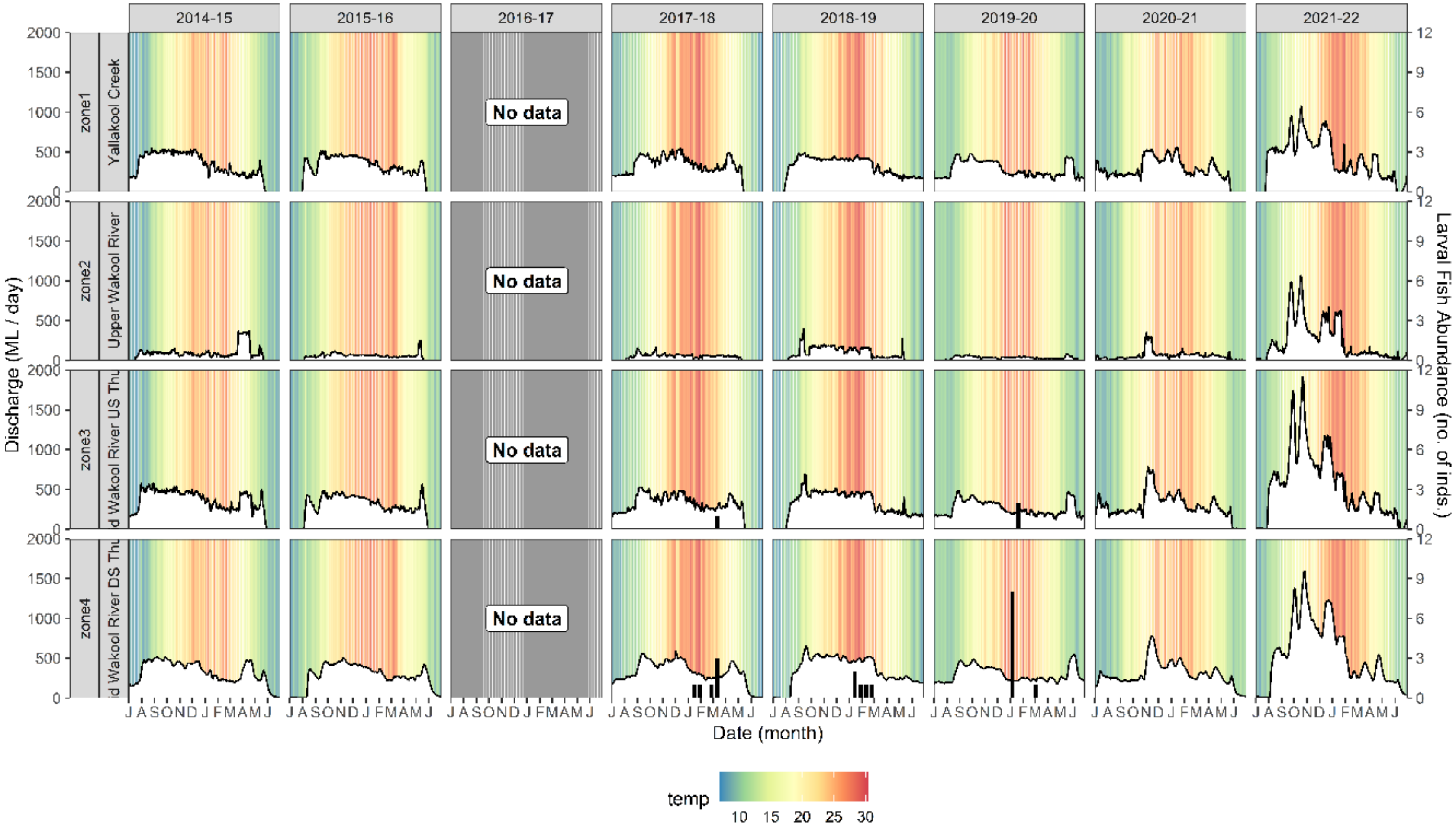


Figure 8.3f Discharge, water temperature and abundance and timing of bony herring larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light 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). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

g) river blackfish

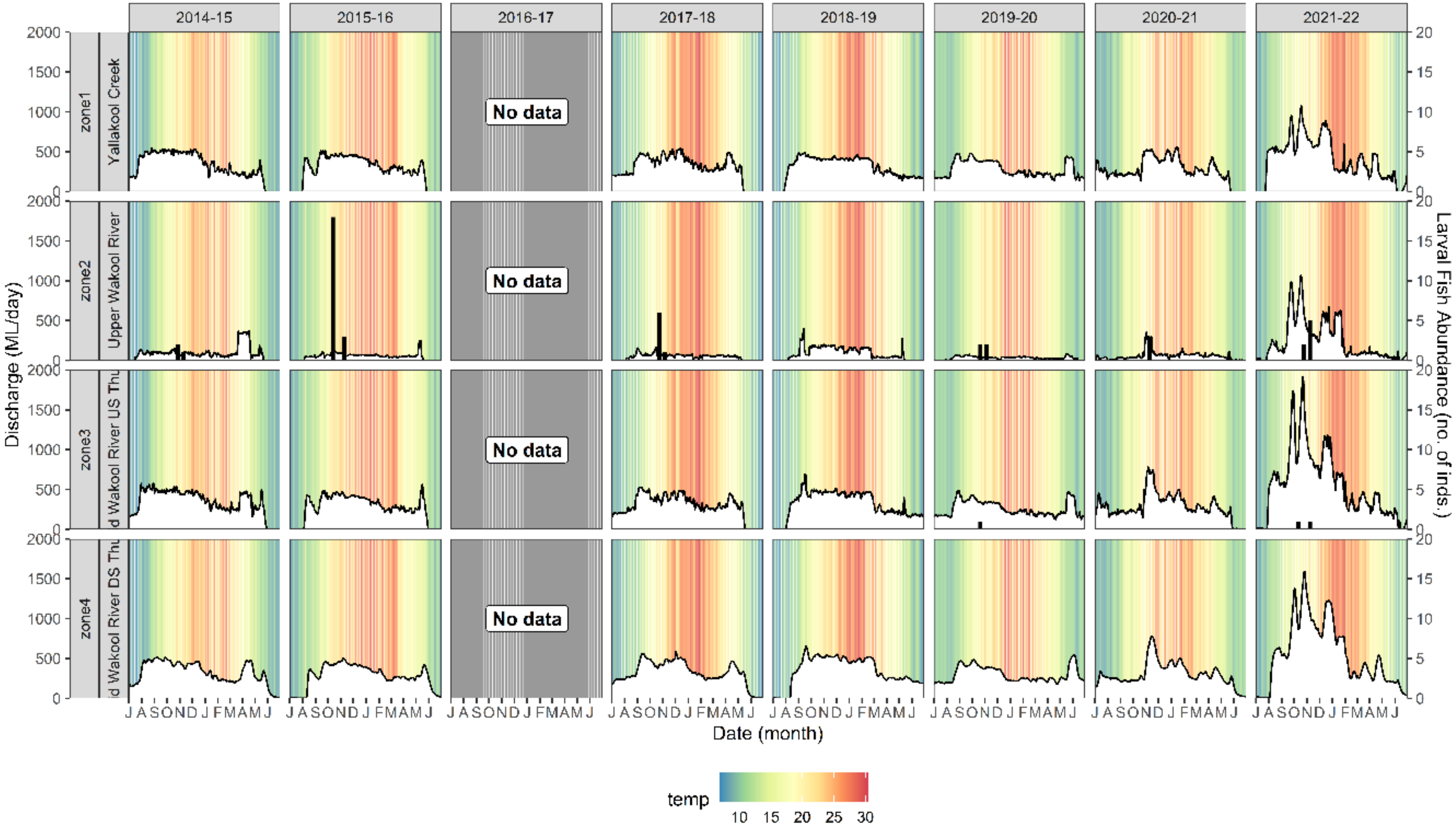


Figure 8.3g Discharge, water temperature and abundance and timing of *g*) river blackfish larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year 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: river blackfish = 18). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

h) silver perch

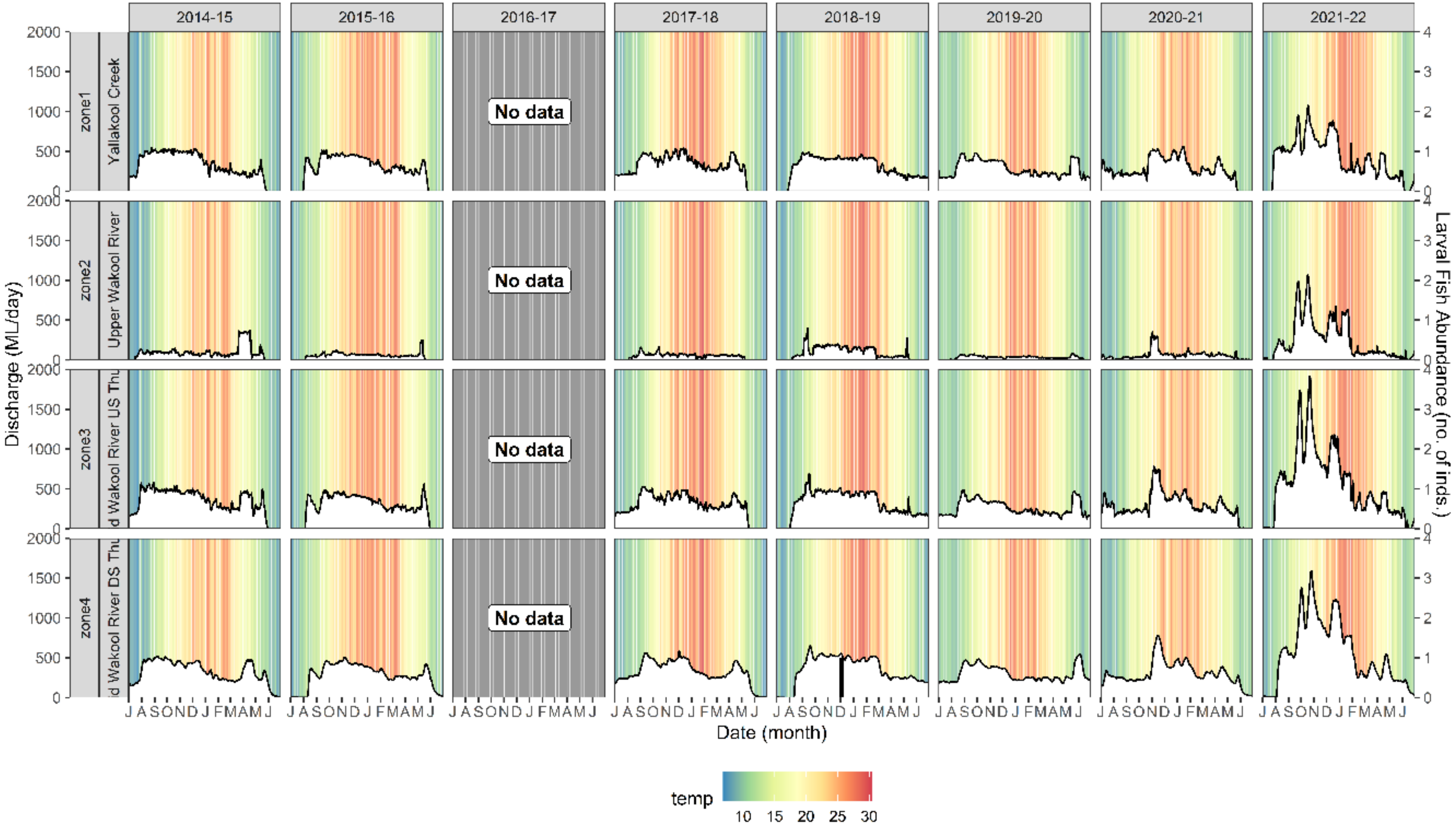


Figure 8.3h Discharge, water temperature and abundance and timing ofsilver perch larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year from light 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). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

i) obscure galaxias

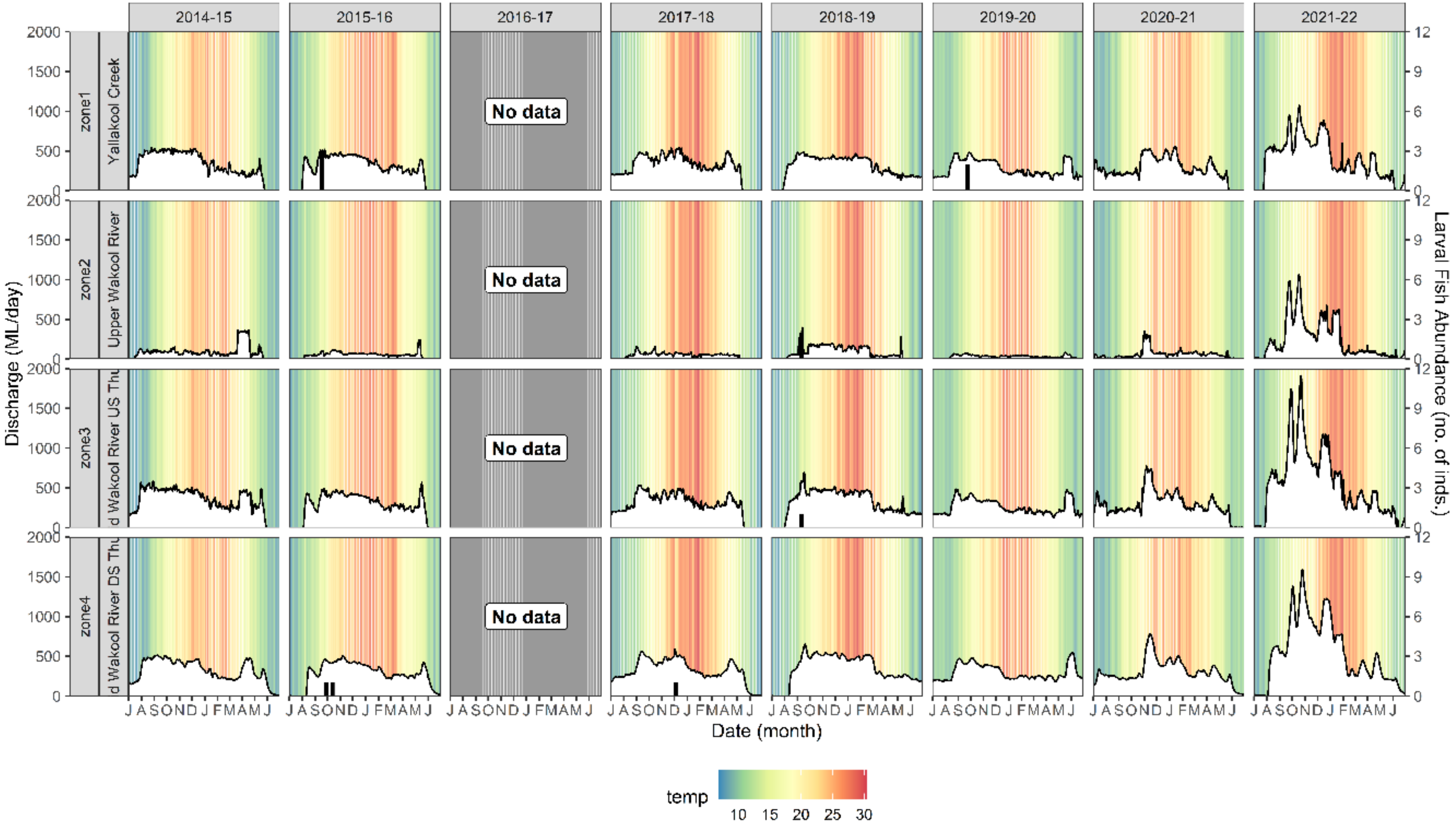


Figure 8.3i Discharge, water temperature and abundance and timing of *i)* obscure galaxias larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year 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: obscure galaxias = 3). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road. *Continued...*

