# Technical information supporting the South Australian Basin Plan Environmental Outcome Evaluation

# Channel and Floodplain Priority Environmental Assets

Department for Environment and Water
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# Summary

South Australia has assessed the achievement of environmental outcomes relating to a subset of the SA River Murray Long-term Watering Plan targets for the Channel and Floodplain Priority Environmental Asset (PEA). By achieving these outcomes, the aim is to maintain or improve the health of vegetation and fish communities, while also maintaining channel flow velocity and floodplain productivity. The assessment of environmental outcomes presents the trend for each indicator, along with an evaluation of the contribution of the Basin Plan and other influences on the achievement of these outcomes. A summary of the assessment is shown below.

| Theme | Indicator | Trend | Information reliability | Key findings |
|---|---|---|---|---|
| **Flow & Ecosystem Function** | Flow velocity | Trend Stable | Reliability Good | The extent of fast-flowing habitats has increased; however we have not seen the range of velocity classes as desired. |
| | Productivity (micro-invertebrates) | Unknown | Reliability Very good | Microinvertebrate densities and species numbers increased following the 2 largest inundation events between 2014 and 2018. |
| **Fish** | Golden perch | Trend Stable | Reliability Fair | The age structure of the golden perch population in 2019 is characteristic of a population with low resilience. |
| | Murray cod | Trend Getting better | Reliability Fair | Recruitment of Murray cod has improved since Basin Plan adoption, with recent recruits present each year of sampling. |
| **Vegetation** | River red gum | Trend Getting better | Reliability Poor | The proportion of red gums in good or excellent condition has increased at some Pike, Katarapko and Chowilla floodplain habitats. |
| | Black box | Trend Getting better | Reliability Poor | The condition of black box has increased at some Chowilla, Pike and Katarapko floodplain habitats. |

The following key messages have come from South Australia's assessment and evaluation of the achievement of environmental outcomes in the SA River Murray Channel PEA and Floodplain PEA:

- Following the impacts of the Millennium Drought and adoption of the Basin Plan, the Channel and Floodplain areas of the River Murray in South Australia have shown some positive signs of recovery, particularly in areas where water for the environment has been delivered.
- High (unregulated) flows are important for the system and are critical to reach areas of the floodplain that cannot be supported through managed inundation, including areas of floodplain at Chowilla, Pike and Katarapko that sit outside of the management influence of regulators.
- Much of our assessment is constrained to sites where there has been targeted delivery of water for the environment, including through weir pool manipulation and managed floodplain inundations. Therefore the results may not be representative of conditions across the wider channel and floodplain assets.
- Full implementation of the Basin Plan, including addressing current water delivery constraints, is required to achieve greater frequency, duration and magnitude of overbank flows along the South Australian River Murray to further improve environmental outcomes in these assets.
- Implementation of the Basin Plan to date has supported:
    - provision of small-scale fast-flowing habitats and enhancing productivity
    - managed floodplain inundations, using infrastructure, at key sites
    - improvements in river red gum and black box tree condition at sites where water has been delivered
    - improvements in the population structure and recruitment of Murray cod, creating a more resilient population.
- Remaining challenges include:
    - addressing the physical and policy constraints to enable the delivery of water to greater areas of the floodplain, including to areas outside managed assets
    - providing fast-flowing habitats over larger areas of the River Murray channel
    - improving the resilience of the golden perch population.
- Continued effort and investment is required to improve the health of the Channel and Floodplain through:
    - striving for full implementation of the Basin Plan
    - undertaking the investigations and works planned under South Australia's Supply Measures and Southern Basin Constraints Measures Projects
    - continued involvement of the local community and First Nations to find enduring solutions

# 1 Introduction

## 1.1 Basin Plan Schedule 12

The reporting requirements outlined in Schedule 12 of the Basin Plan provide the Murray–Darling Basin Authority (MDBA) with the information necessary to evaluate the effectiveness of the Basin Plan against its objectives and outcomes (s13.05).

Matter 8 (achievement of environmental outcomes at an asset scale) is a state-based reporting obligation that is central to communicating the environmental outcomes achieved through the implementation of the Basin Plan.

## 1.2 South Australia's approach to 2020 Basin Plan Environmental Outcome Evaluation and Reporting (Matter 8)

South Australia has identified the following objectives for Matter 8 environmental outcome reporting:

- To meet Basin Plan reporting obligations under Schedule 12
- To communicate Basin Plan outcomes to key stakeholders (including the community)
- To inform South Australia's, the Australian Government's and other states' environmental water delivery decision-making and adaptive management capacity
- To make a meaningful contribution to the Authority's evaluation of the effectiveness of the Basin Plan (at Basin-scale), and our own evaluation of the effectiveness of the Basin Plan at a state-scale.

The South Australian Department for Environment and Water (DEW) has developed an approach to reporting on the achievement of environmental outcomes required for the Matter 8 reporting. This approach recognises the linkages between the Basin Plan environmental objectives, environmental watering plans and strategies (state and Basin-wide) and asset-scale environmental outcome reporting (Matter 8).

South Australia considers Matter 8 an evaluation of the achievement of environmental outcomes at an asset scale, and the reporting of that evaluation to the Authority.

This evaluation is guided by 3 key evaluation questions:

- To what extent are expected environmental outcomes being achieved?
- If expected environmental outcomes are not being achieved, why not?
- To what extent is the provision of environmental water, in line with environmental water requirements, contributing to the achievement of expected environmental outcomes?

For the South Australian River Murray, this evaluation is underpinned by the assessment of expected environmental outcomes (see section 3) for prioritised targets for each of the priority environmental assets within the South Australian River Murray Long-Term Environmental Watering Plan (LTWP). The prioritisation of targets was undertaken against the following key criteria:

1. capability to track environmental trends at a range of spatial scales
2. environmental value
3. response to flow
4. consistency with the Basin-wide Environmental Watering Strategy

5. scientific credibility and reproducibility.

Some additional post-check considerations were then applied to ensure that the prioritised targets:

1. represent all of the key biotic groups (i.e. vegetation, fish and waterbirds), and key ecosystem processes
2. do not over represent any of the key biotic groups or processes
3. resulted in large positive contributions towards the achievement of the targets under the Environmental Water Requirements (EWRs) (as shown in Wallace et al. 2014, Kilsby et al. 2015, and O'Connor et al. 2015)
4. include all of the key hydrological and water quality drivers.

This resulted in a total of 21 prioritised targets from the SA River Murray LTWP for the development of expected environmental outcomes.

### 1.2.1 South Australian River Murray expected environmental outcomes

Targets in the South Australian River Murray LTWP represent what a 'healthy, functioning ecosystem' might look like. Targets also vary in when they are expected to be achieved due to patterns in responses, including responses to environmental watering, and other management actions, over time. In the absence of complete knowledge and data around ecosystem responses, the quantitative expected environmental outcomes (and associated assumptions and limitations) were developed through a structured expert elicitation process (DEW in prep). These outcomes then give a more nuanced approach to evaluation and reporting, as they allow us to track the trajectory towards outcomes and targets and demonstrate progress towards our objectives, rather than just a pass or fail relating to the targets.

Expected environmental outcomes quantify the extent to which we expect to meet the LTWP targets over 3 time points following the adoption of the Basin Plan in 2012 (2019, 2029 and 2042). These time points were chosen to align with key Basin Plan implementation activities and reporting.

This document presents the assessment of achievement of short-term (i.e. the 2019) expected environmental outcomes for the SA River Murray Channel and Floodplain priority environmental assets, and supporting data and information to evaluate why these outcomes have been met or not met since the adoption of the Basin Plan and actions to achieve environmental outcomes in the future.

# 2 River Murray Channel and Floodplain Priority Environmental Assets

## 2.1 The SA River Murray Channel Priority Environmental Asset

The South Australian River Murray Channel Priority Environmental Asset ('the Channel PEA') extends from Wellington, South Australia to the South Australia border, a distance of 560 river km (DEWNR 2015) (Figure 2-1). The breadth of the Channel PEA extends to areas inundated at flows to South Australia of up to 40,000 $ML.day^{-1}$ (QSA) under normal river operation (DEWNR 2015). A total of 28,800 hectares fall within the 40,000 $ML.day^{-1}$ flow band, which includes permanently and temporarily inundated areas (DEWNR 2015).

The Channel PEA is comprised of an array of aquatic habitats, including lentic (fast) and lotic (slow) flowing channel and anabranches, still backwaters and saline swamps. Vegetation communities that border these aquatic habitats include emergent sedgelands, river red gum woodland, river cooba woodland and samphire shrublands (Wallace et al. 2014; Klisby and Steggles 2015). The health, distribution and extent of Channel PEA habitats vary in response to the water regime parameters, such as flow volumes, water velocity, rise and fall of water level and period of inundation (DEWNR 2015).

The permanent water habitats of the Channel PEA provide habitat for water-dependent species including native fish, frogs, waterbirds and macroinvertebrates (Bice et al. 2014). Fauna within the Channel PEA can exhibit distinct preferences for channel or wetland habitats. For example, large-bodied native fish, such as Murray cod and golden perch that require flowing habitat to stimulate spawning or improve recruitment, predominantly occur in the channel), whereas wetland specialists, such as Murray hardyhead prefer permanent and temporarily inundated wetlands (Bice et al. 2014). Likewise, frogs also favour permanent and temporary wetlands for breeding (Bice et al. 2014). The habitat preferences of waterbirds are largely driven by water depth, with deep wetlands and the channel favoured by diving species, such as darters and cormorants, while shallow wetlands are favoured by large waders, shorebirds and cryptic species (DEWNR 2015).

Temporarily inundated habitats of the Channel PEA when wet are also important habitat for water-dependent fauna as they are highly productive and provide abundant food resources (Bice et al. 2014). Re-fill of temporary wetlands following a dry period can stimulate frogs, fish and waterbirds to breed if inundation periods and extent are sufficient (Holland et al. 2013; Bice et al. 2014).

Terrestrial woodlands and shrublands when dry provide feeding and breeding habitat for an array of fauna, including threatened species such as the nationally threatened regent parrot (Butcher et al. 2009; Newall et al. 2009; Mac Nally et al. 2011). Water regime and groundwater depth and salinity strongly influence the condition of terrestrial habitats (Mac Nally et al. 2011; Souter et al. 2012), which in turn, influences their ability to support woodland birds (McGinness et al. 2018).

## 2.2 The SA River Murray Floodplain Priority Environmental Asset

The South Australian River Murray Floodplain Priority Environmental Asset ('the Floodplain PEA') borders the Channel PEA, and therefore also extends from Wellington, South Australia to the South Australian border (DEWNR 2015) (Figure 2-1). The Floodplain PEA encompasses the area inundated between flows of 40,000 $ML.day^{-1}$ and 80,000 $ML.day^{-1}$ under normal river operation (DEWNR 2015). Flows greater than 80,000 $ML.day^{-1}$ cannot be managed with water for the environment and therefore do not meet the definition of a priority environmental asset under the Basin Plan (DEWNR 2015).

The breadth of the Floodplain PEA varies significantly from Wellington to the border, with great expanses of floodplain upstream from Overland Corner. The floodplain upstream from Overland Corner is up to 10-km wide, while downstream the floodplain is constrained to a width of 2-3 km (Walker and Thoms 1993). Very little floodplain remains downstream of Mannum as it was reclaimed for agriculture (DEWNR 2015).

The Floodplain PEA is comprised of ephemeral habitats, namely 'shedding floodplain' and 'temporary wetlands' (Kilsby and Steggles 2015). These ephemeral habitats are defined by their ability (or lack thereof) to retain water after inundation. Shedding floodplains will shed water as water recedes following inundation, while temporary wetlands will retain water following shedding within a depression or basin (Kilsby and Steggles 2015). More specifically, ecological communities in the Floodplain PEA include temporary wetlands, river red gum woodlands, black box woodlands, lignum shrublands, terrestrial shrublands and samphire shrublands (Kilsby and Steggles 2015). The condition and extent of ecological communities on the floodplain are dynamic, responding to flow regime of the River Murray (Souter et al. 2012).

When the Floodplain PEA is inundated, it provides productive habitat for wetland-dependent fauna. Floodplain inundation can stimulate fish, frog and waterbird species to breed, depending upon the extent and duration of flooding (Bice et al. 2014; Hoffmann 2018). Furthermore, the floodplain inundation facilitates the movement of nutrients accumulated on the floodplain to the channel (Wallace et al. 2014). This export of nutrients from the floodplain to the channel drives primary productivity that benefits in-stream foodwebs (Ye et al. 2014).

The Floodplain PEA when dry also provides important habitat for terrestrial fauna and flora species. Water regime influences the species composition of vegetation communities as well as their condition and structure (Mac Nally et al. 2011; McGinness et al. 2018). Variations in the condition and structure of floodplain woodlands and forests have been found to influence habitat quality for woodland birds and subsequently their populations (McGinness et al. 2010; McGinness et al. 2018). Other fauna taxa that occur on the floodplain when dry are also expected to be similarly impacted by water regime (Mac Nally et al. 2011).

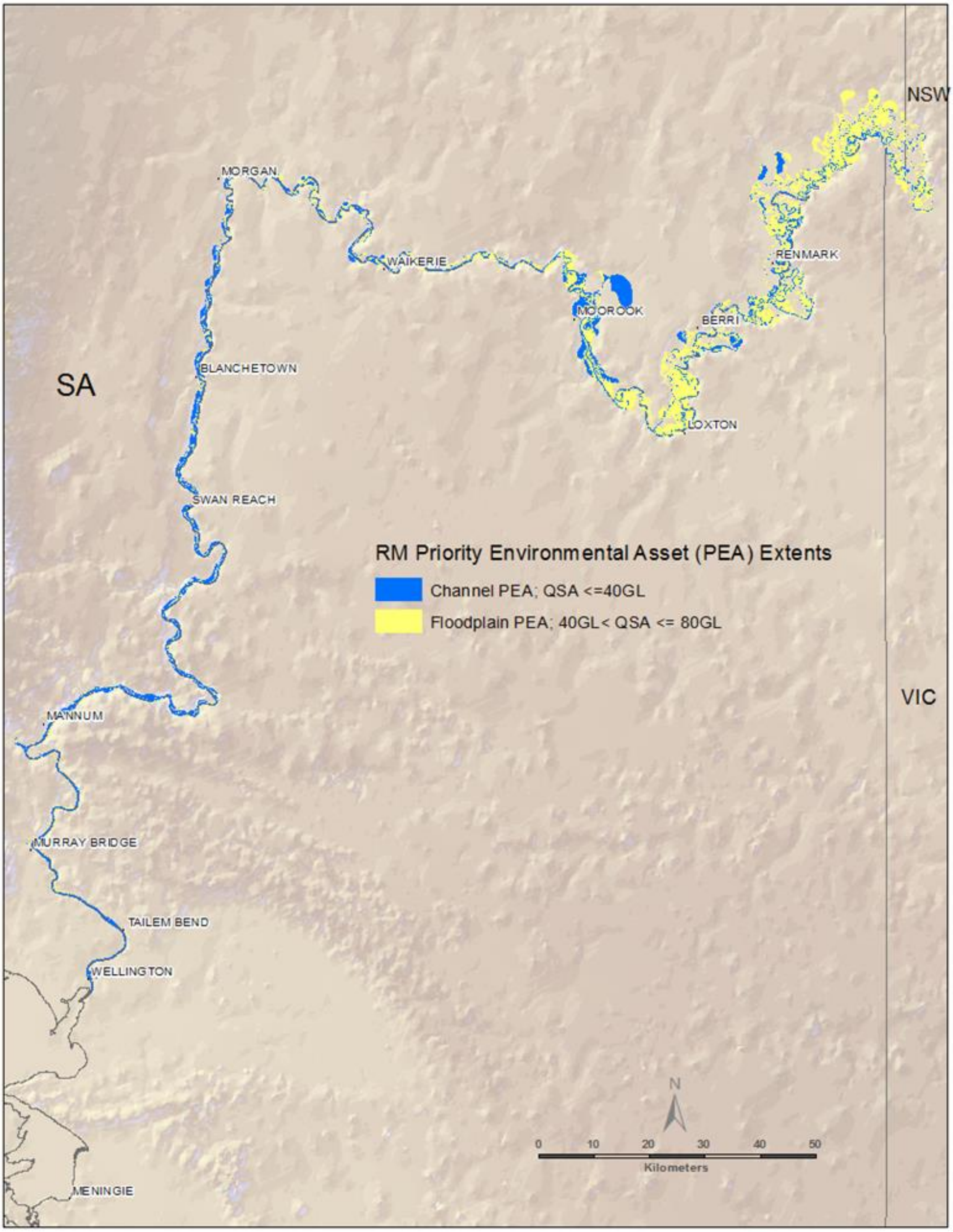


**Figure 2-1. Extent of the Channel PEA and Floodplain PEA in the South Australian River Murray.**

## 2.3 Ramsar sites

The Channel and Floodplain PEAs overlap with the Banrock Station Wetland Complex and Riverland Ramsar listed wetlands of international importance. The area of overlap between the Channel and Floodplain PEAs with the 2 Ramsar wetlands is shown below in Table 2-1.

**Table 2-1. Overlap of the Channel and Floodplain PEAs with Ramsar Wetlands.**

| Priority Environmental Asset | Ramsar Wetland | Area (ha) of overlap |
|---|---|---|
| The Channel PEA | Banrock Station | 190 |
| | Riverland | 3,840 |
| The Floodplain PEA | Banrock Station | 710 |
| | Riverland | 13,250 |

Banrock Station Wetland Complex is located across the River Murray from Overland Corner, in the Riverland of South Australia. The wetland complex covers 1,375 ha of low-lying floodplain and upland mallee (Butcher et al. 2009). Banrock Station Wetland Complex meets the Ramsar criteria to be listed as a wetland of international importance because it supports nationally threatened species (regent parrot and southern bell frog), a range of biodiversity (including habitat types) and provides non-breeding habitat for 9 migratory waterbirds listed under international agreements (Butcher et al. 2009).

The Riverland Ramsar wetland is located between Renmark, South Australia and the South Australian border with New South Wales and Victoria. The wetland stretches across 80 km of river and covers 30,615 ha of which 27,213 ha is allocated to biodiversity conservation (Newall et al. 2009). Aquatic habitats in the Riverland Ramsar wetland include the River Murray, 2 major anabranches (Chowilla and Ral Ral creeks), lagoons, billabongs, swamps and lakes (Newall et al. 2009). The Riverland wetland meets the Ramsar criteria to be listed as a wetland of international importance as its wetlands support nationally threatened species (including regent parrot, southern bell frog, Murray cod and Murray hardyhead). A range of biodiversity (including habitat types) provides non-breeding habitat for 9 migratory waterbirds listed under international agreements and supports more than 1% of global populations of waterbirds (e.g. freckled duck, red-necked avocet and red-kneed dotterel) as well as key native fish species and their important spawning habitats and migration pathways.

## 2.4 Hydrology

Flow to South Australia (QSA) varies seasonally, with flows typically increasing over spring and declining over summer (Figure 2-2). There is also substantial variability in annual QSA volumes between years due to climatic conditions (high rainfall, drought etc.) and upstream extraction and diversion of water. High flows recorded in 2000/01 with 6533 GL of annual QSA. During the Millennium Drought, from 2001/02 to 2009/10, there were prolonged low flow conditions, with mean annual QSA of 1746 GL. Widespread flooding over the MDB in 2010/11 with QSA peaking at ~94,000 $ML.Day^{-1}$ and annual QSA totalling 15106 GL. High flows continued in 2011/12 and 2012/13 with 10248 GL and 7001 GL of annual QSA, respectively. More moderate flows (3570 GL) were recorded over 2013/14 before low flow conditions occurred over 2014/15 and 2015/16 (mean of 2686 GL). Flood throughout the Murray–Darling Basin in 2016/17 substantially increased with QSA peaking at ~94,000 $ML.Day^{-1}$ and annual QSA totalling 9230 GL. Following the 2016/17 flood, extremely dry conditions over the Murray–Darling Basin in 2017/18 and 2018/19 greatly reduced annual QSA to 2697 GL and 2443 GL, respectively.

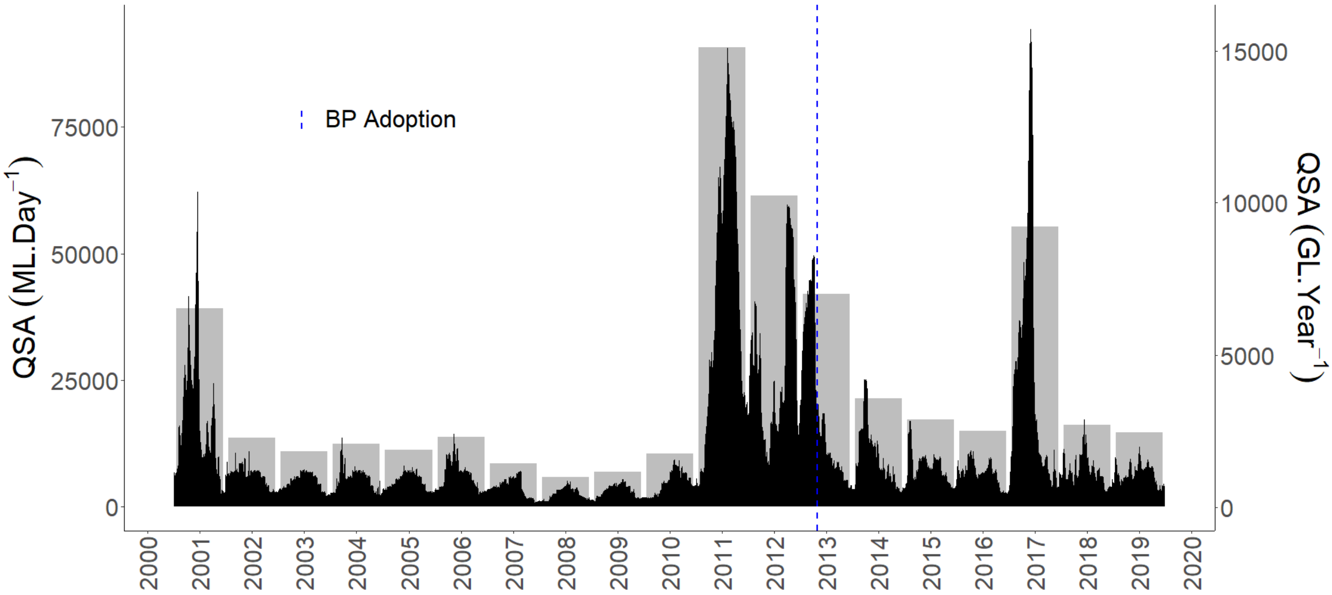


**Figure 2-2. Daily (ML.Day$^{-1}$) and annual flow (GL.Year$^{-1}$) to the South Australian border (QSA) from 2000/01 to 2018/19.**

## 2.5 River regulation and operations

The South Australian River Murray is a highly regulated system with locks, weirs, environmental regulators and wetland flow control structures all contributing to the ability of managers to manipulate water levels. Prior to river regulation, the flows of the SA River Murray were dynamic, with higher frequencies of both low and high flows (Walker and Thoms 1993). Construction of locks and weirs turned a dynamic river into a series of pools with stable water levels with low flow velocity. Operation of the river at pool level has reduced the frequency of inundation for 30% of the wetland area, and led to the permanent inundation of 70% of the wetland area that formerly would have had more frequent water-level fluctuations including periodic drying (Walker 2006). Stable waters within the River Murray and its wetlands has contributed to a decline in vegetation condition, reduction in lateral connection between the river and floodplain and subsequent movement of nutrients, lower productivity and fewer water-level fluctuation cues for soil propagule banks (Wallace et al. 2014). Furthermore, the lower flow velocities within the River Murray channel may have caused limited downstream transport of sediment, salt, nutrients and propagules; lower water quality; fewer flow-related cures for fish migration and reproduction; and the dominance of a phytoplankton assemblage unfavourable to primary consumers and species at higher trophic levels (Wallace et al. 2014).

Weir pool manipulation, the construction of environmental regulators and wetland flow control structures, and the pumping of environmental water aims to mimic the hydrology of the River Murray system prior to river regulation (Nicol et al. 2010; DEWNR 2012; Wallace et al. 2014). Weir pools can be both raised and lowered, to increase either areas of inundation on the floodplain or velocity of flow in the channel (Wallace et al. 2014). Similarly, the environmental regulator at Chowilla Creek constructed in 2014, and those to be completed at Pike and Katarapko in 2020, are designed to raise water levels to facilitate floodplain inundation (Nicol et al. 2010). Flow control structures were constructed at wetlands with permanent connection to the River Murray that formerly would have had greater water-level fluctuations (DEWNR 2012). Flow control structures enable managers to disconnect wetlands from the River Murray to restore dry, draw-downs and filling phases that reflect pre-regulation conditions (DEWNR 2012). Water saved from the managed disconnection of permanently connected wetlands contributes to the supply of water for the environment (see section 2.6).

## 2.6 Water for the environment

Flow to South Australia (QSA) is comprised of SA entitlement flow, additional dilution flow (ADF), water for the environment and unregulated flows (Figure 2-3). Annual volumes of water for the environment to South Australia ranged from 552 to 856 GL since the adoption of the Basin Plan. The relative contribution of water for the environment to QSA for a given year was greatest in years of low flow and highest in years of high flow and flood due to unregulated flows. For example, in 2016/17, a year of flood, water for the environment comprised 8% of annual QSA. In contrast, under low flow conditions in 2017/18, the contribution of water for the environment to annual QSA increased to 30%.

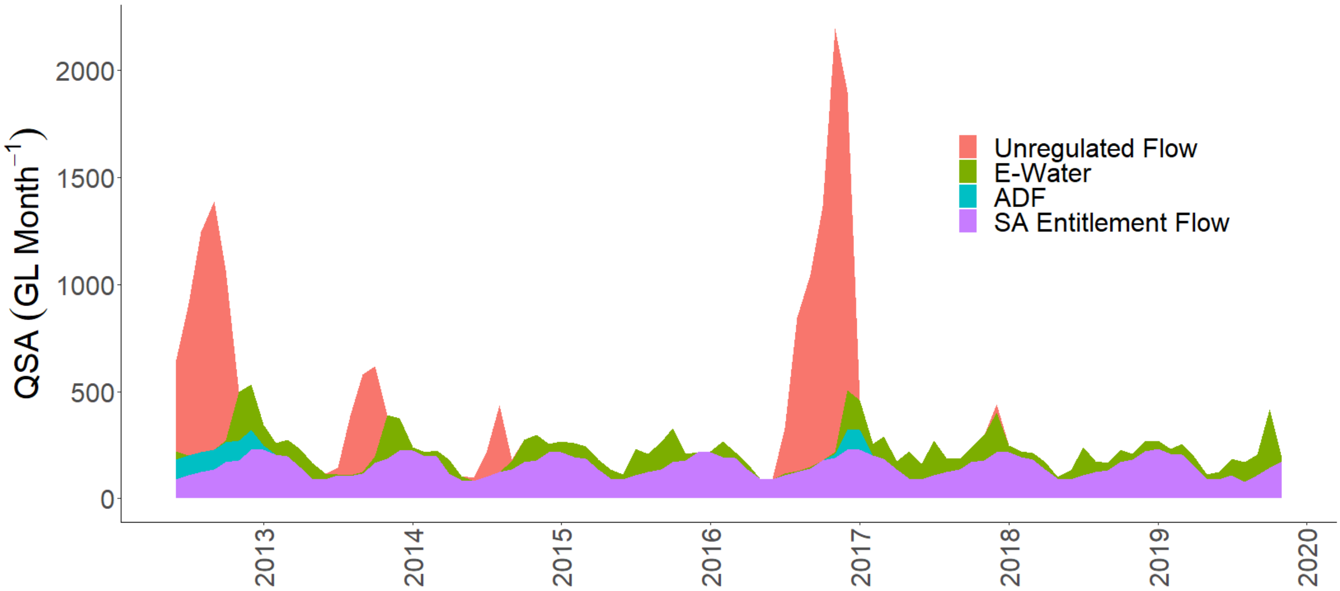


**Figure 2-3. Contribution of unregulated flow, water for the environment (E-Water), additional dilution flow (ADF) and SA entitlement flow to Flow (GL.Month$^{-1}$) to the South Australian border (QSA) from June 2012 (Basin Plan implementation) to November 2019 (Data source: MDBA 2019).**

## 2.7 Rainfall

### 2.7.1 Murray–Darling Basin

Rainfall in the Murray–Darling Basin ('the Basin') declines along an east-west gradient. The eastern border of the Basin that abuts the Great Dividing Range can receive rainfall in excess of 1500 mm per annum, while the arid west often receives less than 300 mm (Gallant et al. 2012).

Timing of rainfall in the Basin varies latitudinally. The southern Basin receives the most of its annual rainfall during the cooler months (May–October), whereas the north receives most of its annual rainfall in the warmer months (November–April) (Gallant et al. 2012). Likewise, variability of rainfall also changes latitudinally in the Basin, with more consistent rain-bearing systems in the south and more variable and intermittent rainfall in the north, leading to a rainfall pattern distinguished by long dry periods interspersed between intense rainfall events (MDBA 2019).

Climate change has contributed to lower annual rainfall in the southern Basin and temporal shifts (MDBA 2019). In the southern Basin, winter and spring rainfall has declined, however, there is slightly more in autumn (MDBA 2019). Likewise, there has been a decline in winter and spring rainfall in the northern Basin and an increase in summer and autumn rainfall (MDBA 2019).

