Australian Government
Commonwealth Environmental Water Office

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project

Lower Murray River

2017-18 Summary Report

A summary report prepared for the Commonwealth Environmental Water Office by the Lower Murray River Selected Area team

March 2019

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Lower Murray River 2017-18 Summary Report. A summary report prepared for the Commonwealth Environmental Water Office by the Lower Murray River Selected Area team.

This monitoring project was commissioned and funded by Commonwealth Environmental Water Office (CEWO) with additional in-kind support from South Australian Research and Development Institute (SARDI) and South Australian Department for Environment and Water (DEW). The authors of this report as well as the CEWO respectfully acknowledge the traditional owners of Country in the Murray-Darling Basin, their Elders past and present, their Nations, and their cultural, social, environmental, spiritual and economic connection to their lands and waters. In particular, the Ngarrindjeri Nation and the First Peoples of the River Murray and Mallee as traditional owners of the land and water on which this publication is focused.

Disclaimer

Table of contents

Table of contents i

Glossary i

Executive summary ii

1 Monitoring and evaluation of environmental water in the Lower Murray River .. 1

1.1 Background 1
1.2 The Lower Murray River and monitoring indicators 1
1.3 Purpose of this summary report 2

2 Environmental watering in the Lower Murray River in 2017-18 3

3 Key outcomes from environmental water use 5

3.1 Expected outcomes 5
3.2 River hydraulics 5
3.3 River metabolism 6
3.4 Salt, nutrient and phytoplankton transport 7
3.5 Microinvertebrate diversity and transport 8
3.6 Golden perch reproduction 9

4 Other findings from monitoring: Fish community 11

5 Implications for future management of environmental water 13

6 References 14

Glossary

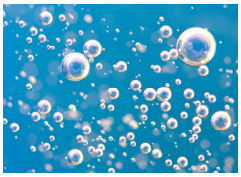
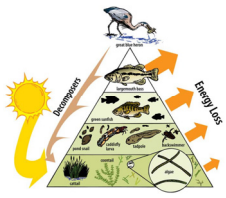
biofilm	A collection of microscopic organisms (made up of algae, bacteria and fungi) attached as a 'film' on living (e.g. tree root) and non-living (e.g. wooden pylon) surfaces.
flowing water habitat	Water defined as flow greater than 0.3 metres per second.
hydraulics	The physical characteristics of water flow, e.g. velocity (speed) and turbulence.
microinvertebrates	Invertebrates of microscopic size (e.g. rotifers, cladocerans and copepods), which may live in the water column, on the river floor or on vegetation along the river bank.
phytoplankton	Microscopic algae suspended in the water column that make their own food from sunlight through photosynthesis.
primary productivity	The rate at which energy is converted to organic compounds (food) by autotrophs (e.g. algae and plants) during photosynthesis.
recruitment	Survival past the critical stages of early life (e.g. larval) to become juveniles in a population. In this report, a fish that is sampled as a juvenile (~6 months old) in autumn is defined as a new recruit.
spawning	The act or process of producing or depositing eggs.

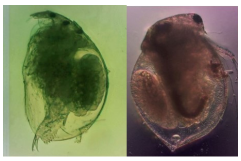
Executive summary

During 2017-18, ~894 GL of Commonwealth environmental water was delivered through a series of watering events to the Lower Murray River (LMR), coordinated to achieve a range of environmental outcomes across the southern connected Basin. Commonwealth environmental water delivery largely consisted of flows continuing down the river from upstream watering events (e.g. Goulburn and Murrumbidgee rivers) and promoted increased flows in spring–early summer ('pulses', up to 18,000 ML/d) in the LMR channel. This report presents the key ecological responses observed in the LMR during 2017-18, which was year four of the five-year Commonwealth Environmental Water Office (CEWO) Long-term Intervention Monitoring (LTIM) project. A series of annual technical reports (Ye *et al.* 2016; 2017; 2018; 2019) provide detailed methods, results and evaluation of ecosystem responses to environmental water delivery.

Key outcomes of environmental watering in 2017-18

In 2017-18, Commonwealth environmental water delivery contributed to a number of ecological outcomes:

	'Flowing water' habitat (greater than 0.3 metres per second) increased in area, and water levels were more variable. More flowing water benefits native plants and animals that are adapted to a riverine environment. Variable water levels generally improve bank vegetation health and increase the diversity of biofilms, which is a key component of riverine food webs.
	Oxygen in the water during spring–summer was maintained at an adequate level (8−10 milligrams per litre, mg/L). Aquatic animals generally need oxygen levels above 5 mg/L, particularly during spring–summer, which is the main reproductive season of many species.
	In the river channel, food production and consumption, and transport of nutrients and phytoplankton all increased. Greater primary production provides more food to aquatic food webs (e.g. for invertebrates and fish). Transported food resources from the river also benefit food webs in the Lower Lakes and the Coorong.
	Flows over the barrages to the Coorong were continuous throughout the year, maintaining a connection between the river and the Coorong estuary to support a functioning river system. Some species need this connection to move between fresh and saltwater habitats to successfully reproduce. Continuous barrage flows in 2017-18 reduced salinity concentrations in the Coorong, providing favourable conditions for estuarine species, and removed excess salt from the Basin.

	Microinvertebrates from upstream sources (e.g. Goulburn River/southern Basin) were transported to the LMR, which contributed to increased diversity and potentially provided a more diverse food source for larger animals (e.g. fish).
	Spawning of golden perch occurred in the LMR, but there was no evidence of successful 'recruitment', i.e. survival to juvenile stage, which would have contributed to the broader population.