j) unspecked hardyhead

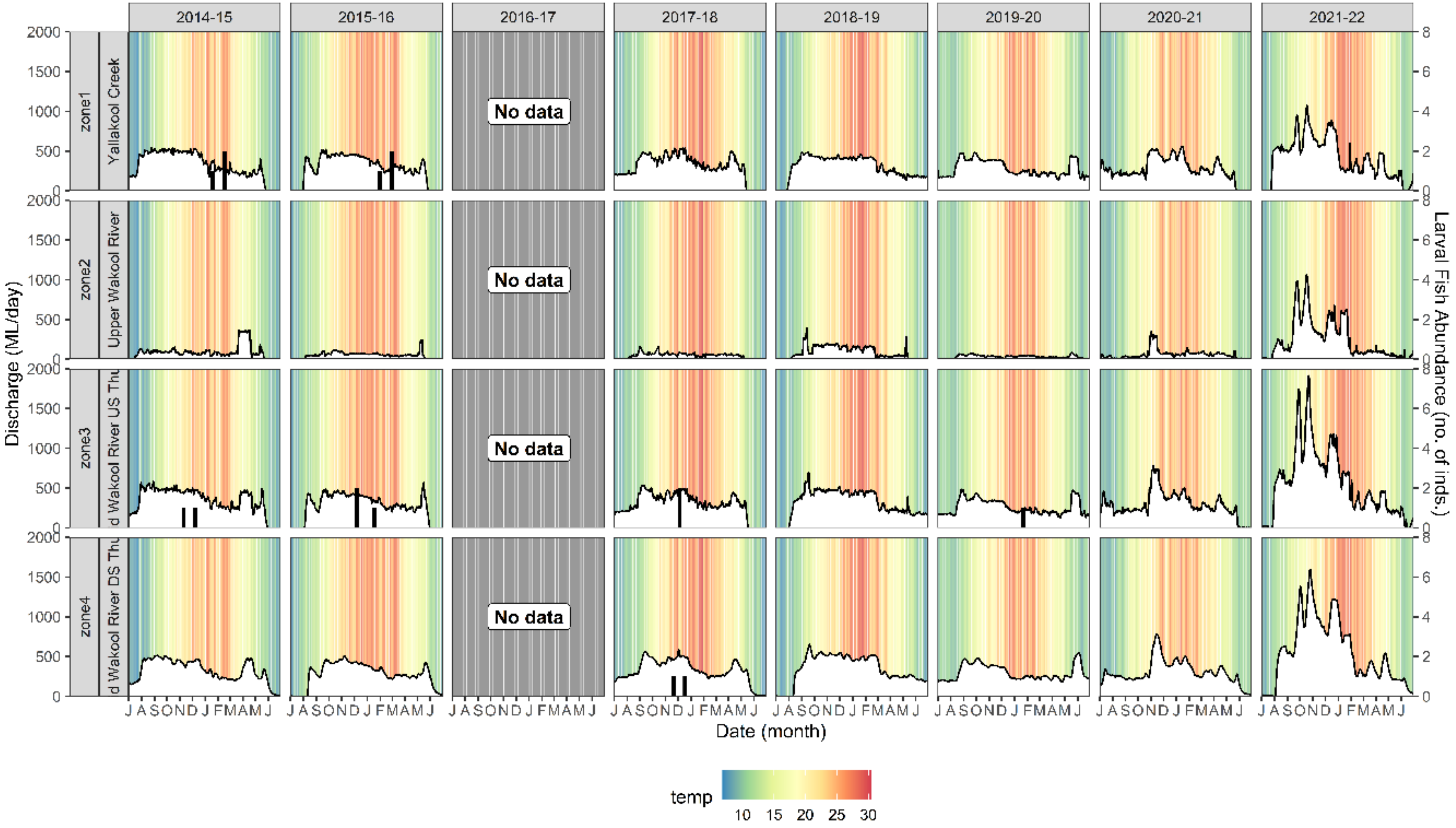


Figure 8.3j Discharge, water temperature and abundance and timing of unspecked hardyhead larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar each year 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). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road.

k) Murray Darling rainbowfish

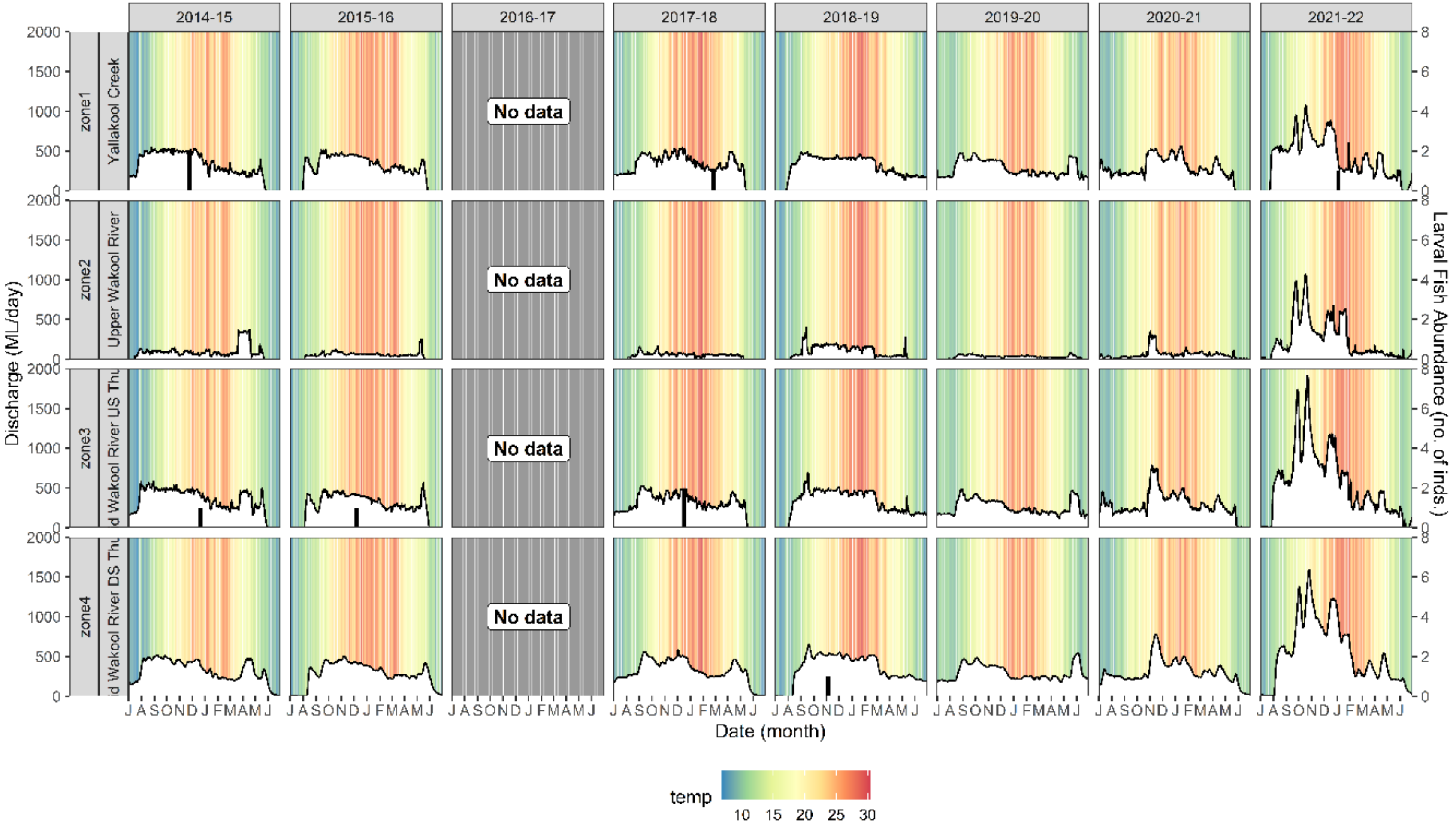
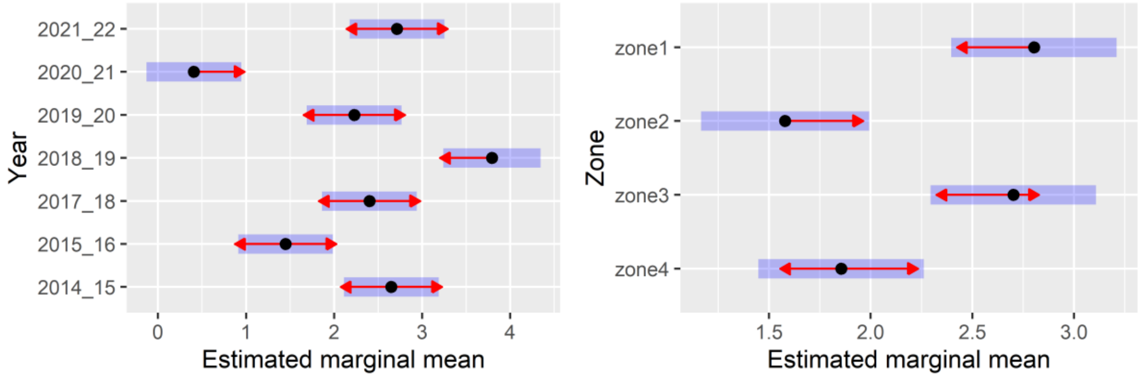
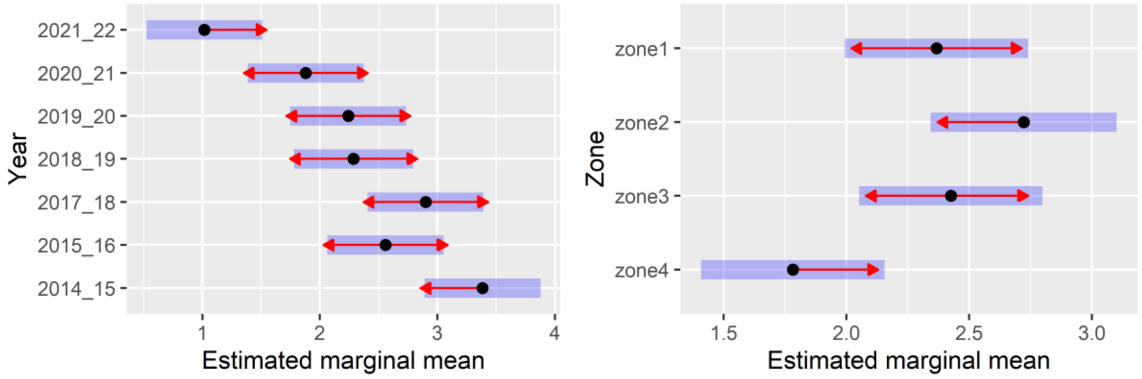


Figure 8.3k Discharge, water temperature and abundance and timing of *k)* Murray Darling rainbowfish larvae in each of the four study zones, from 2014-15 to 2021-22. 2016-17 was a flood year, and it not plotted. Black column bars represent relative abundance of larvae collected fortnightly from Sep-Mar 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 Darling rainbowfish = 2). Daily temperature data obtained from 409045 gauge at Barham-Moulamein Road.

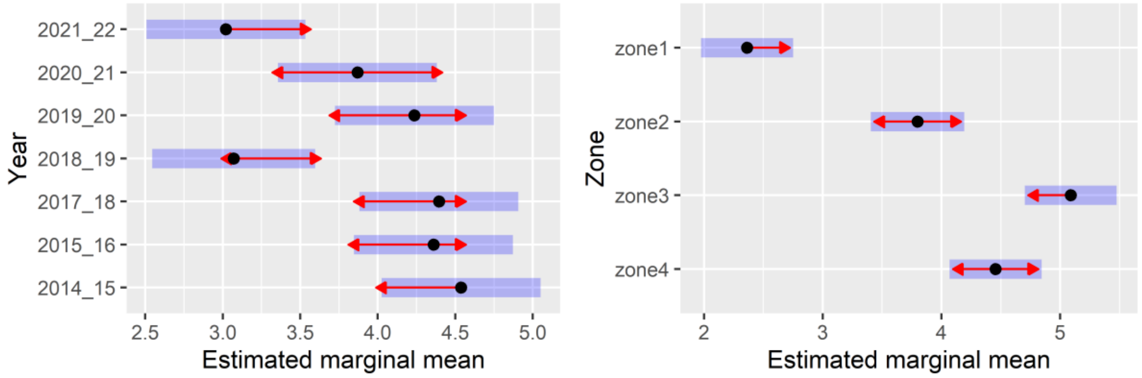
a) Australian smelt



b) Murray cod



c) carp gudgeon



d) flathead gudgeon

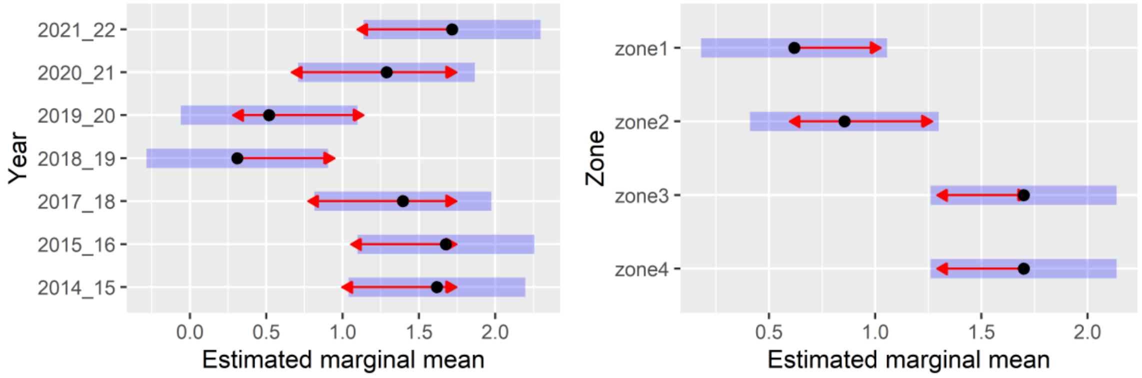


Figure 8.4 Comparison of the estimated marginal means for the factors 'year' and 'zone' in the generalised linear models run for predicting larval light trap catch for a) Australian smelt, b) Murray cod, c) carp gudgeon and d) flathead gudgeon. Black dots represent the marginal means, and the purple shading represents the confidence intervals for each estimate. The year 2016-17 was not included in the analysis.

Fish Recruitment

Murray Cod

A total 93 Murray cod (*Maccullochella peelii*) were captured across all 16 sites using all methods. Fourteen of these were YOY recruits, of which half came from Zone 2 (Table 8.6). YOY recruits were also found in Zones 1 and 3 but were absent in Zone 4 (**Figure** 8.5). Only five juvenile Murray cod in age class 1+ were detected and only in Zones 2 and 4 and were absent in Zones 1 and 3 (Table 8.6, Figure 8.6).