The rainfall decile maps of the Basin from 2006 to 2019 (BOM 2020) show prolonged dry periods broken by years of above average to record rainfall (Figure 2-4). The Millennium drought that commenced in 1996 was broken in

2010 by 2 consecutive years (2010 and 2011) of significant rainfall. Between 2012 and 2015, average to record lower rainfall were recorded over the Basin, dependent on location, with the far south most severely affected. In 2016, above average rainfall was recorded for much of the Basin, with most significant relative rainfall within the southern Basin. Drought conditions commenced in 2017 and continued throughout 2019. The lack of rainfall during this period, from 2017 to 2019, was notable across the entire Basin, however was most prominent in the north near the New South Wales and Queensland border.

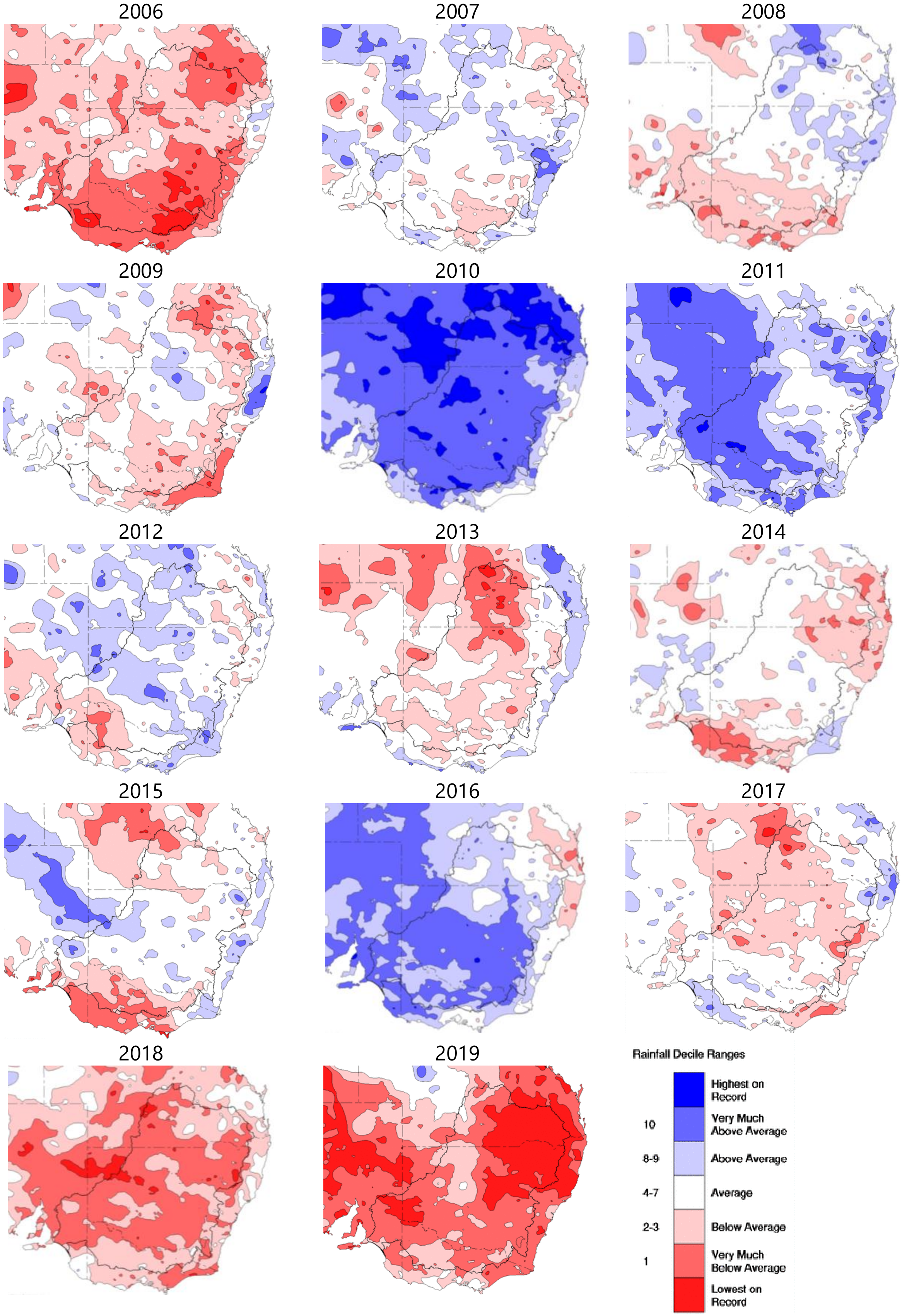


**Figure 2-4. Murray–Darling Basin rainfall deciles from 2006 to 2019 (BOM 2020).**

### 2.7.2 South Australian River Murray

Annual rainfall at Murray Bridge and Renmark showed similar patterns from 2000/01 to 2018/19 (Figure 2-5). During the Millennium Drought, from 2001/02 to 2009/10, annual rainfall totals were below the long-term average, from 2000/01 to 2018/19, for all 9 years except 2004/05 and 2005/06 at Murray Bridge and 2005/06 at Renmark. Rainfall over both Murray Bridge and Renmark were above-average in 2010/11 and 2011/12, with rainfall at Renmark in 2010/11 more than two-fold higher than the long-term average. Following Basin Plan adoption in November 2012, rainfall at both Murray Bridge and Renmark was below average in all years, with the exception of 2013/14 and 2016/17.

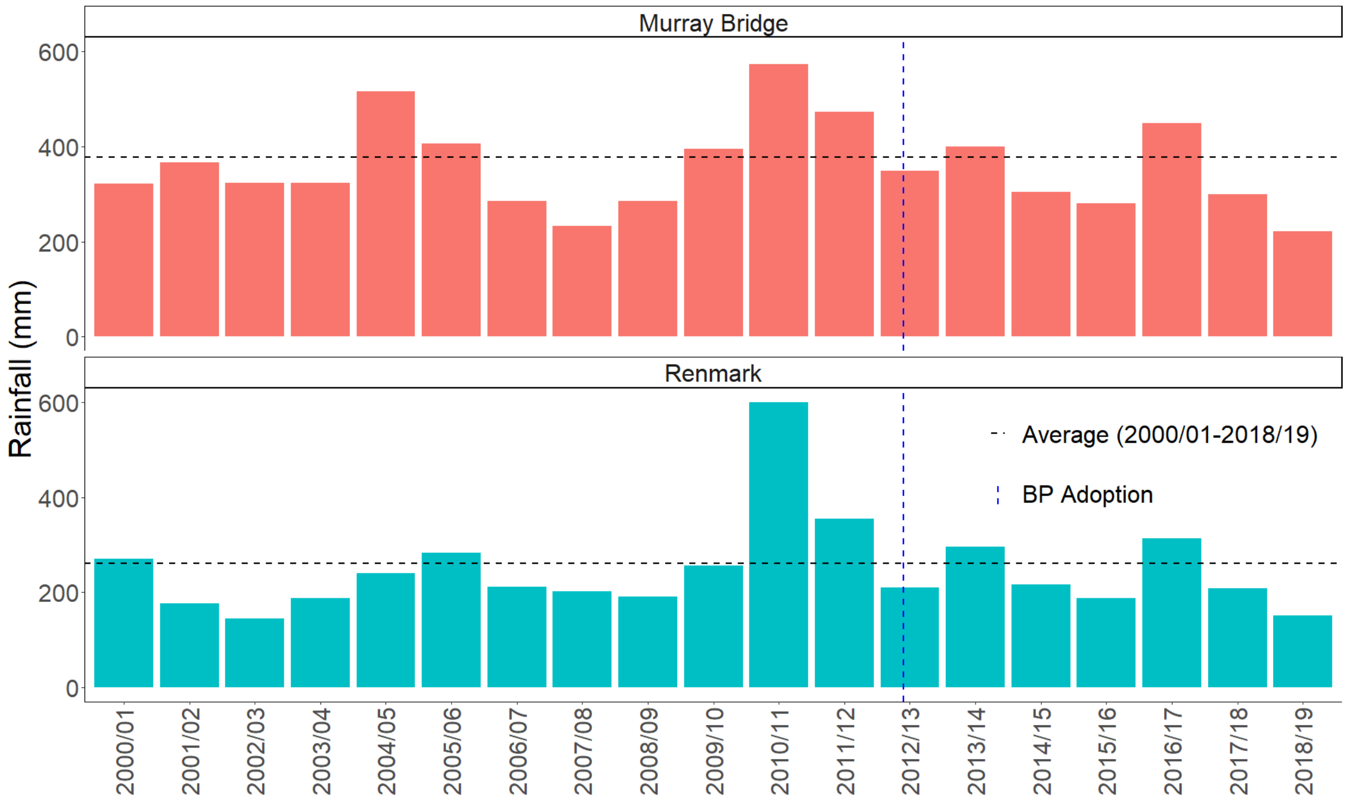


**Figure 2-5. Rainfall recorded at Murray Bridge (station no. 02451) and Renmark (station no. 24003) from 2000/01 to 2018/19.**

# 3 Objectives, targets and expected environmental outcomes

## 3.1 Ecological objectives and targets

Objectives and targets identified in the SA River Murray Long-Term Environmental Watering Plan (LTWP) (DEWNR 2015) represent what is required to support each of the priority environmental assets in a *healthy, functioning* state. As such, the objectives and targets within the LTWP were not constrained to those considered to be achievable under the Basin Plan. The ecological targets provide a means to assess and report on changes in condition over time, tracking progress towards ecological objectives.

### 3.1.1 The Channel PEA

A total of 16 ecological objectives and 29 nested ecological targets are described for the Channel PEA within the SA River Murray LTWP (DEWNR 2015). These objectives and targets focus on abiotic processes, water quality, biofilms, vegetation, wetlands, groundwater and fish.

Of these targets, a total of 6 prioritised ecological targets across 4 ecological objectives (Table 3-1) were used as the basis for this assessment and evaluation of expected environmental outcomes for the Channel PEA.

**Table 3-1. Ecological objectives and targets for the Channel PEA.**

| Ecological objective | Ecological targets |
|---|---|
| Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools, so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained | 1. Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar, at a maximum interval of 2 years. |
| Restore resilient populations of golden perch | 2. Population age structure of golden perch includes YOY with sub-adults and adults in 8 of 10 years.<br>3. Population age structure of golden perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts represented by >30% of the population. |
| Restore resilient populations of Murray cod | 4. Population age structure of Murray cod includes recent recruits, sub-adults and adults in 9 of 10 years.<br>5. Population structure of Murray cod indicates a large recruitment event one in 5 years, demonstrated by a cohort representing >50% of the population. |

| Ecological objective | Ecological targets |
|---|---|
| Maintain a viable, functioning river red gum population below the 40,000 $ML.day^{-1}$ QSA flow band | 6. In standardised transects spanning the elevation gradient in the target zone, 70% of river red gums have a Tree Condition Index (TCI) score of ≥10. |

### 3.1.2 The Floodplain PEA

Twenty-one ecological objectives and 40 nested ecological targets are described for the Floodplain PEA within the SA River Murray LTWP (DEWNR 2015). These objectives and targets are based on the key components of the Floodplain PEA (DEWNR 2015), as well as existing objectives and targets for the Channel (Wallace, et al. 2014a), Chowilla Floodplain (Wallace, et al. 2014), and Pike and Katarapko Floodplains (Wallace, et al. in prep).

Of these targets, a total of 3 prioritised ecological targets across 3 ecological objectives (Table 3-2) were used as the basis for this assessment and evaluation of expected environmental outcomes for the Floodplain PEA.

**Table 3-2. Ecological objectives and targets for the Floodplain PEA.**

| Ecological objective | Ecological targets |
|---|---|
| Maintain a viable, functioning river red gum population within the managed floodplain | 1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70% of all trees have a Tree Condition Index (TCI) Score of ≥ 10. |
| Maintain a viable, functioning Black Box population within the managed floodplain | 2. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70% of all trees have a Tree Condition Index (TCI) Score of ≥ 10. |
| Provide for mobilisation of carbon, nutrients and propagules from the floodplain to the river | 3. During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, nutrients and Dissolved Organic Carbon relative to those available during base flow. |

The expected environmental outcomes (based on the ecological targets shown above) assessed for the Channel PEA and Floodplain PEA as part of the SA River Murray are presented in each of the relevant sections within this report.

## 3.2 Methods

For Matter 8 reporting, assessments included:

- achievement of expected environmental outcomes
- trend (as described in section 3.2.1)

- information reliability (as described in section 3.2.2)
- evaluation of environmental outcomes using expert elicitation supported by available data and information (DEW in prep), including the identification of actions to achieve environmental outcomes in the future.

South Australian Trend and Condition Report Cards include:

- trend (as described in section 3.2.1)
- condition assessments specific to each of the indicators (as described in each section of this report)
- information reliability (as described in section 3.2.2).

### 3.2.1 Trend

A Bayesian modelling approach was used to assess trend in the time series data collected for ecological indicators. This modelling approach was used as it provides more information surrounding the results and allows for a more detailed assessment of trend based on variability inherent in the data. Bayesian models provide an estimate of the likelihood of the trend in the time series data assessed. Bayesian trend analysis was undertaken in R Studio (R version 3.5.0, R Core Team 2018) using Bayesian Generalized Linear Models and Mixed Models (using the stan-glm and stan-glmer functions in the rstanarm package, Goodrich et al. 2020, 4000 runs). If both fixed and random effects were included within a model then Mixed Models were used. Slope (trend) was estimated from the posterior distribution resulting from the Bayesian analysis. Trend direction was assessed using calculated probability (as per McBride 2019) using a graduated scale to present results. Alignment of trend outcomes with the categories used for the South Australian Trend and Condition Report Cards (herein referred to as Report Cards) are presented in Table 3-3.

**Table 3-3. Alignment of trend outcomes based upon their likelihood of an increase or decrease (modified from Mastrandrea et al. 2010) with categories used for Report Cards.**

| Outcome | Likelihood of outcome | Report card |
|---|---|---|
| Virtually certain increase | >+99 – +100% | Getting better |
| Extremely likely increase | >+95 – +99% | |
| Very likely increase | >+90 – +95% | |
| Likely increase | >+66 – +90% | |
| About as likely as not | -66 – +66% | Stable |
| Likely decrease | <-66 – -90% | Getting worse |
| Very likely decrease | <-90 – -95% | |
| Extremely likely decrease | <-95 – -99% | |
| Virtually certain decrease | <-99 – -100% | |

This trend is then summarised as the following:

- Getting better: The indicator is improving over the period of assessment
- Stable: The indicator is neither improving nor declining over the period of assessment
- Getting worse: The indicator is declining over the period of assessment
- Unknown: Data are not sufficient to determine any trend in the status of this indicator

### 3.2.2 Information reliability

The reliability of data to assess the achievement of environmental outcomes and the progression towards the LTWP targets were scored based upon the method devised by Battisti et al. (2014) with modifications to improve its applicability to Matter 8 reporting and the Report Card process. This scoring system assesses answers to questions relating to the method used for data collection, representativeness and repetition. A scoring system as shown in Table 3-4 was used to determine a final score for data reliability that ranges between 0 and 12. Final scores are then converted into an information reliability rating that ranges between poor and excellent using the matrix in Table 3-5.

**Table 3-4. Scoring system for the reliability of data used to assess and analyse trend, condition and LTWP targets and expected outcomes for Matter 8 reporting.**

| **Methods** | **Question** | **Scoring system** | | |
|---|---|---|---|---|
| | | **Yes** | **Somewhat** | **No** |
| Methods used | Are the methods used appropriate to gather the information required for evaluation? | 2 | 1 | 0 |
| Standard methods | Has the same method been used over the sampling program? | 2 | 1 | 0 |
| **Representativeness** | | | | |
| Space | Has sampling been conducted across the spatial extent of the PEA with equal effort? | 2 | 1 | 0 |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | 2 | 1 | 0 |
| **Repetition** | | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | 2 | 1 | 0 |
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | 2 | 1 | 0 |

**Table 3-5. Conversion of the final score (0-12) of data reliability to an information reliability rating that ranges from poor to excellent for Matter 8 reporting and Report Cards.**

| **Final score** | **Information reliability** |
|---|---|
| 12 | Excellent |
| 11 | Very good |
| 10 | Good |
| 9 | Fair |
| ≤8 | Poor |

# 4 Flow velocity

## 4.1 Introduction

Velocity of flow is an important driver of the structure and function of river ecosystems (Bice et al. 2017). The composition of biofilms (Wallace et al. 2014), phytoplankton (Wallace et al. 2014) and riparian vegetation (Nilsson 1987) communities are influenced by flow velocity (Gibbs et al. 2020). Flow velocity also influences the function of river systems through impacts on water quality as well as the transport of nutrients, seeds, sediment, larvae and microinvertebrates, which in turn also influences the structure of fauna communities higher in the trophic system (Gibbs et al. 2020).

In the lower River Murray Channel, river regulation and extraction of water have substantially reduced the velocity of flow and led to a loss of lotic (fast-flowing, i.e. ≥0.3m.s$^{-1}$) habitat and a gain in lentic (slow-flowing) habitat (Bice et al. 2017; Mallen-Cooper and Zampatti 2018). Such changes have had pronounced impacts on ecosystem processes, to the detriment of 'flow-dependent' species. Reductions in flow velocity are suggested to have influenced the population decline, and in some cases regional extinction, of flow-dependent species, such as the Murray crayfish (*Euastacus armatus*), trout cod (*Maccullochella macquariensis*) and Murray cod (*Maccullochella peelii*) (Bice et al. 2017). The decline and loss of these species highlights the need for the restoration of lotic conditions in the River Murray (Ye et al. 2018).

A summary of key velocity thresholds and associated ecological risks and responses in the Murray–Darling Basin are provided in Table 4-1.

**Table 4-1. Key velocity thresholds and associated risks and ecological response in the Murray–Darling Basin.**

| Velocity | Process |
|---|---|
| 0.03 m s$^{-1}$ | Prevents prolonged periods of persistent thermal stratification and *Anabaena* (recently taxonomically revised to *Dolichospermum*, the dominant genus of cyanobacteria) blooms (Mitrovic et al. 2011). |
| <0.1 m s$^{-1}$ | Risk of thermal stratification, especially when temperatures are higher and wind speed is lower (Wallace et al. 2014). |
| 0.15-0.2 m s$^{-1}$ | Beneficial to the entrainment and downstream transport of littoral rotifers from the genus of *Trichocerca* (Gibbs et al. 2020). |
| 0.2 m s$^{-1}$ | Promote the dispersal of Murray cod larvae (Gibbs et al. 2020). |
| 0.3 m s$^{-1}$ | Remove an established cyanobacterial bloom (Mitrovic et al. 2011). |
| >0.3 m s$^{-1}$ | Murray cod larvae were associated with the slack water habitats (<0.1 m.s$^{-1}$) within fast-flowing reaches (>0.3 m.s$^{-1}$) (Gibbs et al. 2020). |
| | Facilitate scouring of biofilms (Wallace et al. 2014). |
| | Habitats used by Murray cod and golden perch (Koehn and Nicol 2014; Fredberg and Zampatti 2017) |

## 4.2 Ecological objective, target and environmental outcome

Flow velocities in the lower third of weir pools in the lower River Murray are less than the middle and upper sections due to storage created by weirs. Impoundment effects of weirs results in water level is greatest directly upstream of a weir, which then typically declines with distance upstream of the weir. Subsequently, the river gradient (drop in elevation over distances) is greatest in the upper section of weir pools, and progressively declines in the middle and lower weir pool sections, with associated influences on water velocity (Bice et al. 2017). To improve the health of the South Australian River Murray and outcomes for flow-dependent biota, the SA River Murray LTWP ecological objective for velocity as described in Klisby and Steggles (2015) aimed to restore a range of velocity classes to the lower third of weir pools (Table 4-2. Ecological objective, target and environmental outcome for flow velocity in the SA River Murray Channel PEA.

| Characteristic | Description |
|---|---|
| Ecological objective | Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained. |
| Ecological targets | Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar, at a maximum interval of 2 years. |
| Environmental outcome | Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar. |

, which then implies that the whole river reach is experiencing a range of velocity classes.

Modelling demonstrates that a wide range (0-0.6 $m.s^{-1}$) of velocity classes is present over the lower third of all weir pools in the SA River Murray when flow to South Australia (QSA) is ≥20,000 $ML.day^{-1}$ (Figure 4-1) (Bonifacio et al. 2016). Hydraulic diversity is more limited at QSA 10,000 $ML.day^{-1}$, with less than 20% of the lower weir pools having mean velocities greater than 0.2 $m.s^{-1}$ (Bonifacio et al. 2016). Therefore, to meet the ecological target as described in Klisby and Steggles (2015), QSA must be equal to or exceed 20,000 $ML.day^{-1}$ for at least 60 consecutive days between September and March, at a maximum interval of 2 years (Table 4-2. Ecological objective, target and environmental outcome for flow velocity in the SA River Murray Channel PEA.

| Characteristic | Description |
|---|---|
| Ecological objective | Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained. |
| Ecological targets | Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar, at a maximum interval of 2 years. |
| Environmental outcome | Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar. |

).

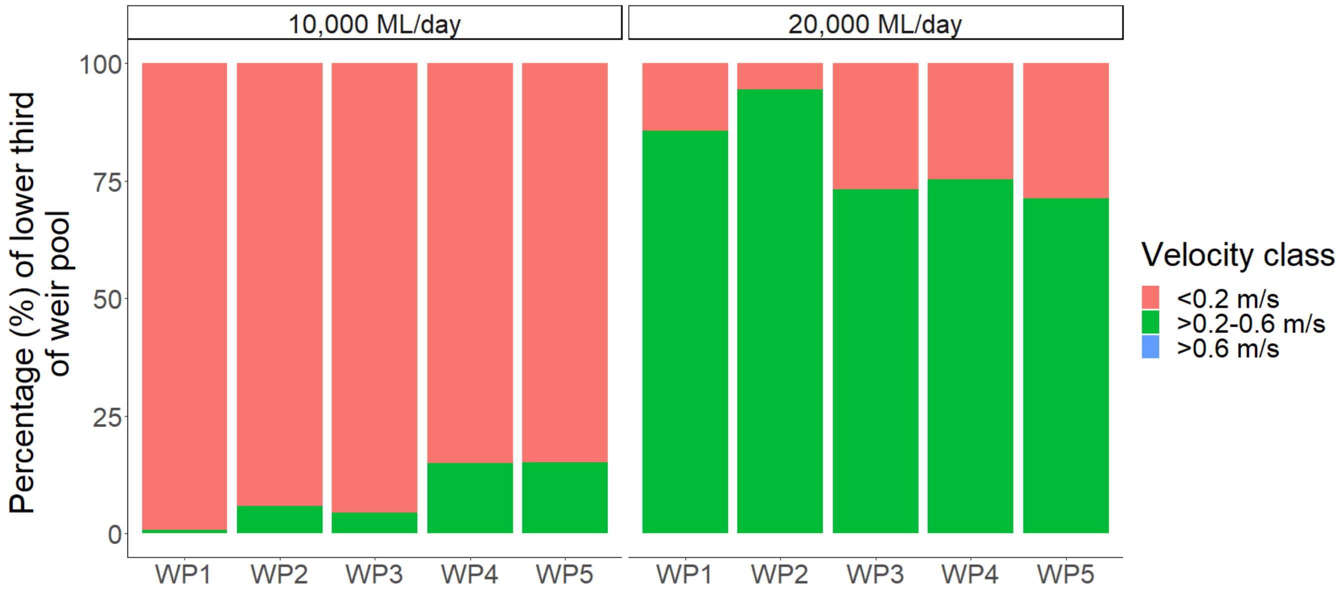


**Figure 4-1. Percentage (%) of each velocity class over the lower third of weir pools (WP 1-5) for QSA of 10,000 ML.day$^{-1}$ and 20,000 ML.day$^{-1}$ in the Channel PEA (Bonifacio et al. 2016).**

An expected environmental outcome was not elicited for flow velocity, but based on the modelling and the ecological target, the environmental outcome was assessed through the identification of years that met the hydrological requirements of the LTWP target, irrespective of the maximum return interval (Table 4-2).

**Table 4-2. Ecological objective, target and environmental outcome for flow velocity in the SA River Murray Channel PEA.**

| Characteristic | Description |
|---|---|
| Ecological objective | Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained. |
| Ecological targets | Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar, at a maximum interval of 2 years. |
| Environmental outcome | Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep-Mar. |

## 4.3 Method

QSA data sourced from Hydstra were filtered to span the period from September to March and show days when mean daily QSA were ≥20,000 $ML.day^{-1}$. The total number of consecutive days when QSA was ≥20,000 $ML.day^{-1}$ were then tallied for each water year from 2000/01 to 2018/19.

Post-hoc assessment was conducted to determine whether the success or failure of the environmental outcomes since Basin Plan adoption were influenced by weir pool manipulation. The influence of weir pool management assessed, included:

- influence of weir pool lowering in years where QSA was not ≥20,000 $ML.day^{-1}$ for 60 consecutive days between September and March
- influence of weir pool raising in 2016/17 when QSA was ≥20,000 $ML.day^{-1}$ for 60 consecutive days between September and March.

### 4.3.1 Trend

The approach used to assess trend with a Bayesian Generalised Linear Model is discussed in section 3.2.1. Trend for velocity ecological objective was assessed based upon the whether or not the ecological index was met for a given year from 2000/01 to 2018/19. Individual years were treated as an independent data point for the analysis, with a 1 allocated to years that met the ecological index and a 0 allocated to years that did not meet the ecological index, resulting in a binary dataset. Time step (years since the commencement of the assessment period) was used as the sole fixed response variable. A binomial family was fitted to the Bayesian Generalised Linear Model.

### 4.3.2 Information reliability

The information reliability assessment for velocity was conducted as per section 3.2.2.

## 4.4 Limitations of assessment

Interpretation of the influence of water for the environment on flow velocity from the assessment against the timing, duration and return interval requirements needs to be treated with caution as it is a pass/fail threshold, and hence not a sensitive metric for assessing change in flow velocity over the Channel PEA. Improvements in the flow velocity attributed to water for the environment will not be detected if they do not exceed these specific requirements.

## 4.5 Results

The number of days of high spring-summer flow (≥20,000 $ML.day^{-1}$ between September and March) were highly variable between 2000/01 and 2018/19 (Table 4-3; Figure 4-3). In 2000/01, a total of 114 consecutive high spring-summer flow were recorded. No days of high spring-summer flow were recorded during Millennium Drought that lasted from 2001/02 to 2009/10. The high (unregulated) flows recorded in 2010/11 included 186 consecutive days with QSA ≥20,000 $ML.day^{-1}$ between late September and March. In the high and moderate flow years that followed, a total of 35, 54 and 29 consecutive days of high spring-summer flow were recorded in 2011/12, 2012/13 and 2013/14, respectively. However, 93 and 60 days of non-consecutive days high spring-summer flow were recorded in 2011/12 and 2012/13, respectively. A total of 60 days with QSA ≥20,000 $ML.day^{-1}$ was reached in 180 and 67 days in 2011/12 and 2012/13, respectively. No days of high spring-summer flow were recorded in 2014/15 and 2015/16. A high flow event in 2016/17 recorded 123 consecutive days of high spring-summer flow. Over the past 2 water years (2017/18 and 2018/19) no days of high spring-summer flow were recorded.

### 4.5.1 Environmental outcome assessment

Since 2000/01, the environmental outcome was met in 3 (2000/01, 2010/11 and 2016/17) of 19 years (Table 4-3). Therefore, since Basin Plan adoption, the environmental outcome was met in one of 7 water years, and as a result, progression towards the LTWP target has not been made.