Management implications

In 2017-18, which was a dry year, a large volume (1,162 GL) of environmental water, which included ~894 GL of Commonwealth environmental water, was delivered to the LMR. Environmental water promoted pulses of flow (up to ~40% of bank height) in the LMR during spring–summer. The proportion of weir pools (stretches of river between weirs) experiencing 'flowing water' habitat increased due to environmental water; although not to the extent that once characterised the LMR under natural (pre-regulation) conditions.

The increased flow by environmental water also contributed to increased food production and consumption in the LMR, increased river connection and microinvertebrate transport from upstream to this region. Whilst golden perch spawning occurred, the flow conditions in 2017-18 did not result in recruitment of golden perch. Environmental water deliveries that reinstate key features of the natural flow regime (e.g. high (>20,000 ML/d) in-channel spring–summer flow pulses) and support the restoration of flowing water habitats should help to restore ecosystem function and rehabilitate riverine plants and animals in the region. To maximise ecological outcomes, however, we need to better understand specific flow (e.g. timing, magnitude and duration) and habitat requirements of flow-dependant species to inform flow management.

Despite limited golden perch outcomes, environmental water has demonstrated its importance in supporting barrage releases to the Coorong, particularly in low flow years (i.e. 2014-15, 2015-16 and 2017-18). Barrage flows are critical in exporting salt from the Basin, maintaining freshwater–estuarine habitat connectivity, reducing salinity levels in the Coorong and improving habitat and enhancing reproductive success for many estuarine species (e.g. fish).

1 Monitoring and evaluation of environmental water in the Lower Murray River

1.1 Background

In 2014, the five-year (2014-15–2018-19) Commonwealth Environmental Water Office (CEWO) Long-Term Intervention Monitoring (LTIM) Project was established to monitor and evaluate long-term ecological outcomes of Commonwealth environmental water delivery in the Murray–Darling Basin (MDB). The project was implemented across seven Selected Areas throughout the MDB, including the Lower Murray River, to enable evaluation at the Basin-scale, in addition to Selected Area (local) evaluation. The overall aims of the project are to demonstrate the ecological outcomes of Commonwealth environmental water delivery and support improvements to how it is managed.

1.2 The Lower Murray River and monitoring indicators

The Murray River, which includes the South Australian section (herein, Lower Murray River, LMR), is a complex system that comprises the main river channel, anabranches, floodplain/wetlands, billabongs, tributaries and the Lower Lakes, Coorong and Murray Mouth, which provide a range of habitats and support significant flora and fauna. Downstream of the Darling River junction, the Murray River is modified by a series of low-level (<3 m) weirs (Figure 1), changing a connected flowing river to a series of 'weir pools' (Walker 2006).

Figure 1. The Lower Murray River comprises various habitats including limestone cliffs in the gorge zone (left) (photo: SARDI) and locks/weir pools (right, Lock 2) (photo: Michael Bell).

The CEWO LTIM Project in the LMR focuses on the main channel of the LMR between the South Australian border and Wellington, with salt and nutrient transport modelling extending to the Lower Lakes and Coorong (Figure 2). Indicators were monitored at various sites, covering three riverine zones (floodplain, gorge and swamplands) and the Lower Lakes and Coorong (Wellington to Murray Mouth) (Figure 2).

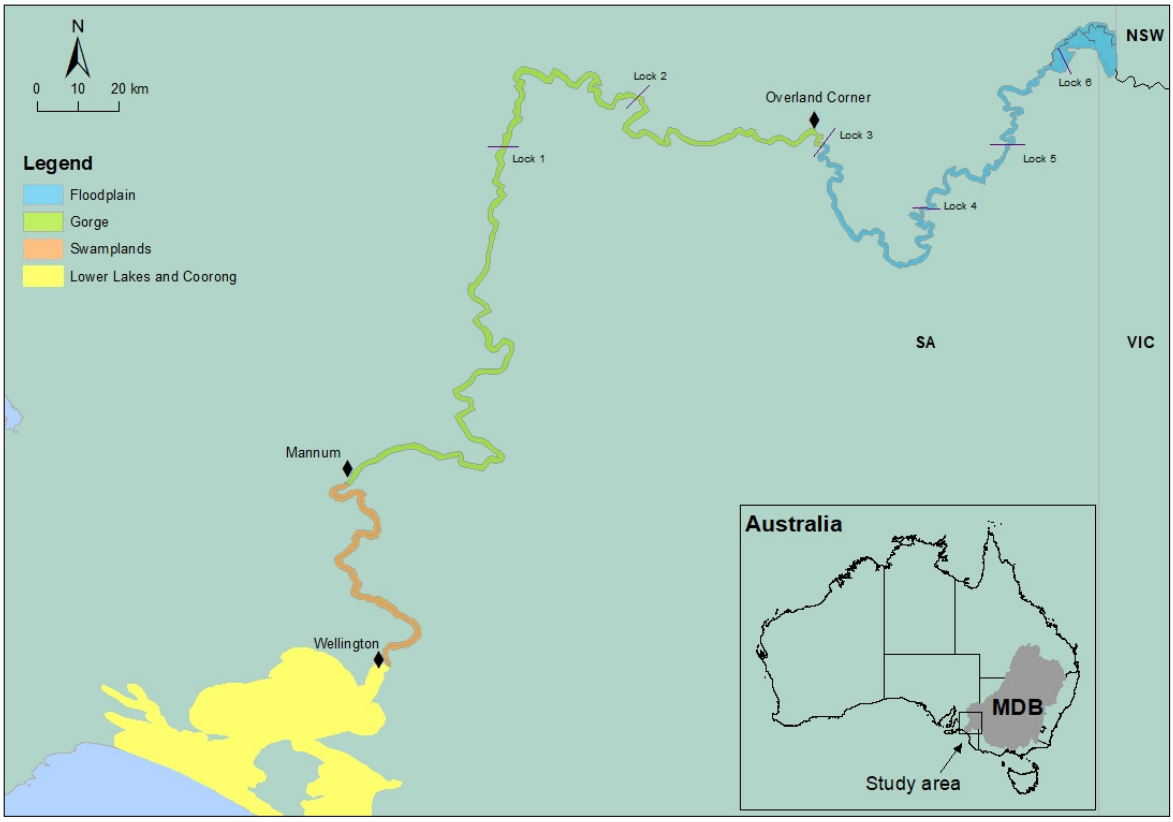


Figure 2. Map of the LMR Selected Area showing the floodplain (blue), gorge (green) and swamplands (orange) zones, and the Lower Lakes, Coorong and Murray Mouth (yellow).