YOY Murray cod were generally bigger than the last 3 years (Figure 8.7) and showed similar growth rates to the cohorts that came both proceeding and succeeding the flood in 2016. Due the low numbers of age class 1+ recruits no growth analysis is possible.

Table 8.6 Number of young-of-year (YOY), age class 1 (1+) recruits and older juveniles or adults (JA) of Murray cod sampled in recruitment and growth monitoring in the EKW system for 2014-15 through 2021-22.

	Yallakool River Zone 1			**Upper Wakool River Zone 2**			**Mid Wakool R. upstream Thule Ck. Zone 3**			**Mid Wakool R. downstream Thule Ck. Zone 4**		
	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA
2014-15	5	15	17	5	11	11	3	14	13	7	6	14
2015-16	2	8	1	9	16	19	8	9	16	5	17	11
2016-17	-	-	-	-	-	-	-	-	-	-	-	-
2017-18	2	-	4	6	1	2	-	-	-	-	-	-
2018-19	5	2	1	2	6	4	-	-	2	-	-	-
2019-20	4	15	8	5	11	8	4	12	17	1	10	5
2020-21	2	7	29	4	6	15	2	16	27	4	8	5
2021-22	2	-	19	7	2	19	5	-	16	-	3	20

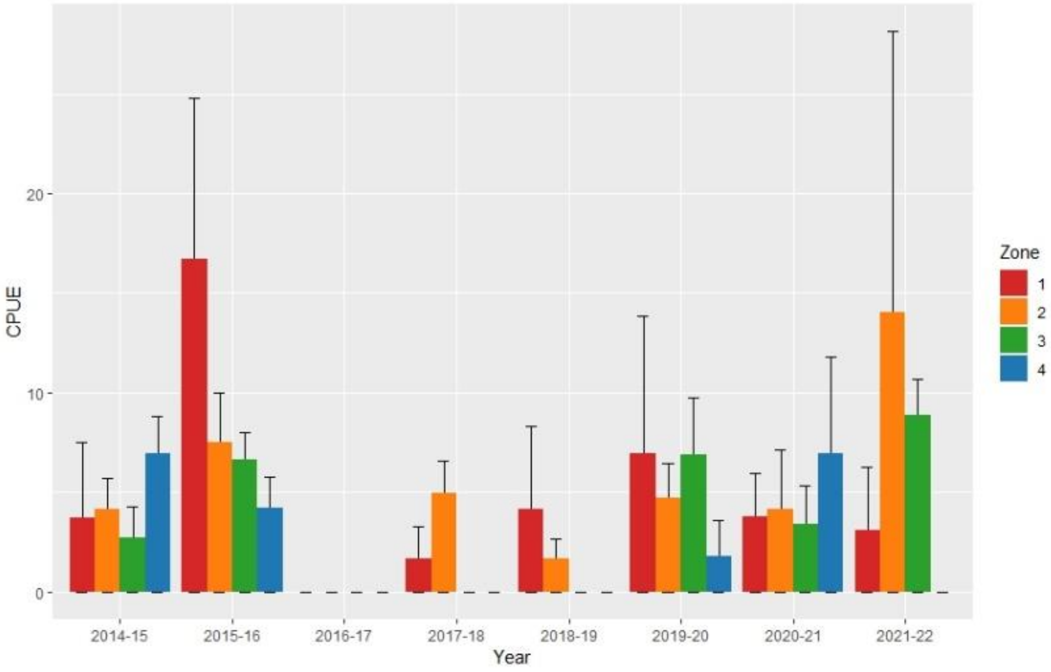


Figure 8.5 Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of electrofishing) of YOY Murray cod in the Edward/Kolety-Wakool LTIM/Flow-MER zones from 2021-22.

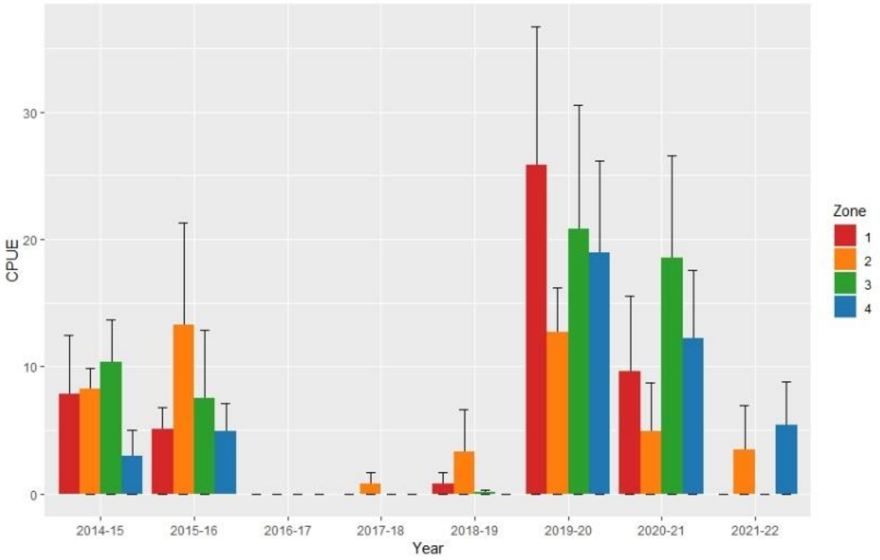


Figure 8.6 Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of sampling time) of 1+ age class Murray cod in the Edward/Kolety-Wakool LTIM/Flow-MER zones using electrofishing, setlines and angling from 2014-15 to 2021-22.

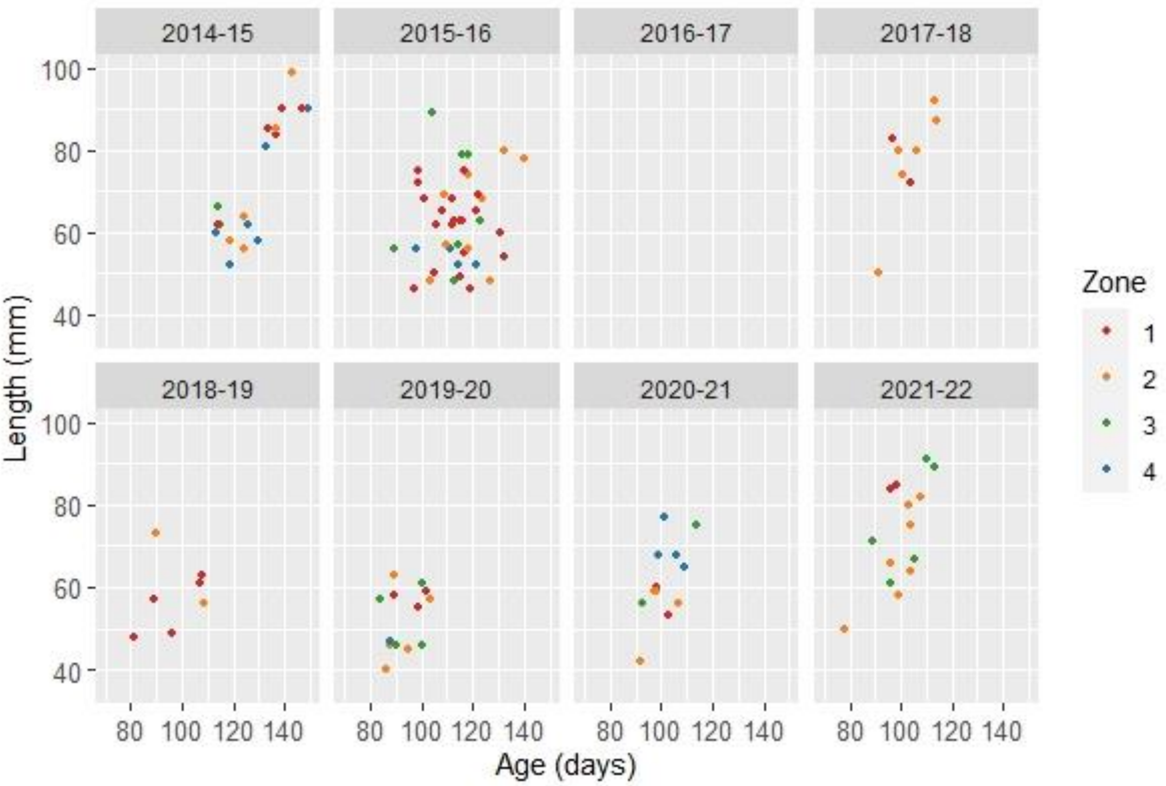


Figure 8.7 Length-at-age for each YOY Murray cod captured between 2014-15 and 2021-22.

Silver Perch

A total of 63 silver perch (*Bidyanus bidyanus*) were captured across all 16 sites using all methods which is the largest total catch since surveys began in 2014-15. A total of 25 juveniles in the 1+ age class were detected across all four zones for the first time since surveys began (Figure 8.8). The higher number of juvenile (sub 200 mm) silver perch compared to previous years can be seen in Figure 8.9. Zones 3 and 4 contributed most of these recruits with 10 in each, and zones 1 and 2 had their highest number of recruits since surveys began (

Table). No YOY recruits were detected.

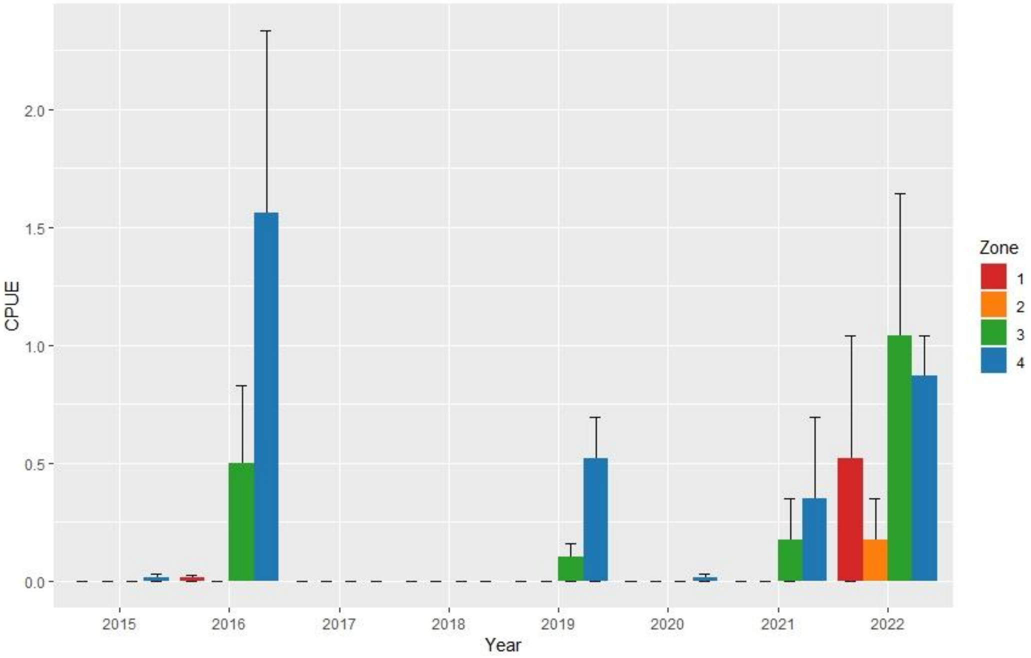


Figure 8.8 Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of sampling time) of 1+ age class silver perch in the Edward/Kolety-Wakool LTIM/Flow-MER zones using setlines and angling from 2014-15 to 2021-*22.*

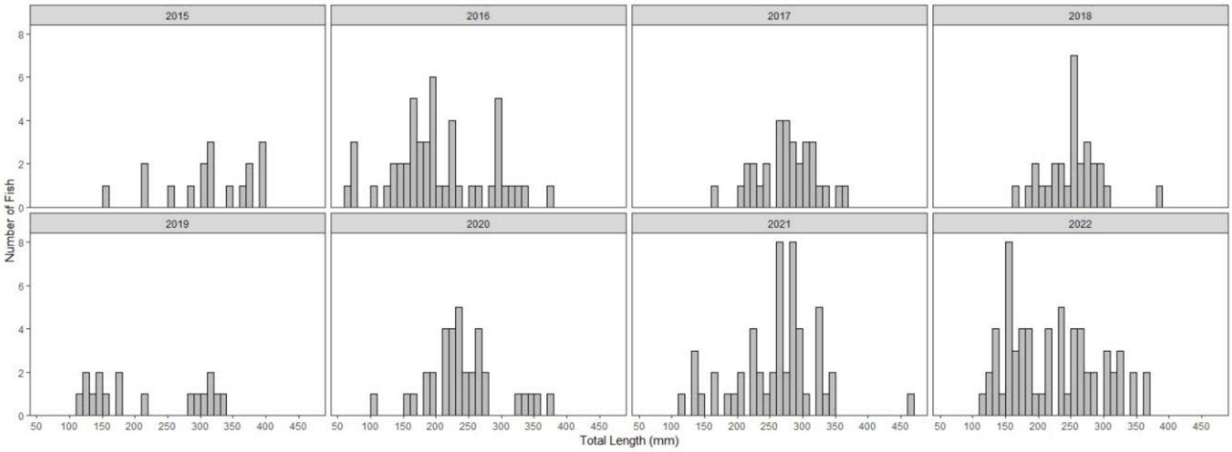


Figure 8.9 Length frequencies for all silver perch caught across all zones in each year from 2014-15 to 2021-22.

Table 8.7 Number of young-of-year (YOY), age class 1 (1+) recruits and older juveniles or adults (JA) of silver perch (*Bidyanus bidyanus*) sampled in recruitment and growth monitoring in the Edward/Kolety-Wakool system for 2014-15 through 2021-22.

	Yallakool River Zone 1			**Upper Wakool River Zone 2**			**Mid Wakool R. upstream Thule Ck. Zone 3**			**Mid Wakool R. downstream Thule Ck. Zone 4**		
	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA
2014-15	-	-	7	-	-	2	-	-	6	-	1	1
2015-16	-	1	5	-	-	3	-	4	9	5	15	14
2016-17	-	-	12	-	-	3	-	-	13	-	-	7
2017-18	-	-	2	-	-	1	-	-	9	-	-	14
2018-19	-	-	1	-	-	-	-	7	1	-	3	4
2019-20	-	1	3	-	1	-	-	1	5	1	-	17
2020-21	-	-	9	-	1	7	-	1	17	-	7	11
2021-22	-	3	5	-	2	7	-	10	10	-	10	16

Golden Perch

Two juvenile (1+) golden perch (*Macquaria ambigua*) were detected in Zone 3, which is the first time juveniles have been found since surveys began in 2014-15 (Table 8.8, Figure 8.10).

Table 8.8 Number of young-of-year (YOY), age class 1 (1+) recruits and older juveniles or adults (JA) of golden perch (Macquaria ambigua) sampled in recruitment and growth monitoring in the Edward/Kolety-Wakool system for 2014-15 through 2021-22.