**Table 4-3. The number of days and consecutive days of QSA ≥20,000 $ML.day^{-1}$ in September to March and whether the environmental outcome was met.**

| Year | Days (non-consecutive) of QSA ≥20,000 $ML.day^{-1}$ in September to March | Number of consecutive days QSA ≥20,000 $ML.day^{-1}$ in September to March | Outcome met/not met |
|---|---|---|---|
| 2000/01 | 114 | 114 | Met |
| 2001/02 | 0 | 0 | Not met |
| 2002/03 | 0 | 0 | Not met |
| 2003/04 | 0 | 0 | Not met |
| 2004/05 | 0 | 0 | Not met |
| 2005/06 | 0 | 0 | Not met |
| 2006/07 | 0 | 0 | Not met |
| 2007/08 | 0 | 0 | Not met |
| 2008/09 | 0 | 0 | Not met |
| 2009/10 | 0 | 0 | Not met |
| 2010/11 | 186 | 186 | Met |
| 2011/12 | 93 | 35 | Not met |
| 2012/13 | 60 | 54 | Not met |
| 2013/14 | 29 | 29 | Not met |
| 2014/15 | 0 | 0 | Not met |
| 2015/16 | 0 | 0 | Not met |

| Year | Days (non-consecutive) of QSA ≥20,000 ML.day$^{-1}$ in September to March | Number of consecutive days QSA ≥20,000 ML.day$^{-1}$ in September to March | Outcome met/not met |
|---|---|---|---|
| 2016/17 | 123 | 123 | Met |
| 2017/18 | 0 | 0 | Not met |
| 2018/19 | 0 | 0 | Not met |

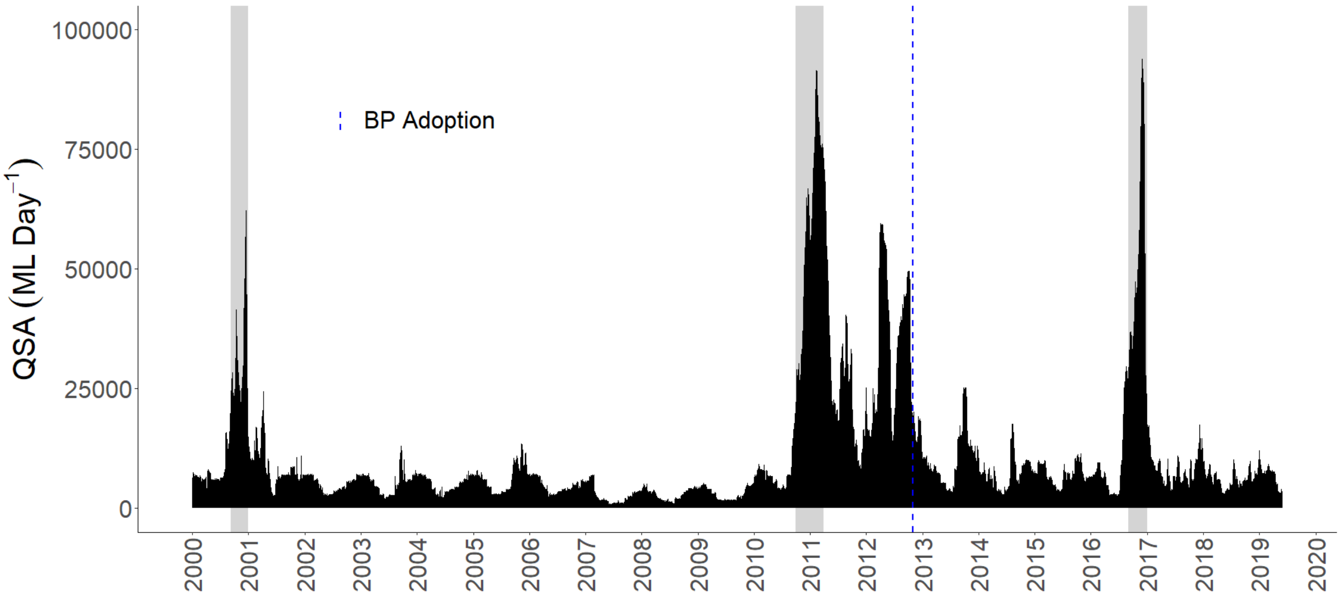


**Figure 4-2. QSA (ML.day$^{-1}$) from 2000 to 2019 showing periods where flow met the environmental outcome (≥20,000 ML.day$^{-1}$ for at least 60 consecutive days between September and March) as shown by grey shading. Basin Plan (BP) adoption is marked by the vertical dashed blue line.**

### 4.5.2 Assessment of the influence of weir pool management

***Weir pool lowering***

Weir pool lowering has not helped to meet the environmental outcome. While weir pool lowering events have occurred at all locks, except for Lock 4, since Basin Plan adoption, the greatest depth of lowering for an individual lock was -0.18m. Weir pool lowering of up to -0.18 m has a relatively minor impact on the proportion of weir pools with median cross-sectional velocities exceeding 0.3 m.s$^{-1}$ (Ye et al. 2018; Ye et al. 2020). When median cross-sectional velocities exceed 0.3 m.s$^{-1}$, a range of velocity classes occur (Bice et al. 2017). Therefore, the environmental outcome would not have been met outside of periods where QSA was >20,000 ML.day$^{-1}$ for 60 consecutive days between September and March.

***Weir pool raising***

Weir pool raising occurred at locks 2 and 5 when the environmental outcome was met in 2016/17. These events (Table 4-4) did not detract from the achievement of the outcome in 2016/17, as 10$^{th}$ percentile velocities in weir pools 2 and 5 were modelled to exceed 0.3 m.s$^{-1}$ from approximately September to late December and 0.5 m.s$^{-1}$

from approximately November to late December (Ye et al. 2018). Therefore, neither weir pool raising event impacted the achievement of the environmental outcome in 2016/17.

Lock 6 was raised in association with operation of the Chowilla regulator when the environmental outcome was met in 2016/17. As QSA was >20,000 $ML.day^{-1}$ for 93 days following the peak of the Chowilla regulator operation and for 53 days following the end of Chowilla regulator operation (Table 4-5), it is highly unlikely that these actions impacted the achievement of the environmental outcome in 2016/17.

**Table 4-4. Summary of weir pool raising events that occurred when the environmental outcome was met in 2016/17.**

| Lock | WPM (+/- m) | Start date | Dates of max | | End date |
|---|---|---|---|---|---|
| | | | Start | End | |
| 2 | +0.48 | 03-07-2016 | 29-08-2016 | 07-10-2016 | 17-11-2016 |
| 5 | +0.75 | 03-07-2016 | 01-10-2016 | 11-10-2016 | 03-11-2016 |

**Table 4-5. Summary of managed inundation event at Chowilla in 2016/17 with raises of Lock 6 and operation of the Chowilla regulator (Ghaderi and Wood 2017).**

| Lock 6 - Max WPM (+/-m) | Chowilla regulator (+/- m) | Start date | Dates of max | | End date |
|---|---|---|---|---|---|
| | | | Start | End | |
| +0.59 | +3.40 | 10-08-2016 | 22-09-2016 | 01-10-2016 | 10-11-2016 |

### 4.5.3 Trend

This trend analysis determined that the frequency of years that met the environmental outcome from 2000/01 to 2018/19 was about as likely as not (53.55% likelihood) to have declined, and therefore, is considered to be **stable** (Figure 4-3). Therefore, progression towards to the LTWP target has not occurred.

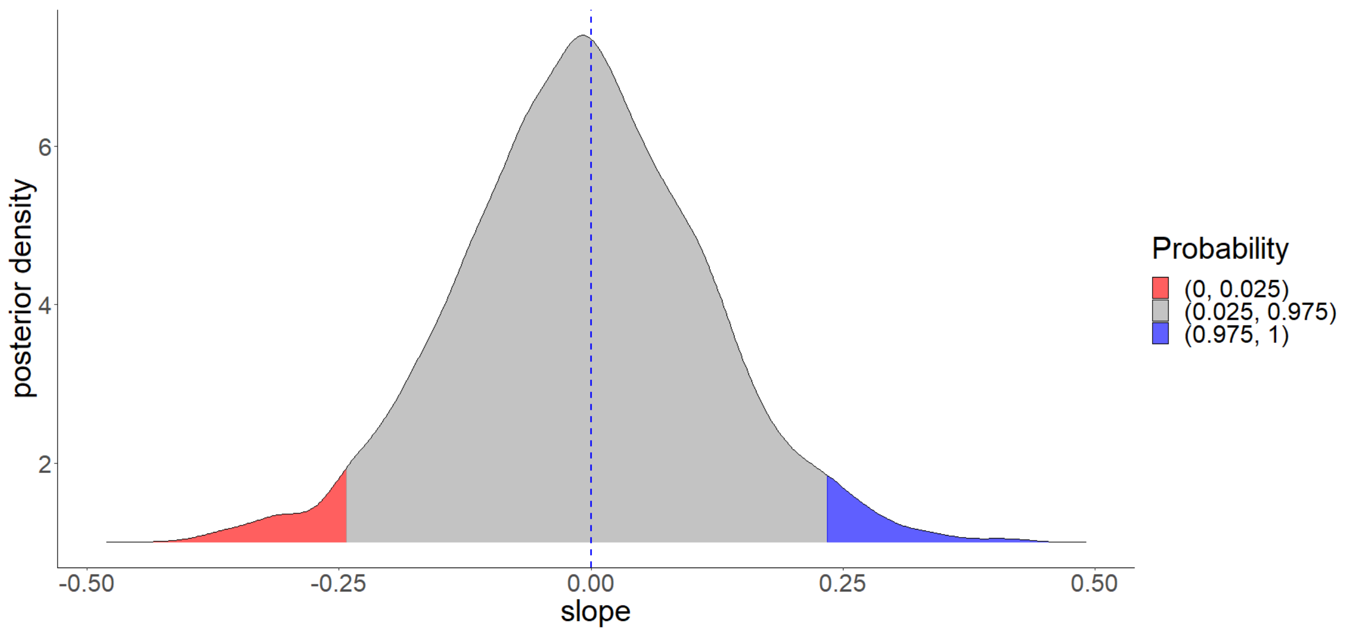


**Figure 4-3. Estimated values for the slope generated from Bayesian modelling for the success of the environmental outcome (QSA was ≥ 20,000 ML.day$^{-1}$ for 60 consecutive days between September and March) from 2000/01 to 2018/19. Posterior density values with a slope >0 infer a positive trend (getting better) and values with a slope <0 infer a negative trend (getting worse).**

### 4.5.4 Information reliability

The information reliability rating for velocity was **good** (final score of 10). Justification for the scoring of velocity data reliability is provided in Table 4-6

**Table 4-6. Reliability of QSA data to assess the environmental outcome for flow velocity. The methods used in data collection as well as the representativeness and repetition of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions were scored 2 points – Yes, 1 point – Somewhat and 0 points – No.**

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| Methods used | Are the methods used appropriate to gather the information required for evaluation? | **Somewhat.** Flow velocities in the lower third of weir pools have not been directly measured or modelled. However, modelling by Bonifacio et al. (2016) identified that the majority of the lower third of weir pools had flow velocities >0.2m.s$^{-1}$ and therefore had a range of velocity classes when QSA was ≥20,000 ML.day$^{-1}$. | **1** |
| Standard methods | Has the same method been used over the sampling program? | **Yes**. Mean daily QSA data has been sourced from Hydstra to cover the assessment period from 2000/01 to 2018/19. | **2** |

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| **Representativeness** | | | |
| Space | Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort? | **Somewhat.** Only QSA data has been used in their assessment rather than discharge from each lock. However, modelling by Bonifacio et al. (2016) identified that the majority of the lower third of weir pools had flow velocities >0.2m.s$^{-1}$ and therefore had a range of velocity classes. | **1** |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | **Yes**. Mean daily QSA data were sourced from Hydstra to cover the assessment period from 2000/01 to 2018/19. | **2** |
| **Repetition** | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | **Yes**. Mean daily QSA has been based upon the same telemetered water stations over the assessment period from 2000/01 to 2018/19. | **2** |
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | **Yes**. Mean daily QSA data were sourced from Hydstra to cover the assessment period from 2000/01 to 2018/19. | **2** |
| **Final score** | | | **10** |
| **Information reliability** | | | **Good** |

## 4.6 Evaluation

A range of flow velocity habitats (by proxy of QSA ≥20,000 ML.day$^{-1}$) were recorded in the lower thirds of weir pools for 60 consecutive days between September and March on 3 occasions since 2000/01, and only once since the adoption of the Basin Plan (2012). While weir pool manipulation (raising and lowering) can impact the range of flow velocity habitats at a given discharge, raising and lowering events have been of insufficient magnitude to influence whether or not the environmental outcome was met. Therefore, progression towards to the LTWP target has not occurred. Rainfall deficits (i.e. drought) (see section 4.6.1) combined with the operation of weirs (see section 4.6.2) as well as insufficient volumes of water for the environment and constraints on its delivery (see section 4.6.3) have all contributed to the failure to achieve the environmental outcome for flow velocity in the SA River Murray Channel PEA. The lack of achievement of the environmental outcome has also meant that no progression towards the LTWP target has been made.

### 4.6.1 Rainfall

Rainfall anomalies over the Murray–Darling Basin during the assessment period (2000/01–2018/19) (Figure 4-4) influenced flow conditions over the Murray–Darling Basin, including the SA reach of the River Murray. Prolonged drought over the Murray–Darling Basin (‘the Millennium Drought’) was recorded from 1996/97 until widespread rainfall and associated flood in 2010/11. With the exception of 2016/17, annual rainfall over the Murray–Darling Basin in all water years following Basin Plan adoption has been below average, with rainfall in 2017/18 and 2018/19 particularly low. Such reductions in rainfall over the Murray–Darling Basin were attributed to climate change and drought and have reduced flows within the Basin (MDBA 2019).

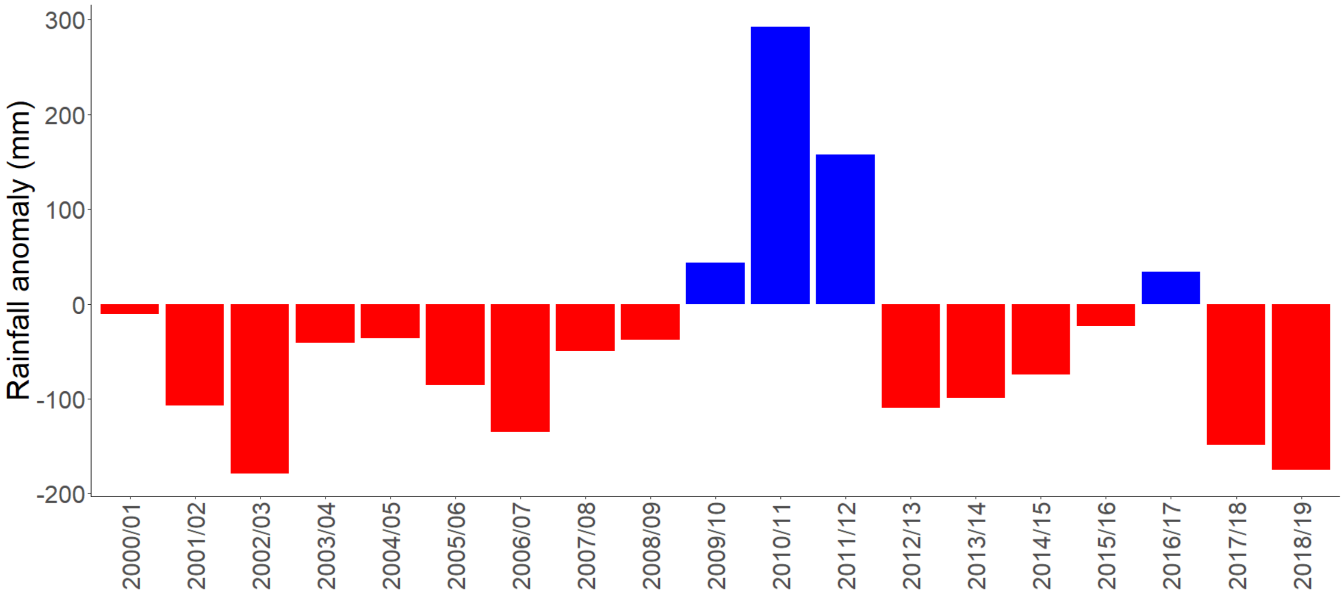


**Figure 4-4. Annual rainfall anomaly (mm) over the Murray–Darling Basin from 2000/01 to 2018/19 with respect to the long-term average (489.4 mm from 1961 to 1990) (BOM 2020).**

### 4.6.2 Weirs

Construction and operation of the 11 weirs from Mildura to Blanchetown (6 weirs in the SA reach of the lower River Murray) has substantially reduced average flow velocities from those that would be achieved at the same discharge without the weirs. This has influenced the ability to meet the environmental outcome and progression towards achieving the LTWP target. For example, at sites between Lock 1 and 3, modelled mean cross-sectional flow velocities at discharge of 10,000 $ML.day^{-1}$ have reduced by 8-66%, which subsequently has altered the reach from predominantly lotic (>0.3 $m.s^{-1}$) to lentic habitats (<0.3 $m.s^{-1}$) (Bice et al. 2017). As such, substantially greater discharge is required to achieve the hydraulic outcomes of the lower River Murray prior to the construction and operations of weirs (Bice et al. 2017).

Rainfall deficits in combination with the operation of weirs have contributed to a lack of high (unregulated) flow events that under current delivery constraints are required to meet the environmental outcome as occurred in 2016/17 (Figure 4-5). In the absence of a high (unregulated) flow event, volumes of water for the environment coupled with SA entitlement flows and additional dilution flows were insufficient to achieve QSA of ≥20,000 $ML.day^{-1}$ for 60 consecutive days following the adoption of the Basin Plan.

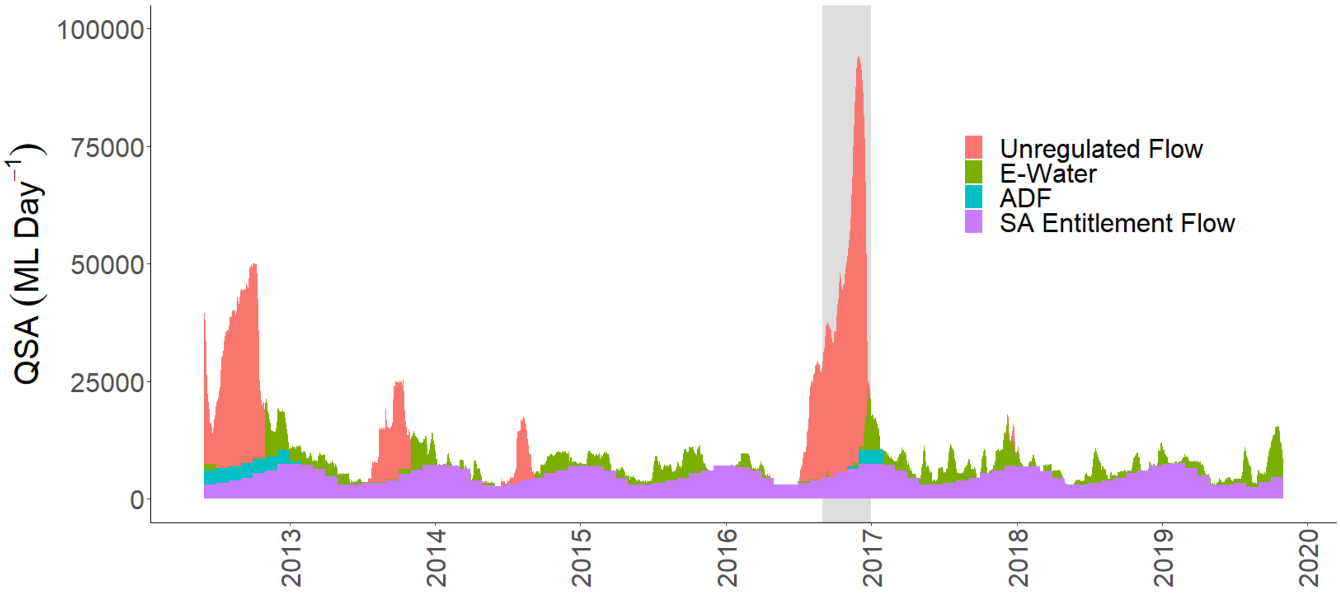


**Figure 4-5. Contribution of unregulated flow, water for the environment (E-Water), additional dilution flow (ADF) and SA entitlement flow to Flow (ML.Day$^{-1}$) to the South Australian border (QSA) from June 2012 to November 2019. Periods where QSA was ≥20,000 ML.day$^{-1}$ for at least 60 consecutive days between September and March are shaded in grey (Data Source: MDBA 2019).**

### 4.6.3 Water for the environment

South Australia's Entitlement is insufficient alone to achieve fast-flowing conditions within the SA River Murray. To meet the required flow volume and duration, both high (unregulated) flows and water for the environment will be required, as the delivery of water for the environment independent of high (unregulated) flows did not contribute to the achievement of the environmental outcome since the adoption of the Basin Plan. Water for the environment delivered at the tail-end of the unregulated flow event in 2016/17, which helped to prolong the duration of the days that QSA was ≥20,000 ML.day-1 by 12 days (Figure 4-5).

Under current water delivery constraints and volumes, the delivery of water for the environment under regulated conditions is insufficient to meet the environmental outcome for flow velocity in the absence of a high (unregulated) flow event. With significant coordination of delivery of water for the environment between water holders and across River Murray tributaries, ability to contribute to the achievement of the environmental outcome may improve by increasing the number of consecutive days when QSA is ≥20,000 ML.day$^{-1}$.

Despite the failure to meet the environmental outcome and progress towards the LTWP target, water for the environment did increase the extent of lotic habitat in the main channel of the SA River Murray. Commonwealth Environmental Water (CEW) was modelled to have a minor increase in the extent of lotic habitat in 2015/16, 2016/17 and 2018/19 (≤20 km for ≥30 days) and a moderate increase in 2017/18 (36 km for ≥30 days) (Ye et al. 2020). The improvement in the extent of lotic habitat may have contributed to enhanced recruitment of Murray cod (see section 7.7).

## 4.7 Actions to achieve environmental outcome

To improve the ability to achieve the environmental outcome for flow velocity in the SA River Murray Channel, the restoration of lotic habitat needs to be enhanced. This is only likely to occur with full implementation of the Basin Plan, including the addressing of current water delivery constraints. The relaxation of flow constraints is critical to the achievement of more frequent flows of ≥20,000 ML/day in September-March in South Australia.

Restoration of fast-flowing habitat may be enhanced under current constraints and volumes of water for the environment through the following:

- ***Coordinated water delivery***: QSA of 20,000 ML.day$^{-1}$ restores lotic habitats to large reaches of the River (Bonifacio et al. 2016; Bice et al. 2017). The coordinated delivery of water for the environment from all tributaries (Darling, Murrumbidgee and Goulburn) and increased releases from Lake Victoria could result in QSA reaching 20,000 ML.day$^{-1}$ under regulated flows and current constraints. However, a significant volume would be required to increase flows for the full duration required (60 consecutive days) to meet the ecological index (M Gibbs, personal communication, 18 August 2020).
- ***Actions such as weir pool lowering*:** Lowering weir pools by 1 m at discharge of 10,000 ML.day$^{-1}$ would increase the length of lotic habitat three-fold in the Lock 1-2 and 2-3 weir pools, while a minor increase would occur in the Lock 3-4 weir pool (Bice et al. 2017). Water for the environment could be delivered in synergy with weir pool lowering and/or removal to further enhance hydraulic diversity (Bice et al. 2017).

The use of weir pool management to support flow velocities in the SA River Murray channel needs further investigation, particularly any potential impacts on sites (such as Chowilla) that already provide fast-flowing habitats. Knowledge of the spatio-temporal scales of the riverine species life histories and ecological processes that the restoration of fast-flowing habitats aims to promote is required (Bice et al. 2017).

## 4.8 Conclusion

The Basin Plan is yet to have a significant impact on flow velocities across the extent of the SA River Murray Channel. As a result there has been limited achievement of the environmental outcome and no progression towards the LTWP target for flow velocity in the River Murray Channel PEA. However, more sensitive metrics have identified that implementation of the Basin Plan, including delivery of water for the environment, has increased the localised extent of lotic habitats in the main channel of the SA River Murray and contributed to increases in the number of days QSA were ≥20,000 ML/day, but below 60 days in spring-summer .

Key messages:

- Construction and operation of weirs has meant that substantial increases in QSA are needed to promote increases in average flow velocities within the SA River Murray.
- Volumes of water for the environment delivered were insufficient to meet the environmental outcome, however, it did increase the localised temporal and spatial extent of lotic habitat (≥0.3 m.s$^{-1}$) in the main channel of the SA River Murray, which may have contributed to enhanced recruitment of Murray cod (Ye et al. 2020).
- Under current delivery volumes and constraints, the contribution of water for the environment to QSA is insufficient to meet the environmental outcome and progression towards the LTWP target in the absence of an unregulated flow event.
- Suitable flow velocities could be enhanced through the coordination of water delivery and actions such as weir pool lowering. The use of weir pool management to support flow velocities in the SA River Murray

channel needs further investigation, particularly any potential impacts on sites that already provide fast-flowing habitats, such as Chowilla.

- To improve the ability to achieve the environmental outcome in the future, significant action is expected to be required, particularly the relaxation of current water delivery constraints.

# 5 Floodplain productivity: microinvertebrates

## 5.1 Introduction

Overbank flooding can deliver large amounts of terrestrially derived dissolved and particulate organic matter and nutrients as well as phytoplankton and microinvertebrates (zooplankton) from the inundated floodplain to the river channel, which are then assimilated into the river-floodplain trophic system (Gibbs et al. 2020). Microinvertebrates are a critical link in the river-floodplain trophic system between primary producers and higher order consumers, as they consume bacteria, phytoplankton and organic material, and provide a food resource for fish, birds, amphibians and macroinvertebrates (Furst et al. 2014; Gibbs et al. 2020).

Floodplain inundation triggers the emergence of microinvertebrates from the egg bank, and provides access to still or slow-flowing habitats where microinvertebrates have increased survival, feeding and reproduction (Gibbs et al. 2020). The timing, duration and frequency of floodplain inundation significantly influence the biomass of microinvertebrates (Bice et al. 2014). Floodplain inundation is most beneficial to microinvertebrates during their peak growing season in spring and summer (Bice et al. 2014), when water temperatures increase (~25°C) (Ye et al. 2018; Ye et al. 2019). The duration of water residence on the floodplain is also positively associated with the biomass and abundance of microinvertebrates (Bice et al. 2014). Frequency of inundation events also impacts the biomass of microinvertebrates, with flooding events replenishing the egg bank, while extended dry periods can reduce the diversity and abundance of microinvertebrate emergence (Bice et al. 2014).

The quality of microinvertebrate food resources for higher order consumers is likely to be dependent upon their diet. Microinvertebrates have a limited ability to synthesise long-chain polyunsaturated fatty acids, and therefore, must obtain them from their food (Guo et al. 2017). As such, microinvertebrates that consume more nutritious foods are potentially a high-quality food resource for higher order consumers (Gibbs et al. 2020). The nutritional value of phytoplankton food resources are influenced by hydrology, with nutritious diatoms dominant under high flows and nutritionally poor Cyanophyta dominant under low flows (Aldridge et al. 2012; Ye et al. 2014). Consequently, the quality of microinvertebrate food resources for higher order consumers is also expected to be influenced by hydrological conditions.

Transfer of microinvertebrates from the floodplain to the river channel can occur with hydrological mixing and exchange that entrains microinvertebrates within flow (Ye et al. 2014; Furst et al. 2014). The entrainment of microinvertebrates within channel flow and their subsequent settling within slack waters are critical to the recruitment of flow-dependent fish species (Gibbs et al. 2020).

## 5.2 Ecological objective, targets and environmental outcomes

The ecological objective and targets for floodplain productivity from the SA River Murray LTWP are presented in Table 5-1. An expected outcome was not elicited for floodplain productivity but, based on the conceptual understanding (i.e. expect to see an increase microinvertebrates during overbank flooding and managed floodplain inundation), the environmental outcome uses this understanding and the ecological target as the basis. Water quality parameters (i.e. nutrients and dissolved organic carbon; DOC) were not included as part of the environmental outcome or assessed in Matter 8 reporting, as Matter 12 reporting assessed key water quality events.

**Table 5-1. Ecological objective, target and environmental outcome for floodplain productivity (microinvertebrates).**

| Characteristic | Description |
|---|---|
| Ecological objective | Provide for mobilisation of carbon, nutrients and propagules from the floodplain to the river. |
| Ecological target | During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, nutrients and DOC relative to those available during base flow. |
| Environmental outcome | During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, relative to those available during base flow. |

## 5.3 Method

Microinvertebrate data were sourced from the CEWO Long-Term Intervention Monitoring (LTIM) program.

The method used to sample microinverebrates was described in Ye et al. (2019) and includes 'Mid-channel microinvertebrate assemblages were sampled by a Haney plankton trap (4.5 L capacity) approximately fortnightly. Three replicate 9 L (4.5 top and 4.5 L bottom depth) samples were taken during the day at 3 sites below Lock 1 and Lock 6. Microinverebrates were preserved (70-95% ethanol) in the field and returned to the laboratory for processing)'. Sampling periods were grouped into trips based on the dates of survey. Sampling conducted at similar date ranges (within 11 days for a given year) were grouped into tripsTable 2-1 (Table 5-2).

**Table 5-2. Microinvertebrate sampling dates between 2014/15 and 2017/18 in the Lower River Murray, South Australia (Ye et al. 2020).**

| Trip | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
|---|---|---|---|---|
| 1 | | | 26-28/09/2016 | |
| 2 | | 6-7/10/2015 | 11-12/10/2016 | 3-4/10/2017 |
| 3 | | 20-21/10/2015 | 24-25/10/2016 | 16-17/10/2017 |
| 4 | 3-4/11/2014 | 2-3/11/2015 | 7-8/11/2016 | 30-31/10/2017 |
| 5 | 19-20/11/2014 | 17-18/11/2015 | 21-22/11/2016 | 13-14/11/2017 |
| 6 | 1-2/12/2014 | 30/11-1/12/2015 | 6-8/12/2016 | 27-28/11/2017 |
| 7 | 14-15/12/2014 | 15-16/12/2015 | 21/12/2016 | 11-12/12/2017 |
| 8 | 7-8/01/2015 | 5-6/01/2016 | 10-11/01/2017 | 3-4/01/2018 |
| 9 | 19-20/01/2015 | 20-21/01/2016 | | |

For the purposes of the assessment of the floodplain productivity environmental outcome, microinvertebrate density is used as a surrogate for abundance and species richness as a surrogate for diversity.

To assess the achievement of the environmental outcome for floodplain productivity, the abundance and diversity of microinvertebrates since the adoption of the Basin Plan were compared between years with and without floodplain inundation. This assessment does not include Basin Plan adoption (i.e. 2012) as a reference point as data is only available from 2014/15.

This assessment focuses on the 2 largest inundation events that occurred and compares microinvertebrate densities and species richness against time periods where floodplain inundation did not occur or the spatial extent of inundation was more limited.

The 2 largest inundation events that occurred during the sampling program were:

1. overbank flooding in 2016/17 with QSA peaking at >93,000 ML.day$^{-1}$
2. inundation of 2,142 ha of low-lying floodplain and most temporary wetlands following Chowilla regulator operation and raising of Lock and Weir 6 from October to December 2014 (Gehrig et al. 2015).