Seven indicators were used to assess ecological responses to environmental water delivery in the LMR. *Hydrology*, *Stream Metabolism* and *Fish Community* followed standard protocols to support comparisons across other areas of the MDB (Hale *et al.* 2014). *Hydrological Regime*, *Matter Transport*, *Microinvertebrates* and *Fish Spawning and Recruitment* were developed to address objectives and test a series of LMR-specific hypotheses with respect to biological/ecological response to environmental flows.

1.3 Purpose of this summary report

This report provides a summary of environmental water use in the LMR during the fourth year (2017-18) of the CEWO LTIM Project, key outcomes from this watering year, and general implications for environmental flow management. Detailed information, including methods, results and evaluation of Commonwealth environmental water, are provided in the technical report (Ye *et al.* 2019).

Monitoring and evaluation of Commonwealth environmental water in the LMR for previous years of LTIM (2014-15–2016-17) is available in the annual evaluation reports (http://www.environment.gov.au/water/cewo/catchment/lower-murray-darling/monitoring). While results specific to the LMR are reported here, a broader Basin-scale analysis including results from all seven Selected Areas will be produced by the Centre for Freshwater Ecosystems at La Trobe University.

2 Environmental watering in the Lower Murray River in 2017-18

Overall, 2017-18 was a dry year. A total of ~894 gigalitres (GL)[a] of Commonwealth environmental water was delivered to the LMR from 1 July 2017 to 30 June 2018, in conjunction with other sources of environmental water (e.g. the Murray-Darling Basin Authority, MDBA, The Living Murray Initiative, 176 GL) (Figure 4). All environmental water sources contributed to 43% of the total flow in the LMR in 2017-18, with Commonwealth environmental water contributing 33%. Without environmental water, flow would have been at minimum 'entitlement' levels for most of the year, except for a small flow event in late December.

Commonwealth environmental water delivery to the LMR largely consisted of flows continuing down the river from upstream watering events (e.g. Goulburn and Murrumbidgee rivers). These flows promoted multiple in-channel flow pulses in the LMR during early October (peak flow 10,700 megalitres per day, ML/d), early December (17,800 ML/d) and late December (15,800 ML/d) (Figure 4). Commonwealth environmental water also enabled the raising of water levels in the Lock 2 and 5 weir pools from August to October 2017, and contributed to continuous barrage releases into the Coorong (~757 GL) throughout the entire 2017-18 water year (Figure 3).

Figure 3. Flows over the barrages from the Lower Lakes into the Coorong (photo: SARDI).

[a] In addition to ~894 GL of Commonwealth environmental water delivered to the South Australian border, approximately 13 GL of this was used by the CEWO to water off-channel wetlands and for net losses associated with weir pool manipulation at Locks 2 and 5 (source: CEWO).