	Yallakool River Zone 1			**Upper Wakool River Zone 2**			**Mid Wakool R. upstream Thule Ck. Zone 3**			**Mid Wakool R. downstream Thule Ck. Zone 4**		
	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA
2014-15	-	-	-	-	-	-	-	-	1	-	-	2
2015-16	-	-	-	-	-	-	-	-	3	-	-	1
2016-17	-	-	-	-	-	-	-	-		-	-	-
2017-18	-	-	-	-	-	-	-	-	-	-	-	-
2018-19	-	-	-	-	-	-	-	-	-	-	-	-
2019-20	-	-	-	-	-	-	-	-	1	-	-	4
2020-21	-	-	1	-	-	-	-	-	4	-	-	2
2021-22	-	-	-	-	-	-	-	2	4	-	-	1

Figure 8.10 1+ Juvenile golden perch (*Macquaria ambigua*) from mid-Wakool River upstream of Thule Creek (Zone 3).

Adult Fish Community

System-wide adult fish community surveys in the Edward/Kolety-Wakool River system

System-wide adult fish community sampling (category 3) in the EKW River system in 2022 identified a total of 2,163 fish consisting of eight native fish species and three alien species (Table 8.9). This represents the year with the highest catch rates of fish during Category 3 sampling in the broader EKW River system, with 992 fish being captured in 2019 and 1,165 fish captured in 2015 (Table 8.9). In order, Australian smelt, carp gudgeon, common carp and bony herring were the most abundant species in 2022 (Table 8.9, Figure 8.11). By weight, common carp, Murray cod, golden perch and silver perch contributed the most to biomass (Figure 8.12). Numbers of Australian smelt, bony herring, carp gudgeon, common carp, goldfish and unspecked hardyhead were greater in 2022 than in the 2015 and 2019 surveys.

In 2022, there were new recruits for all small-bodied native species that were captured in the Category 3 surveys (Australian smelt, carp gudgeon, Murray Darling rainbowfish and un-specked hardyhead). Large proportions of the total catch of these species was driven by the abundance of new recruits, for example approximately 95% of the recorded un-specked hardyhead in 2022 were classified as new recruits. Similarly, approximately 80% of carp gudgeon, 75% of Murray Darling rainbowfish and 50% of Australian smelt captured in 2022 were new recruits (Figure 8.11 & 8.14). New recruits were identified in the catches of two long-lived native fish species, Murray cod (approx. 20% of total catch) and bony herring (approx. 70% of total catch) (Figure 8.11 & 8.13). No new recruits of silver perch or golden perch were captured in 2022. New recruits were found for two alien species (common carp and goldfish) and constituted >70% of the catch for both species (Figure 8.11 & 8.13).

Significant differences in relative abundance ($Pseudo\text{-}F_{2,\,57}$=2.386,P=0.0109) of the fish community were detected between years (Figure 8.11). Pair-wise comparisons revealed that abundance differed between 2015 and 2019 (t = 3.193, P = 0.030) and 2015 and 2022 (t = 3.386, P = 0.009). There was no significant difference in abundance between 2019 and 2022 (t = 0.823, P = 1.000). Dissimilarities in the abundance were mainly explained by higher catch rates of bony herring (14% contribution) and carp gudgeon (13%) and lower catch of Murray Darling rainbowfish (13%) in 2015 compared to 2019. In 2022 dissimilarities were driven by higher catch rates of Australian smelt (15% contribution), carp gudgeon (12%), Murray Darling rainbowfish (12%) and lower catch rates of bony herring (13%) when compared to 2015.

Significant differences in the biomass ($Pseudo\text{-}F_{2,\,57}$=4.878,P< 0.0001) of the fish community were detected between years (Figure 8.12). Pair-wise comparisons revealed that biomass differed between 2015 and 2019 (t = 6.173, P = 0.003) and 2015 and 2022 (t = 7.436, P = 0.003). There was no significant difference in biomass between 2019 and 2022 (t = 1.607, P = 0.555). Dissimilarities were mostly driven by a greater biomass of golden perch (up to 24% contribution) and Murray cod (up to 23%) in 2015 compared to both 2019 and 2022.

The abundance and biomass of the larger-bodied native species has generally decreased over the three years of Category 3 sampling in the EKW River system, in 2022 the abundance and biomass of both Murray cod and golden perch was equal to or lower than recorded in other sample years (2015 & 2019). Similar trends have been observed in Category 1 sampling within the Mid Wakool River –

Zone 3 (see below). There was a small proportion of the total Murray cod catch that were classified as new recruits (i.e., <222mm, 4 out of 24) and there were no new recruits of golden perch recorded. Native bony herring abundance was higher than 2015 and 2019 (Table 8.9, Figure 8.11), however biomass was the lowest across the three Category 1 study years (Figure 8.12). This can be explained by a high proportion of the abundance being driven by new recruits (~70%).

Although alien common carp abundance had not changed considerably in 2022 compared to 2015 and 2019, biomass was comparatively low. This is likely due to the high proportion of new recruits within the population sampled in 2022 (~70%), which is greater than 2019 (~25%) and 2015 (<10%).

Table 8.9 Summary of fish captured during Category 3 system-wide sampling in 2015, 2019 and 2022 in the Edward/Kolety-Wakool River system. Fish numbers are pooled from the boat electrofishing and bait trap sampling methods.

	2015	***2019***	***2022***
Native species			
Australian smelt	446	433	1231
bony herring	148	90	158
carp gudgeon	112	95	246
flathead gudgeon	4	0	0
golden perch	46	7	7
Murray cod	61	41	24
Murray Darling rainbowfish	99	117	102
silver perch	7	3	4
trout cod	0	1	0
unspecked hardyhead	30	5	168
Alien species			
common carp	172	179	189
Eastern gambusia	14	0	0
goldfish	26	19	32
oriental weatherloach	0	2	2

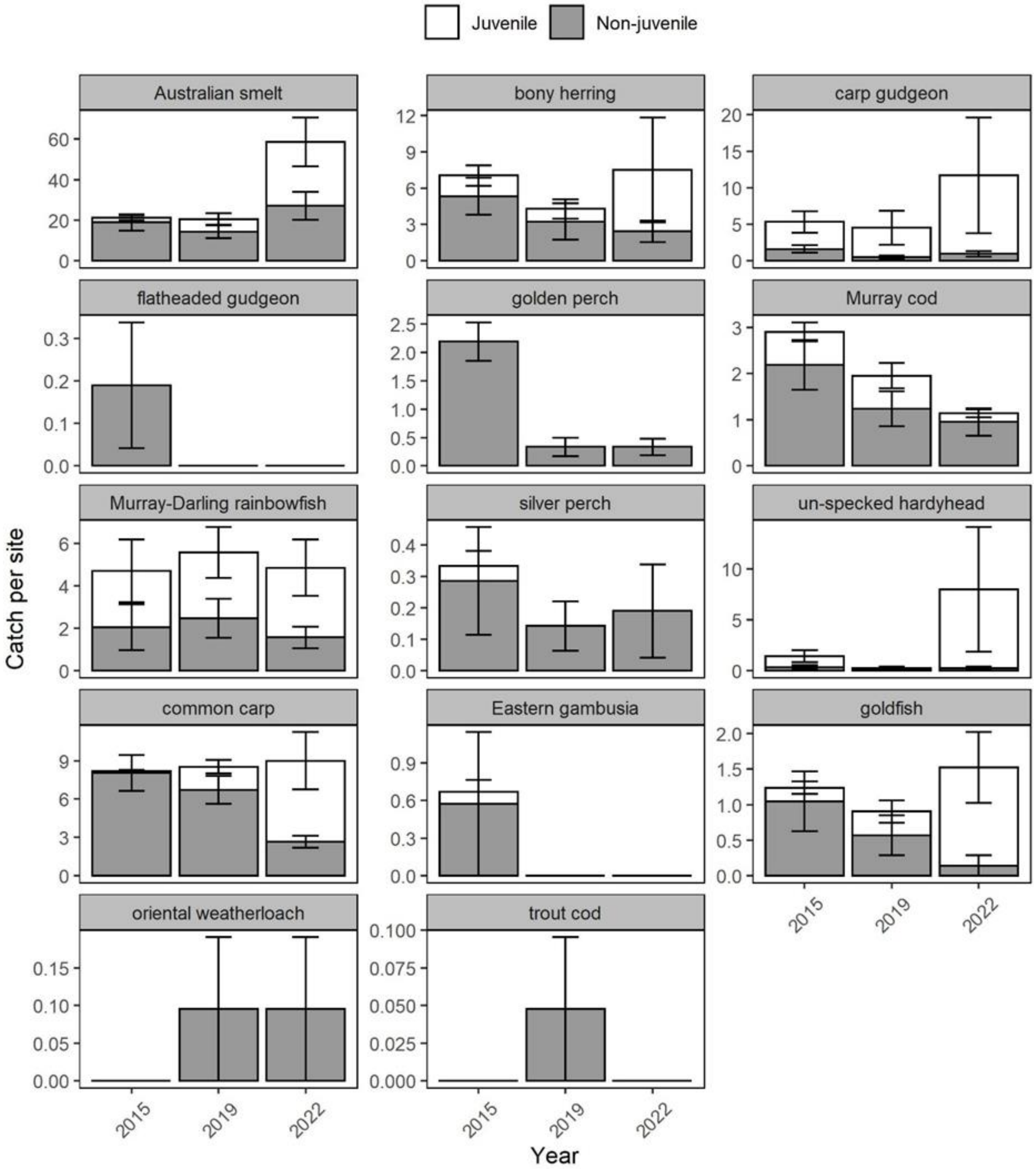


Figure 8.11 Catch per site (number of fish; mean ± SE) for fish species within the Edward/Kolety-Wakool river system, sampled in 2015, 2019 and 2022 in the Category 3 system-wide surveys. Cumulative stacked bars separate the catch of juveniles (white bars) based on length cut-off's presented in Table 1 and non-juveniles (grey bars).

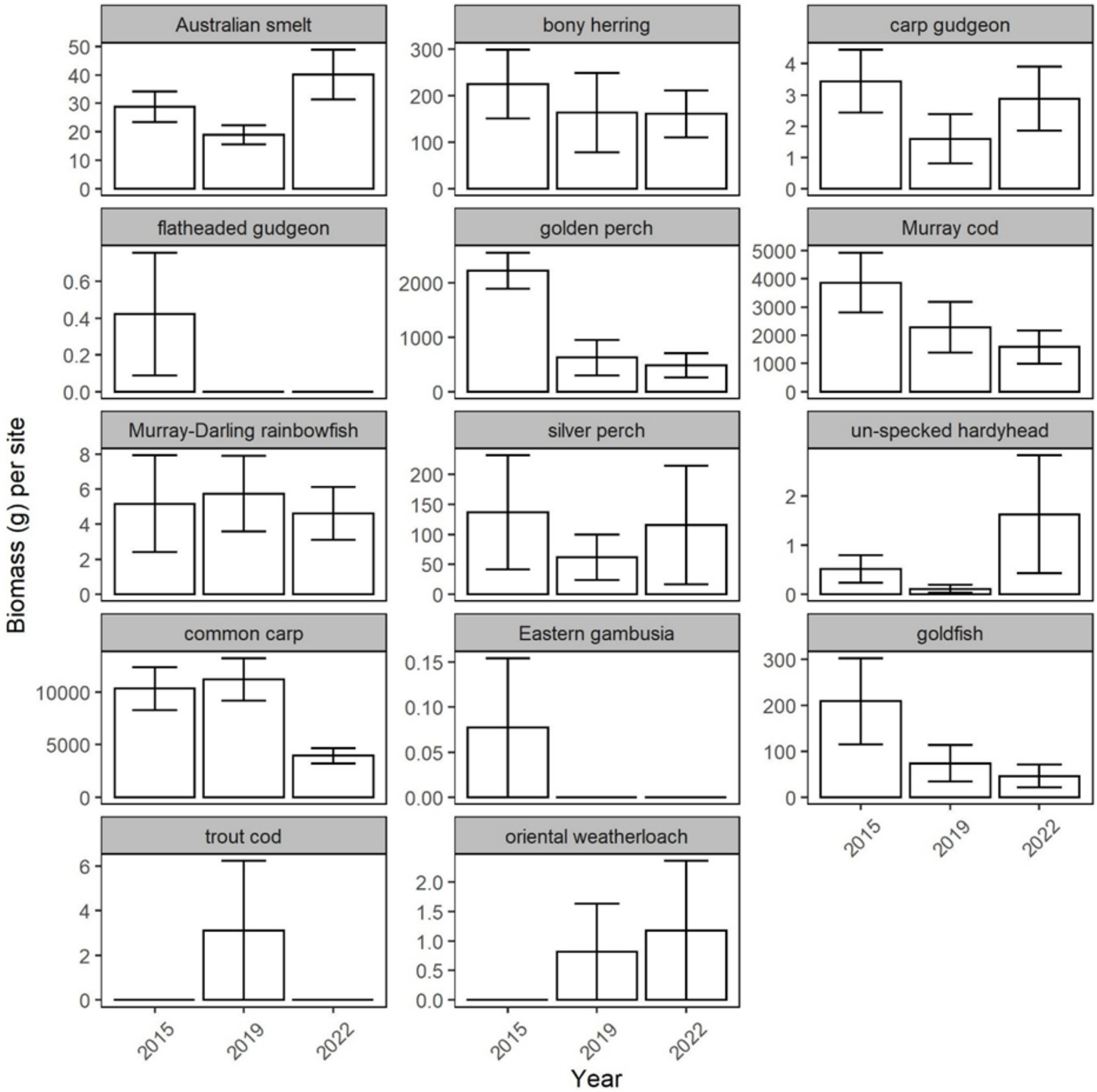


Figure 8.12 Biomass per site (weight of fish; mean ± SE) for fish species sampled within the Edward/Kolety-Wakool River System in the Category 3 surveys in 2015, 2019 and 2022.

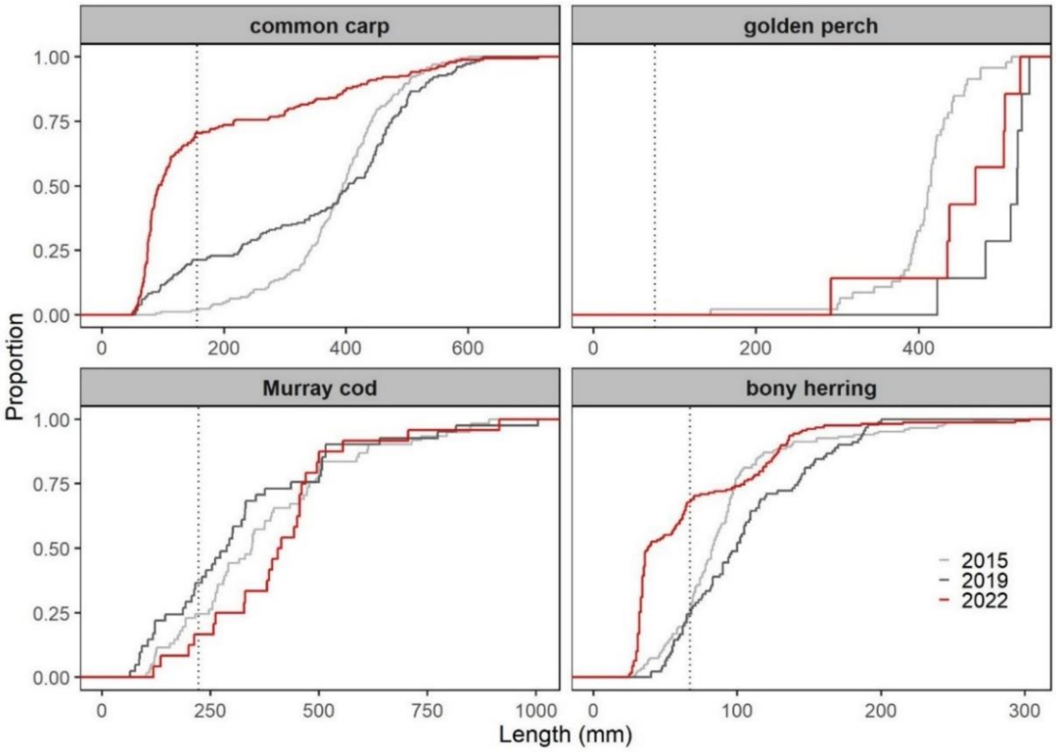


Figure 8.13 Cumulative length-frequency histograms of the four most common large-bodied species captured during Category 3 sampling in the Edward/Kolety-Wakool River system in 2015, 2019 & 2022. The dashed line indicates approximate length at one year of age (See Table 8.4) and annual sample sizes are provided for each respective species and sampling year in Table 8.9.