### 5.3.1 Analysis

The effect of sampling year and site were analysed by Ye et al. (2020) using permutational multivariate analysis of variance (PERMANOVA) in the program PERMANOVA + v.1.02. To ensure a balanced survey design between the four years of sampling, only trips 4 to 8 (between early November and January) were used in the PERMANOVA analysis, with all other trips excluded. Analyses were simplified by using the mean of the 3 replicates from each of the 3 sites sampled below Lock 1 and Lock 6. The mean of each site was then used as a replicate for each sampled lock (i.e. Lock 1 and 6).

### 5.3.2 Information reliability

The information reliability assessment for the floodplain productivity environmental outcome assessment was conducted as per section 3.2.2.

## 5.4 Results

### 5.4.1 Environmental outcome assessment

The environmental outcome was partially met as microinvertebrate densities and species richness were greater during periods of overbank flows (2016/17). However, during a large-scale managed floodplain inundation event at Chowilla (October to December 2014) increases in both density and species richness were spatially and temporally limited (Figure 5-1; Figure 5-2; Figure 5-3; Figure 5-4).

The managed large-scale inundation of the Chowilla floodplain between October and December 2014 was associated with the highest recorded microinvertebrate densities at Lock 6 (Figure 5-1). Although this was not observed at Lock 1, through sampling conducted between October and early November (Figure 5-2). Similarly, species richness at both Lock 1 and 6 were high in November 2014 in comparison to those recorded in early November sampling periods across all other years of the study, with the exception of Lock 1 in 2015/16 during weir pool raising (Figure 5-3; Figure 5-4).

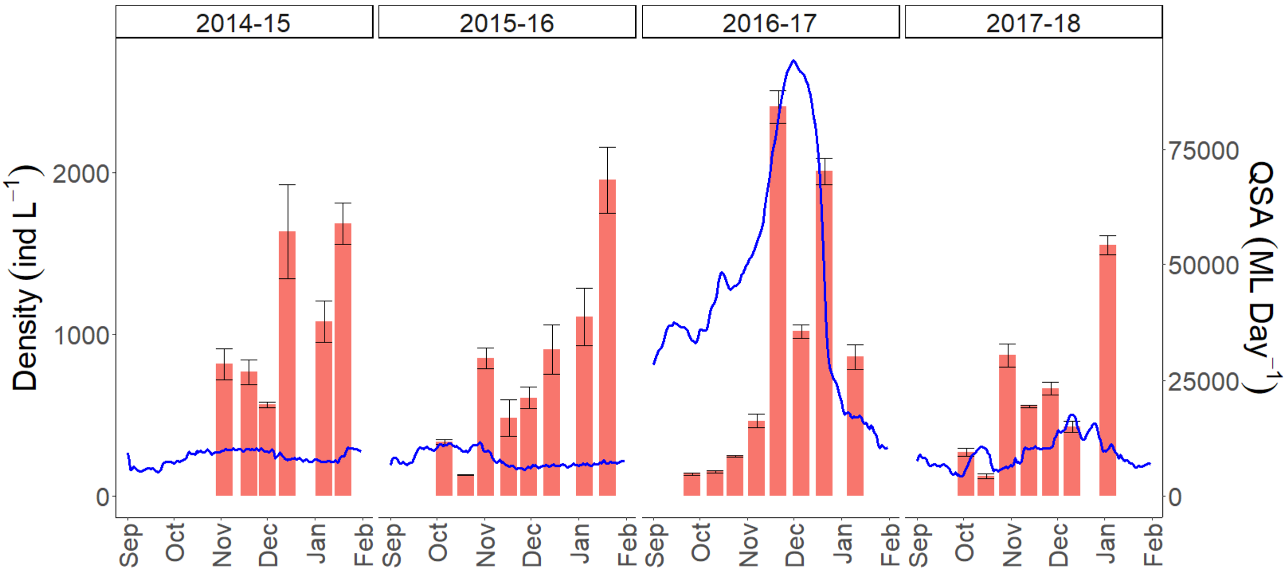


**Figure 5-1. Mean (±S.E.) density (individuals.L$^{-1}$) of microinvertebrates collected at sites below Lock 6 from 2014-15 to 2017-18. Data are plotted against flow (ML.day$^{-1}$) at the South Australian border (QSA). Sampling was conducted between 26 October and 21 January.**

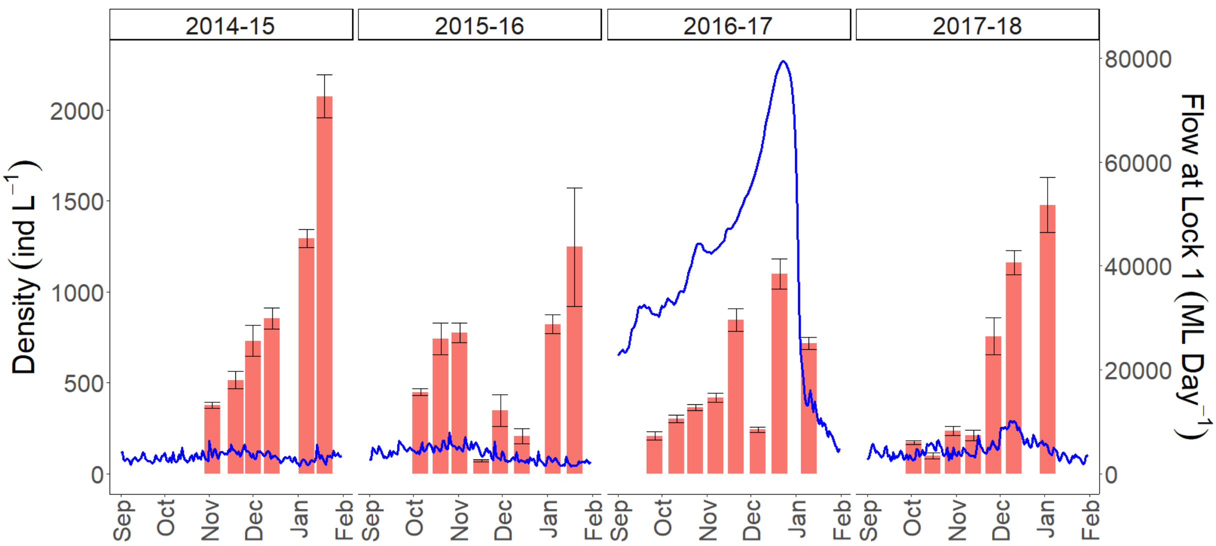


**Figure 5-2. Mean (±S.E.) density (individuals.L$^{-1}$) of microinvertebrates collected at sites below Lock 1 from 2014-15 to 2017-18. Data are plotted against flow (ML.day$^{-1}$) below Lock 1. Sampling was conducted between 26 October and 21 January.**

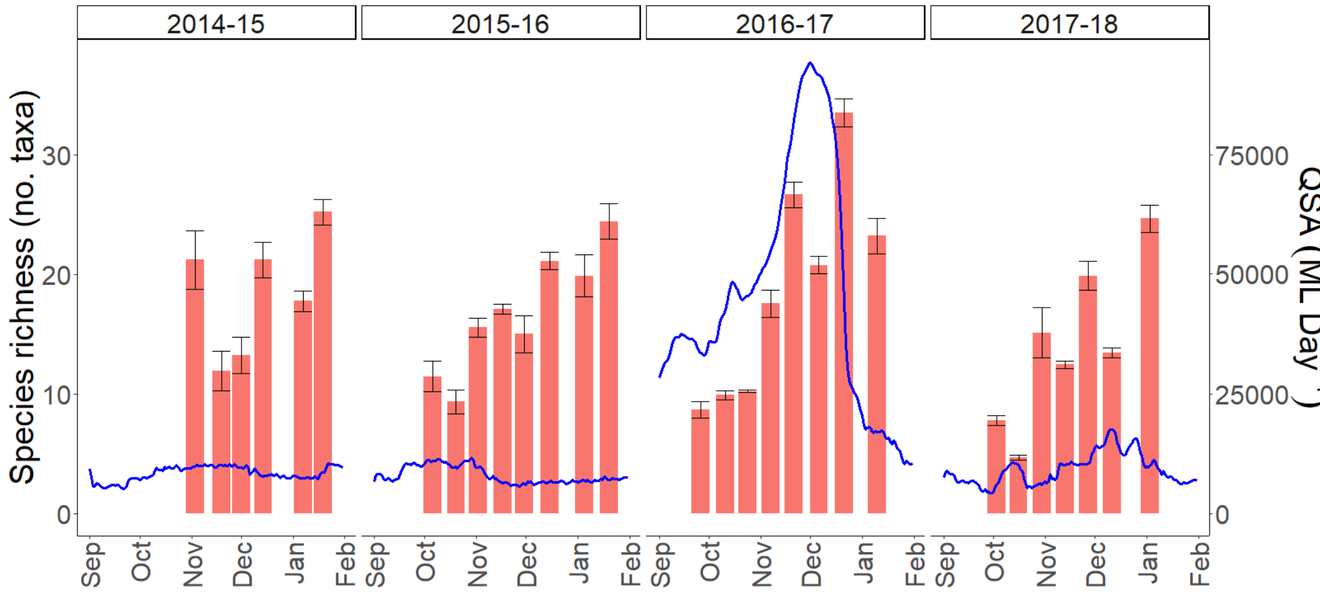


**Figure 5-3. Mean (±S.E.) species richness (no. taxa) of microinvertebrates collected at sites below Lock 6 from 2014-15 to 2017-18. Data are plotted against flow (ML.day$^{-1}$) at the South Australian border (QSA). Sampling was conducted between 26 October and 21 January.**

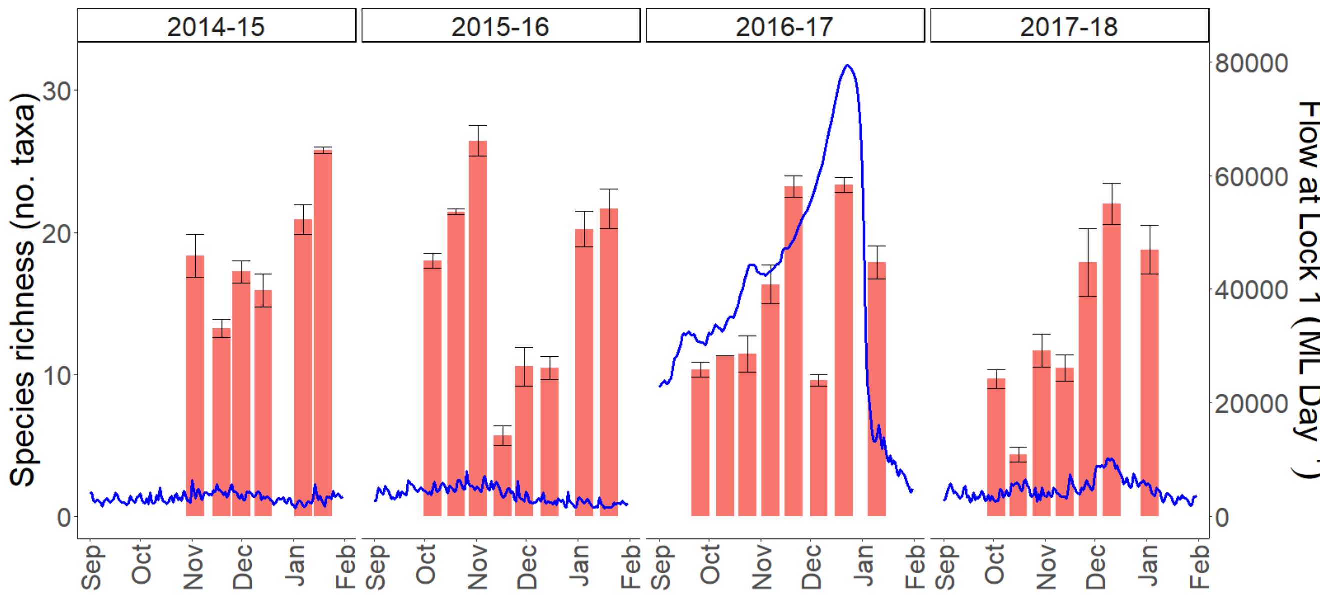


**Figure 5-4. Mean (±S.E.) species richness (no. taxa) of microinvertebrates collected at sites below Lock 1 from 2014-15 to 2017-18. Data are plotted against flow (ML.day$^{-1}$) below Lock 1. Sampling was conducted between 26 October and 21 January.**

Microinvertebrate densities in 2016/17 were significantly higher than those in 2015/16 ($P$=0.002) and 2017/18 ($P$=0.019) (Table 5-3), while microinvertebrate species richness was significantly greater in 2016/17 than all other years ($P$=0.039–0.0078) (Table 5-4). Microinvertebrate densities did not significantly differ between 2016/17 and

2014/15 (*P*=0.2267) (Table 5-3), however, during the 2014/15 survey the Chowilla regulator was in operation from October to December 2014 and facilitated a large-scale inundation event (Gehrig et al. 2015).

**Table 5-3. PERMANOVA table of results of pairwise comparisons on density data between years and sites surveyed (Ye et al. 2020)**

| Groups | t | P(perm) | Unique perms |
|---|---|---|---|
| Years: | | | |
| 2014/15, 2015/16 | 3.1176 | 0.0017 | 9940 |
| 2014/15, 2016/17 | 1.2240 | 0.2267 | 9929 |
| 2014/15, 2017/18 | 2.0070 | 0.0469 | 9933 |
| 2015/16, 2016/17 | 3.1110 | 0.002 | 9929 |
| 2015/16, 2017/18 | 1.2507 | 0.2145 | 9938 |
| 2016/17, 2017/18 | 2.3583 | 0.019 | 9938 |
| Sites: | | | |
| Lock 1, Lock 6 | 4.6502 | 0.0001 | 9958 |

**Table 5-4. PERMANOVA table of results of pairwise comparisons on species richness data between years and sites surveyed (Ye et al. 2020)**

| Groups | t | P(perm) | Unique perms |
|---|---|---|---|
| Years: | | | |
| 2014/15, 2015/16 | 1.2876 | 0.2016 | 9926 |
| 2014/15, 2016/17 | 2.7371 | 0.0078 | 9912 |
| 2014/15, 2017/18 | 0.64407 | 0.5236 | 9923 |
| 2015/16, 2016/17 | 3.1158 | 0.0042 | 9936 |
| 2015/16, 2017/18 | 0.72906 | 0.4797 | 9925 |
| 2016/17, 2017/18 | 3.0018 | 0.0039 | 9911 |
| Sites: | | | |
| Lock 1, Lock 6 | 2.8099 | 0.0046 | 9909 |

### 5.4.2 Information reliability

**The information reliability rating for microinvertebrates was** very good **(final score of 11). Justification for of microinvertebrate data reliability is provided in (**

Table 5-5).

**Table 5-5. Reliability of data to assess the floodplain productivity (microinvertebrates) environmental outcome. The methods used in data collection as well as the representativeness and repetition of data were scored based upon the answers provided to question related to each facet of data collection. Answers to questions were scored 2 points – Yes, 1 point – Somewhat and 0 points – No.**

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| Methods used | Are the methods used appropriate to gather the information required for evaluation? | **Yes.** A standardised methodology has been used throughout the monitoring program that has determined the densities and species richness of microinvertebrates in relation to flow and floodplain inundation. | **2** |
| Standard methods | Has the same method been used over the sampling program? | **Yes.** The same method for microinvertebrate sampling, analysis and identification was used throughout the monitoring program. | **2** |
| **Representativeness** | | | |
| Space | Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort? | **Somewhat.** Sampling was conducted at 3 core LTIM sites within each of the floodplain (Lock 6) and gorge (Lock 1) geomorphic zones of the lower Murray River. | **1** |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | **Yes.** Sampling was conducted approximately fortnightly each year, with the total number of trips ranging from 6 to 8. Samples therefore occurred before, during and after floods and flow pulses. | **2** |
| **Repetition** | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | **Yes.** Samples were collected at the same sites over the monitoring program. | **2** |
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | **Yes.** Sampling has been conducted annually, typically from October to January. | **2** |
| **Final score** | | | **11** |
| **Information reliability** | | | **Very good** |

## 5.5 Evaluation

The density and species richness of microinvertebrates increased during overbank flows and large-scale managed inundations in the SA River Murray following the adoption of the Basin Plan. However, such increases were spatially and temporally limited when large-scale managed inundations occurred. The contribution of water for the environment to these results recorded during the overbank flows in 2016/17 and during the managed inundation the Chowilla floodplain in 2014/15 are detailed in sections 5.5.1 and 5.5.2, respectively. Measures to enhance microinvertebrate densities and species richness in the SA River Murray may include the delivery of water for the environment combined with managed floodplain inundation (see section 5.6.1). However, the timing of managed floodplain inundations needs to be considered to ensure it does not compromise within-channel spring flow pulses (see section 5.6.2).

### 5.5.1 Overbank flows in 2016/17

The contribution of water for the environment to the increased density and species richness of microinvertebrates in 2016/17 was limited, as the overbank flooding occurred due to the high (unregulated) flows. Water for the environment was delivered at Chowilla ahead of the high flows at the tail-end of the flow event to mitigate the impact of hypoxic blackwater (Ye et al. 2020).

The hypoxic blackwater event was associated with a significant decline in the density of microinvertebrates at both Lock 6 and Lock 1 in early December (Ye et al. 2020), and the increased delivery of water for the environment in mid-December 2016 may have contributed to the recovery of microinvertebrate densities in late-December 2016 (Ye et al. 2020).

### 5.5.2 Managed inundation of Chowilla floodplain in 2014/15

Managed inundation of 2,142 ha of the Chowilla floodplain in 2014/15 was supported by the operation of the Chowilla Regulator between October and December 2014, raises of Lock and Weir 6 and water delivered for the environment. Water for the environment contributed between 3,000 and 4,500 $ML.day^{-1}$ to QSA between early October and the end of November 2014/15. The synergistic effects of the delivery of water for the environment and operation of the Chowilla regulator enhanced lateral and longitudinal connectivity, which facilitated dispersal of microinvertebrates and potentially contributed to increases in their density, species richness and biomass (Ye et al. 2020). Lateral connectivity likely increased microinvertebrate emergence from the eggbank and the extent of habitat available for reproduction and replenishment of the eggbank (Gibbs et al. 2020), while longitudinal connectivity, facilitated dispersal of microinvertebrates, which is a crucial process in the maintenance of species and genetic diversity of downstream communities (Ye et al. 2020).

## 5.6 Actions to achieve environmental outcomes

Measures to enhance microinvertebrate densities and species richness in the SA River Murray may include the delivery of water for the environment combined with managed floodplain inundations and the provision of in-channel spring flow pulses. The consideration of the timing and duration of managed floodplain inundation events will enhance the achievement of the floodplain productivity (microinvertebrate) environmental outcome.

### 5.6.1 Managed floodplain inundation

Managed floodplain inundation events were associated with increases in microinvertebrate density and species richness in the SA River Murray (Ye et al. 2020). Water for the environment enhanced QSA, which in combination with weir pool raising and/or operation of the Chowilla regulator, increased the extent of floodplain inundated and also improved longitudinal connectivity. Construction of regulators at Pike and Katarapko floodplains were completed in 2020, and will enable greater expanses of each floodplain to be inundated in future years. This should contribute to an increase in channel and floodplain productivity in the SA River Murray.

Floodplain inundation events should occur during warmer months (spring and early summer) as water temperature is positively associated with microinvertebrate biomass (Ye et al. 2020). The most beneficial duration of floodplain inundation events is unknown, although it is expected that inundation for at least 3 weeks would allow time for microinvertebrate community development, diapause egg production and eggbank replenishment (D Furst, personal communication, 14 April 2020).

### 5.6.2 Within-channel spring flow pulses

It is important that managed floodplain inundations do not compromise within-channel spring flow pulses, which are important for the downstream transport of microinvertebrates, including rotifers from the genus *Trichocerca* (Furst et al. 2018; Furst et al. 2020; Gibbs et al. 2020). *Trichocerca* are thought to be a high-quality food resource for higher order consumers (Gibbs et al. 2020) and are hypothesised to require velocity and/or turbulence to stay in suspension (Furst 2019). As such, *Trichocerca* density in the lower River Murray were positively associated with longitudinal connectivity and average cross-sectional water velocities greater than 0.15-0.2 $m.s^{-1}$ in addition to the inundation of littoral zones and water temperatures between ~19-21°C that are favourable to microinvertebrates more generally (Furst et al. 2018; Furst et al. 2020; Gibbs et al. 2020). Therefore, the protection and restoration of spring flow pulses are likely to have a positive effect on the aquatic food-web.

### 5.6.3 Future assessment of environmental outcome

Further monitoring and research is required to fill knowledge gaps, particularly around how microinvertebrates respond to different flow and management scenarios. This is a current priority of South Australia's Integrated Operations Program and is also included as part of the Commonwealth Environmental Water Office Monitoring, Evaluation and Research Program.

Future assessment of the achievement of the floodplain productivity (microinvertebrate) environmental outcome, including evaluation of the contribution of water for the environment, in the SA River Murray should be done irrespective of whether the floodplain was inundated. Water for the environment contributed to a small within-channel flow pulse (up to ~17,000 $ML.day^{-1}$) in 2017/18 that was associated with an increase in microinvertebrate density and species richness (Ye et al. 2020). Therefore, improving the densities and species richness of microinvertebrates with water for the environment is likely to be achievable without floodplain inundation.

## 5.7 Conclusion

The density and species richness of microinvertebrates increased following overbank flows and managed floodplain inundations in the SA River Murray following the adoption of the Basin Plan. The contribution of water for the environment to this outcome is unclear (Ye et al. 2020), and further monitoring is required to increase our knowledge of and evaluate how microinvertebrates respond to different flow and management scenarios.

Key messages:

- The density and species richness of microinvertebrates increased following overbank flows and managed floodplain inundations in the SA River Murray following the adoption of the Basin Plan. These results were however, temporally and spatially limited following managed inundations.
- Water for the environment in combination with weir pool raising and the use of the Chowilla regulator in 2014/15 contributed to increased microinvertebrate densities and species richness at limited temporal and spatial scales, and also improved their longitudinal transport in the SA River Murray Channel.

- A hypoxic blackwater event associated with overbank flows from the high (unregulated) flows in 2016/17 likely caused microinvertebrate densities and species richness to decline. However, delivery of water for the environment helped to increase the microinvertebrate densities and species richness by mitigating the impact of hypoxic blackwater.
- The delivery of water for the environment in combination with weir pool raising and the operation of regulators at appropriate times and durations may improve microinvertebrate densities and species richness.

# 6 Golden perch

## 6.1 Introduction

Golden perch is a medium- to large-bodied fish (commonly reaches 400-500 mm) that inhabits the Murray-Darling, Lake Eyre and Bulloo drainage systems in western Queensland, New South Wales and South Australia, and the Dawson-Fitzroy stem in south-eastern Queensland (Lintermans 2007; Ferguson and Ye 2012). In the South Australian Murray–Darling Basin, golden perch are widespread, and occur within the River Murray and Lakes Alexandrina and Albert (Bice et al. 2010). The species supports a commercial fishery in the Lower Lakes and a significant recreational fishery throughout the Basin, and is culturally significant to Indigenous communities.

Golden perch occur in warm, turbid, slow-flowing inland rivers and associated floodplain lakes and anabranches (Lintermans 2007; Ferguson and Ye 2012). Within these environments, they are typically associated with structural habitats (e.g. woody debris) (Koehn and Nicol 2014). Golden perch are able to acclimatise to low dissolved oxygen (3 mg $O_2.L^{-1}$ and lower) (Gilmore et al. 2018) and withstand temperatures between 4 and 37 ºC (McDowall 1996).

The periodic life history of golden perch (*sensu* Winemiller and Rose 1992) is characterised by high growth rate (K=0.45-0.56) (Anderson et al. 1992), high longevity (maximum lifespan of 26 years) (Mallen-Cooper and Stuart 2003), intermediate age at maturity – four years for females and 2 years for males (Mallen-Cooper and Stuart 2003) – and high fecundity (up to 500,000 eggs) (Lintermans 2007). In the southern Murray–Darling Basin, spawning predominantly occurs during spring and summer (water temperature ≥17 ºC) and is stimulated by elevated flow, within-channel or overbank (Zampatti et al. 2015). Specifically in the lower River Murray, years of strong recruitment typically follow spring-summer periods when peak flows are >20,000 ML $day^{-1}$ and water temperatures exceed 20ºC (Ye et al. 2020). As such, in the lower River Murray, the species typically exhibits episodic recruitment with populations often dominated by a small number of age classes.

Hydrological connectivity at large spatial scales (>100 km) is important for golden perch populations. Changes in hydrology at the catchment scale (100-1000s kms), rather than site scale (10s of kms), are required to stimulate spawning and recruitment (Leigh and Zampatti 2011; Zampatti et al. 2015). Furthermore, system connectivity is important for the bi-directional movements of adults, eggs/larvae and juveniles. In the lower River Murray, adults often migrate upstream (up to >1000 km; Reynolds 1983, Zampatti et al. 2018a), presumably to spawn. Alternatively, drifting eggs and larvae can travel substantial distances (potentially 100 kms) downstream (Zampatti et al. 2015). Additionally, juveniles (e.g. 1+ years of age) can travel extensive distances downstream or upstream, typically during high flows. The large distances of dispersal of early life stages and juveniles means that population demographics in the lower River Murray can be driven by spawning events in distant upstream reaches, including the lower Darling River and mid-River Murray, as well as locally within the lower Murray (Zampatti et al. 2015).

The ecology of golden perch, particularly long-distance migration (Zampatti et al. 2018a), flow-cued spawning (Zampatti and Leigh 2013b), and obligate drifting phases for eggs and larvae (Koster et al. 2014), and inter-regional meta-population dynamics (Zampatti et al. 2015; 2018b) render the species susceptible to altered flow regimes and barriers to movement (e.g. weir pool environments may impact drift of eggs/larvae) (Zampatti et al. 2018a, b).

## 6.2 Ecological objective, targets and environmental outcomes

The SA River Murray LTWP ecological objective and targets for golden perch in the Channel PEA (Klisby and Steggles 2015) are shown in Table 6-1. The presence of all age classes represents a good population structure, and in addition to the recruitment events are required for a resilient golden perch population.

**Table 6-1. Ecological objective and targets for golden perch population resilience.**

| Characteristic | Description |
|---|---|
| Ecological objective | Restore resilient populations of golden perch |
| Ecological targets | 1. Population age structure of golden perch includes YOY with sub-adults and adults in 8 of 10 years<br>2. Population age structure of golden perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts represented by >30% of the population |

The expected environmental outcomes for golden perch population age structure (Table 6-2) and recruitment events (Table 6-3) for 2019, 2029 and 2042 (Figure 6-1) were determined by elicitation with key experts. These form the basis of the assessment of golden perch environmental outcomes in the SA River Murray Channel PEA.

**Table 6-2. Expected environmental outcomes for golden perch population age structure in 2019, 2029 and 2042.**

| Year | Expected environmental outcome |
|---|---|
| 2019 | The population age structure of golden perch will include sub-adults and adults on 5 of 7 (71%) years since Basin Plan adoption (80% confidence range of 53-92% of years). |
| 2029 | The population age structure of golden perch will include sub-adults and adults on 11 of 17 (65%) years since Basin Plan adoption (80% confidence range of 51-78% of years). |
| 2042 | The population age structure of golden perch will include sub-adults and adults on 21 of 30 (70%) years since Basin Plan adoption (80% confidence range of 49-81% of years). |

**Table 6-3. Expected environmental outcomes for golden perch recruitment in 2019, 2029 and 2042.**

| Year | Expected environmental outcome |
|---|---|
| 2019 | The population age structure of golden perch will indicate a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population in 3 of 7 (43%) years since Basin Plan adoption (80% confidence range of 33-62% of years). |
| 2029 | The population age structure of golden perch will indicate a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population in 8 of 17 (47%) years since Basin Plan adoption (80% confidence range of 29-65% of years). |
| 2042 | The population age structure of golden perch will indicate a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population in 13 of 30 (43%) years since Basin Plan adoption (80% confidence range of 49-81% of years). |

Over time, it is expected that the frequency of years that feature sub-adults and adults within the golden perch population will be maintained until 2042 (Figure 6-1). Likewise, the frequency of years that indicate a large recruitment event has occurred within 2 of the last 5 years is also expected to be maintained until 2042. Confidence ranges for expected outcomes are comparable across the 3 time points.