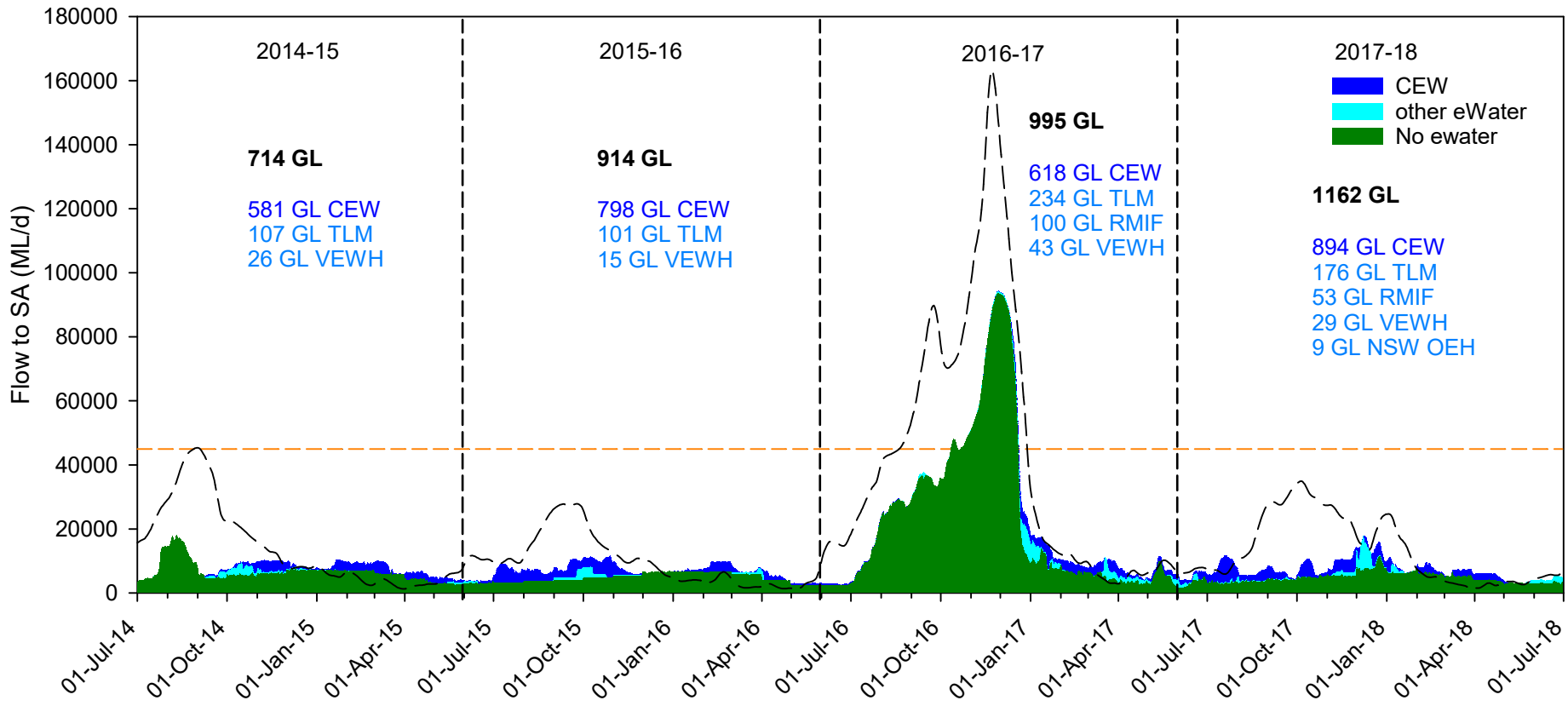


Figure 4. Murray River flow to South Australia (SA) showing the contribution of environmental water, compared to modelled flow under natural conditions without weirs and extraction (black dashed line) (source: MDBA). Orange dashed line represents the flow (45,000 ML/d) required to reach the bank in the Lower Murray River. CEW = Commonwealth environmental water. Other eWater = The Living Murray (TLM), Victorian Environmental Water Holder (VEWH), New South Wales Office of Environment and Heritage (NSW OEH) and River Murray Increased Flows (RMIF). The 'no eWater' component includes the South Australian entitlement held by the Commonwealth Environmental Water Holder and TLM, which are also excluded from the total volumes in blue text.

3 Key outcomes from environmental water use

3.1 Expected outcomes

Commonwealth environmental water use in the LMR during 2017-18 aimed to contribute to elevated base (low) flows and create pulses of flow within the Murray River channel, and to provide continuous barrage flows into the Coorong, which were accomplished (see Section 2). These particular flows intended to achieve a variety of outcomes including those relating to fish, birds, vegetation, river function, Lower Lakes water levels and salt export, although not all of these are monitored through this project (also see https://www.mdba.gov.au/managing-water/water-for-environment/lower-lakes-coorong-murray-mouth-report-card-2016-17).

3.2 River hydraulics

Velocities

Improving riverine hydraulics (e.g. water velocity (speed) and turbulence) is critical for restoring the ecology of the LMR. Many native plants and animals that are adapted to a flowing river are currently extinct or have suffered major declines due to the largely non-flowing weir pool environment in this region (Mallen-Cooper and Zampatti 2017). In 2017-18, Commonwealth environmental water increased hydraulic variability in the LMR by creating flowing habitat (i.e. >0.3 metres per second, m/s) in up to 20% of each weir pool for brief periods between July and November 2017, and up to 50% of Weir Pool 5 during December 2017 (Figure 5). Pre-regulation, the Murray River downstream of the Darling River, was characterised by flowing, riverine habitats, with water velocities of ~0.2–0.5 m/s, even at low flows <10,000 ML/d (Bice *et al.* 2017).

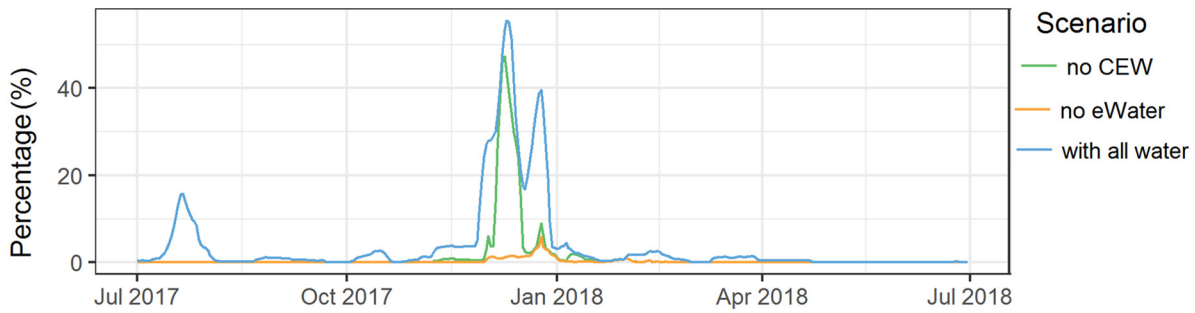


Figure 5. Percentage of the Lock 5 weir pool in the Lower Murray River representing flowing water habitat, defined as a velocity greater than 0.3 metres per second. Coloured lines represent the modelled environmental water scenarios.

Water levels

Environmental water delivery also created variability in water levels, particularly at the upstream end of weir pools during spring–summer, where water levels increased by 0.6–0.8 m during December (Figure 6). Without environmental flows, water levels would have been stable throughout most of 2017-18. Periodic increases in water levels

can improve the condition of bank vegetation (Gehrig *et al.* 2016) and increase the diversity of biofilms (Steinman and McIntire 1990), which is a key component of river food webs.