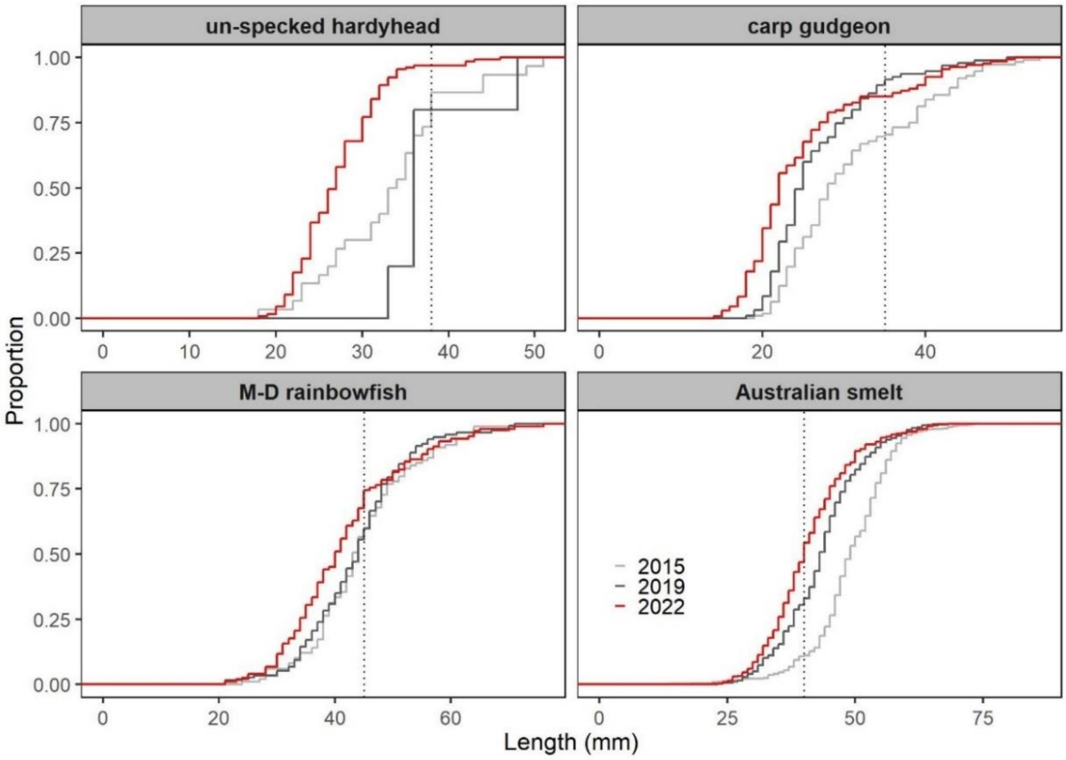


Figure 8.14 Cumulative length-frequency histograms of the four most common small-bodied species captured during Category 3 sampling in the Edward/Kolety-Wakool River system in 2015, 2019 & 2022. The dashed line indicates approximate length at one year of age (See Table 8.4) and annual sample sizes are provided for each respective species and sampling year in Table 8.9.

Category 1 adult fish community surveys in the Mid Wakool River - Zone 3

Category 1 fish community sampling of the EKW River system (undertaken in Mid. Wakool River upstream of Thule Creek - Zone 3) identified 10,707 fish consisting of nine native fish species and four alien species in 2022 (Table 8.10, Figure 8.15 & 8.16). Total fish captured in the Category 1 surveys represented the highest catch since the commencement of sampling in 2015 (Table 8.10). In order, carp gudgeon, bony herring, eastern gambusia and common carp were the most abundant species in 2022 (Table 8.10). However, common carp, Murray cod, bony herring and golden perch contributed the most to biomass (Figure 8.18). Numbers of bony herring, carp gudgeon, flathead gudgeon and Eastern gambusia were greater than any previous year in the 2015-22 surveys. A singular alien Oriental weatherloach (*Misgurnus anguillicaudatus*) was captured for in the Mid Wakool River - Zone 3 annual surveys (Table 8.10). This fish was captured by boat electrofishing on the 31/3/2022, at 128 mm it represents a mature fish (>100 mm, Lintermans 2007). Adult oriental weatherloach have previously been recorded in the EKW River system in Category 3 surveys (Table 8.9), and occasionally in recruitment and larval fish monitoring. This fish was excluded from the remaining analyses.

In 2022, new recruits (juveniles) were found for only two long-lived native fish species (Murray cod at 7 of 10 sites and bony herring at 4 of 10 sites) but there were new recruits for all five short-lived native species (Australian smelt at 4 of 10 sites, carp gudgeon at 10 of 10 sites, flatheaded gudgeon at 4 of 10 sites, Murray Darling rainbowfish at 10 of 10 sites and un-specked hardyhead at 7 of 10 sites) (Figure 9 & 10). No new recruits of silver perch or golden perch were captured. However ten 1+ silver perch and two 1+ golden perch were found during the targeted recruitment surveys (see Fish Recruitment Section). New recruits were found for all three introduced species (common carp at 10 of 10 sites, goldfish at 10 of 10 sites, Eastern gambusia at 1 of 10 sites).

Significant differences in relative abundance ($Pseudo\text{-}F_{7,\ 72}$ = 9.953, $P < 0.001$) of the fish community were detected between years (Figure 8.17). 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 = 0.084), 2019 and 2021 (t = 3.871, P = 0.084). 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%), 2018 (up to 17%) and 2022 (up to 21%); un-specked hardyhead in 2016 (up to 22%) and 2017 (up to 18%); carp gudgeon in 2017 (up to 12%), 2018 (up to 15%) and 2022 (up to 11%); and bony herring in 2020 (up to 21%) and 2022 (up to 19%).

Differences in biomass ($Pseudo\text{-}F_{7,\ 72}$ = 5.434, $P < 0.001$) of the fish community were also found between years (Figure 8.18). Differences were evident between 2015 and 2017, 2015 and 2018, 2015 and 2020, 2015 and 2022, 2016 and 2017, 2016 and 2018, 2016 and 2019, 2016 and 2020, 2016 and 2022, 2017 and 2020, 2017 and 2021, 2017 and 2022, 2018 and 2022 and 2020 and 2022 (t > 15.50, 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%). Dissimilarity existed between 2022 and all years, largely driven by lower biomass of golden perch and higher biomass of bony herring when compared to other years.

Abundance and biomass of native Murray cod and golden perch decreased from 2021 (Figure 8.17 and 8.18). The abundance and biomass of golden perch was the lowest recorded since surveys started. There were new recruits of Murray cod identified (~25% of the total catch of 110), however no new recruits of golden perch were identified. In the previous survey in 2021, there was an increase in sub-adult golden perch between 100-300 mm in 2021 compared to other years (representing ~25% of the total catch). 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 1). In 2022, there was no sub-adult golden perch identified, however a similar proportion (~25%) were within a slightly higher size-class (325-400 mm), indicating survival and growth of this cohort in the system.

Native bony herring abundance and biomass in 2022 was higher than all previous years (Figure 8.17 & 8.18). Differences in length-frequency distributions (Figure 9) between years confirmed that the largest proportion of bony herring catch was dominated by fish within the 100 – 130 mm size class, these fish do not represent new recruits (<67 mm) and would likely represent survival of recruitment events in years prior. New recruits of bony herring were most recently identified in the Mid Wakool River - Zone 3 in the 2020 Category 1 surveys.

Alien common carp abundance increased considerably in 2022 and was similar to the abundance recorded in 2017 following extensive recruitment following the flooding/hypoxia event in 2016/17 (Table 8.10, Figure 8.19). Despite the abundance being high, biomass was comparatively low and not dissimilar to 2021 and 2020. This is likely due to the high proportion of new recruits within the population sampled (~80%). Length-frequency distributions (Figure 8.19) revealed greater proportions of smaller fish in 2017, 2021 and 2022 and larger fish in 2015 and 2016.

Table 8.10 Summary of fish captured during annual Category 1 standardised sampling from 2015–2022 in the Edward/Kolety-Wakool River system Selected Area. Fish numbers are pooled from the boat electrofishing, small fyke net and bait trap sampling methods.

	2015	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***
Native species								
Australian smelt	131	53	303	305	313	118	94	129
bony herring	31	27	108	148	20	326	72	733
carp gudgeon	4400	2450	7045	7954	2457	4934	3380	8074
flathead gudgeon	1	3	0	0	0	0	5	8
golden perch	107	116	19	38	39	27	59	13
Murray cod	210	334	12	21	43	66	164	110
Murray Darling rainbowfish	507	435	669	537	591	507	431	196
silver perch	5	5	3	2	4	7	9	4
unspecked hardyhead	150	600	582	89	31	47	17	38
Alien species								
common carp	167	176	778	252	161	89	252	664
Eastern gambusia	193	403	164	55	12	0	8	665
goldfish	21	38	75	15	44	3	17	72
Oriental weatherloach	0	0	0	0	0	0	0	1

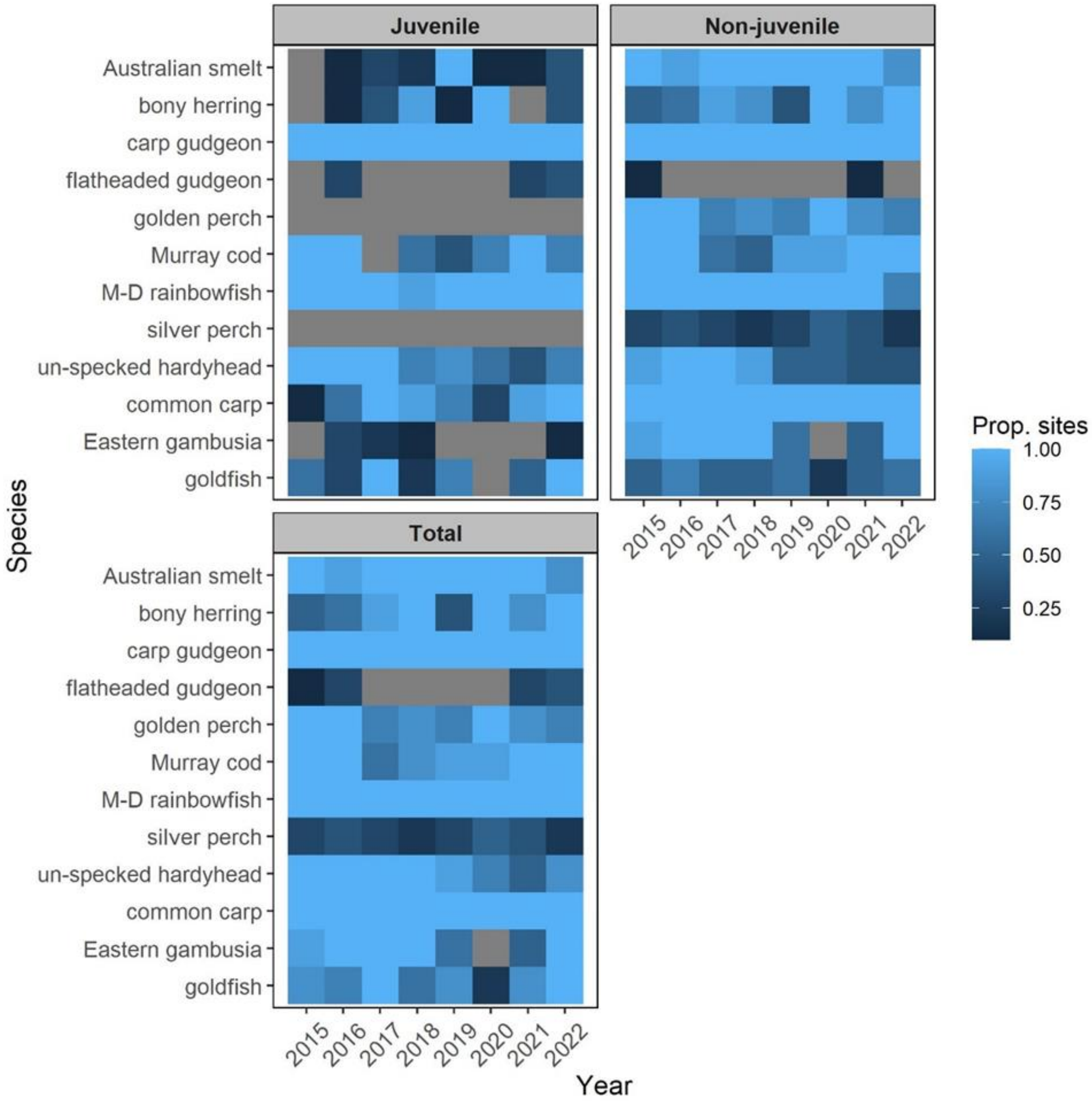


Figure 8.15 Proportion of sites (blue colour coding, grey indicates no captures) that each fish species were caught at from 2015-2022, separated into juvenile (based on length cut-off's presented in Table 8.4), non-juvenile or total fish categories.