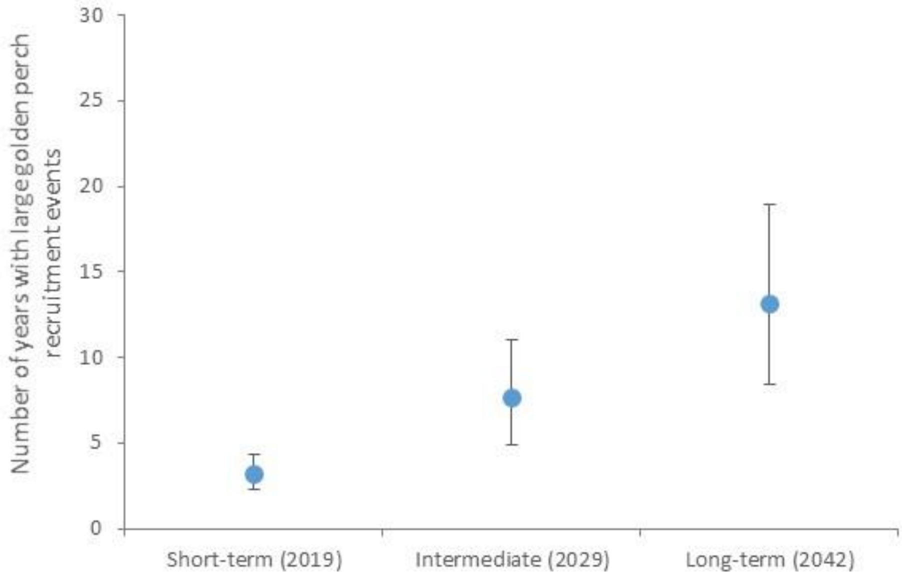


**Figure 6-1. Expected environmental outcomes for golden perch age structure and recruitment in 2019, 2029 and 2042.**

## 6.3 Data sources

Assessments of the expected environmental outcomes for golden perch used age data collated from the following sources:

- Commonwealth Environmental Water Office (CEWO) Short Term Intervention Monitoring (STIM) program
- CEWO Lower River Murray Long Term Intervention Monitoring (LTIM) program Category 1 (mandatory indicators with standard protocols)
- CEWO Lower River Murray LTIM program Category 3 (targeted hypothesis-driven monitoring)
- The Living Murray (TLM) Chowilla Condition Monitoring program
- MDBA/Native Fish Strategy Intervention Monitoring at Katarapko.

## 6.4 Method

A total of 1878 golden perch were captured throughout the Lower River Murray from 2004/05 to 2018/19. All golden perch were captured in South Australia (SA) or within 5 km of the SA border in New South Wales. The majority of records were captured in the floodplain geomorphic zone (1265 records) and secondarily from the gorge geomorphic zone (612 records), with one recorded from the swamp geomorphic zone (Figure 6-2).

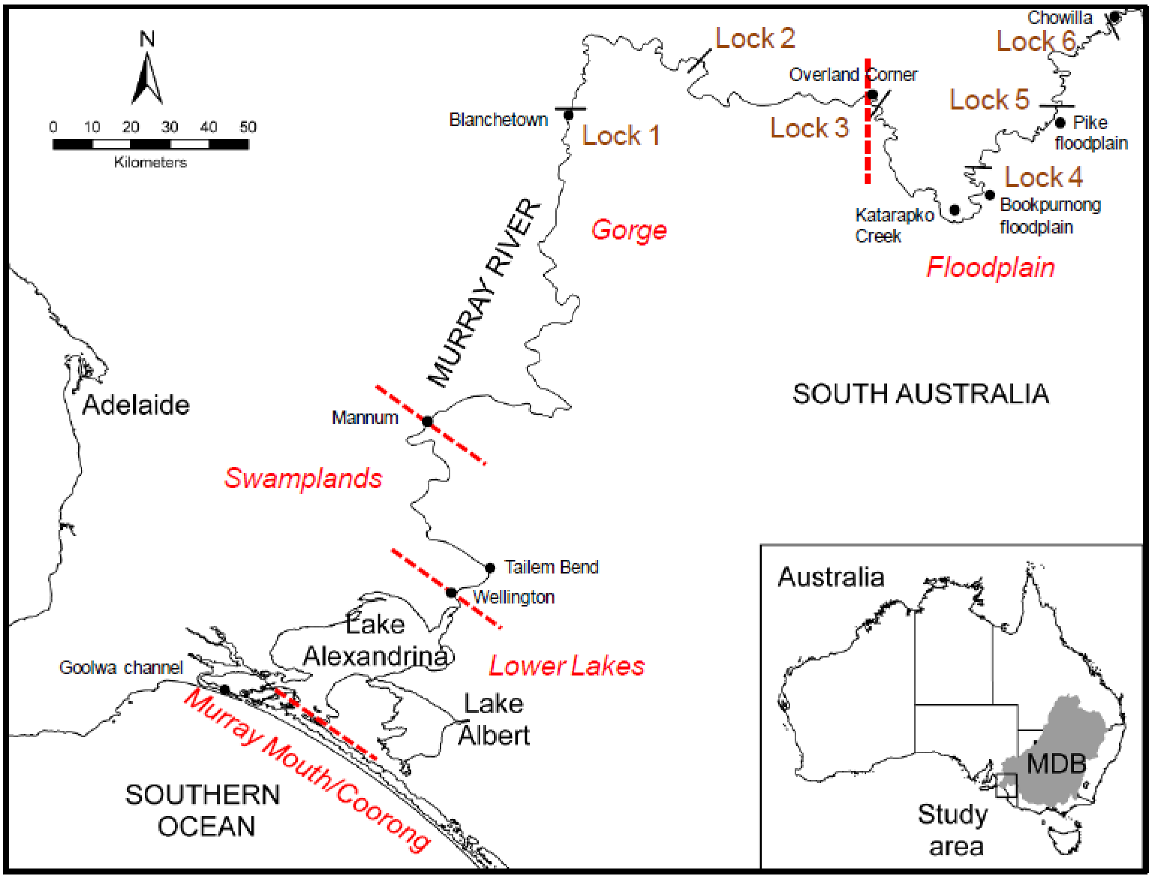


**Figure 6-2. The lower River Murray, South Australia, showing four geomorphic regions and 6 locks and weirs (Ye et al. 2014).**

Electrofishing was conducted across all data sources to capture golden perch (Wilson et al. 2013; Ye et al. 2016; Fredberg et al. 2019; Ye et al. 2019), while fyke nets were also used for Katarapko Intervention Monitoring (Wilson et al. 2013) (Table 6-4). Captured golden perch were aged using otoliths (ear stones) as length measures do not accurately reflect the age of individuals in the MDB (Anderson et al. 1992). The method for aging golden perch using otoliths is detailed in Zampatti et al. (2015).

The number of golden perch captured for a given year within each of the data sources is shown below in Table 6-4.

**Table 6-4. The number of golden perch captured for a given year within each data source. The duration of each data source sampling is shown by the green shading. Golden perch were sampled in the gorge and floodplain geomorphic zones. Note: The number of golden perch captured each year should not be used to infer trends in population due to discrepancies in sampling effort and location between years.**

| | Data Source | | | | |
|---|---|---|---|---|---|
| Year | CEWO STIM | CEWO LTIM Cat 1 | CEWO LTIM Cat 3 | TLM Chowilla Condition Monitoring | Katarapko Intervention Monitoring |
| 2004/05 | | | | 15 | |
| 2005/06 | | | | 112 | |
| 2006/07 | | | | 39 | |
| 2007/08 | | | | 49 | |
| 2008/09 | | | | 48 | |
| 2009/10 | | | | 50 | 48 |
| 2010/11 | | | | 62 | 50 |
| 2011/12 | 35 | | | 70 | |
| 2012/13 | 156 | | | 65 | |
| 2013/14 | 140 | | | 67 | |
| 2014/15 | | 87 | 60 | 33 | |
| 2015/16 | | 65 | 76 | 59 | |
| 2016/17 | | 30 | | 58 | |
| 2017/18 | | 77 | 128 | 20 | |
| 2018/19 | | 68 | 63 | 48 | |

### 6.4.1 Trend

The approach to assess trend using a Bayesian generalised linear mixed model is discussed in section 3.2.1. Trend for the golden perch environmental objective was assessed based upon the presence of YOY in the annual population age structure of golden perch from 2004/05 to 2018/19. Years were treated as independent data points for the analysis, with a 1 allocated to years with YOY detected and a 0 allocated to years with no YOY detected. Time step (years since the commencement of the assessment period) was included as a random effect. A binomial family was fitted to the Bayesian generalised linear mixed model.

### 6.4.2 Condition

The condition of the golden perch population in the SA River Murray was assessed based upon the presence of YOY, sub-adults and adults in the annual population age structure over the past 10 years (Table 6-5).

**Table 6-5. Criteria used to assess the condition of the golden perch population over the past 10 years.**

| Condition | Criteria |
|---|---|
| Excellent | Population age structure includes YOY, sub-adults and adults in **10** of the last 10 years. |
| Very good | Population age structure includes YOY, sub-adults and adults in **9** of the last 10 years. |
| Good | Population age structure includes YOY, sub-adults and adults in **8** of the last 10 years. |
| Fair | Population age structure includes YOY, sub-adults and adults in **6 or 7** of the last 10 years. |
| Poor | Population age structure includes YOY, sub-adults and adults in **<6** of the last 10 years. |

### 6.4.3 Information reliability

The information reliability assessment for the golden perch evaluation was conducted as per section 3.2.2.

## 6.5 Limitations of assessment

The basis for the golden perch recruitment environmental outcome, i.e. 'a large recruitment event 2 years in 5, demonstrated by separate cohorts represented by >30% of the population' needs to be treated with caution as it is possible for a resilient population of golden perch to fail to achieve this requirement. For example, if several years of strong recruitment (or more) were to occur within a 5-year period, the contribution of each recruitment event to the population may not exceed 30% due to the dampening effect of other years with strong recruitment.

## 6.6 Results

### 6.6.1 Environmental outcome assessment: Population age structure

The expected environmental outcome in 2019 was met, as sub-adults and adults featured in the population age structure of golden perch in 6 of 7 years since Basin Plan adoption in 2012/13 (Table 6-6; Figure 6-3). The failure to detect sub-adults in 2017/18 was likely an artefact to sampling, due to the presence of sub-adults in the years preceding (2016/17) and following (2018/19). Since the adoption of the Basin Plan, progression towards the achievement of the LTWP target has been limited with the golden perch population age structure has featured YOY, sub-adults and adults in 2 of 7 years (i.e. 29% of years) (Table 6-6; Figure 6-3). This is comparable though to pre-Basin Plan adoption as the percentage of years that YOY, sub-adults and adults featured in the population age structure of golden perch was 25% (2004/05-2011/12).

**Table 6-6. Presence/absence of YOY, sub-adults and adults in the population structure of golden perch from 2004/05 to 2018/19 in the SA River Murray Channel PEA. Note: trends in abundance should not be inferred by inter-annual differences in the number of captured individuals due to discrepancies in the catch per unit effort between years.**

| Year | # of individuals captured | YOY | Sub-adults | Adults |
|---|---|---|---|---|
| 2004/05 | 15 | Absent | Absent | Present |
| 2005/06 | 112 | Absent | Absent | Present |
| 2006/07 | 39 | Absent | Present | Present |
| 2007/08 | 49 | Absent | Present | Present |
| 2008/09 | 48 | Absent | Absent | Present |
| 2009/10 | 98 | Present | Absent | Present |
| 2010/11 | 112 | Present | Present | Present |
| 2011/12 | 105 | Present | Present | Present |
| 2012/13 | 221 | Present | Present | Present |
| 2013/14 | 207 | Present | Present | Present |
| 2014/15 | 180 | Absent | Present | Present |
| 2015/16 | 200 | Absent | Present | Present |
| 2016/17 | 88 | Absent | Present | Present |
| 2017/18 | 225 | Absent | Absent | Present |
| 2018/19 | 179 | Absent | Present | Present |

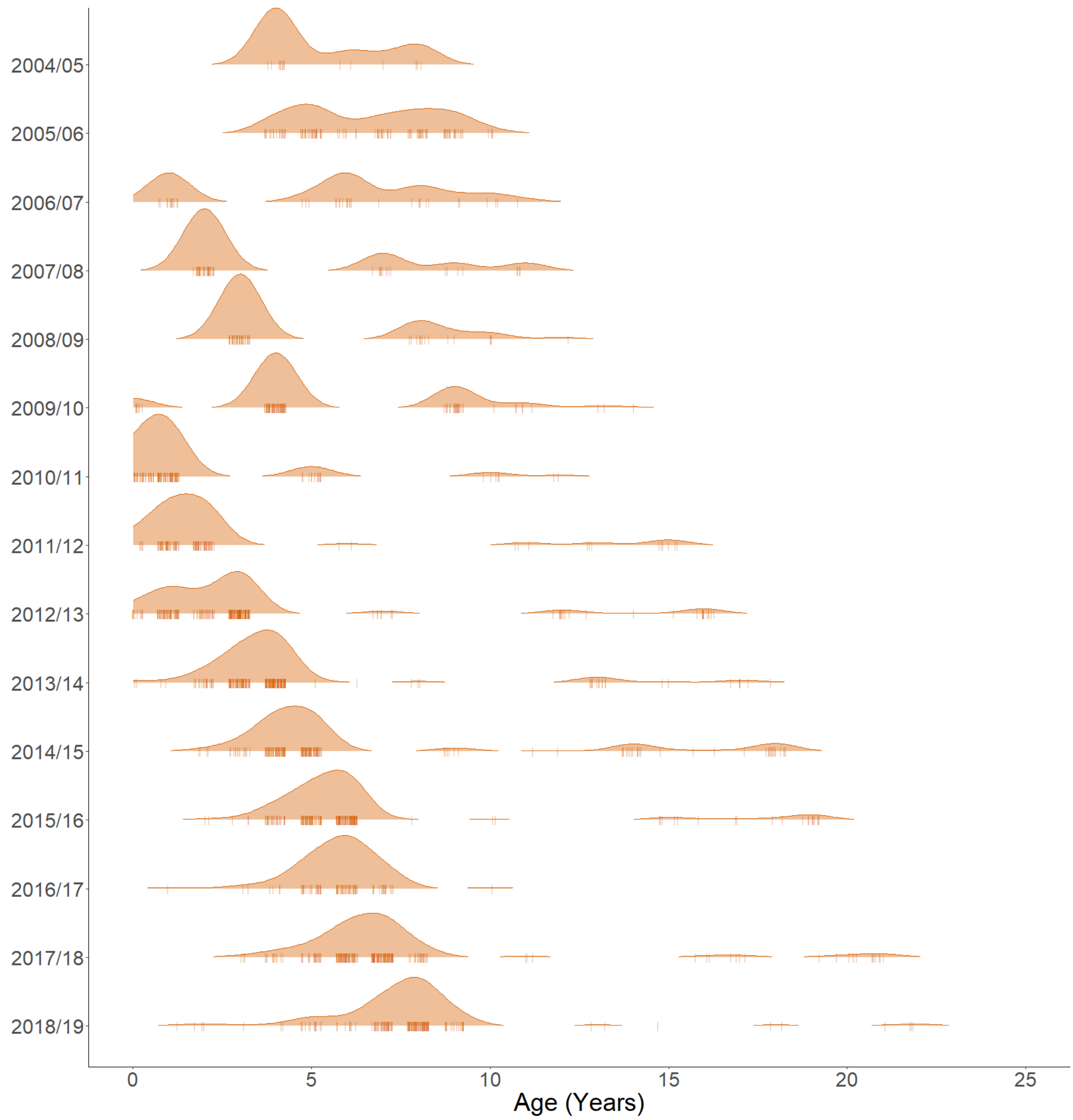


**Figure 6-3. Density plot of golden perch age (years) from 2004/05 to 2018/19 in the Channel PEA. Ages of individual fish in each water year are marked by |. Markers have been jittered to prevent overlap of individual fish with the same age. Note: YOY are <1 year of age, sub-adults are 1-3 years old and adults >3 years old.**

### 6.6.2 Trend: Presence of YOY in the annual population structure of golden perch

This trend analysis determined that the presence of YOY in the annual population age structure of golden perch between 2004/05 and 2018/19 was about as likely as not (50.98% likelihood) to be improving, and therefore, is considered to be **stable** (Figure 6-4). Therefore, there has been no progress towards the LTWP target.

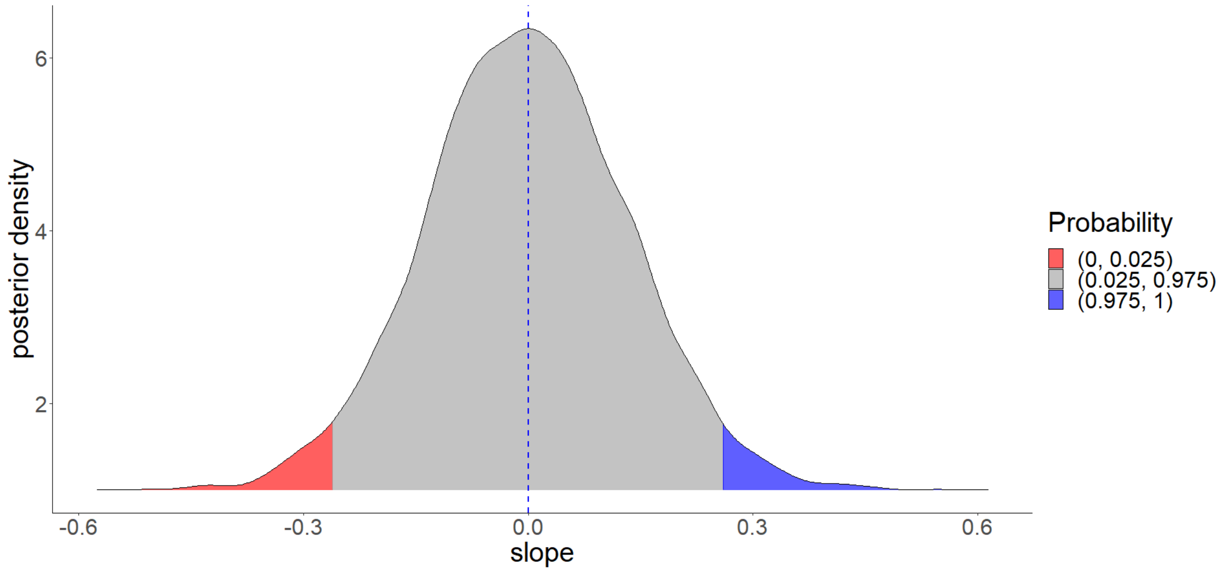


**Figure 6-4. Estimated values for the slope generated from Bayesian modelling for the presence of YOY in the annual population age structure of golden perch from 2004/05 to 2018/19. Posterior density values have a slope >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).**

### 6.6.3 Environmental outcome assessment: Recruitment

The population age structure of golden perch featured 2 large recruitment events in the past 5 years in one (2014/2015) of the 7 years since the adoption of the Basin Plan in 2012/13. In 2019, it was expected that such events would have occurred in 3 of 7 years, and therefore, the expected environmental outcome was not met (Table 6-7). Since the adoption of the Basin Plan, progression towards the LTWP has not been made, with the frequency of years with large golden perch recruitment events detected having declined: 2 of 8 years (2010/11 and 2011/12) prior to the adoption of the Basin Plan compared to one (2014/15) of 7 years since adoption of the Basin Plan in 2012/13.

**Table 6-7. Percentage (%) contribution of each age class ≤5 years to the overall population of golden perch from 2004/05 to 2018/19 in the SA River Murray Channel PEA. Note: trends in abundance should not be inferred by inter-annual differences in the number of captured individuals due to discrepancies in the catch per unit effort (CPUE) between years.**

| Year | # of individuals captured | Age (Years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | YOY | 1 | 2 | 3 | 4 | 5 |
| 2004/05 | 15 | 0 | 0 | 0 | 0 | 60 | 0 |

| Year | # of individuals captured | Age (Years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | YOY | 1 | 2 | 3 | 4 | 5 |
| 2005/06 | 112 | 0 | 0 | 0 | 0 | 15 | 25 |
| 2006/07 | 39 | 0 | 31 | 0 | 0 | 0 | 8 |
| 2007/08 | 49 | 0 | 0 | 65 | 0 | 0 | 0 |
| 2008/09 | 48 | 0 | 0 | 0 | 69 | 0 | 0 |
| 2009/10 | 98 | 10 | 0 | 0 | 0 | 58 | 0 |
| 2010/11 | 112 | 38 | 45 | 0 | 0 | 0 | 11 |
| 2011/12 | 105 | 10 | 37 | 39 | 0 | 0 | 0 |
| 2012/13 | 221 | 9 | 24 | 13 | 41 | 0 | 0 |
| 2013/14 | 207 | 2 | 1 | 10 | 29 | 46 | 0 |
| 2014/15 | 180 | 0 | 0 | 2 | 8 | 34 | 36 |
| 2015/16 | 200 | 0 | 0 | 1 | 2 | 13 | 28 |
| 2016/17 | 88 | 0 | 1 | 0 | 2 | 5 | 27 |
| 2017/18 | 225 | 0 | 0 | 0 | 1 | 5 | 9 |
| 2018/19 | 179 | 0 | 1 | 2 | 1 | 1 | 8 |

### 6.6.4 Condition

The population condition of golden perch was assessed to be **poor** as only 4 of the past 10 years featured YOY, sub-adults and adults in the annual population age structure.

### 6.6.5 Information reliability

The information reliability rating for golden perch was **fair** (final score of 9). Justification for the scoring of golden perch information reliability is provided in Table 6-8.

**Table 6-8. Reliability of golden perch data used to assess the LTWP targets and expected outcome. The metrics of methods, representativeness and repetition are scored against their response to the metric question. Metrics of methods used, representativeness and repetition are scored 2 points – Yes, 1 point – Somewhat, 0 points – No.**

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| Methods used | Are the methods used appropriate to gather the information required for evaluation? | **Somewhat.** Data collection is appropriate in determining the presence of YOY, sub-adults and adults in the annual population age structure. However, the percentage (%) contribution of each age class ≤5 years to the overall population of golden perch could be influenced by differences in sampling locations over the duration of data collection used for the evaluation (2004/05-2018/19). | **1** |

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| Standard methods | Has the same method been used over the sampling program? | **Yes**. The vast majority of golden perch were captured through standardised electrofishing. However, fyke nets were also used in Katarapko intervention monitoring. A standard method exists for aging golden perch from their otoliths. | **2** |
| **Representativeness** | | | |
| Space | Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort? | **Somewhat.** Golden perch have been sampled throughout the Channel PEA, however, the majority of records are from the floodplain geomorphic zone, especially the Chowilla floodplain. The gorge geomorphic zone has been better represented in sampling since 2011/12. | **1** |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | **Yes.** Sampling has been conducted from 2004/05 to 2018/19, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years and range of hydrological conditions. | **2** |
| **Repetition** | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | **Somewhat**. Differences in the commencement and duration of monitoring programs has led to inconsistency in the sites sampled each year from 2004/05 to 2013/14. However, from 2014/15 to 2018/19 there has been consistency in the sites sampled each year. | **1** |
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | **Yes.** Annual data regarding the population age structure of golden perch was acquired to assess the LTWP targets and expected outcomes. | **2** |
| **Final score** | | | **9** |
| **Data reliability** | | | **Fair** |

## 6.7 Evaluation

The trend for the presence of YOY in the annual population age structure of golden perch in the SA River Murray from 2004/05 to 2018/19 was stable, despite the improved flow conditions following the Millennium Drought and adoption of Basin Plan. While the trend for YOY presence was stable over the assessment period, no YOY have been detected since 2013/14 and therefore the resilience of the golden perch population has declined since the adoption of the Basin Plan. The condition of the golden perch population in 2019 is poor as the age structure is characteristic of a population with low resilience, as the vast majority of individuals are adults aged between 5 and 9 years, there are few individuals in younger cohorts and there is low age structure diversity (Ye et al. 2020).

Adult golden perch (5 to 9 years old) were recruited between 2009/10 and 2013/14 (Ye et al. 2020), with a particularly strong cohort recruited during flood in 2010/11 (Zampatti and Leigh 2013a). Since these recruitment events, the catch per unit effort (CPUE) of golden perch larvae in the SA River Murray has been negligible, recruitment from localised spawning or fish immigrating from the Darling and Mid-Murray rivers has been poor, and the relative proportions of older age cohorts (fish recruited prior to 2010/11) has declined (Ye et al. 2020). The decline in the relative proportion of adult fish (greater than 9 years old) may be caused by mortality (natural and fishing) and/or their upstream emigration, with large-scale movement most extensive during overbank flows (i.e. 2016/17) (Zampatti et al. 2018b). All these factors in unison have likely caused the abundance of golden perch in the SA River Murray to decline (Zampatti et al. 2018b; Fredberg et al. 2019; Ye et al. 2020).

The water regime since the adoption of the Basin Plan has failed to improve recruitment and restore a resilience population of golden perch in the SA River Murray. Factors implicated in the failure to achieve a resilient population of golden perch include delivery of flow pulses that have failed to elicit significant local spawning and recruitment responses (see section 6.7.1) and a hypoxic blackwater event (see section 6.7.2). Measures to improve the future outlook and achievement of environmental outcomes for golden perch include delivery of spring/summer flow pulses of greater volume and duration than preceding years (see section 6.8.1) and restoring physical habitat (see section 6.8.2).

### 6.7.1 Spring-summer flow pulses

To promote golden perch spawning and recruitment, elevated within-channel flows in late spring/summer that exceed 20,000 $ML.day^{-1}$ need to be restored (Ye et al. 2020). Since the adoption of the Basin Plan, maximum late spring/summer flow exceeded 20,000 $ML.day^{-1}$ in 2012/13 (~50,000 $ML.day^{-1}$), 2013/14 (~25,000 $ML.day^{-1}$) and 2016/17 (>93,000 $ML.day^{-1}$). These flow events likely supported substantial spawning of golden perch (with the exception of 2016/17 due to a blackwater event) and led to relatively high CPUE of larval golden perch (Ye et al. 2020). Therefore, the water regime since Basin Plan adoption has had limited influence on golden perch population structure and recruitment, as only high (unregulated) flow events have facilitated golden perch spawning and recruitment.

A spring/early summer flow pulse was recorded in 2017/18 (~17,800 $ML.day^{-1}$) that was largely supported by water for the environment (up to ~11,000 $ML.day^{-1}$). The spring/early summer flow pulse in 2017/18 approached flows thought to be required for spawning and recruitment of golden perch, however, the CPUE of larval golden perch was low and reflective of observations recorded in years without spring-early summer flow pulses (Ye et al. 2020). As such, while delivery of water for the environment since the adoption of the Basin Plan has contributed to spring/early summer flow pulses (i.e. 2017/18), constraints upon its delivery meant that flows of adequate magnitude and duration for golden perch spawning and recruitment did not occur.

### 6.7.2 Blackwater event

A blackwater event associated with substantial overbank flows (peak >93,000 $ML.day^{-1}$) of the high (unregulated) flow event in 2016/17 is likely to have contributed to the failure of golden perch recruitment in that year (Ye et al. 2020). Years of golden perch recruitment and distinct cohorts in the lower River Murray are associated with elevated in-channel (>20,000 $ML.day^{-1}$) and overbank flows (>40,000 $ML.day^{-1}$) (Zampatti and Leigh 2013a, b; Wilson et al. 2014; Ye et al. 2020). However, despite overbank flows in 2016/17, YOY golden perch were absent in 2017, suggesting localised recruitment failure and/or negligible immigration from individuals spawned in the lower Darling and mid-Murray rivers (Ye et al. 2018). While the abundance of golden perch eggs in 2016/17 was comparable to other high flow years (2010/11 to 2013/14) that recorded recruitment and distinct cohorts of golden perch (Ye et al. 2020), the low dissolved oxygen (hypoxia) conditions likely compromised the survival of eggs and larvae. The survival of eggs and larvae may have been adversely affected as a direct result of hypoxia and/or indirectly through the impact of hypoxia on their food resources (Ye et al. 2018).

## 6.8 Actions to achieve environmental outcomes

The continued delivery of water for the environment through Basin Plan implementation aims to improve flows for fish reproduction and recruitment. Improvements in water delivery and management to support golden perch populations include spring-summer flow pulses ≥20,000 ML/day, weir pool lowering and coordinated water delivery (see section 6.8.1). Other actions that may benefit golden perch such as physical habitat restoration (the reintroduction of woody debris to fast-flowing habitats, see section 6.8.2) could also support regular recruitment and enhance the response of golden perch to improvements in hydraulic diversity.

### 6.8.1 Spring–summer flow pulses and hydraulic diversity

The restoration of late spring/summer flow pulses of >20,000 ML.day$^{-1}$ are expected to improve golden perch recruitment (Ye et al. 2020) by restoring hydraulic diversity to weir pools (Bonifacio et al. 2016; Bice et al. 2017). Flows of 20,000 ML.day$^{-1}$ can be delivered under current constraints if the delivery of water out of all tributaries (Darling, Murrumbidgee and Goulburn) and potentially water delivery from Lake Victoria are coordinated (M Gibbs personal communication, 18 August 2020). As flow constraints through the Basin are addressed, these spring pulses will likely make an increasing contribution to improved channel and floodplain productivity throughout the system, including in the SA River Murray and thus support outcomes for species such as golden perch.

Weir pool lowering events may be used to enhance the drift of golden perch eggs and larvae, when present, and potentially enhance recruitment at lower discharges (Ye et al. 2020). Lowering weir pools by 1m at discharge of 10,000 ML.day$^{-1}$ would increase the length of lotic habitat (>0.3 ms$^{-1}$) three-fold in the Lock 1-2 and 2-3 weir pools, while a minor increase would occur in the Lock 3-4 weir pool (Bice et al. 2017). Successive weir pool lowering events could extend lotic habitat over appropriate lengths of river (i.e. >100 km) (Zampatti et al. 2015) to facilitate the drift of eggs and larvae and provide suitable rearing habitat (Bice et al. 2017). However, the role of flow velocity in the suspension, transport and retention of eggs and larvae remains a knowledge gap (Ye et al. 2020).

Proposed weir pool lowering events need to consider the impacts (with aim not to negatively impact) on existing important lotic habitats (i.e. Chowilla Anabranch and upper sections of weir pool 3) created through the head loss at weirs (Bice et al. 2017).