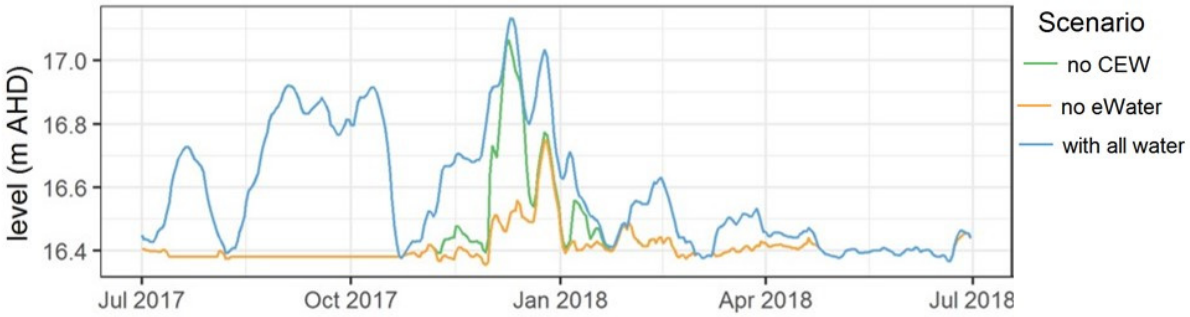


Figure 6. Modelled water level (metres relative to the Australian Height Datum) at the upstream end of the Lock 5 weir pool in the Lower Murray River. Coloured lines represent the modelled environmental water scenarios.

3.3 River metabolism

Dissolved oxygen

In 2017-18, Commonwealth environmental water contributed to maintaining high oxygen levels (8−10 milligrams per litre, mg/L) during spring–summer in the LMR. Favourable dissolved oxygen concentrations (generally >5 mg/L) in water are critical for the survival of aquatic biota, particularly during spring–summer, which is the main reproductive season of many species. The consequences of low oxygen on the survival of larger aquatic animals are evident from the flood year in 2016-17, when dissolved oxygen levels fell to zero in the LMR for a short period (Ye *et al.* 2018) and resulted in extensive kills of Murray cod.

Figure 7. Loggers that are deployed in the Lower Murray River to measure dissolved oxygen concentrations (photo: University of Adelaide).

Food production and consumption

In spring–summer 2017-18, increased flow from environmental water deliveries widened the river size, increasing the volume of water available for aquatic plant and animals. As a result, the rates of food production and consumption increased for each section of river length, by 5% at Lock 6 and 20% at Lock 1, indicating an increased food supply from primary producers (e.g. algae and plants) and greater use of food resources in the food web. For each kilometre of river length, environmental water increased the carbon (food) supply from aquatic primary producers from 31 to 33 tonnes at Lock 6 and from 46 to 57 tonnes at Lock 1.

3.4 Salt, nutrient and phytoplankton transport

Salt transport

There is approximately 100 billion tonnes of salt in groundwater in the MDB and an additional 1.5 million tonnes of salt is deposited in the MDB each year by rainfall (Herczeg *et al.* 2001). Unless salt is exported from the basin with flow, there will be an accumulation of salt within the MDB, potentially leading to salinisation of habitats, particularly wetlands.

In the high flow year (2016-17), when annual barrage flow was ~7,161 GL, 1.5 million tonnes of salt was exported from the MDB and Commonwealth environmental water contributed 8% of salt export. In low flow years (2014-15, 2015-16 and 2017-18), however, environmental water played a vital role in salt export from the MDB, contributing to 64%, 87% and 69% of salt export, respectively (Ye *et al.* 2016; 2017) (Table 1). The lower salinity concentrations in the Coorong during 2017-18, as a result of environmental water delivery, likely created conditions suitable for estuarine species.

Table 1. Four year record of modelled salt export (tonnes) over the barrages to the Coorong. CEW = Commonwealth environmental water, eWater = environmental water.

Scenario	2014-15	2015-16	2016-17	2017-18
With all water	446,855	288,516	1,504,541	349,893
Due to CEW	285,064	251,632	120,867	240,722
Due to eWater	294,449	257,485	186,750	300,970

Nutrient and phytoplankton transport

In addition to the transport of salt in 2017-18, there was increased transport of nutrients and phytoplankton, which would likely stimulate food production in downstream ecosystems, providing potential benefit to food webs of the LMR, Lower Lakes, Coorong and Southern Ocean, adjacent to the Murray Mouth (Figure 8). Environmental flow deliveries during periods when there would otherwise be negligible water exchange between the Lower Lakes and Coorong can promote connectivity and allow exchange between these two water-bodies.

Figure 8. The estuary mouth (Murray Mouth) of the Murray-Darling River system connecting the river to the Southern Ocean (photo: Adrienne Rumbelow).

3.5 Microinvertebrate diversity and transport

Aquatic microinvertebrates are a major food source for larger animals (e.g. larger invertebrates) (Schmid-Araya and Schmid 2000), and important for early life stages of fish (i.e. larvae) (Tonkin *et al.* 2006). Therefore, a diverse and abundant microinvertebrate community may be important for the survival and growth of larval fish and in turn, fish production.

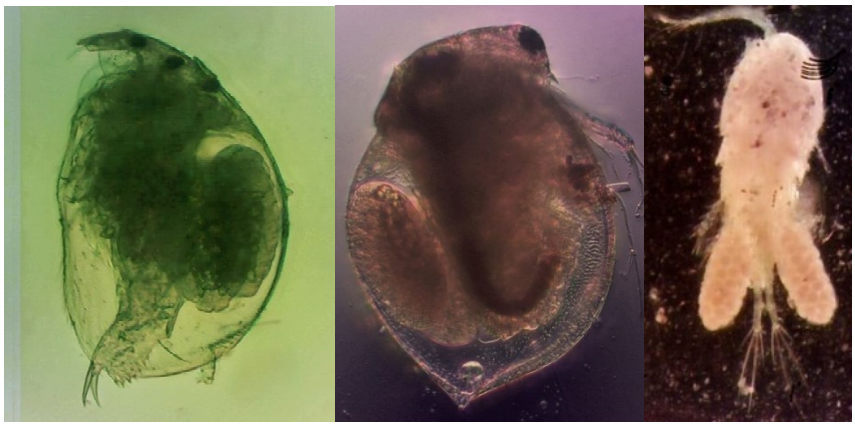


Figure 9. Microinvertebrates of the Lower Murray River that are prey for large-bodied fish larvae. Left: Cladocera (Chydoridae), middle: Cladocera (Daphniidae), right: Copepoda (Cyclopoida: Cyclopidae) (photos: University of Adelaide).