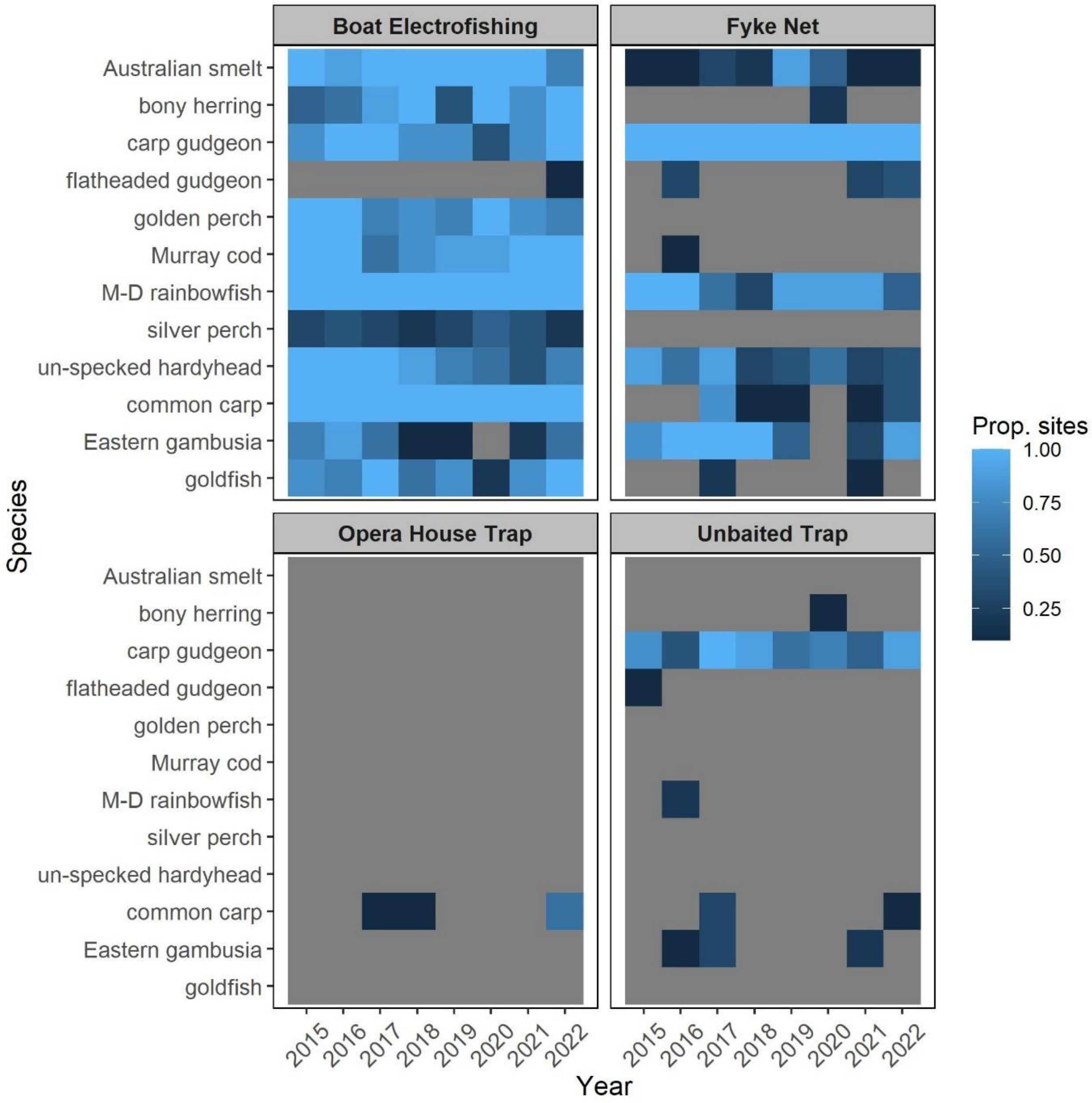


Figure 8.16 Proportion of sites (blue colour coding, grey indicates no captures) that each fish species were caught at from 2015-2022, separated by capture method.

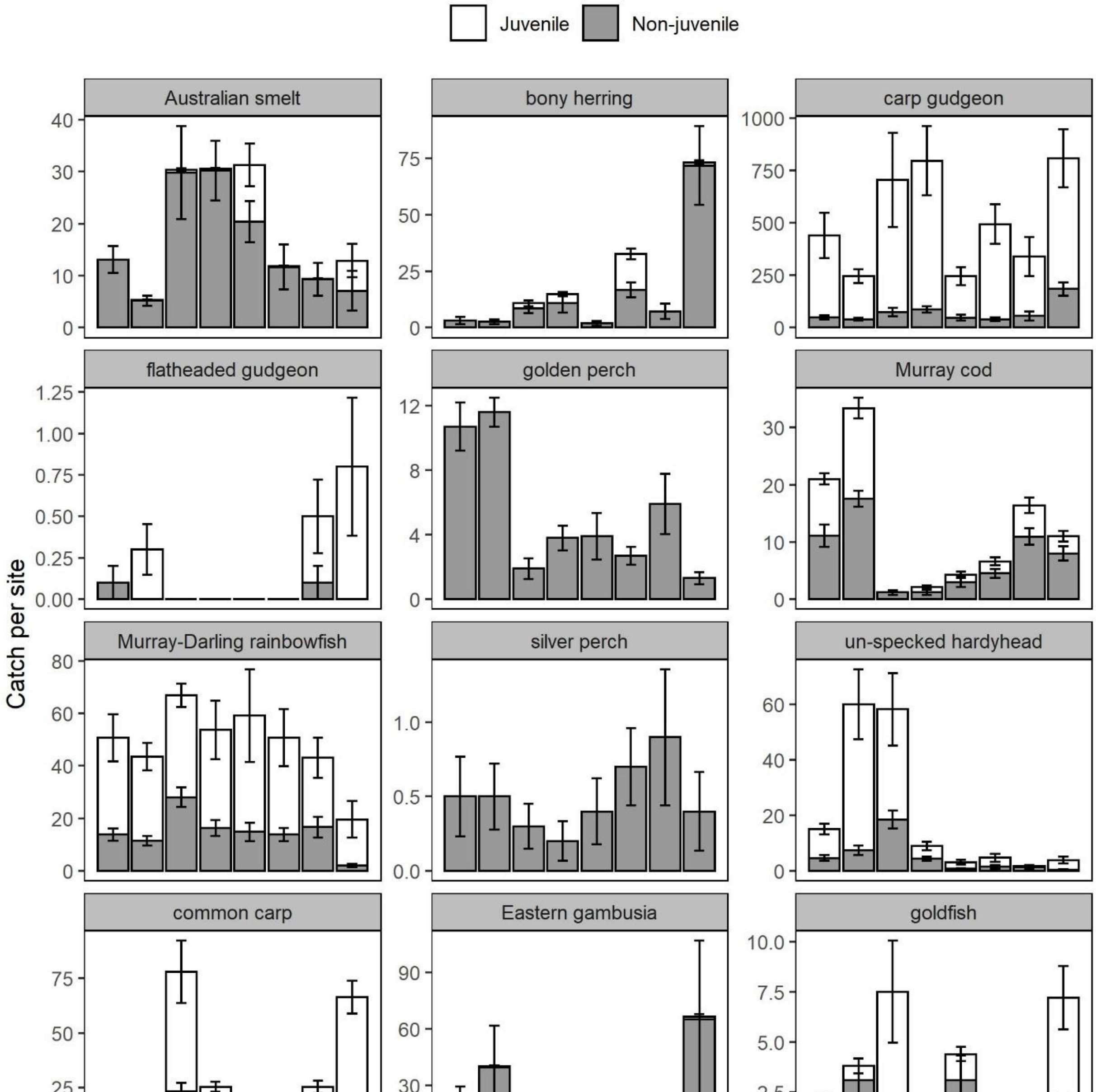


Figure 8.17 Catch per site (number of fish; mean ± SE) for each fish species within the Edward/Kolety-Wakool River System Selected Area, sampled from 2015–2022. Cumulative stacked bars separate the catch of juveniles (white bars) based on length cut-off's presented in Table 1 and non-juveniles (grey bars).

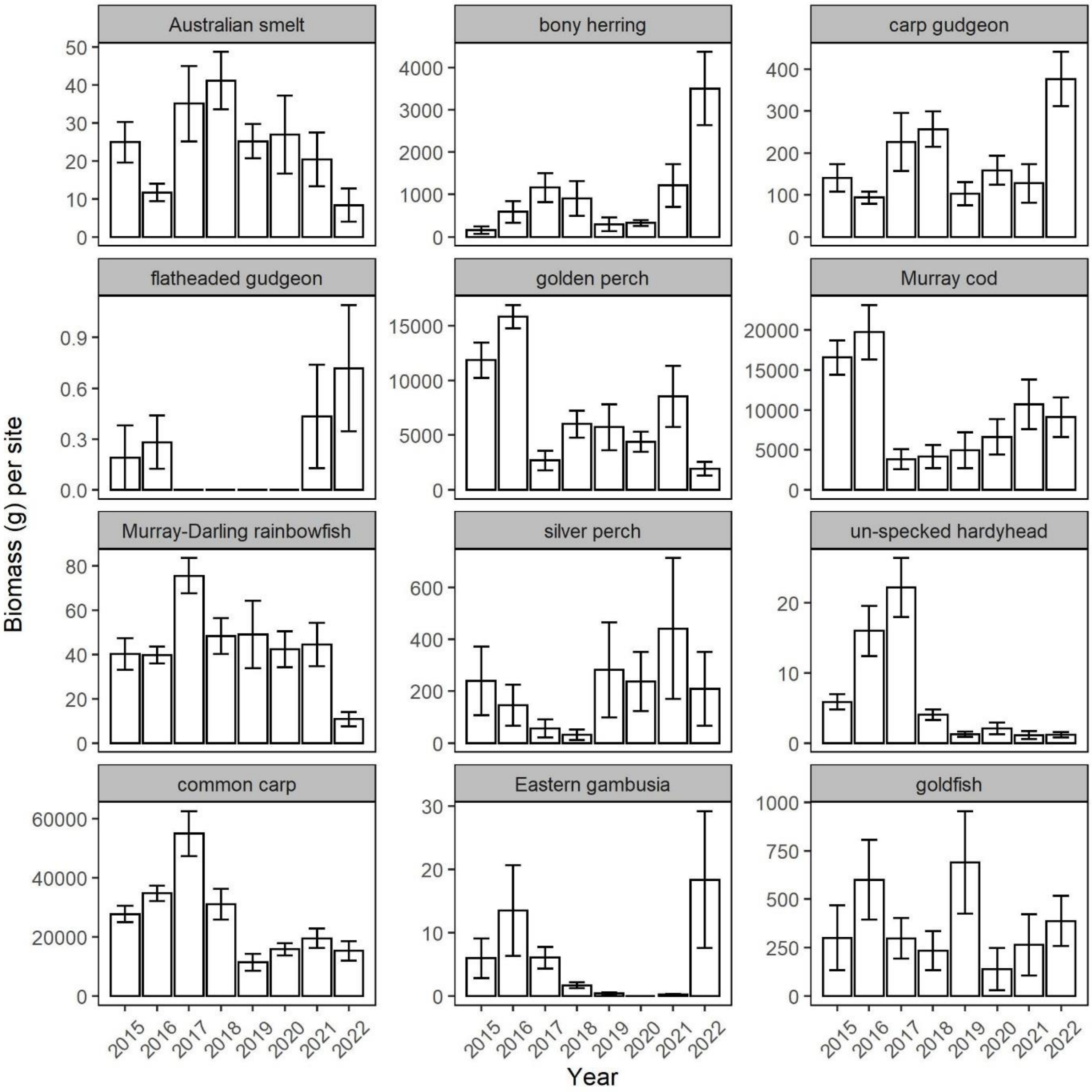


Figure 8.18 Biomass per site (weight of fish; mean ± SE) for each fish species within the Edward/Kolety-Wakool River system Selected Area, sampled from 2015–2022.

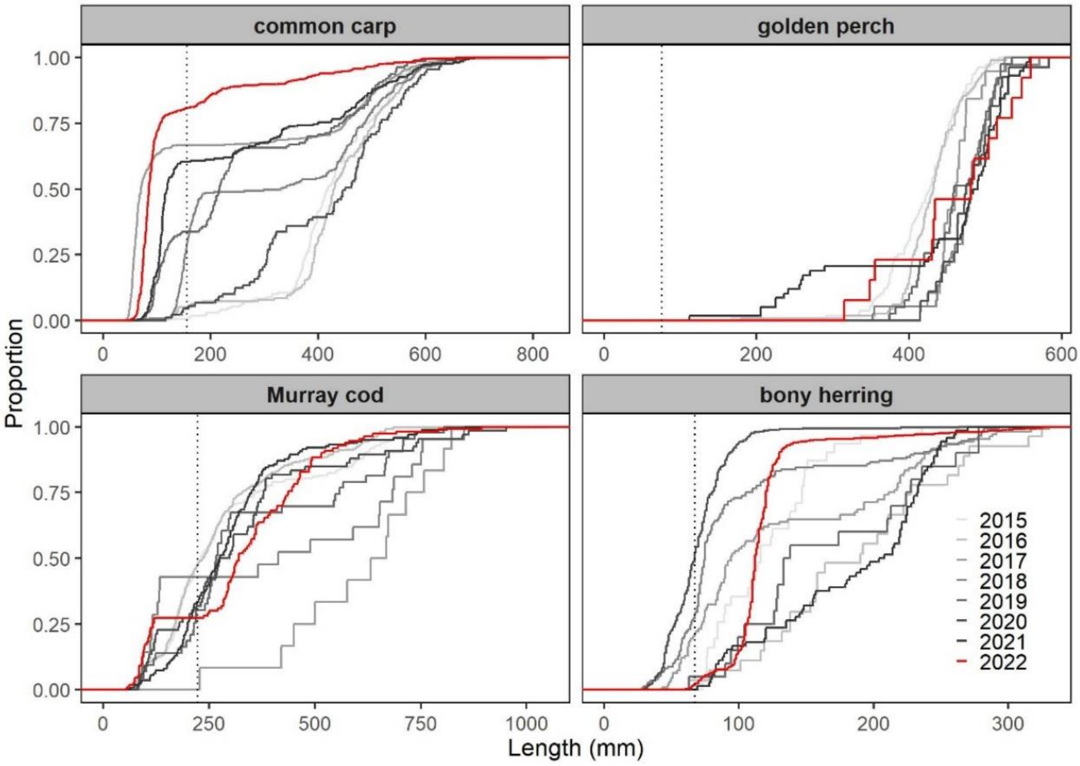


Figure 8.19 Cumulative length-frequency histograms of the four most common large-bodied species captured during Category 1 sampling in the Edward/Kolety-Wakool River system Selected Area in 2015–2022. The dashed line indicates approximate length at one year of age found in Table 8.4 and annual sample sizes are provided for each respective species and sampling year in Table 8.9.

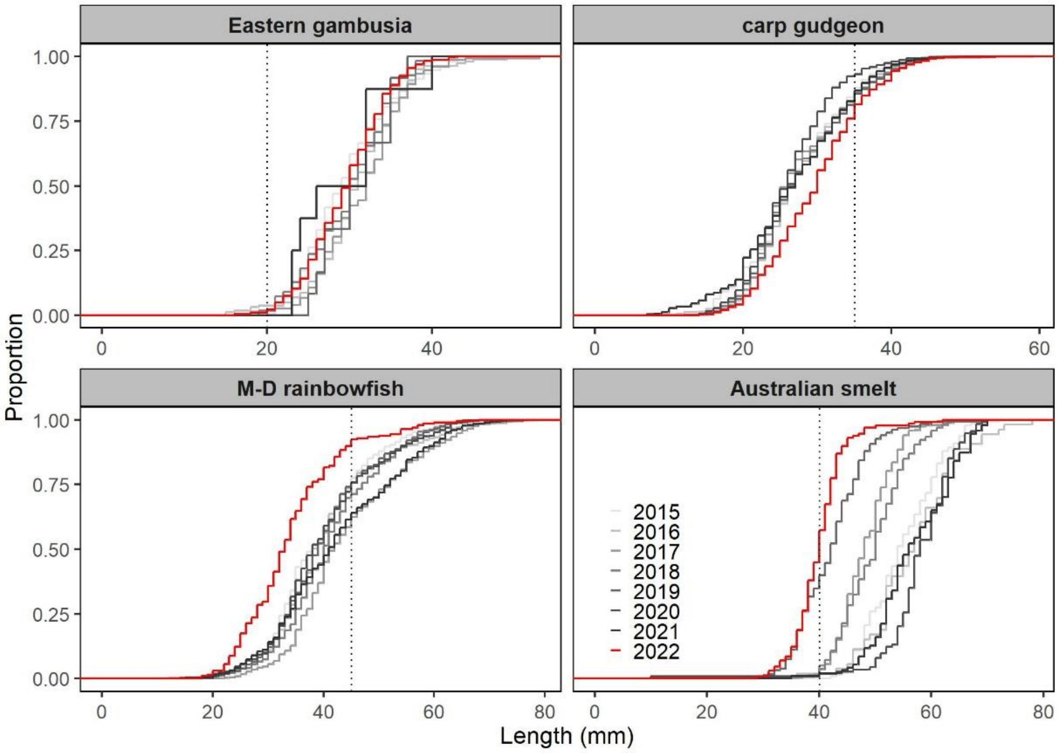


Figure 8.20 Cumulative length-frequency histograms of the four most common small-bodied species captured during Category 1 sampling in the Edward/Kolety-Wakool River system Selected Area in 2015–2022. The dashed line indicates approximate length at sexual maturity specified in Table 8.4 and annual sample sizes are provided for each respective species and sampling year in Table 8.9.