### 6.8.2 Physical habitat restoration

Woody debris were extensively removed from the rivers in the Murray–Darling Basin for navigation and water conveyance (Nicol et al. 2002). The removal of woody debris from the River Murray has threatened native fish species that are reliant upon structural woody habitats (Nicol et al. 2002). The potential benefit of woody debris to golden perch and other riverine fish species include the provision of cover to decrease predation risk and interactions with other fish, a velocity refuge to minimise energy expenditure and a reference point to orientate themselves within their surroundings (Crook and Robertson 1999). Habitat use of golden perch is strongly associated with woody debris, especially that which extends higher in the water column (Koehn and Nicol 2014). Restoration of woody debris to lotic stretches of the river could likely enhance the response of golden perch to improvements in hydraulic diversity throughout the SA River Murray (Koehn and Nicol 2014; Bice et al. 2017).

## 6.9 Conclusion

The water regime since the adoption of the Basin Plan has had limited influence on golden perch population structure and recruitment in South Australia due to delivery of flow pulses that were not of sufficient magnitude and hydraulic character over large spatial scales (>100 km) to support significant spawning and recruitment responses; and the unfavourable water quality conditions caused by the 2016/17 hypoxic blackwater event. It is expected that the frequency of future years that feature all age classes, as well as years with large recruitment events within the golden perch population, will be similar to current observations.

Key messages:

- Population age structure of golden perch has been stable between 2004/05 and 2018/19, however, YOY were last detected in 2013/14 and therefore recruitment has been poor since the adoption of the Basin Plan.
- The age structure of the golden perch population in 2019 is poor and characteristic of a population with low resilience, as the majority of individuals are adults aged between 5 and 9 years, there are few individuals in younger cohorts and there is low age structure diversity.
- Spring–summer flow pulses and associated hydraulics have been insufficient to promote localised recruitment or immigration from other sources of recruitment, i.e. mid-Murray or Darling rivers.
- A hypoxic blackwater event likely prevented strong recruitment in 2016/17 when overbank flows occurred.
- Improvements in water delivery (e.g. coordination of spring-summer flow pulses) and other management actions (e.g. weir pool management, physical habitat restoration) are needed if we are to see further improvements for the golden perch population in the SA River Murray.
- As flow constraints through the Basin are addressed, water delivery and associated conditions will likely make an increasing contribution to improved channel and floodplain productivity throughout the system, including the SA River Murray, and thus support outcomes for species such as golden perch.

# 7 Murray cod

## 7.1 Introduction

Murray cod are a large-bodied freshwater fish (up to 1400 mm and 45 kg) that inhabits the low to mid-altitude reaches of the Murray–Darling Basin (Anderson et al. 1992; Lintermans 2007; Zampatti et al. 2014). It is an iconic species within the Basin, once supporting a substantial commercial fishery and maintaining great cultural and recreational importance, and also representing the apex aquatic predator (Koehn 2010). Murray cod are nationally threatened and are listed as 'vulnerable' under the *Environment Protection and Biodiversity Conservation Act 1999* (Koehn 2010). The key threatening processes to Murray cod include altered flow regimes resulting from river regulation; barriers to migration; exploitation through commercial (now ceased) and recreational fishing; deteriorating water quality (e.g. cold water pollution); degradation of habitat, especially from de-snagging and loss of lotic habitats; and climate change (Koehn 2010).

Lotic (flowing, >0.3m.s$^{-1}$) reaches of the river channel and anabranches (Koehn and Nicol 2014) are the preferred habitat of Murray cod, even during flood when ephemeral habitats are available (Leigh and Zampatti 2013). Within these lotic environments, they are associated with structural habitat (e.g. woody debris, cliff) and deep, slower flowing water closer to the river bank (Koehn and Nicol 2014). In the lower Murray, river regulation, most notably weir construction, which has transitioned the river from a lotic to lentic (still to very slow flowing) environment (Bice et al. 2017), and the removal of woody debris for navigation and water conveyance (Nicol et al. 2002), has severely degraded habitat quality for Murray cod (Koehn 2010).

Murray cod prefer warm waters (Lintermans 2007) and are sensitive to low water temperatures (Ryan et al. 2003; Todd et al. 2005) and low dissolved oxygen (Leigh and Zampatti 2013; Ye et al. 2020). Cold water pollution and hypoxic (low dissolved oxygen) blackwater events are associated with limited recruitment success (Lugg and Copeland 2014; Ye et al. 2020), while hypoxic blackwater events have also caused the mass mortality of adult Murray cod (Leigh and Zampatti 2013).

The life history of Murray cod is characterised by a relatively slow growth rate (k = 0.060-0.108), high longevity (up to 47 years), high age at maturity (5 years) and high fecundity (5000 eggs.kg$^{-1}$ of body weight) (Rowland 1985; Anderson et al. 1992; Rowland 1998a,b), however, there is variability dependent on location and the prevailing climatic conditions (Anderson et al. 1992).

In the lower River Murray, Murray cod exhibit high levels of site fidelity, but have been shown to move moderate distances (10s km) in the Chowilla system during winter-spring, prior to spawning, and undertake long-distance upstream movements associated with flood (Leigh and Zampatti 2013). Spawning takes place annually in October to December independent of hydrological conditions and when the water temperatures exceed 15 ºC (Humphries 2005; Leigh and Zampatti 2011). Eggs are adhesive and deposited onto firm surfaces, including snags, rocks and clay banks (Rowland 1983). After 8 days, larvae hatch and drift downstream (Humphries 2005). Following spawning, adult Murray cod rapidly return to their home location in early summer (Koehn et al. 2009).

Recruitment success appears to be strongly linked to hydraulic diversity (Leigh and Zampatti 2013; Zampatti et al. 2014; Ye et al. 2020) as demonstrated by the regular recruitment of Murray cod in the lotic Chowilla Anabranch during the Millennium Drought when recruitment in the lentic main channel of the River Murray was negligible (Zampatti et al. 2014). Hydraulic diversity facilitates the drift of larvae to slackwaters of lotic reaches (Gibbs et al. 2020), where food resources are likely to concentrate (Humphries et al. 2020), which in turn, likely promote larvae survival and enhance recruitment.

## 7.2 Ecological objective, target and environmental outcomes

The SA River Murray LTWP ecological objective for Murray cod is underpinned by 3 targets relating to population age structure, detection of large recruitment events and CPUE (Klisby and Steggles 2015), however, only the population age structure target has been used as the basis for the Murray cod environmental outcomes (Table 7-1).

**Table 7-1. Ecological objective and target for Murray cod population resilience.**

| Characteristic | Description |
|---|---|
| Ecological objective | Restore resilient populations of Murray cod |
| Ecological target | Population age structure of Murray cod includes recent recruits, sub-adults and adults in 9 of 10 years. |

The expected environmental outcomes for Murray cod population age structure for 2019, 2029 and 2042 were determined by elicitation with key experts. These form the basis of the assessment of Murray cod environmental outcomes in the SA River Murray Channel PEA.

**Table 7-2. Expected environmental outcomes for Murray cod population age structure in 2019, 2029 and 2042.**

| Year | Expected outcome |
|---|---|
| 2019 | The population age structure of Murray cod will include recent recruits, sub-adults and adults on 5 of 7 (71%) years since Basin Plan adoption (80% confidence range of 48-86%). |
| 2029 | The population age structure of Murray cod will include recent recruits, sub-adults and adults on 10 of 17 (61%) years since Basin Plan adoption (80% confidence range of 45-76%). |
| 2042 | The population age structure of Murray cod will include recent recruits, sub-adults and adults on 18 of 30 (59%) years since Basin Plan adoption (80% confidence range of 36-71%). |

Over time, it is expected that the frequency of years that the Murray cod population age structure will include recent recruits, sub-adults and adults is expected to decline between 2019 and 2029 and then be generally maintained between 2029 and 2042 (Table 7-2; Figure 7-1). Confidence in expected outcomes remains relatively stable over the 3 time points.

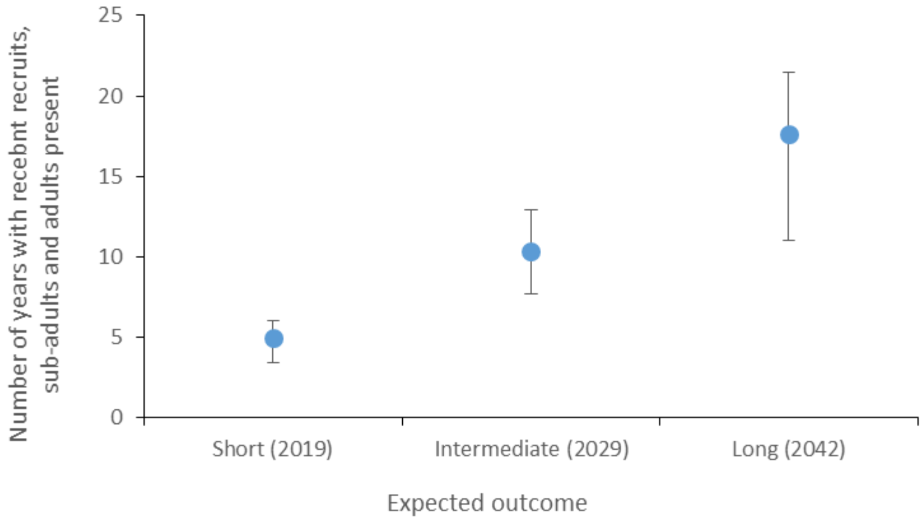


**Figure 7-1. Expected environmental outcomes for Murray cod population age structure in 2019, 2029 and 2042.**

## 7.3 Data sources

Assessments of the expected environmental outcomes for Murray cod used length-frequency data collated from the following sources:

- Primary Industries and Regions South Australia (PIRSA) and CEWO Native Fish Monitoring Program
- MDBA Murray River Fishway Assessment Program Lock 1-3
- CEWO Short Term Intervention Monitoring program
- CEWO Lower River Murray Long Term Intervention Monitoring (LTIM) program Category 1 (mandatory indicators with standard protocols)
- CEWO Lower River Murray LTIM program Category 3 (targeted hypothesis-driven monitoring)
- The Living Murray (TLM) Chowilla Condition Monitoring program
- MDBA Chowilla Murray cod targeted monitoring program
- MDBA Murray–Darling Basin Fish Survey
- Australian Research Development Corporation Murray cod angler surveys.

## 7.4 Method

A total of 822 Murray cod were captured throughout the Lower River Murray from 2002/03 to 2018/19. All Murray cod were captured in South Australia or within 5 km of the SA border in New South Wales. Murray cod were primarily captured over the floodplain geomorphic zone (n=506) and secondarily over the gorge geomorphic zone (n=316) of the South Australian River Murray from 2002/03 to 2018/19 (Table 7-3).

Six of the data sources were conducted for 5 or more years and captured and measured over 30 Murray cod individuals (Table 7-3). The methods used by these 6 sources to capture and measure Murray cod are described for the Murray Fishway Assessment, Chowilla Condition Monitoring and Native Fish Monitoring programs in Zampatti et al. (2014), Chowilla Target Monitoring in Fredberg et al. (2019b) and the LTIM (Cat 1 and 3) in Ye et al. (2019). Murray cod were captured in the main channel of the River Murray and its associated anabranches primarily using electrofishing and secondarily drum nets (Table 7-3). Electrofishing targeted habitats used by Murray cod in the Chowilla Targeted Monitoring and LTIM Cat 3 programs. Murray cod captured were measured for total length (TL) (±1 mm) and released after processing.

**Table 7-3. The number of Murray cod captured and the duration (blue shading) of each data source that contributed captured more than 30 individuals to the overall dataset. Fish were sampled in the gorge (G) and floodplain geomorphic (FP) zones.**

| Year | Data Source | | | | | |
|---|---|---|---|---|---|---|
| | Murray Fishway Assessment (G) | Chowilla Condition Monitoring (FP) | Chowilla Targeted Monitoring (FP) | Long Term Intervention Monitoring Cat 1 (G) | Long Term Intervention Monitoring Cat 3 (FP & G) | Native Fish Monitoring Program (FP & G) |
| | Electrofishing | | | | | Drum nets |
| 2002/03 | 10 | | | | | |
| 2003/04 | 13 | | | | | |
| 2004/05 | 9 | 6 | | | | 11 |
| 2005/06 | N.S. | 10 | | | | 83 |
| 2006/07 | 12 | 10 | | | | 12 |
| 2007/08 | 8 | 11 | | | | 2 |
| 2008/09 | 8 | 16 | | | | 0 |
| 2009/10 | 7 | 9 | | | | 4 |
| 2010/11 | 68 | 6 | | | | 28 |
| 2011/12 | 7 | 8 | | | | 4 |
| 2012/13 | 10 | 6 | | | | 3 |
| 2013/14 | | 29 | 32 | | | |
| 2014/15 | | 9 | | 11 | 20 | |
| 2015/16 | | 12 | 50 | 16 | 28 | |
| 2016/17 | | 3 | 15 | 8 | | |
| 2017/18 | | 17 | 33 | 14 | 21 | |
| 2018/19 | | 13 | 27 | 18 | 17 | |

### 7.4.1 Trend

The approach to assess trend using a Bayesian Generalised Linear Mixed Model is discussed in section 3.2.1. Trend for the Murray cod environmental outcome was assessed based upon the presence of YOY in the annual population age structure of Murray cod from 2002/03 to 2018/19. Years were treated as independent data points for the analysis, with a 1 allocated to years with YOY detected and a 0 allocated to years with no YOY detected. Time step (years since the commencement of the assessment period) was included as a random effect. A binomial family was fitted to the Bayesian Generalised Linear Mixed Model.

### 7.4.2 Condition

The condition of the Murray cod population in the SA River Murray was assessed based upon the presence of YOY, sub-adults and adults in the annual population age structure over the past 10 years (Table 7-4).

**Table 7-4. Criteria used to assess the condition of the Murray cod population over the past 10 years.**

| Condition | Criteria |
|---|---|
| Excellent | Severe historic declines and a highly regulated River Murray in SA mean that an excellent population condition is not feasible. |
| Very good | Population age structure includes YOY, sub-adults and adults in **10** of the last 10 years. |
| Good | Population age structure includes YOY, sub-adults and adults in **9** of the last 10 years. |
| Fair | Population age structure includes YOY, sub-adults and adults in **7 or 8** of the last 10 years. |
| Poor | Population age structure includes YOY, sub-adults and adults in **<6** of the last 10 years. |

### 7.4.3 Information reliability

The information reliability assessment for the Murray cod evaluation was conducted as per section 3.2.2.

## 7.5 Limitations of assessment

Caution needs to be taken when interpreting the results of Murray cod population age structures due to discrepancies in sampling effort, timing and location between years. Furthermore, in high flow years, there may be considerable delay (2-4 years) before Murray cod recruits are detectable in the population (Zampatti et al. 2014). Therefore, number of individuals captured each year should not be over-interpreted to infer trends in population size and the length percentage frequency and length density plots should not be over-interpreted to infer the proportionate size classes within the population. Rather, the length percentage frequency and length density plots provide a visual guide of the age classes represented (rather than their proportions) within the Murray cod population for a given year.

## 7.6 Results

### 7.6.1 Environmental outcome assessment

The expected environmental outcome was met for Murray cod population age structure in 2019. All 7 years following the adoption of the Basin Plan, from 2013 to 2019, had a Murray cod age population structure featuring recent recruits, sub-adults and adults (Table 2-1Table 6-6; Figure 7-2; Figure 7-3). Progress towards the LTWP target is on track to bet met, with all 7 years following the adoption of the Basin Plan having a Murray cod population age structure that featured recent recruits, sub-adults and adults (Table 6-6; Figure 7-2; Figure 7-3). The percentage of years that the population age structure of Murray cod features recent recruits, sub-adults and adults has improved following Basin Plan adoption (100% of years) with respect to pre-adoption years from 2004/05 to 2011/12 (20% of years).

**Table 7-5. Presence/absence of recent recruits (<200 mm, includes YOY and 1+ fish), sub-adults (200-600 mm) and adults (>600 mm) in the population structure of Murray cod from 2002/03 to 2018/19.**

| Year | # of individuals captured | Recent recruits | Sub-adults | Adults |
|---|---|---|---|---|
| 2002/03 | 10 | Absent | Absent | Present |
| 2003/04 | 13 | Absent | Absent | Present |
| 2004/05 | 26 | Absent | Present | Present |
| 2005/06 | 93 | Absent | Present | Present |
| 2006/07 | 34 | Absent | Present | Present |
| 2007/08 | 21 | Absent | Present | Present |
| 2008/09 | 24 | Present | Present | Present |
| 2009/10 | 20 | Present | Present | Present |
| 2010/11 | 102 | Absent | Present | Present |
| 2011/12 | 19 | Absent | Present | Present |
| 2012/13 | 23 | Present | Present | Present |
| 2013/14 | 73 | Present | Present | Present |
| 2014/15 | 43 | Present | Present | Present |
| 2015/16 | 114 | Present | Present | Present |
| 2016/17 | 39 | Present | Present | Present |
| 2017/18 | 93 | Present | Present | Present |
| 2018/19 | 75 | Present | Present | Present |

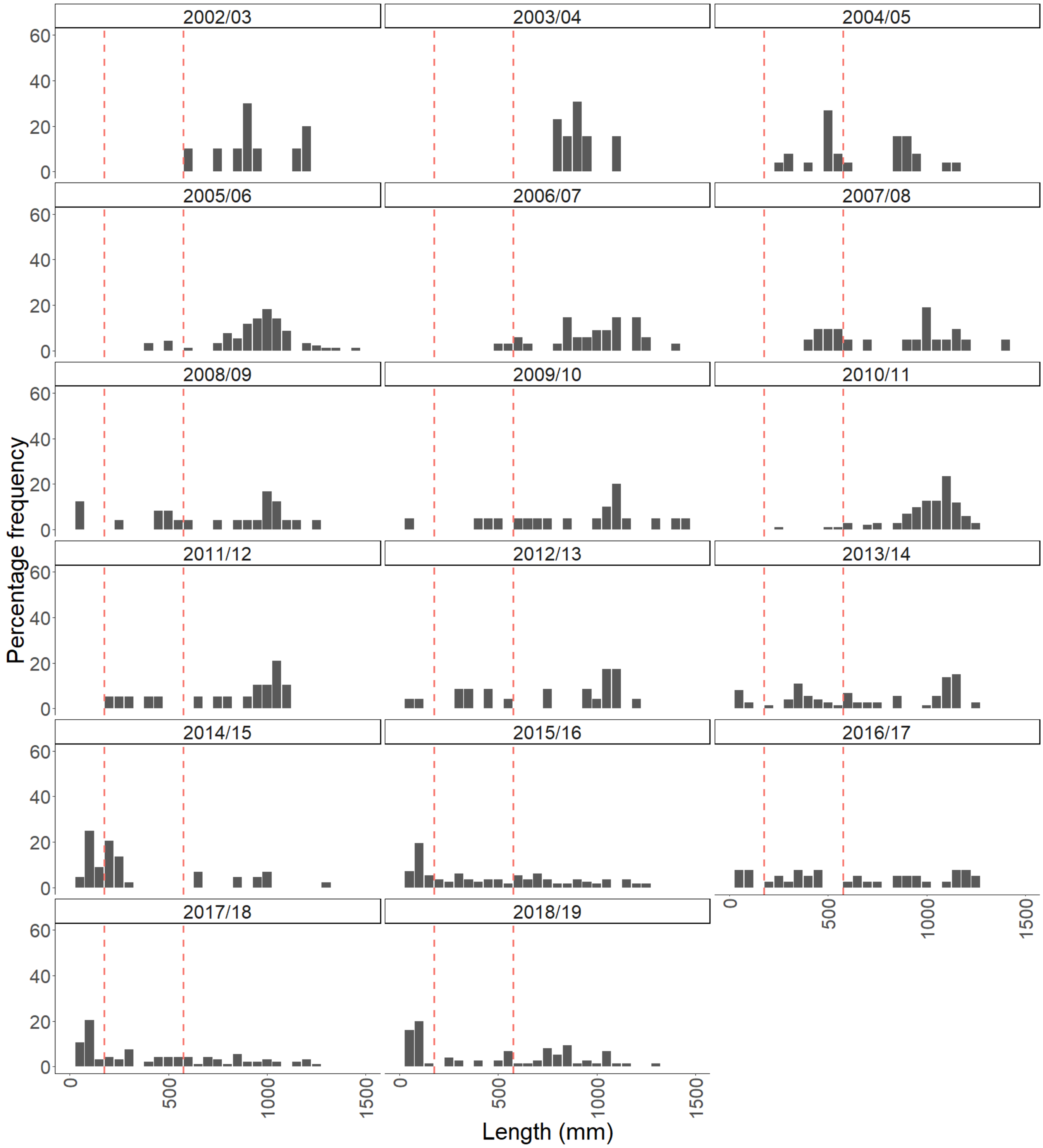


**Figure 7-2. Length percentage frequency for Murray cod sampled from 2002/03 to 2018/19. Vertical red lines delineate recent recruits (<200 mm, includes YOY and 1+ fish), sub-adults (200-600 mm) and adults (>600 mm).**

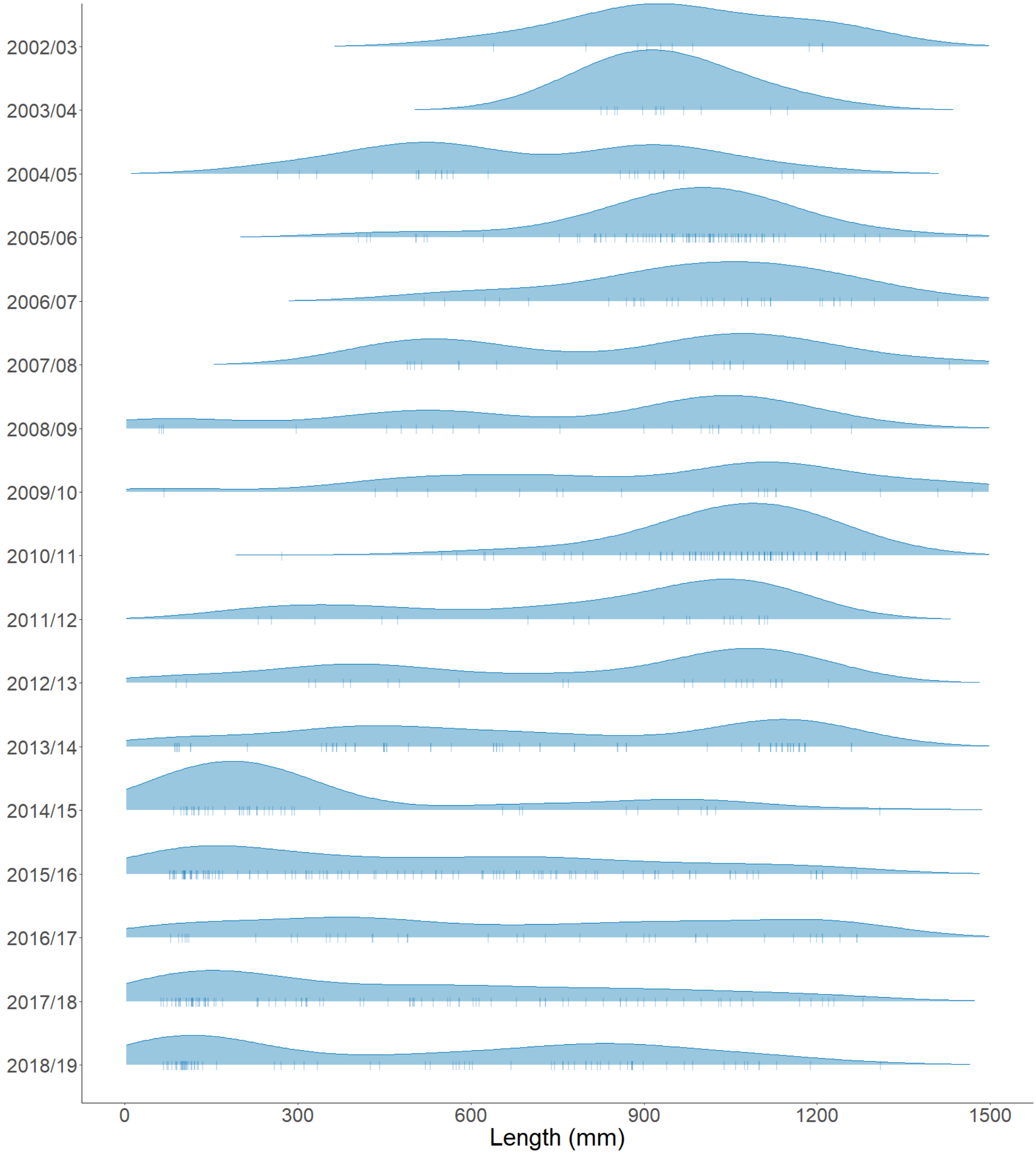


**Figure 7-3. Density plot of Murray cod length (mm) sampled from 2002/03 to 2018/19. Lengths of individual fish in each water year are marked by |. Note: recent recruits (includes YOY and 1+ fish) are <200 mm, sub-adults are 200-600 mm and adults are >600 mm in length.**

### 7.6.2 Trend: Presence of recent recruits within the annual population age structure of Murray cod

The presence of recent recruits within the annual population age structure of Murray cod from 2002/03 to 2018/19 was virtually certain (100% likelihood) to be **getting better**, as shown by all posterior slope values >0 (Figure 7-4).

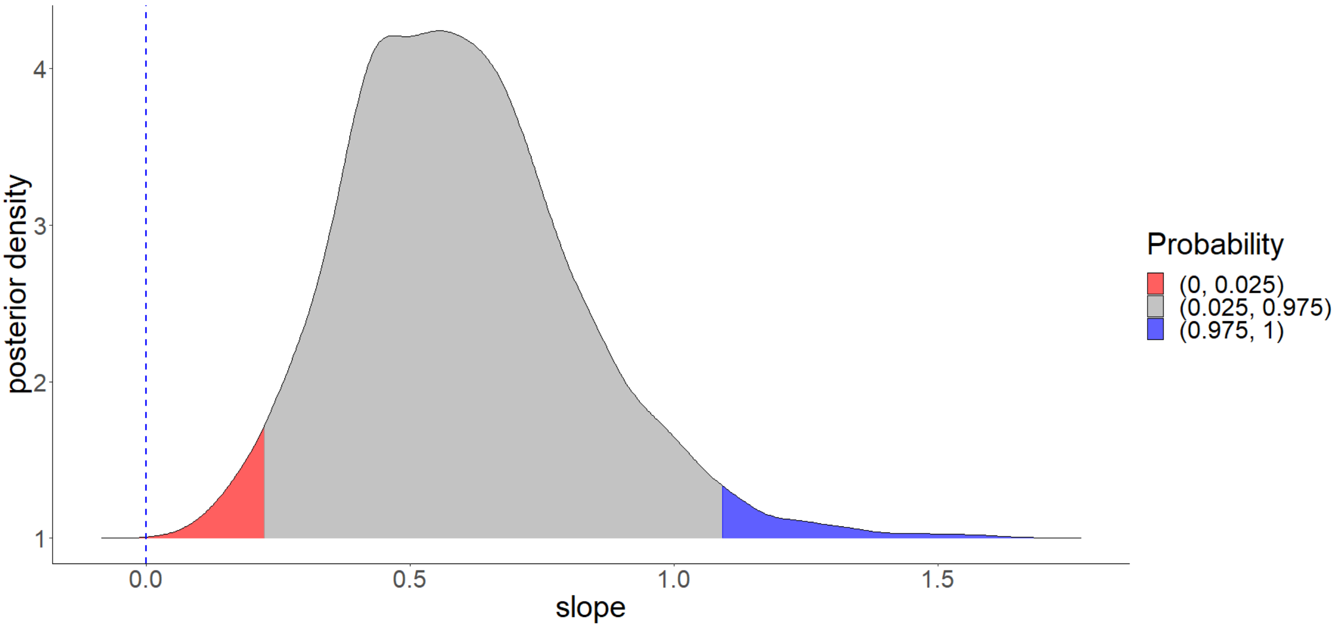


**Figure 7-4. Estimated values for the slope generated from Bayesian modelling for the presence of recent recruits in the annual population age structure of Murray cod from 2002/03 to 2018/19. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).**

### 7.6.3 Condition

The population condition of Murray cod were assessed to be **fair** as 8 of the past 10 years featured YOY, sub-adults and adults in the annual population age structure.

### 7.6.4 Information reliability

The information reliability rating for Murray cod was **fair** (final score of 9). Justification for the scoring of Murray cod data reliability is provided in Table 7-6.