In 2017-18, the transport of microinvertebrates from upstream sources (e.g. Goulburn River/southern Basin) to the LMR, which contributed to increased diversity, was associated with Commonwealth environmental water delivery. The increased dispersion of microinvertebrates suggested improved connection in food sources along the length of the river system, which is important for river function. During the 2016-17 flood, increased transport of microinvertebrates from upstream catchments (i.e. Goulburn, Murrumbidgee, upper Murray and Darling rivers) and between off-channel and main channel habitats resulted in greater microinvertebrates densities and diversities, relative to low flow years such as 2014-15, 2015-16 and 2017-18.

3.6 Golden perch reproduction

Spawning and recruitment of golden perch in the southern MDB corresponds with increases in water temperature and river flow, either in-channel or overbank (Zampatti and Leigh 2013a; 2013b). In the LMR, the golden perch population is made up of fish that are from local spawning, and those that immigrate to the LMR from other spawning sources, such as the lower Darling River (Figure 10).

In spring–early summer 2017-18, golden perch spawning occurred in the LMR in association with in-channel flow pulses (flow to South Australia 17,800 ML/d). Nevertheless, the absence of young (<1 year old) golden perch in autumn 2018 indicates that the larvae from spring–summer did not survive, nor did juvenile fish move into the LMR from upstream.

The lack of reproductive success of golden perch in the LMR over the last four years (2014-15–2017-18) has resulted in an absence of young golden perch (<4 years old) in the LMR population (Figure 10). In 2018, the population was mostly made up of older fish (6 to 8 years old) that resulted from spawning at the end of the Millennium drought and the wet years that followed, in the lower Darling River and the Murray River below the Darling River junction (Figure 10).

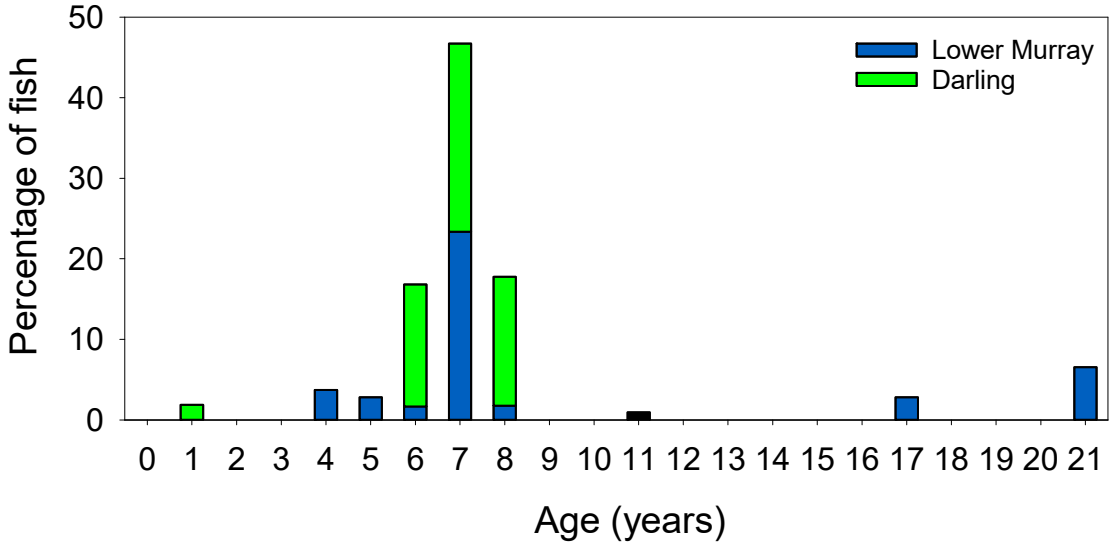


Figure 10. Ages of golden perch (expressed as a percentage) from the Lower Murray River in 2017-18 showing the birth (spawning) location (i.e. Murray River below the Darling River (Lower Murray) and Darling River) of fish inferred from fish earbone and water chemistry. A total of 107 fish were sampled. 11 year old fish (black bar) were not assessed for birth location (photo: SARDI).

4 Other findings from monitoring: Fish community

Background

Fish monitoring data from the LMR (2015–2018) were analysed to investigate annual changes in the fish community, with findings discussed in a river flow context (Ye *et al.* 2019). Evaluation of fish community responses to Commonwealth environmental water is being undertaken at the Basin-scale (e.g. Stoffels *et al.* 2018). The patterns described here have not been associated with environmental water delivery.

Fish community changes

Following in-channel flows (up to 17,800 ML/d) in spring–early summer 2017-18, the abundance of small-bodied fish (e.g. carp gudgeon) increased in 2018, returning to similar levels prior to the 2016-17 flood (i.e. in 2015 and 2016), likely due to the presence of preferred habitats (i.e. underwater vegetation and stable water levels) favourable to small-bodied fish in the main river channel (Figure 11). Simultaneously, the large-bodied fish community trended back towards one typical of 'low flows' (e.g. 2015 and 2016), being characterised by relatively low abundances of flow -cued spawning species (i.e. golden perch, and silver perch) and those that use floodplain habitats for spawning (e.g. common carp). Common carp, however, were more abundant in 2018, relative to 2015 and 2016, indicating that some fish born in 2016-17 survived to autumn 2018.