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 EKW system has responded to targeted watering events and the broader hydrological conditions of 2021-22. In addition to annual adult fish surveys that take place in the Mid-Wakool River upstream of Thule Creek (Category 1 methods), 2021-22 marked the third, near three-yearly, broad-scale adult fish survey of the larger Edward/Kolety Wakool River system. A summary of the species of larvae, recruits and adults present in the system in 2021-22 is provided in Table 8.11. Using these multiple lines of evidence, we provide a summary on how fish responded to hydrological conditions of 2021-22, a year characterized by high-in channel freshes in spring and summer and high connectivity of flows right throughout the southern Murray-Darling Basin, and provide recommendations for future water delivery.

It is important to provide some context of the 2021-22 fish surveys. In 2016-17 the EKW 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 that commenced in 2014. Since this time, LTIM (2014-2019) and Flow-MER (2019- present day) fish monitoring are identifying a continued, but 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 most species (Table 8.11, Watts et al. 2019). Of the fourteen native fish species that have been recorded in the EKW Selected Area since LTIM commenced in 2014, eleven were detected as either eggs/larvae, recruits or adults in 2021-22 (Table 8.11).

Table 8.11 Multiple lines of evidence: a summary of 2021-22 fish monitoring results in the Edward/Kolety-Wakool Selected Area, of the species known to occur in the area prior to 2021. For the 2021-22 sampling season – ticks denote the presence of larvae/eggs (indicating successful spawning), juveniles (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	**2021-22**			
Fish species	**Larvae**	**Juveniles**		**Adults**
		YOY recruits	**1+ juveniles**	
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 Darling rainbowfish	✓	✓		✓
flathead gudgeon	✓	✓		✓
unspecked hardyhead		✓		✓
obscure galaxias				
dwarf flathead gudgeon				
gambusia ^	✓			✓
oriental weatherloach ^				✓

Summary of key fish findings 2021-22

In the context of these longer-term results, key findings from 2021-22 EKW fish population surveys include:

- **Increase in juvenile (1+) golden perch subadults (1+) in the Selected Area.** This is the second consecutive year golden perch juveniles (as either YOY or 1+ fish) have been detected in the EKW River System monitored sites since surveys commenced in 2014. Similarly with other years, no eggs/larvae or YOY golden perch were recorded, so the capture of two 1+ golden perch in the targeted recruitment surveys in February 2022 may indicate immigration of juvenile golden perch into the system.
- **A high number of juvenile (1+) silver perch were recorded in the 2021-22 targeted recruitment surveys, with juveniles widespread across the four study zones.** This is the second consecutive year where we have observed high numbers of juveniles (1+) silver perch in the Edward/Kolety - Wakool Selected Area.
- **The Murray cod population continues to recover since the 2016-17 fish kills**. As with previous years, both spawning and recruitment appears widespread throughout the EKW Selected area.

Catches of adult Murray cod remain lower that those observed prior to the 2016-17 hypoxic blackwater event. Even though larval Murray cod catch was lowest on record in 2021-22, YOY recruitment was evident and widespread, with the largest catch rates of YOY fish in the Upper Wakool (zone 2) and Mid-Wakool River upstream of Thule Creek (zone 3) since the 2016-17 fish kills. Growth rates of juvenile Murray cod were also some of the highest recorded, indicating strong levels of productivity within the rivers to sustain growth.

- **Strong spawning and recruitment of flathead gudgeon.** 2021-22 marks the second consecutive year of strong spawning and recruitment in flathead gudgeon in the Edward/Kolety Wakool River system, as evidenced by higher catches of both larval and juvenile stages than in previous years.
- **Carp biomass dominated the 2021 adult fish assemblage**, at both the Mid-Wakool River (zone 3) target reach, as well as the broad-scale surveys. However, across the broad-scale surveys, carp biomass in 2022 was approximately 30% of that observed in 2015 and 2019. Carp responded to the high spring/summer in-channel freshes, with the majority of fish captured during the adult fish considered juvenile size.
- **Range expansion of river black fish.** River black were recorded at the greatest number of larval survey sites in 2021-22 than any other year in the LTIM/Flow-MER program. They were found at all five sites in the Upper Wakool River, and two sites in the Mid. Wakool River upstream Thule Creek. In addition, the targeted recruitment surveys also recorded river blackfish at one site in Yallakool Creek. These results confirm our previous observations of a positive range expansion for this species.

We discuss these key findings in detail below.

Periodic species (e.g., golden perch, silver perch, carp, bony herring)

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 EKW 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

This is the second consecutive year golden perch juveniles (as either YOY or 1+ fish) have been detected in the EKW River System monitored sites since surveys commenced in 2014.

Spawning of golden perch has not been detected in the EKW 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 2021-22, despite the highest spring/summer in-channel freshes that the Wakool and Yallakool Creek have experienced (in non-flood years) since 2014, and all other years of monitoring in the system, further supports our conceptual understanding of the role of the EKW River system in supporting juvenile and adult golden and silver perch as components of broader meta-populations.

The presence of juvenile (1+) golden perch in the EKW river system is most likely explained by immigration from the nearby Murray River. Previous flow recommendations 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 and again in this current year, both recommendations were taken up with specific watering actions delivered with the objective of achieving these outcomes. Results from 2020-21, and again in 2021-22 suggest that the high spring/summer in channel freshes created by both unregulated flows and the Southern Connected Spring Flow provided suitable immigration cues for juveniles into the system.

Silver perch

A high number of juvenile (1+) silver perch were recorded in the 2021-22 targeted recruitment surveys, with juveniles widespread across the four study zones. This is the second consecutive year where we have observed juveniles (1+) silver perch in the Edward/Kolety – Wakool Selected Area. Similarly to golden perch, evidence of localised spawning and recruitment in silver perch throughout the Edward/Kolety Wakool River System 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). Recent evidence has demonstrated that movement from the Murray mainstem into major tributaries (including the EKW) 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 EKW system resulted in rapid emigration of resident silver perch (Thiem et al. 2020). The 2021-22 spring/summer unregulated flows, in combination with the Southern Connected Flow saw not only the highest in-channel freshes moving through the Yallakool and Wakool River (in a non-flood year) since 2014, but also resulted in high connectivity of rivers, tributaries and anabranches right throughout the southern Murray Darling Basin. Such conditions are likely to have resulted in these flows acting as successful 'attracting' flows facilitating the movement of juvenile silver perch into the Selected Area.

Carp

While 2021-22 hydrological conditions in the EKW River system and throughout the Southern Murray Darling Basin more generally provided positive outcomes for native fish species, particularly golden and silver perch, responses by introduced species were also observed. Carp recruitment was associated with the high flows that moved through the entire EKW River system, with abundance of juveniles in 2021-22 matching that observed after the 2016-17 floods. 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).

Future tradeoffs between timing and delivery 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, whilst the large-channel flows and delivering earlier, cooler late winter in-channel freshes may reduce the likelihood of carp spawning and recruitment, whilst still providing positive outcomes for vegetation establishment (Chapter 7), hydrological connectivity and fish movement and pre-spawning conditions. Acknowledging and quantifying the trade-off between carp spawning and recruitment opportunities as a result of increasing flows into distributary creeks that connect back to the system, versus the benefit of spawning, recruitment and habitat provision for native species (see small-bodied fish responses below) will be continue to be important to take into consideration when developing future multiple objective environmental watering plans.

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 EKW 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 EKW 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 EKW River system continues to show a steady, but slow recovery towards levels observed prior to the 2016-17 fish-kill. 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 with previous years, Murray cod spawning and recruitment in 2021-22 was widespread throughout the EKW system, though less spawning and recruitment was observed in Wakool River downstream Thule Creek (zone 4) compared to previous years when spawning and recruitment has been strong.

Larval Murray cod catch was lowest on record in 2021-22. Nest construction, spawning and nest protection in Murray cod typically take place August through to December, with larval Murray cod typically first picked up by our surveys in late October. The large in-channel flows the EKW river system experienced from September to October 2021 may explain the low larval catches recorded, as the flow pulse most likely causing the wash out eggs and pre-drifting larval from nests. In contrast, high catch rates of Murray cod larvae are associated with years where i) large spring in-channel freshes are absent, ii) flows have been kept relatively stable but exceed base flows (yet still allowing 30% variability in discharge) and where iii) the timing of these stable but higher than base flows occurred from August to early January. In future years where spring unregulated flows are absent, continued consideration of future water delivery in the upper Wakool River that provides flows of a minimum of 100 ML/day with variability up to 200 ML/day from September until the end of the breeding season (early December) are recommended for maximising the availability of suitable nesting areas during Murray cod breeding season, whilst still allowing for in-channel flow variability so that river does not run flat for several months.

Opportunistic small-bodied 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 EKW Selected Area: Australian smelt, carp gudgeon, flathead gudgeon, unspecked hardyhead, Murray Darling 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, often with good, submerged plant cover, are important nursery areas for this group of fish (Humphries et al. 1999, Lyon et al. 2010, Bice et al. 2014; Ye et al. 2021). 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 slow water habitat are likely to result in an increase larval production and subsequent adult abundance (Humphries et al. 1999, Lyon et al. 2010).

Indeed, we observed this second set of conditions in 2021-22: where high in-channel flows inundated low-lying regions of the main river channels, ephemeral creeks and backwaters including Black Dog Creek, Cochran's Creek, Jimaringle Creek and Bullatale Creek for several months during spring and early summer (See Sentinel Imagery, Chapter 4). Associated with these conditions, both the broad-scale (cat 3) and Mid-Wakool River (cat 1) adult fish surveys recorded above average recruitment for the Australian smelt, carp gudgeon, unspecked hardyhead, flathead gudgeon and Murray Darling Rainbowfish. These findings provide an interesting contrast to previous studies where increases in abundance and biomass of small-bodied fish have been associated with low stable flows (Hladyz et al. 2021, Ye et al. 2022), and declines in abundances and biomass are associated with high spring/summer flows (Ye et al. 2022). These seemingly different responses of small bodied native fish to high in-channel flows in the EKW in 2021-22 to these previous studies can most likely be explained by differences in magnitude of slow-slack water habitat that may either created, or destroyed by in-channel flows as a result of the interaction between discharge and geomorphology of the area.

9 Recommendations for management of environmental water

Recommendations from previous reports (2014-2021)

A summary of recommendations from all previous EKW LTIM annual reports (Watts et al. 2015, 2016, 2017b, 2018, 2019) and EKW Flow-MER annual reports (Watts et al. 2020, 2021) 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 from 2021-22 monitoring and evaluation

The following nine recommendations are based on findings from this report, with some reference made to recommendations and findings in previous reports.

Recommendation 1

The hydrographs in 2021-22 for the rivers and tributaries of the EKW system were more complex than in previous LTIM/Flow-MER years. The flows included unregulated freshes during spring and summer as well as delivery of Commonwealth environmental water from a wide range of sources; Edward escape, Wakool escape, Niemur escape, Yallakool offtake, Colligen Offtake, Wakool offtake, and return flows from Millewa Forest due to the delivery of environmental water from Hume Weir. At times there was more than one source of water contributing to the hydrograph.

The return flows from Hume Weir in combination with the unregulated freshes from mid-August to the end of December 2021, provided benefits for the EKW system by contributing carbon rich water to boost productivity. Compared to years when flows were highly regulated, the magnitude of variation between low flows and peak flows was larger in 2021-22 than in previous years. However, the environmental water returning from Millewa Forest to the EKW system in 2021-22 reduced the magnitude of variation between low flows and peak flows in Yallakool Creek, and Colligen Creek compared to what would have occurred in 2021-22 in the absence of CEW returning from MIllewa Forest. Thus, there is a trade-off of between the benefits of the EKW system receiving carbon rich water returning from Millewa Forest, versus possible detrimental effects of reduced variability of daily discharge.

Recommendation 1: Explore ways to gain benefits from Commonwealth environmental water returning from Millewa Forest, whilst at the same time maintaining variability of flows in the Edward/Kolety-Wakool tributaries.

Recommendation 2

Environmental water delivery to Wakool River and Yallakool Creek combined with unregulated flows in spring/early summer 2021-22 was the closest yet (since the LTIM/Flow-MER project commenced in 2014) to achieving environmental flows that included the timing, magnitude, duration of freshes that could potentially support spawning of golden perch and silver perch. The continued absence of any evidence of major spawning activity in these two species in Yallakool Creek and the Wakool River monitoring sites supports the hypothesis that these two river systems are not a key location for spawning of golden perch and silver perch.

Recommendation 2: Do not include spawning of golden perch as one of the key objectives for future environmental watering actions in Yallakool Creek and the Wakool River.

Recommendation 3

The outcomes of environmental watering actions in 2021-22, combined with outcomes from previous years, provide strong evidence that one of the key roles of the EKW system in the context of the broader Murray River system is to provide suitable spawning habitat for some fish species (e.g Murray cod, River blackfish, small bodied native fish), support recruitment and growth of juvenile fish, and provide habitat and refuge for adult fish. These benefits for fish and other components of the ecosystem can be supported by maintaining and enhancing connectivity within the system, and connectivity between the EKW system and Murray system throughout the year.

Recommendation 3: Undertake watering actions each watering year that promote connectivity within the EKW system, and connectivity between the EKW system and the Murray River. This includes; i) deliver in-channel freshes in late winter/spring that exceed the current normal operating rules to increase connectivity within tributaries and connectivity via runners between tributaries, ii) deliver continuous base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat and prevent negative consequences of winter cease-to-flow; iii) Undertake watering actions to improve the connectivity and other outcomes in intermittent and ephemeral streams and flood runners in the EKW system.

Recommendation 4

The management of the offtake regulator for Colligen Creek is automated, and thus can be more easily operated than some of the other manually operated regulators in the EKW system. In addition, Colligen Creek is closer to the Stevens Weir structure and the offtake for Wakool Main Canal, so it is more convenient for water managers to use the Colligen Creek offtake to facilitate the balance of operational water in Stevens Weir when there is excess water in the system, such as water orders being withdrawn due to rain.

Consequently, Colligen Creek continues to experience short-lived flow peaks and rapid recession of flows that can be detrimental for maintaining a balance of erosion and sedimentation on riverbanks. Rapid recession of flows means that the sediment removed by natural processes during a rise is not the replaced by deposition of sediment on recession. In addition to this negative physical outcome, rapid recession of flows can also have negative ecological outcomes such as reducing the replenishment of seedbank.