**Table 7-6. Reliability of Murray cod data to assess the expected environmental outcome. The metrics of methods, representativeness and repetition are scored against their response to the metric question. Metrics of methods, representativeness and repetition are scored 2 points – Yes, 1 point – Somewhat, 0 points – No.**

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| Methods used | Are the methods used appropriate to gather | **Yes.** Data collection is appropriate in determining the presence of YOY, sub- | **2** |

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| | the information required for evaluation? | adults and adults in the annual population age structure. | |
| Standard methods | Has the same method been used over the sampling program? | **Somewhat**. Murray cod were captured primarily using electrofishing and secondarily drum nets. | **1** |
| **Representativeness** | | | |
| Space | Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort? | **Somewhat.** The sampling effort over the gorge and floodplain geomorphic zones of the SA River Murray has been relatively equitable. However, captures from the floodplain geomorphic zones are largely from the Chowilla floodplain. | **1** |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | **Yes.** Sampling has been conducted from 2004/05 to 2018/19, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years and range of hydrological conditions. | **2** |
| **Repetition** | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | **Somewhat**. Differences in the commencement and duration of monitoring programs and accessibility issues from flood and high flow events has led to inconsistency in the sites sampled each year. Despite this, regular sites are visited annually within monitoring programs. | **1** |
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | **Yes.** Annual data regarding the population age structure of Murray cod was acquired to assess the LTWP targets and expected outcomes. | **2** |
| **Final score** | | | **9** |
| **Data reliability** | | | **Fair** |

## 7.7 Evaluation

The trend for the presence of recent recruits in the annual population age structure of Murray cod in the SA River Murray improved from 2002/03 to 2018/19, with recent recruits present in all years following the adoption of the Basin Plan. Recruitment of Murray cod following the adoption of the Basin Plan has therefore occurred during overbank flows (2012/13 and 2016/17), in-channel pulses (2013/14, 2014/15 and 2017/18) and low stable in-channel flows (2015/16 and 2018/19). The peak spring/summer QSA of these different flow events ranged from <11,000 ML.day$^{-1}$ to >93,000 ML.day$^{-1}$.

The population condition of Murray cod is considered to be fair as YOY were detected in 8 of the past 10 years of sampling. However, there has been continual improvement in population condition since 2015/16 with diverse length-frequency representation observed in 2018/19 suggestive of a healthy population age structure (Ye et al. 2020).

It is unclear how the Murray cod population has responded to the delivery of water for the environment (Ye et al. 2020). However, it is likely that hydraulic diversity (see section 7.7.1) and productivity (see section 7.7.2) are associated with enhanced recruitment, while the 2016/17 blackwater event (see section 7.7.3) caused negligible recruitment and adult mortality (Ye et al. 2020).

### 7.7.1 Hydraulic diversity

Murray cod within the main channel and anabranches of the SA River Murray have an affinity for hydraulically diverse lotic habitats (Leigh and Zampatti 2011; Zampatti et al. 2014; Fredberg et al. 2019). Lotic habitats are also associated with greater recruitment than lentic habitats (Zampatti et al. 2014). During the Millennium Drought, recruitment of Murray cod in the main channel was negligible as indicated by the lack of small, younger fish (Zampatti et al. 2014). However, during this time, YOY regularly recruited in the Chowilla Anabranch system (Zampatti et al. 2014; Fredberg et al. 2020). These contrasting levels of recruitment may be attributed to hydraulic diversity, with the Chowilla Anabranch consisting predominantly of lotic (0.30-0.50 $m.s^{-1}$) habitat even during low flow conditions, while those in the main channel of the River Murray were lentic (0.00-0.12 $m.s^{-1}$).

The contribution of water for the environment to the achievement of the Murray cod environmental outcome is unclear. However, water for the environment contributed to a minor increase in the extent of lotic habitat in 2014/15, 2015/16, 2016/17 and 2018/19 (≤20 km for ≥30 days), while a moderate increase was recorded in 2017/18 (36 km for ≥30 days) (Ye et al. 2020). Although in most years of the increase in the extent of lotic habitat was ≤20 km for ≥30 days, Murray cod are capable of recruitment over mesohabitat scales (1-10 km) (Leigh and Zampatti 2011), and therefore, improvement in the temporal and spatial extent of hydraulically diverse habitat attributed to water for the environment may have been a factor in the successful recruitment of Murray cod from 2014/15 to 2018/19 (Ye et al. 2020).

### 7.7.2 Productivity

Food resource availability may influence recruitment of Murray cod. Microcrustaceans, including cladocerans and copepods, are the primary prey items for Murray cod larvae (Gibbs et al. 2020; Ye et al. 2020), however, other dominant food resources can include chironomid larvae and leptophlebiid mayflies (Kaminskas and Humphries 2009). It is hypothesised that spring/summer flows that inundate the floodplain generate abundant food resources for Murray cod larvae that enhances their recruitment (King et al. 2008). However, at this point, it is difficult to draw links between specific flows and the availability of food resources of Murray cod larvae (Ye et al. 2020). Murray cod larvae are selective feeders, so much so that microcrustaceans found to be abundant in gut contents of larvae were not collected during microinvertebrate sampling for that given year (Gibbs et al. 2020). Conceptually, the entrainment of microcrustaceans during flows where littoral and limnetic habitats are engaged (without causing hypoxic blackwater) may be important, with these food resources settling and concentrating in the slackwaters of lotic habitats (Humphries et al. 2019), where Murray cod larvae themselves have settled (Gibbs et al. 2020).

### 7.7.3 Blackwater event

Overbank flows in 2016/17 would have been expected to result in a strong cohort of Murray cod. However, the resultant hypoxic blackwater event, which caused dissolved oxygen levels to fall to zero in the lower River Murray for a short period (Ye et al. 2018) may have been the cause of negligible recruitment and mortality of Murray cod (Ye et al. 2019). Water for the environment was delivered to reduce the steepness of the flood recession and to mitigate the impacts (i.e. low dissolved oxygen) of the blackwater event (Ye et al. 2020), and this may have lessened the impact on Murray cod populations.

## 7.8 Actions to achieve environmental outcomes

The continued delivery of water, including water for the environment, through the implementation of the Basin Plan aims to improve flows for fish reproduction and recruitment. Improvements in water delivery and management to support Murray cod populations include the restoration of late spring-summer flow pulses and weir pool lowering to improve hydraulic diversity (see section 7.8.1). Physical habitat restoration (the reintroduction of woody debris to fast-flowing habitats, see section 7.8.2) could also support regular recruitment of Murray cod. A targeted monitoring program would also improve our understanding of how the Murray cod population responds to water delivery, including water for the environment.

### 7.8.1 Hydraulic diversity

Murray cod recruitment may further improve with the restoration of late spring/summer flow pulses of ≥15,000 $ML.day^{-1}$ (Zampatti et al. 2014). Restoration of 15,000 $ML.day^{-1}$ flow pulses would increase hydraulic complexity as least within the upper half of the SA River Murray weir pools (Bice et al. 2017), while restoration of 20,000 $ML.day^{-1}$ would restore hydraulic diversity to upper and middle thirds of the SA River Murray weir pools as well as the majority of the lower third (Bonifacio et al. 2016; Bice et al. 2017).

Weir pool lowering events may be used to enhance Murray cod recruitment. Lowering weir pools by 1 m at discharge of 10,000 $ML.day^{-1}$ would increase the length of lotic habitat (>0.3 $ms^{-1}$) three-fold in the Lock 1-2 and 2-3 weir pools, while a minor increase would occur in the Lock 3-4 weir pool (Bice et al. 2017). As Murray cod can recruit at local scales (Zampatti et al. 2014), lowering of one weir pool in isolation, i.e. the Lock 1-2 or Lock 2-3 weir pools, may be sufficient to enhance Murray cod recruitment within that reach of river.

Any proposed weir pool lowering events should not negatively impact lotic habitats (i.e. Chowilla Anabranch) through head loss at weirs nor affect the availability of deep water habitats used by Murray cod (C Bice, personal communication, 27 February 2020; Koehn and Nicol 2014).

### 7.8.2 Physical habitat restoration

The removal of woody debris from the River Murray has threatened native fish species that are reliant upon structural woody habitats (Nicol et al. 2002). Murray cod are strongly associated with woody debris in river channels and anabranches across all life stages (Koehn 2009; Koehn and Nicol 2014; Gibbs et al. 2020). The presence of woody debris in lotic habitats provides areas of low flow velocities for shelter and allows fish to remain close to faster flow velocities for feeding (Koehn and Nicol 2014). These benefits may help to support regular recruitment and a robust population of Murray cod (Gibbs et al. 2020). As such, the reintroduction of woody debris to lotic habitats could enhance Murray cod populations and is complementary to other actions aiming to improve hydraulic diversity in the SA River Murray (Koehn and Nicol 2014; Bice et al. 2017).

### 7.8.3 Systematic monitoring program

A systematic monitoring program is recommended to be established in order to determine the casual mechanisms driving change in the recruitment and population size of Murray cod over the SA River Murray (C Bice, personal communication, 27 February 2020). Monitoring sites are recommended to be located within every tail-water (water below weirs) and are to be sampled annually. The results from such a monitoring program would enhance our understanding of how the Murray cod population responds to changes in hydrology, including delivery of water for the environment, and provide robust data with which to undertake reporting of Basin Plan environmental outcomes.

## 7.9 Conclusion

The resilience of the Murray cod population has improved since the adoption of the Basin Plan, as recent recruits were present each year within the population age structure. The contribution of water for the environment to the Murray cod outcome is unclear, however, it may have improved recruitment through greater lotic habitat or potentially food resources. It is expected the percentage of years featuring YOY, sub-adults and adults in the population age structure will decline from 2019 to 2029 and then remain stable until 2042.

Key messages:

- Overall, regular recruitment of Murray cod was observed following the adoption of the Basin Plan, between 2012 and 2019.
- Delivery of water for the environment contributed to minor (≤20 km for ≥30 days) to moderate (36 km for ≥30 days) localised increases in the extent of lotic habitat, which may have been a factor in the successful recruitment of Murray cod in the main channel of the River Murray between 2014/15 and 2018/19.
- The hypoxic blackwater event associated with overbank flows in 2016/17 likely prevented strong recruitment and caused some mortality of adult Murray cod.
- The Chowilla Anabranch system continues to be an important site for regular recruitment of Murray cod in South Australia.
- Improvements in water delivery (e.g. restoration of spring-summer flow pulses ≥15,000 $ML.day^{-1}$) and other management actions (e.g. weir pool management, physical habitat restoration) may further improve Murray cod recruitment in the SA River Murray.
- Further monitoring and research are required to improve our understanding of Murray cod populations within the Basin, which should inform the use of management actions to support Murray cod communities over the longer-term.

# 8 River red gum condition

## 8.1 Introduction

The river red gum (*Eucalyptus camaldulensis* ssp. *camaldulensis*) is a medium-large (up to 42 m) and single-stemmed tree that grows along watercourses, floodplains, grassy woodlands or forest in southern South Australia as well as Queensland, New South Wales and Victoria (SASCC 2018). Riparian and lower floodplain habitats of the River Murray in South Australia are dominated by river red gum woodland and forest (George et al. 2005), where they grow in areas subject to flooding (Doody et al. 2014). River red gums are considered an iconic species due to their ecological, cultural, recreational and economic value (MDBC 2003).

River red gums perform essential hydrological (e.g. hydraulic redistribution) and biogeochemical (e.g. carbon uptake and provision) functions that support and maintain the productivity and health of the River Murray system (Francis and Sheldon 2002; Smith and Reid 2013; Doody et al. 2014). Furthermore, river red gum dominated communities provide habitat for a suite of fauna and flora species (Jansen and Robertson 2005).

There has been a long-term decline in the condition of river red gums, with significant deterioration having occurred during the Millennium Drought (Doody et al. 2014; Doody et al. 2015). Decline in river red gum condition was attributed to drought, river regulation, river water extraction, irrigation drainage, grazing and land clearance (Overton et al. 2006a; Doody et al. 2015). These drivers of decline have increased groundwater level, soil salinity and reduced wetland connectivity and the frequency of flooding (Overton et al. 2006a; Wen et al. 2009).

Floodplain trees, including river red gum, transpire water from the unsaturated soil profile (i.e. between the top of the water table and the ground surface). Sources of this soil water may be (i) rainfall events of sufficient magnitude to generate vertical infiltration (Baldwin et al. 2011), (ii) vertical infiltration and lateral movement of floodwaters from temporary waterbodies, (iii) lateral movement of surface water from permanent waterbodies (bank recharge) (Holland et al. 2006) and, (iv) low salinity groundwater accessed from the capillary fringe (Mensforth et al. 1994; Thorburn and Walker 1994; Doody et al. 2009; Holland et al. 2011; Roberts and Marston 2011).

The biological availability of soil moisture is influenced by soil type, salinity and water content (Holland et al. 2006; Holland et al. 2011). When soil moisture availability is limited, river red gums may undergo a range of physiological responses including sacrificial leaf loss and reduced sapwood area (Doody et al. 2015), with consequential decline in visual canopy condition. The environmental water requirements stated in the SA LTWP (DEWNR 2015) to sustain river red gums are provided in Table 8-1.

**Table 8-1. Environmental water requirements for river red gums (Kilsby and Steggles 2015).**

| Duration | Timing | Frequency | Maximum interval | Condition description |
|---|---|---|---|---|
| 1-4 months; <2 years | Spring-early summer | 1-4 years | 5-7 years | Condition improves with greater duration and frequency of inundation (with preferred range). Inundation greater than 2-4 years likely to cause tree death. Maximum interval dependent on prior tree condition, local conditions (e.g. groundwater salinity) and access to other water sources (including |

| Duration | Timing | Frequency | Maximum interval | Condition description |
|---|---|---|---|---|
| | | | | rainfall); if conditions are favourable this could be longer. |

## 8.2 Ecological objective, targets and environmental outcomes

The ecological objective and targets for river red gum populations within the Channel and Floodplain PEAs are described in Table 8-2. The condition of river red gums are scored using the Tree Condition Index (TCI) (Wallace et al. 2020) (see section 0), with a score of ≥ 10 reflective of a tree in good (TCI score 10–12) or excellent condition (TCI score 12–14).

**Table 8-2. Ecological objectives and targets for river red gum populations within the Channel and Floodplain PEAs (DEWNR 2015).**

| Ecological objective | Ecological target |
|---|---|
| Throughout the length of the Channel asset (i.e. SA border to Wellington), establish and maintain a diverse native flood-dependent plant community in areas inundated by flows of 10,000–40,000 ML/day QSA | 1. In standardised transects spanning the elevation gradient in the target zone, >70% of all trees have a TCI score ≥10. |
| Maintain a viable, functioning river red gum population within the Floodplain PEA | 2. In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all trees have a TCI score ≥10. |

The expected environmental outcomes for the river red gum tree condition in 2019, 2029 and 2042 were determined by elicitation with key experts (Table 8-3). These form the basis of the assessment of river red gum environmental outcomes in the SA River Murray Channel and Floodplain PEAs.

**Table 8-3. Expected environmental outcomes for river red gums in the Channel and Floodplain PEAs in 2019, 2029 and 2042.**

| PEA | Year | Expected outcome |
|---|---|---|
| Channel | 2019 | 52% (80% confidence range of 27-62%) of river red gums in the Channel PEA will have a TCI score of ≥10. |
| | 2029 | 53% (80% confidence range of 23-69%) of river red gums in the Channel PEA will have a TCI score of ≥10. |
| | 2042 | 58% (80% confidence range of 22-77%) of river red gums in the Channel PEA will have a TCI score of ≥10. |
| Floodplain | 2019 | 46% (80% confidence range of 26-61%) of river red gums in the Floodplain PEA will have a TCI score of ≥10. |

| PEA | Year | Expected outcome |
|---|---|---|
| | 2029 | 47% (80% confidence range of 14-67%) of river red gums in the Floodplain PEA will have a TCI score of ≥10. |
| | 2042 | 48% (80% confidence range of 12-67%) of river red gums in the Floodplain PEA will have a TCI score of ≥10. |

Over time, it is expected that the percentage of trees with a TCI score of ≥10 will be maintained in the Channel and Floodplain, whilst annual fluctuation are expected to occur in response to soil moisture availability driven by cycles of wetting and drying. However, the confidence of this prediction attenuates with time (Table 8-3; Figure 8-2). In 2019, it is expected that 52% of river red gums in the Channel PEA and 46% in the Floodplain PEA will have a TCI of ≥10.

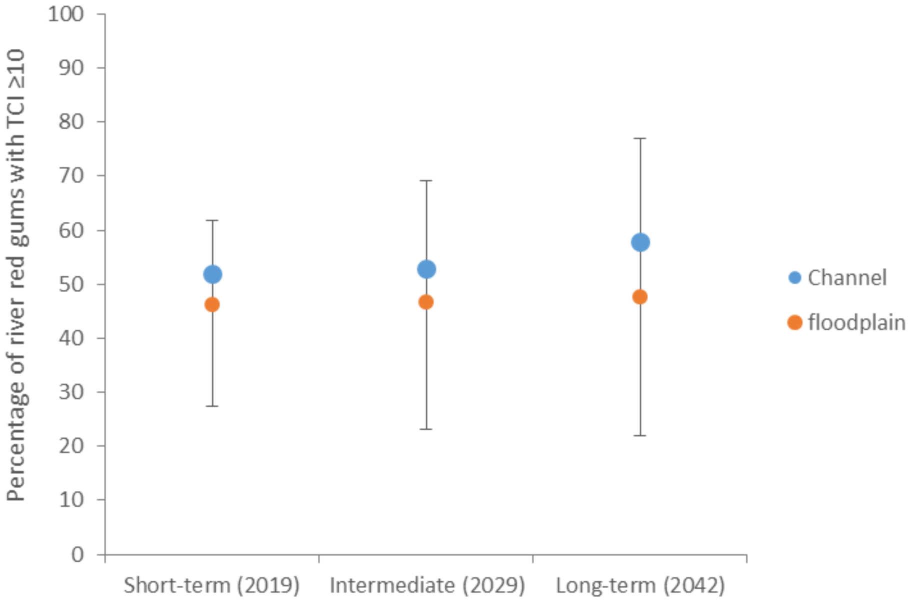


**Figure 8-1. Expected environmental outcomes for river red gums in the Channel and Floodplain PEAs in 2019, 2029 and 2042.**

## 8.3 Data source

Tree condition data were sourced from the Biological Database of South Australia (BDBSA). To reduce location confounding trends in river red gum TCI scores, the database was subset to data collected across the Chowilla, Pike and Katarapko floodplains, where annual data were collected most consistently.

The River Murray Floodplain Inundation Model (RiM-FIM) developed by Overton et al. (2006b) was used to determine whether surveyed trees fell in either the Channel PEA (<40,000 $ML.day^{-1}$) or Floodplain PEA (40–80,000 $ML.day^{-1}$). River red gums in flow bands above 80,000 $ML.day^{-1}$ were excluded from analyses.

Tree condition data collected on the Chowilla floodplain were collected as part of The Living Murray (TLM) program and data for the Pike and Katarapko floodplains were collected as part of the South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP) and the Riverine Recovery Project.

## 8.4 Method

Tree condition data were collected using the standardised TLM tree condition method (Souter et al. 2010). Trees assessed using the TLM method are arranged in transects. At each transect, the condition of 30 trees with a diameter at breast height of ≥10 cm are visually assessed. The crown cover and density of each tree is allocated a score from 0 to 7 and these 2 scores are summed (Table 8-4). The TCI score is the sum of the crown cover and density scores, and therefore range from 0 to 14. A TCI score of 0 is interpreted as a non-viable tree and a score of 14 is reflective of a tree in excellent condition with a high degree of resilience (Table 8-5) (Wallace et al. 2020). The number of individual river red gums assessed over each floodplain (Chowilla, Pike and Katarapko) in the Channel and Floodplain PEAs for each water year are shown in Table 8-6.

**Table 8-4. Categories for reporting crown extent (CE) and crown density (CD) (adapted from Souter et al. 2010).**

| Score | Description | Percentage of CE/CD |
|---|---|---|
| 0 | None | 0% |
| 1 | Minimal | 1-10% |
| 2 | Sparse | 11-20% |
| 3 | Sparse-Medium | 21-40% |
| 4 | Medium | 41-60% |
| 5 | Medium-Major | 61-80% |
| 6 | Major | 81-90% |
| 7 | Maximum | 91-100% |

**Table 8-5. Score system for TCI and corresponding condition description (Wallace et al. 2020).**

| TCI score | Condition | Description |
|---|---|---|
| 0 | Non-viable | Tree may be dead or very near to the critical point of loss. A small proportion of trees may respond to delivery of water, but are likely to be in a precarious position i.e. response may not be sustained and tree may not recover. |
| 2-4 | Very poor | Tree viable but in very poor condition and in a precarious position i.e. continuation of dry conditions is likely to lead to death. Trees with low TCI scores have a slow response. A single watering may stabilise condition. Multiple, back-to-back watering will be required to achieve ‘good’ condition. |
| 5-7 | Poor | Most trees would be expected to respond positively to watering. Inundation may stabilise condition or result in an improvement. Trees may be at the edge of the resilience period, i.e. continuation of dry conditions is likely to lead to a marked loss of condition. Multiple, back to back watering is likely to be required to achieve ‘good’ condition. |

| TCI score | Condition | Description |
|---|---|---|
| 8-9 | Moderate | Most trees with TCI scores ≥8 would be expected to respond positively to watering and increase to the next condition class. |
| 10-12 | Good | Trees are expected to have a moderate degree of resilience and should be able to withstand a short dry period with minimal loss of condition. |
| 13-14 | Excellent | Trees are expected to have a high degree of resilience and should be able to withstand a short period with minimal loss of condition. |

**Table 8-6. The number of river red gums assessed each year over Chowilla, Pike and Katarapko floodplains in the Channel PEA (CH), Floodplain PEA (FP) and for both assets from 2007/08 to 2018/19.**

| Year | Chowilla | | Pike | | Katarapko | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | CH | FP | CH | FP | CH | FP | CH | FP | Total |
| 2007/08 | 49 | 1116 | | | | | 49 | 1116 | 1165 |
| 2008/09 | 66 | 1877 | 76 | 153 | | | 142 | 2030 | 2172 |
| 2009/10 | 71 | 1175 | | | | | 71 | 1175 | 1246 |
| 2010/11 | 39 | 857 | | | | | 39 | 857 | 896 |
| 2011/12 | 39 | 897 | | | | | 39 | 897 | 936 |
| 2012/13 | 50 | 1210 | | | | | 50 | 1210 | 1260 |
| 2013/14 | 113 | 1292 | | | | | 113 | 1292 | 1405 |
| 2014/15 | 98 | 1095 | 76 | 157 | | | 174 | 1252 | 1426 |
| 2015/16 | 94 | 1058 | | | 16 | 143 | 110 | 1201 | 1311 |
| 2016/17 | 59 | 1069 | 16 | 60 | 16 | 143 | 91 | 1272 | 1363 |
| 2017/18 | 50 | 1071 | 16 | 60 | 43 | 399 | 109 | 1530 | 1639 |
| 2018/19 | 50 | 968 | 16 | 60 | 42 | 409 | 108 | 1437 | 1545 |
| **Grand Total** | **778** | **13685** | **200** | **490** | **117** | **1094** | **1095** | **15269** | **16364** |

### 8.4.1 Trend assessment

The approach to assess trend using a Bayesian Generalised Linear Mixed Model is discussed in section 3.2.1. Trend for the river red gum outcome was assessed based upon the proportion of trees in good or excellent condition (TCI ≥10) for a given year over the assessment period, from 2007/08 to 2018/19, in both the Channel and Floodplain PEAs. Individual trees were treated as independent data points for the analysis, with a 1 allocated to trees with a TCI ≥10 and a 0 allocated to trees with a TCI ≤9, resulting in a binary dataset. Time step (years since the commencement of the assessment period) was included as a fixed effect and transect was included as a random effect within the model to account for the difference in spatial location of trees. A binomial family was fitted to the Bayesian Generalised Linear Mixed Model.

### 8.4.2 Condition

The condition of the river red gum population in 2019 was assessed based on the percentage of viable trees in the <80,000 ML.day$^{-1}$ QSA flow band that had TCI scores of ≥10 and 2–8. Therefore, the condition of the river red gum population were assessed against a target condition (TCI ≥10) and management threshold (TCI = 8) as per Wallace and Whittle (2014). The percentage of trees within the river red gum population that had TCI scores of ≥10 and 2–8 provide an understanding of the percentage of trees that are in good or excellent condition (TCI≥10) that should be able to withstand a short dry period with minimal loss of condition (Table 8-5), and the percentage of trees that require multiple back to back watering events to attain good condition or may do so if un-watered for another year (TCI 2–8) (Table 8-5) (Wallace et al. 2020). The percentage of viable trees in the TCI score ranges of 2–8 and ≥10 were compared against Table 8-7 to determine a population condition rating for the South Australian River Murray Report Cards. The condition ratings in Table 8-7 read as consecutive criteria that must all be satisfied to meet the requirements of that condition class. For example, for a population to be in 'very good' condition, no viable trees can have a TCI score of 2–8 and ≥70% of trees must have a TCI score ≥10. If one of these criteria is not satisfied, then the population is assessed against the next highest population condition rating (i.e. 'good') until all criteria are met.

**Table 8-7. Assessment of river red gum population condition based upon the percentage of viable trees in the <80,000 ML.day$^{-1}$ QSA flow band that had TCI scores of 2–8 and ≥10. The percentage of trees must meet the criteria for each TCI score range for a given population condition class to be considered of that class. If one or more criteria are not met then the population is assessed against the next highest condition class until all criteria are met.**

| Population Condition Class | TCI score | |
|---|---|---|
| | 2–8 | ≥10 |
| Very good | 0% | ≥70% |
| Good | 1–9% | ≥70% |
| Fair | 25–10% | ≥70% |
| Poor | <25% | <70% |

### 8.4.3 Information reliability

The information reliability assessment for the river red gum evaluation was conducted as per section 3.2.2.

## 8.5 Limitations of assessment

The ability to assess change in the condition of the river red gum population, and therefore assess the achievement of the expected environmental outcomes and evaluate progression towards the LTWP targets are influenced by site scale management actions that impact condition at localised scales. For example, environmental watering activities that encompass weir pool raising, pumping and the use of regulators, deliver water to higher elevations than otherwise would be possible without such interventions. Trees that have received water for the environment may be in better condition than trees that have only been inundated by high discharge events (Denny et al. 2019; Wallace et al. 2020).

Over time, the condition of river red gums that occur within and adjacent to areas inundated by operation of the Pike and Katarapko environmental regulators may change depending on the frequency and duration of inundation events and any consequential effects on the local shallow groundwater systems. Construction of the regulators at

Pike and Katarapko were completed in 2020, whilst the Chowilla environmental regulator has been operational since 2014, with use in 2014/15, 2015/16, 2016/17 (before flood peak) and in 2018/19 (Nicol et al. 2020). Watering by pumping to individual wetland basins has occurred on all 3 floodplains over the assessment period, with provisions of water for the environment lowest on the Pike floodplain and greatest on the Chowilla floodplain.

River red gum condition is very sensitive to changes in river height (Doody et al. 2014), and therefore, weir raisings at Lock 5 and Lock 6 during the assessment period likely influenced river red gum condition over small areas on the Chowilla floodplain. Raises at Lock 6 occurred in conjunction with the use of the regulator to increase the operating height that enabled greater extents of inundation on the Chowilla floodplain. At Lock 5, there were four consecutive years, from 2015 to 2018, of weir raises, which ranged in height from 0.37 to 0.48 m. At Lock 6, weir raises occurred in 2014, 2016 and 2018, and ranged from 0.22 to 0.62 m. Raises of Locks 3 and 4 only occurred in 2016 and were 0.15 m and 0.20 m, respectively, however, these raises are expected to have negligible impacts on inundation extent (D McCullough, personal communication, 23 July 2020).

All tree condition data used in this assessment were collected in the valley floodplain reach (border to Overland Corner) which receives lower rainfall and is subject to different groundwater conditions compared with the gorge reach (Overland corner to Wellington). There was highly unequal sampling between the 3 floodplains and over time within the assessment period (Table 8-6) Therefore, the results of this assessment should not be used to infer the condition of river red gums over the entirety of the Channel and Floodplain PEAs within the SA River Murray.

## 8.6 Results

### 8.6.1 Environmental outcome assessment: Channel PEA river red gum condition

The percentage of trees with a TCI score ≥10 increased from 4% in 2007/08 to 69% in 2018/19. The observed increase was non-linear and variable over the assessment period. Increases in the percentage of trees with a TCI score ≥10 were recorded between 2009/10 and 2011/12 and again between 2013/14 and 2018/19 and declines occurred in intervening periods (Figure 8-2). The density plot of annual distribution of TCI scores for river red gums in the Channel PEA (Figure 8-3) show that condition was typically poor between 2007/08 and 2009/10 before improving in 2010/11 and again in 2011/12. Condition from 2012/13 to 2016/17 was relatively stable and then improved markedly in 2017/18 and has been largely maintained in 2018/19.

The expected environmental outcome for the river red gum tree condition in the Channel PEA in 2019 was exceeded, with 69% of river red gums in had a TCI score ≥10 (in 2018/19), exceeding the expected environmental outcome of 52% of river red gums with a TCI score ≥10 in 2019 (Figure 8-2). As at 2019, progression towards the LTWP target has been made (despite the target not being met in any year of the assessment period), with the percentage of trees with a TCI score ≥10 nearing the target threshold of 70% of trees. Caution should be taken when interpreting results against the LTWP target and expected outcome for 2019 due to variations in sample size, location of sampling and site-specific management actions.