Figure 11. A catch of small-bodied fish (predominately carp gudgeon) (left) and structural habitat (submerged vegetation) conducive to small-bodied fish (photos: SARDI).

Recruitment of large-bodied species

Spawning of freshwater catfish and Murray cod occurs in spring–early summer, irrespective of flow (Rowland 1998; Davis 1977). However, recruitment of both species may be more successful with increased flow (Ye *et al.* 2015; Zampatti *et al.* 2014). No small freshwater catfish (i.e. <150 mm) were observed in the LMR during the CEWO LTIM Project from 2014-15–2017-18, indicating unsuccessful recruitment. In the LMR,

recruitment of this species is poorly understood and the current population abundance in this region is historically low (Ye *et al.* 2015).

For the fourth consecutive year, small Murray cod (<150 mm) were sampled in the LMR during 2018, indicating successful recruitment (Figure 12). Furthermore, Murray cod born in 2014-15 to 2016-17 appear to have survived to 2017-18, which means there are now young Murray cod aged from less than a year old through to three years old in the LMR. The reasons why recruitment of Murray cod has been successful in the last four years, which ranged from dry through to wet years, remains unclear.

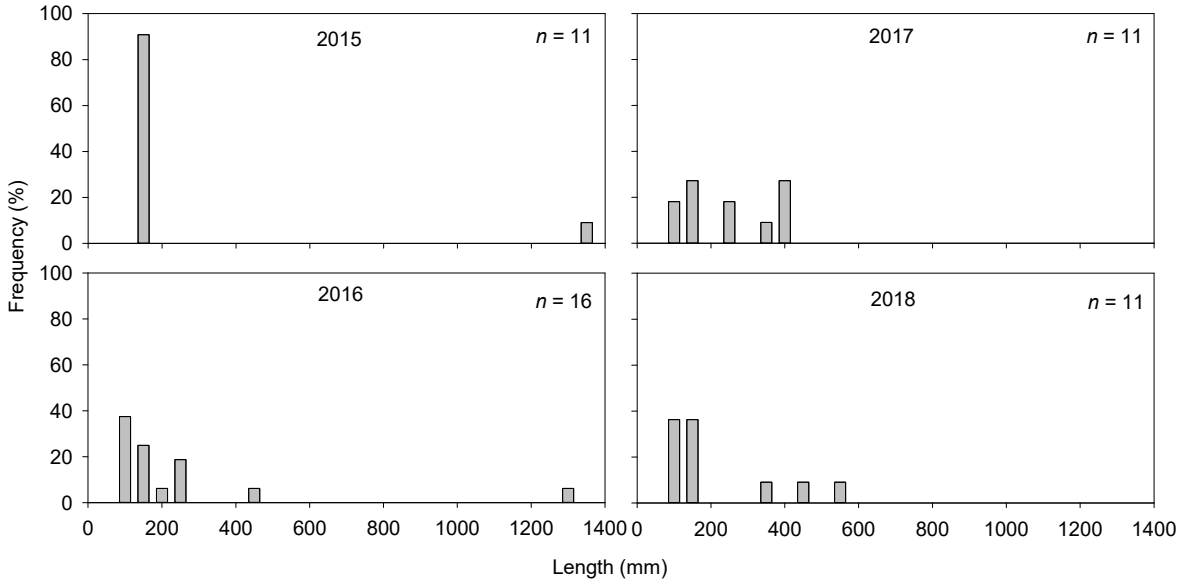


Figure 12. Lengths of Murray cod, expressed as a percentage of the sampled population from the Lower Murray River during electrofishing in autumn 2015–2018 (photo: SARDI).

5 Implications for future management of environmental water

In 2017-18, which was a dry year, 1,162 GL of environmental water, including 894 GL Commonwealth environmental water, was delivered to the LMR through watering events in the southern connected Basin that benefitted several sites as it moved through the length of the river system. Water delivery contributed to multiple spring–early summer in-channel flow pulses (up to ~18,000 ML/d) and a range of ecological outcomes in the LMR. These included increasing areas of flowing water habitats; maintaining favourable dissolved oxygen concentrations to support riverine biota; enhanced in-stream food resources; increased connectivity and microinvertebrate dispersion; lower salinities in the Coorong and increased salt export from the Basin.

While environmental water promoted pulses of flow (up to ~40% of bank height) in the LMR during spring–summer 2017-18, the magnitude and duration of these flow pulses were well below modelled flow under natural (pre-regulation) conditions (Figure 3). Pre-regulation, the Murray River, downstream of the Darling River, was characterised by flowing habitats, with water velocities ranging ~0.2–0.5 m/s, even at flows <10,000 ML/d; whereas currently much greater flow (>~20,000 ML/d) is required to reinstate a 'flowing river' due to the presence of weirs (Bice *et al.* 2017). Many native plants and animals, adapted to riverine habitats, are now extinct or suffered major declines due to the largely weir pool environment in this region. Over the last four years, there has been no reproductive success in golden perch despite some spawning. The current (2018) fish assemblage in the main channel of the LMR represents one typical of low flows, abundant with small-bodied fish.

Environmental water deliveries to support the restoration of flowing water habitats will help to restore ecosystem function and rehabilitate riverine plants and animals in the LMR. Reinstating key features of the natural flow regime in this region, such as high, in-channel spring–early summer flow pulses (>20,000 ML/d), will improve river habitat conditions and should be considered a priority for management. To maximise ecological outcomes, however, we need to better understand specific flow (e.g. timing, magnitude and duration) and habitat requirements of flow-dependant species to inform flow management.