Recommendation 4: Mitigate the negative consequences of rapid rises and falls in Colligen Creek hydrograph by working with water managers and river operators to achieve better outcomes through planning options such as i) increasing the rate of recession following rapid rises in flows due to river operations, ii) delivery of the excess water to other parts of the system instead of delivering a short flow peak to Colligen Creek.

Recommendation 5

The delivery of environmental water through irrigation escapes to improve water quality has proven to be an effective management tool that has provided benefits but has not resulted in recorded negative outcomes in the river system.

Recommendation 5: Continue to include a water use option in water planning that enables environmental water to be used to mitigate adverse water quality events and potential fish kills. Work with a range of organisations and the community to 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}.

Recommendation 6

In 2020-21 and 2021-22 environmental watering actions from the Wakool escape delivered variable base flows to the upper Wakool River to maintain water quality during warmer months. In addition to achieving this water quality outcome, these watering actions provided other significant outcomes, including increasing longitudinal connectivity, increasing flow variability, and helping to improve riverbank plant outcomes. These findings suggest that there are benefits to be gained from using the Wakool Escape to deliver environmental water to the Wakool River, even at times when there are no refuge flows required.

Recommendation 6: Undertake further watering actions from the Wakool escape to improve the connectivity and ecosystem outcomes in the Upper Wakool River and reaches further downstream in the mid- and lower Wakool River. Deliver larger freshes with increased variability to maintain water quality, enable riverbank vegetation to establish and be maintained, and support good fish outcomes.

Recommendation 7

There are many ecosystem and cultural benefits to be gained from watering Werai Forest. The multiple unregulated pulses in 2021-22 resulted in high flows downstream of Stevens Weir and several events inundated Werai Forest and returned flows from Werai Forest to Colligen Creek. This did not result in adverse outcomes for water quality or any recorded deaths of fish in the Colligen-Niemur system in 2021-22. Research undertaken in 2021-22 showed that response of aquatic plants and algae in Werai Forest can assist the productivity and help maintain good water quality of outflows from the forest. Research on patterns of inundation in Werai Forest (Watts et al. 2022) showed that return flows from the forest into the Edward/Kolety River commenced when the discharge downstream of Stevens Weir was between 3,152 - 3,237 ML/d, and return flows from Tumudgery Creek into Colligen Creek commenced when the discharge DS Stevens Weir was between 5,471 ML/d and 9,340 ML/d.

Recommendation 7: Explore options to use environmental water to support high flow event downstream of Stevens Weir (>2700 ML/day) that inundates low lying parts of Werai forest. If possible, use environmental water to support higher flow events downstream of Stevens Weir (> 5471 ML/d) to inundate low lying part of Werai forest as well as support return flows to Colligen Creek and the Edward/Kolety River.

Recommendation 8

Evidence from the fish recruitment monitoring and adult fish strongly suggests that there was immigration of silvers and golden juveniles/sub adults into the EKW system during the high unregulated flows in 2021-22 which were enhanced by environmental water delivered from irrigation escapes. We continue to support recommendation 4 from 2019-20 report that encourages the use of environmental water to support movement of native fish.

Recommendation 8: 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.

Recommendation 9

The combination of unregulated spring/early summer flows in the Murray, environmental watering of ephemeral and intermittent creeks, and environmental watering from MIL escapes, created more connectivity in the EKW system in 2021-22 than has been seen in any other year, except during large flood years. The river ecosystem greatly benefits from connectivity, that includes the maintenance of flow during winter that promotes temporal availability and continuity of instream habitat, fish movement, and survival of aquatic plants.

Winter shutdown of regulators is an operational norm to facilitate maintenance of infrastructure and related shut down of the MIL delivery system. Unfortunately, this means that some of the benefits from the increased connectivity created by environmental watering in spring, summer and autumn will be reduced due to operational shutdown periods that occur in tributaries during winter. Previous winter watering has shown that the provision of winter base flows also enables partial drying of some wetland areas attached to Stevens weir and within its connected river and creek channels. It would maximise the benefit to the river ecosystem to deliver winter flows to the tributaries in as many years as possible.

Recommendation 9: Maximise the benefits of connectivity flows by working with river managers and river operators to maximise the opportunities to deliver environmental water to tributaries during winter, and minimise the frequency and duration of operational shutdowns in winter.

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12 Appendices

Appendix 1.

Summary of watering action/s (from CEWO 2021b, Edward/Kolety-Wakool 2021-22 Acquittal report)

Dates (start/end)	**Target asset (Refer to Figure 9 for location of asset)**	**Watering Action Reference No. (WAR)**	**Flow component type and target/planned magnitude, duration, timing and/or inundation extent**	**CEW volume used (ML)**	**Other volumes (ML)**	**Total volume – all contributors (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may have affected expected outcomes**	**Observed hydrological outcomes** (e.g., flow velocity, area/depth of inundation, number of wetlands inundated)
Start: 01/07/2021 End: 30/06/2022	Yallakool-Wakool Colligen-Niemur	WUM10117-01	Refer to hydrograph in Figure 1 and Figure 2 above. **Summary:** provision of spring fresh, elevated spring baseflow, three summer freshes and autumn fresh.	0	8,156	NSW EHG provided a total of 8,156ML below choke for Autumn pulse in both colligen/ Niemur and Yallakool/Wakool	An autumn pulse is Delivering Colligen/Niemur and the Yallakool/Wakool.	Unregulated flows prevented CEW delivery.	N/A
Start: 04/08/2021 End: 31/12/2021	The Pollack (K-P)	WUM10117-02	**Summary:** Wetland inundation.	3,500	0	3,500	**Primary** • inundated wetland area • maintaining aquatic vegetation **Secondary** • Provide habitat for SBF and frogs • provide waterbird foraging habitat	**Summary:** No operational issues. For planned vs actual delivery see hydrograph in Figure 5 above.	Planned flood depth and inundation extent were both achieved (Hutton, 2022) Primary and secondary objectives both achieved (Hutton, 2022) Refer to Figures 6 and 7 (Hutton, 2022).
Start: 12/10/2021 End: 10/12/2021	Little Forest (K-P)	WUM10117-03	**Summary:** Wetland inundation.	994	0	994	**Primary** • inundated wetland area	**Summary:** No operational issues.	Planned flood depth and inundation extent were both achieved (Hutton,

Dates (start/end)	**Target asset (Refer to Figure 9 for location of asset)**	**Watering Action Reference No. (WAR)**	**Flow component type and target/planned magnitude, duration, timing and/or inundation extent**	**CEW volume used (ML)**	**Other volumes (ML)**	**Total volume – all contributors (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may have affected expected outcomes**	**Observed hydrological outcomes** (e.g., flow velocity, area/depth of inundation, number of wetlands inundated)
							• maintaining aquatic vegetation **Secondary** • Provide habitat for SBF and frogs provide waterbird foraging habitat	For planned vs actual delivery see hydrograph in Figure 8 above.	2022) Primary and secondary objectives both achieved Little Forest Event 2021/22 Notes – March 6th Event Day 134 (Hutton, 2022)
Start: 01/11/2021 End: 29/05/2022	Tuppal Creek	WUM10117-04	**Summary:** provision of elevated flows in the creeks.	3,591	NSW 500	4,091	**Primary** • maintain connectivity with the Edward River • maintain riparian vegetation • maintain water quality **Secondary** maintain habitat for native fish and frogs	**Summary:** Delivery was agreed to be 50/50 CEW/NSW however, due to a lack of availability the contributions were modified so that contributions were CEW 3,591ML and NSW 500ML. Delivery of 20ML/d baseflow maintained through summer and autumn	
Start: 10/09/2021 End: 07/01/2022	Jimaringle-Cockran-Gwynnes Creek System	WUM10117-05	**Summary:** provision of elevated flows in the creeks.	13,258	NSW 2,557	15,815	**Primary** • maintain riparian and aquatic vegetation condition.	Delivery was agreed to be 50/50 CEW/NSW however, due to a lack of availability	There was a positive response from fringing vegetation, including river red gum and black box.

Dates (start/end)	**Target asset (Refer to Figure 9 for location of asset)**	**Watering Action Reference No. (WAR)**	**Flow component type and target/planned magnitude, duration, timing and/or inundation extent**	**CEW volume used (ML)**	**Other volumes (ML)**	**Total volume – all contributors (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may have affected expected outcomes**	**Observed hydrological outcomes** (e.g., flow velocity, area/depth of inundation, number of wetlands inundated)
							• maintain habitat and support breeding for native animals including frogs. **Secondary** • maintain connectivity. • maintain water quality.	the contributions were modified so that contributions were CEW 13,258ML and NSW 2,557ML. Spring fresh was provided and small top up deliveries continued through summer.	Some wetland plant species recruitment, including duckweed, water primrose, water couch and common spike-rush. Southern bell frogs were heard calling in Jimaringle.
Start: 10/09/2021 End: 08/12/2021	Murrain-Yarrien Creek	WUM10117-06	**Summary:** provision of elevated flows in the creeks.	2,442.6	NSW 1,407	3,849.6	**Primary** • maintain riparian and aquatic vegetation condition. • maintain habitat and support breeding for native animals including frogs. **Secondary** • maintain connectivity. maintain water quality.	Delivery was agreed to be 50/50 CEW/NSW however, due to a lack of availability the contributions were modified so that contributions were CEW 2,442.6ML and NSW 1,407ML. Delivery of autumn fresh	
Start: 28/09/2021	Thule Creek	WUM10117-07	**Summary:** provision of elevated flows in the creeks.	306	NSW 94	400	**Primary** • maintain riparian and aquatic	Delivery was agreed to be 50/50 CEW/NSW	

Dates (start/end)	**Target asset (Refer to Figure 9 for location of asset)**	**Watering Action Reference No. (WAR)**	**Flow component type and target/planned magnitude, duration, timing and/or inundation extent**	**CEW volume used (ML)**	**Other volumes (ML)**	**Total volume – all contributors (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may have affected expected outcomes**	**Observed hydrological outcomes** (e.g., flow velocity, area/depth of inundation, number of wetlands inundated)
End: 26/12/2021							vegetation condition. - maintain habitat and support breeding for native animals including frogs. **Secondary** - maintain connectivity. maintain water quality.	however, due to a lack of availability the contributions were modified so that contributions were CEW 306ML and NSW 94ML. Delivery of small top up flows to the creek to maintain habitat and water quality for native fish.	
Start: 29/10/2021 End: 26/01/2022	Whymoul Creek	WUM10117-08	**Summary:** provision of elevated flows in the creeks.	143	NSW 64	207	**Primary** - maintain riparian and aquatic vegetation condition. - maintain habitat and support breeding for native animals including frogs. **Secondary** - maintain connectivity. maintain water quality.	Delivery was agreed to be 50/50 CEW/NSW however, due to a lack of availability the contributions were modified so that contributions were CEW 143ML and NSW 64ML.	

Dates (start/end)	**Target asset (Refer to Figure 9 for location of asset)**	**Watering Action Reference No. (WAR)**	**Flow component type and target/planned magnitude, duration, timing and/or inundation extent**	**CEW volume used (ML)**	**Other volumes (ML)**	**Total volume – all contributors (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may have affected expected outcomes**	**Observed hydrological outcomes** (e.g., flow velocity, area/depth of inundation, number of wetlands inundated)
Start: 10/09/2021 End: 08/12/2021	Yarrein Creek	WUM10117-09	**Summary:** provision of elevated flows in the creeks.	8,838	NSW 1,953	10,791	**Primary** • maintain riparian and aquatic vegetation condition. • maintain habitat and support breeding for native animals including frogs. **Secondary** • maintain connectivity. • maintain water quality.	Delivery was agreed to be 50/50 CEW/NSW however, due to a lack of availability the contributions were modified so that contributions were CEW 8,838ML and NSW 1,953ML. Deliveries for an autumn fresh.	
Start: 14/09/2021 End: 08/12/2021	Murray Irrigation area private wetlands	WUM10117-10	**Summary:** Wetland inundation.	6,955.9	0	6,955.9	**Primary** • maintain aquatic vegetation condition. • maintain habitat and support breeding for native animals including frogs. **Secondary** • maintain connectivity. • maintain water quality.	Delivery is for a few sites in Autumn to provide habitat for waterbirds and maintain vegetation condition.	

Dates (start/end)	**Target asset (Refer to Figure 9 for location of asset)**	**Watering Action Reference No. (WAR)**	**Flow component type and target/planned magnitude, duration, timing and/or inundation extent**	**CEW volume used (ML)**	**Other volumes (ML)**	**Total volume – all contributors (ML)**	**Expected outcomes (primary and secondary as at delivery)**	**Actual delivery details and any operational issues that may have affected expected outcomes**	**Observed hydrological outcomes** (e.g., flow velocity, area/depth of inundation, number of wetlands inundated)
Start: 10/09/2021 End: 15/01/2022	Wakool, Edward, Niemur, and Billabong/Finley escapes	WUM10117-11 WUM10117-12 WUM10117-13 WUM10117-14	**Summary:**Fresh	73,422.1	0	73,422.1	**Primary** maintain water quality during hypoxic blackwater conditions to provide refuge habitat for fish.	Delivery was agreed as 100% CEW	
Start: 01/09/2021 End: 1/05/2022	Buccaneit-Cunninyeuk Creek	WUM10117-15	**Summary:** provision of elevated flows in the creeks.	301	0	301	**Primary** • maintain riparian and aquatic vegetation condition. • maintain habitat and support breeding for native animals including frogs. **Secondary** • maintain connectivity. maintain water quality.	Delivery was agreed to be 50/50 CEW/NSW however, due to a lack of availability the contributions were modified so that contributions were 100% CEW.	

Appendix 2

Summary of recommendations from Edward/Kolety-Wakool LTIM annual reports (2014-15, 2015-16, 2016-17, 2017-18, 2018-19) and Flow-MER annual report (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 Undertake watering actions to improve the aquatic and riverbank vegetation outcomes in the Upper Wakool River.	2014-15 (R3) 2015-16 (R6) 2016-17 (R5) 2019-20 (R9) 2020-21 (R4)	2018-19 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) 2015-16 (R4) 2016-17 (R4) 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. 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) 2015-16 (R3) 2017-18 (R4) 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 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) 2015-16 (R8)	2015-16 2016-17 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. 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. 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) 2015-16 (R2) 2016-17 (R3) 2019-20 (R7, R8) 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 EKW 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. 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) 2015-16 (R5) 2018-19 (R2) 2019-20 (R1)	2015-16 2016-17 2018-19 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) 2020-21 (R2)	
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) 2015-16 (R7)	2014-15 2015-16 2016-17 2017-18 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}. 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) 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 EKW system to better inform future decisions on environmental watering in this system.	2014-15 (R9) 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 EKW system	2016-17 (R2)	Not yet implemented
19. Undertake in-channel habitat mapping for key reaches of the EKW 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 (R1)	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) 220-21 (R3)	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
26. Undertake watering actions to improve the connectivity and other outcomes in intermittent and ephemeral streams and flood runners in the EKW system. Consideration of timing of delivery that reduces opportunities for carp spawning whilst minimising hypoxic blackwater may need to also be taken in account.	2020-21 (R5)	