Despite limited golden perch outcomes, environmental water has demonstrated its importance in supporting barrage releases to the Coorong, particularly in low flow years (i.e. 2014-15, 2015-16 and 2017-18). Barrage flows are critical in exporting salt from the MDB, maintaining freshwater–estuarine habitat connectivity, reducing salinity levels in the Coorong and improving habitat and reproductive success for many estuarine species (e.g. fish).

6 References

Bice, C.M., Gibbs, M.S., Kilsby, N.N., Mallen-Cooper, M. and Zampatti, B.P. (2017). Putting the "river" back into the lower River Murray: quantifying the hydraulic impact of river regulation to guide ecological restoration. *Transactions of the Royal Society of South Australia*, DOI: 10.1080/03721426.2017.1374909.

Davis, T.L.O. (1977). Reproductive biology of the freshwater catfish, *Tandanus tandanus* Mitchell, in the Gwydir River, Australia. II. Gonadal cycle and fecundity. *Australian Journal of Marine and Freshwater Research* **28**, 159–169.

Gehrig, S.L., Frahn, K.A. and Nicol, J.M. (2016). Monitoring the response of littoral and floodplain vegetation and soil moisture flux to weir pool raising - 2015. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000390-2.

Herczeg, A.L., Dogramaci, S.S. and Leaney, F.W.J. (2001). Origin of dissolved salts in a large, semi-arid groundwater system: Murray Basin, Australia. *Marine and Freshwater Research* **52**, 41–51.

Mallen-Cooper, M. and Zampatti, B.P. (2017). History, hydrology and hydraulics: Rethinking the ecological management of large rivers. *Ecohydrology* **11**, e1965 https://doi.org/10.1002/eco.1965.

Rowland, S.J. (1998). Aspects of the reproductive biology of Murray cod, *Maccullochella peelii peelii*. Proceedings of the Linnean Society of New South Wales **120**, 147–162.

Schmid-Araya, J.M. and Schmid, P.E. (2000). Trophic relationships: Integrating meiofauna into a realistic benthic food web. *Freshwater Biology* **44**, 149–163.

Steinman, A.D. and McIntire, C.D. (1990). Recovery of lotic periphyton communities after disturbance. *Environmental Management* **14**, 589–604.

Stoffels, R., Stratford, D., Bond, N. and Hale, J. (2018). 2016–17 Basin-scale evaluation of Commonwealth environmental water – Fish. Report prepared for the Commonwealth Environmental Water Office by La Trobe University, Publication 192/2018.

Tonkin, Z.D., Humphries, P. and Pridmore, P.A. (2006). Ontogeny and feeding in two native and one alien fish species from the Murray–Darling Basin, Australia. *Environmental Biology of Fishes* **76**, 303–315.

Walker, K.F. (2006). Serial weirs, cumulative effects: the Lower Murray River, Australia. In: Ecology of Desert Rivers (Ed. R. Kingsford) pp. 248–279. Cambridge University Press, Cambridge.

Ye, Q., Bucater, L., Zampatti, B., Bice, C., Wilson, P., Suitor, L., Wegener, I., Short, D. and Fleer, D. (2015). Population dynamics and status of freshwater catfish (*Tandanus tandanus*) in the lower River Murray, South Australia. South Australian Research and Development Institute (SARDI) Aquatic Sciences, Adelaide. SARDI Publication No. F2014/000903-1. SARDI Research Report Series No. 841.

Ye, Q., Giatas, G., Aldridge, K., Busch, B., Gibbs, M., Hipsey, M., Lorenz, Z., Maas, R., Oliver, R., Shiel, R., Woodhead, J. and Zampatti, B. (2017). Long-Term Intervention Monitoring of the Ecological Responses to Commonwealth Environmental Water Delivered to the Lower Murray River Selected Area in 2015/16. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences.

Ye, Q., Giatas, G., Aldridge, K., Busch, B., Gibbs, M., Hipsey, M., Lorenz, Z., Maas, R., Oliver, R., Shiel, R., Woodhead, J. and Zampatti, B. (2018). Long-Term Intervention Monitoring of the Ecological Responses to Commonwealth Environmental Water Delivered to the Lower Murray River Selected Area in 2016/17. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences.

Ye, Q., Giatas, G., Aldridge, K., Busch, B., Gibbs, M., Hipsey, M., Lorenz, Z., Maas, R., Oliver, R., Shiel, R., Woodhead, J. and Zampatti, B. (2019). Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Lower Murray River Selected Area 2017-18 Technical Report. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences.

Ye, Q., Giatas, G., Aldridge, K., Busch, B., Gibbs, M., Hipsey, M., Lorenz, Z., Oliver, R., Shiel, R. and Zampatti, B. (2016). Long-Term Intervention Monitoring for the Ecological Responses to Commonwealth Environmental Water Delivered to the Lower Murray River Selected Area in 2014/15. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences.

Zampatti, B.P. and Leigh, S.J. (2013a). Effects of flooding on recruitment and abundance of Golden Perch (*Macquaria ambigua ambigua*) in the lower River Murray. *Ecological Management and Restoration* **14**, 135–143.

Zampatti, B.P. and Leigh, S.J. (2013b). Within-channel flows promote spawning and recruitment of golden perch, *Macquaria ambigua ambigua*: implications for environmental flow management in the River Murray, Australia. Marine and Freshwater Research **64**, 618–630.

Zampatti, B.P., Bice, C.M., Wilson, P.J. and Ye, Q. (2014). Population dynamics of Murray cod (*Maccullochella peelii*) in the South Australian reaches of the River Murray: A synthesis of data from 2002–2013. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014-000089-1. SARDI Research Report Series No. 761.