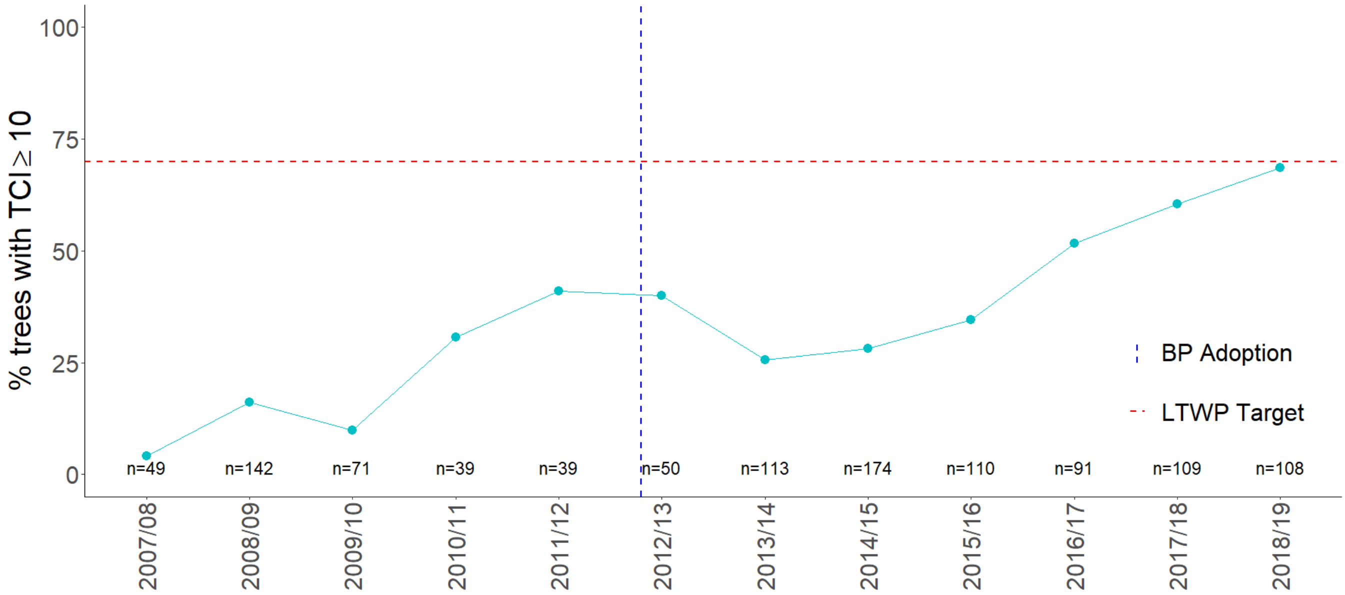


**Figure 8-2. Percentage (%) of river red gums with TCI ≥10 in the Channel PEA extent of the Chowilla, Pike and Katarapko floodplains between 2007/08 and 2018/19. Sample size (n) is provided above the x axis for the corresponding water year.**

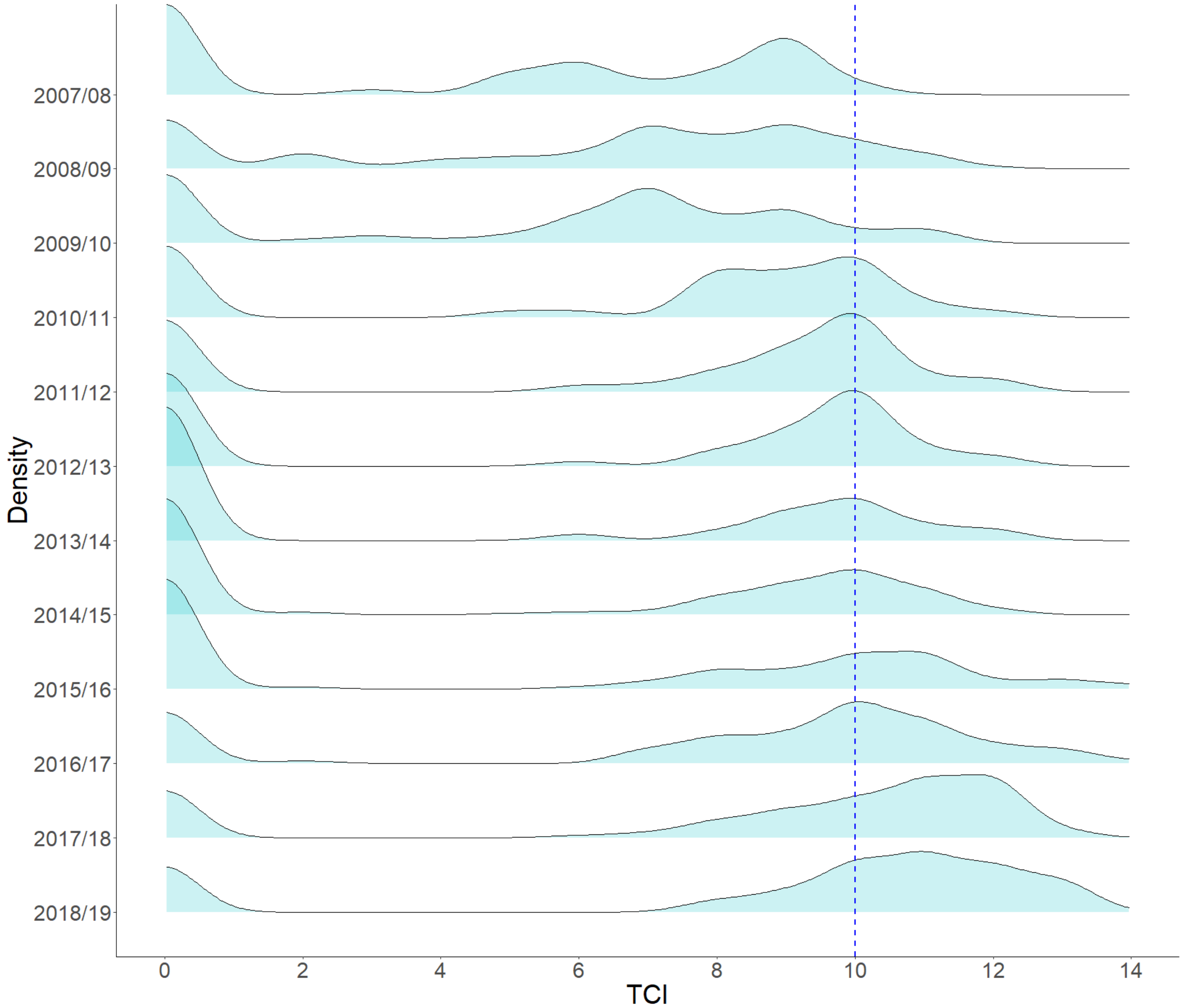


**Figure 8-3. Density distribution of TCI scores for river red gums in the Channel PEA extent of the Chowilla, Pike and Katarapko floodplains between 2007/08 and 2018/19.**

### 8.6.2 Trend: Channel PEA river red gum condition

It is virtually certain (100%) that the proportion of river red gums with a TCI score of ≥10 in the Channel PEA extent of the Chowilla, Pike and Katarapko floodplains has increased between 2007/08 and 2018/19 (Figure 8-4). Therefore, the proportion of river red gum in good or excellent condition is **getting better**.

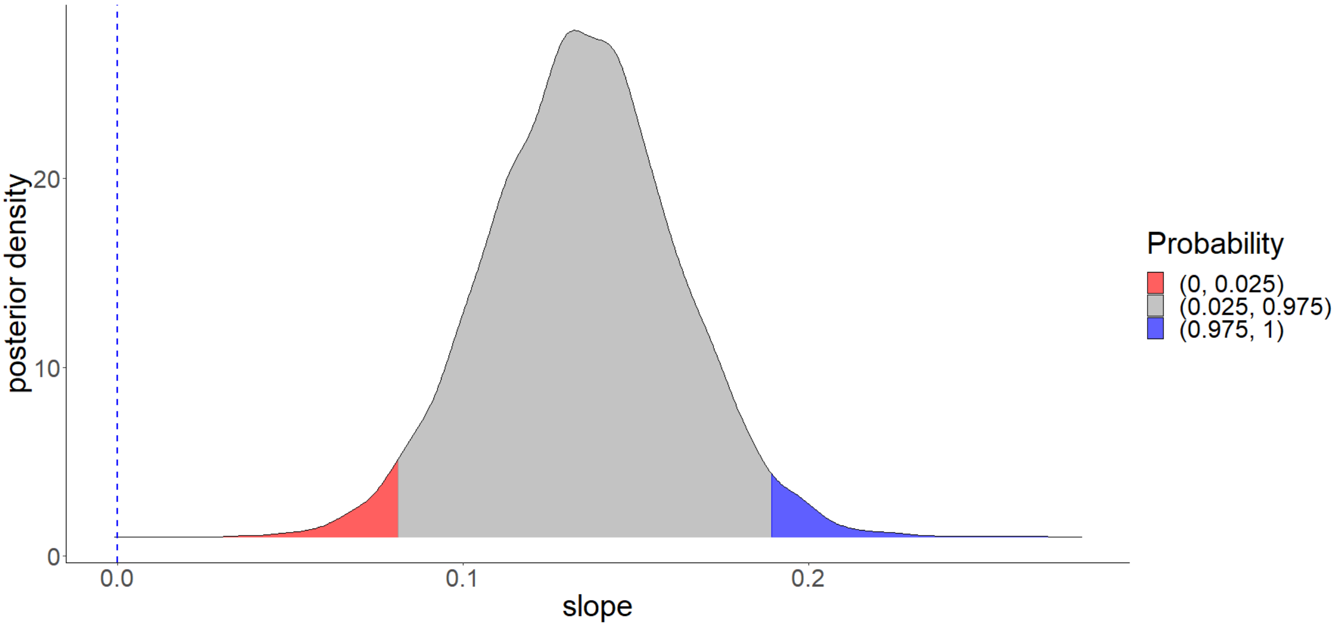


**Figure 8-4. Estimated values for the slope generated from Bayesian modelling for river red gum in good or excellent condition (TCI score ≥10) in the Channel PEA extent of the Chowilla, Pike and Katarapko floodplains from 2007/08 to 2018/19. As all posterior density values have a slope >0, there is a 100% likelihood that the proportion of river red gum in good or excellent condition has increased.**

### 8.6.3 Environmental outcome assessment: Floodplain PEA river red gum condition

The percentage of trees with a TCI score ≥10 increased from 10% in 2007/08 to 65% in 2018/19. The observed increase was non-linear and staged over the assessment period. Increases in the percentage of trees with a TCI score ≥10 were recorded between 2009/10 and 2011/12 and again in 2017/18 and declines occurred in intervening periods (Figure 8-5). The density plot of annual distribution of TCI scores for river red gums in the Floodplain PEA (Figure 8-6) follow the same trends as recorded for the percentage of trees with a TCI score of ≥10.

The expected environmental outcome for the river red gum tree condition in the Floodplain PEA in 2019 was exceeded. In 2018/19, 65% of river red gums in had a TCI score ≥10, and therefore, the expected environmental outcome of 46% with a TCI score ≥10 was exceeded (Figure 8-5). As at 2019, progression towards the LTWP target has been made (despite the target not being met in any year of the assessment period), with the percentage of trees with a a TCI score of ≥10 nearing the target threshold of 70% of trees.

Caution should be taken when interpreting results for the assessment of the expected environmental outcome for 2019 and the progression towards the LTWP target due to variations in sample size, location of sampling and site specific management actions (see section 8.7).

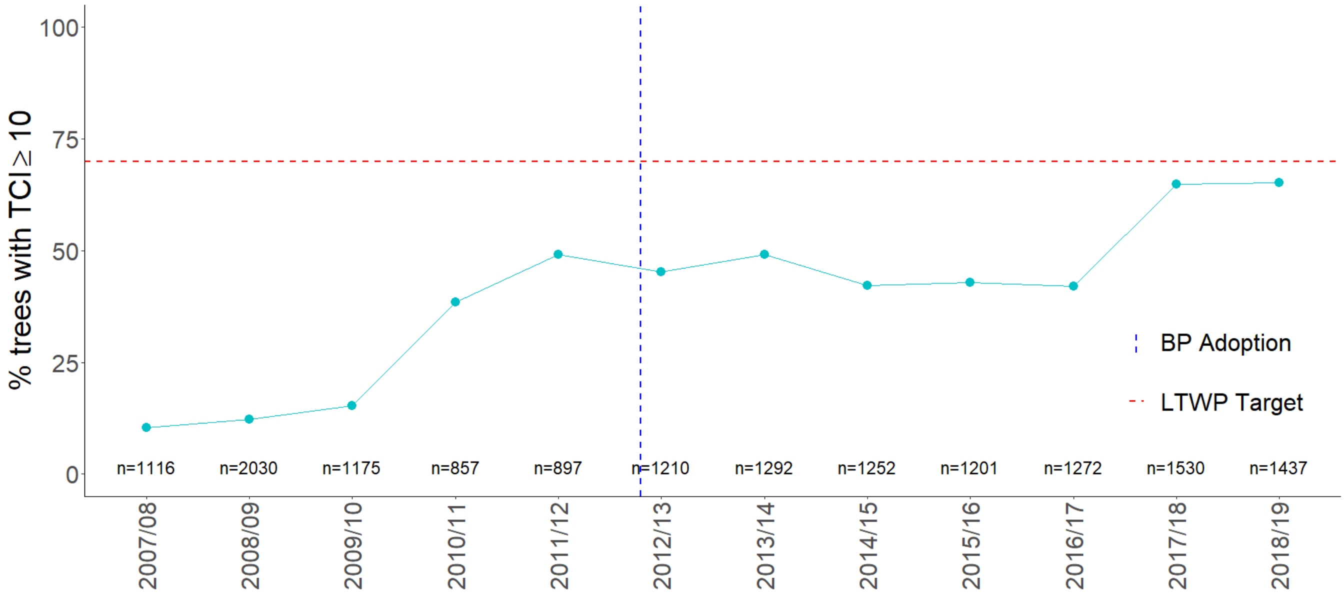


**Figure 8-5. Percentage (%) of river red gums with TCI ≥10 in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains from 2007/08 to 2018/19. Sample size (n) is provided above the x axis for the corresponding water year.**

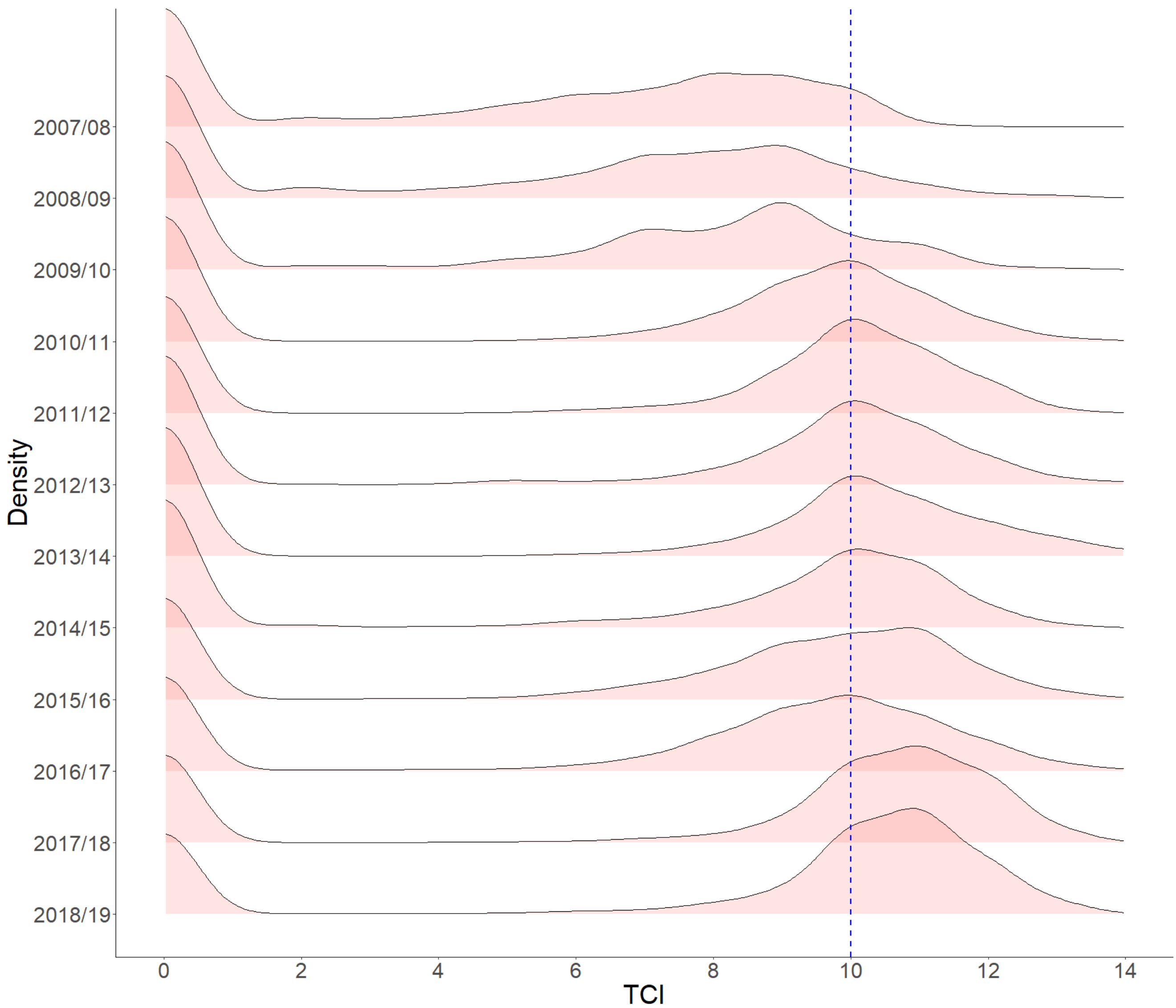


**Figure 8-6. Density distribution of TCI scores for river red gums in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains from 2007/08 to 2018/19.**

### 8.6.4 Trend: Floodplain PEA river red gum condition

It is virtually certain (100%) that the proportion of river red gums with a TCI score of ≥10 in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains has increased between 2007/08 and 2018/19 (Figure 8-7). Therefore, the proportion of river red gums in good or excellent condition is **getting better**.

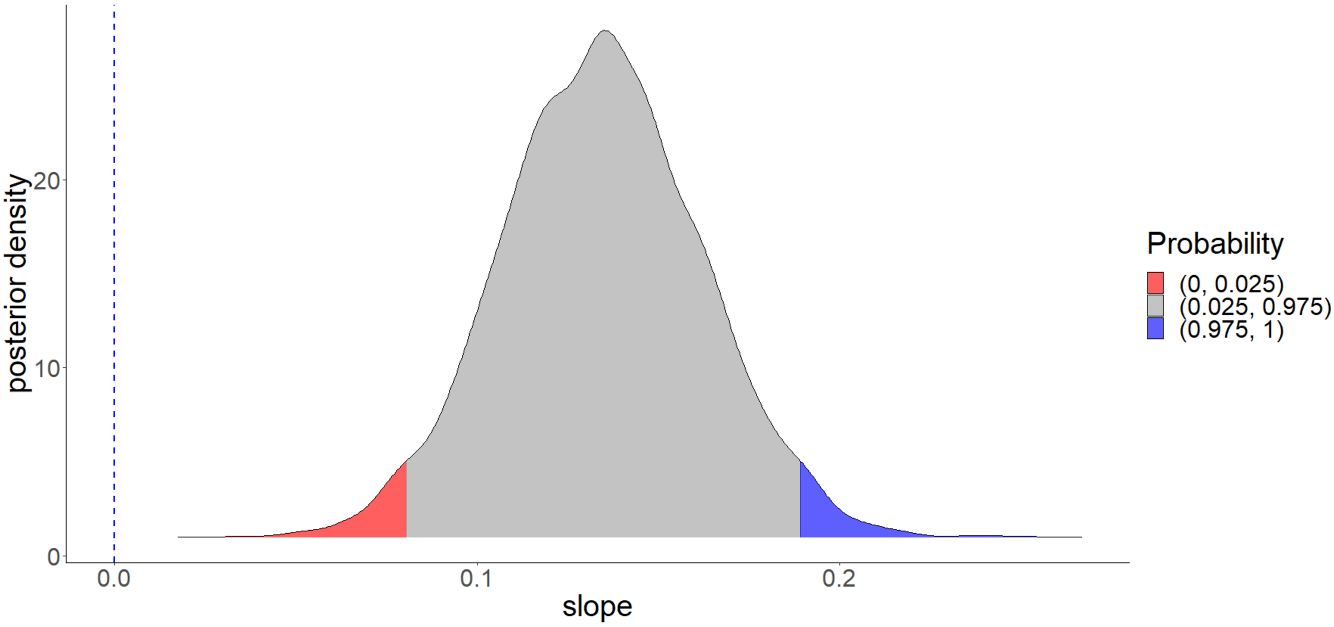


**Figure 8-7. Estimated values for the slope generated from Bayesian modelling for river red gum in good or excellent condition (TCI score ≥10) in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains from 2007/08 to 2018/19. As all posterior density values have a slope >0, there is a 100% likelihood that the proportion of river red gum in good or excellent condition has increased.**

### 8.6.5 Condition

In 2018/19, a total of 1178 viable river red gums from flow bands between 0-80,000 ML.day$^{-1}$ on the Chowilla, Pike and Katarapko floodplains were scored using the TCI. Overall, 6.8% (n=80) of trees had TCI scores of 2–8 and 85.7% (n=543) of trees had TCI scores ≥10. Therefore, the population of river red gum in 2018/19 met the criteria as per Table 8-7 to be classed as **good**.

**Table 8-8. The percentage of viable trees in the sampled river red gum population in 2018/19 in flows bands from 0–80,000 ML.day$^{-1}$ on the Chowilla, Pike and Katarapko floodplains that had TCI scores of 2–8 and ≥10.**

| TCI scores | | Total no. viable trees |
|---|---|---|
| **2–8** | **≥10** | |
| 6.8% (n=80) | 85.7% (n=1010) | 1178 |

### 8.6.6 Information reliability

The data reliability rating for river red gum in the Channel PEA and Floodplain PEA was **poor** (final score of 8). Justification for the scoring of river red gum data reliability is provided in Table 8-9.

**Table 8-9. Reliability of river red gum data to assess the expected environment outcomes. The metrics of methods, representativeness and repetition are scored against their response to the metric question. Answers are scored 2 points – Yes, 1 point – Somewhat, 0 points – No.**

| **Methods** | **Question** | **Answer and justification** | **Score** |
|---|---|---|---|
| Methods used | Are the methods used appropriate to gather the information required for evaluation? | **Yes**. The LTWP target and expected outcomes were established upon data collected using the TCI method. | **2** |
| Standard methods | Has the same method been used over the sampling program? | **Yes**. Tree condition data were collected using the standardised 'The Living Murray' tree condition method. | **2** |
| **Representativeness** | | | |
| Space | Has sampling been conducted across the spatial extent of the PEA with equal effort? | **No.** Only data from Chowilla, Pike and Katarapko floodplains were analysed. The protocol for establishing transects at other managed wetlands excluded dead (defoliated) trees from inclusion within transects. Consequently, these non-standardised transects were not compared to standardised transects which include defoliated trees at the time of transect establishment. Furthermore, within the dataset analysed, data from Chowilla comprised 70% and 80% of the database for the Channel PEA and Floodplain PEA, respectively. | **0** |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | **Somewhat.** Tree condition data were recorded annually since Basin Plan adoption and baseline data exists. However, there were fluctuations in sample size between years, with four-fold fluctuations in the Channel PEA and two-fold in the Floodplain PEA. Sample sizes were relatively comparable in the Channel PEA from 2015/16 to 2018/19 and in the Floodplain PEA from 2012/13 to 2018/19. | **1** |
| **Repetition** | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | **Somewhat**. There are differences in the inaugural year of monitoring between trees sampled on the Pike, Katarapko and Chowilla floodplains. Moreover, data were not collected on an annual basis since the inaugural year of monitoring on the Pike floodplain. Additional sites were allocated to monitoring programs as they progressed. Sites were re-visited between years for each monitoring program. | **1** |

| Methods | Question | Answer and justification | Score |
|---|---|---|---|
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | **Yes.** Tree condition data were recorded annually since Basin Plan adoption and baseline data exists. | 2 |
| **Final score** | | | **8** |
| **Data reliability** | | | **Poor** |

## 8.7 Evaluation

The trend assessment determined that the proportion of river red gums in good or excellent condition across the Chowilla, Pike and Katarapko floodplains in the Channel and Floodplain PEAs increased from 2007/08 to 2018/19, with results compared across individual transects between years. However, the results from the assessment of the environmental outcomes should be treated with caution, as changes in sample size and the location of trees sampled may have confounded the results.

The distribution of condition scores of river red gums between 2007/08 and 2018/19 were similar between the Channel and Floodplain PEAs. This was an unexpected result, as Doody et al. (2014) determined that river red gum condition was highest 90 m from the River Murray channel and progressively declined with greater distance. Causes behind the similarity in results between the PEAs may have been due to a high proportion of the trees sampled on the Chowilla floodplain coming from managed wetlands and temporary creeks, while discrepancies in sample size may have also contributed to this result, with the number of trees sampled in the Floodplain PEA 15 times higher than the Channel PEA.

Changes in the condition of river red gums over the assessment period, from 2007/08 to 2018/19, followed similar patterns in the Channel and Floodplain PEA, with poor condition between 2007/08 and 2009/10 before an improvement in 2010/11 and again in 2011/12. Condition was maintained in 2012/13 (adoption of the Basin Plan) and gradually declined between 2013/14 and 2016/17. There was marked improvement in the condition in 2017/18, which was largely maintained in 2018/19.

Over the assessment period, there were 3 years (2010/11, 2011/12 and 2017/18) where there was marked improvement in the condition of the river red gum population. As data collection in 2010/11 were completed before the flood (i.e. data was collected in winter and spring 2010), improvement in the condition of river red gums in 2010/11 may have been associated with a reduction in sample size from 2009/10, high rainfall or higher within-channel flows. Further improvement in 2011/12 was likely associated with the flood in 2010/11, which peaked at ~94,000 $ML.day^{-1}$ in February 2011. Improvement in 2017/18 may have been in part due to the establishment of new transects at Katarapko, which increased sampling effort four-fold on that floodplain. However, it is highly likely that a large unregulated flood in 2016/17 was a key driver of widespread improvement in tree condition; data collected in 2016/17 on the Chowilla and Katarapko floodplains (which comprised >95% of the data collected) were completed before the flood (i.e. data were collected in August 2016), which peaked at ~94,000 $ML.day^{-1}$ in December 2016.

Improvement in the proportion of river red gums in good or excellent condition on the Chowilla, Pike and Katarapko floodplains over the assessment period, from 2007/08 to 2018/19, were likely primarily influenced by unregulated flood events (see section 8.7.1). Targeted delivery of environmental water by pumping, rainfall (see section 8.7.2), elevated within-channel flows (see section 8.7.3) and managed floodplain inundations (see section 8.7.4) supported by environmental water may also have had an influence on river red gum condition, however, the magnitude of the contribution of these respective actions were not separated in this assessment.

### 8.7.1 High (unregulated) flow events

The duration and frequency of unregulated flood events have significant influence on the condition of river red gums (Doody et al. 2014; Denny et al. 2019; Wallace et al. 2020). While differences in the trends in the condition of river red gums solely inundated by unregulated floods (i.e. did not receive water through managed floodplain inundations), and those that were also supported by delivery of environmental water between the unregulated floods, were not assessed as part of this study, the unregulated floods in 2010/11 and 2016/17 were associated with an improvement in the condition of the river red gum population over the Chowilla, Pike and Katarapko floodplains. In the water years following the large unregulated flood events, there were higher proportions of trees in good or excellent condition and much lower proportions trees in poor and very poor condition.

These results support the findings of Doody et al. (2014) who observed a large increase in Normalised Difference Vegetation Index (NDVI) of river red gums adjacent to the River Murray channel and feeder creeks on the Chowilla floodplain following the unregulated flood in 2010/11. Furthermore, Wallace et al. (2019) also recorded improvement in the proportion of river red gum in good or excellent conditions (TCI ≥10) between July 2010 (pre-flood) and October 2011 (post-flood) at all 17 assessment locations surveyed in both periods on the Chowilla floodplain.

Significant improvement in the condition of river red gums following the 2016/17 unregulated flood were also recorded. Wallace et al. (2019) recorded improvement in the proportion of river red gum in good or excellent condition (TCI ≥10) between August 2016 (pre-flood) and May 2017 (post-flood) at 26 of the 28 assessment locations on the Chowilla floodplain. Moreover, on the Katarapko floodplain, 6 of 7 transects had significant improvement in the proportion of river red gum in good or excellent condition (TCI ≥10) between August 2016 (pre-flood) and March 2018 (post-flood) (Wallace 2020).

River red gums in the Floodplain PEA were expected to have had a larger improvement in condition following an unregulated flood than trees in the Channel PEA, as Denny et al. (2019) determined that following an unregulated flood, trees within 50 m of a permanent anabranch on the Katarapko floodplain maintained their good condition, while trees that were only inundated during unregulated floods and flows greatly improved in condition. However, trees in the Floodplain PEA were not found to have greater improvement in condition than those in the Channel PEA following unregulated floods, possibly due to managed floodplain inundations and discrepancies in sample size, with the number of trees sampled in the Floodplain PEA 15 times higher than the Channel PEA.

### 8.7.2 Rainfall

Rainfall is one of 3 main water sources for river red gums (Wen et al. 2009) and therefore periods of high rainfall may improve their condition (Doody et al. 2014). The influence of rainfall on river red gum has not been separated in this assessment. There were 2 years of high rainfall (2010/11 and 2016/17) during the monitoring program, which coincided with high (unregulated) flow events (Figure 2-4). Data collection in 2010/11 were completed prior to flood that year, however, sample size halved from 2009/10 and higher within-channel flows (see section 8.7.3) may have contributed to the improvement in TCI scores. In 2016/17, data collection was completed prior to the high rainfall and unregulated flood events and there was a three-fold increase in sample size on the Katarapko floodplain in 2017/18, meaning that relative contribution of each of these hydrological influences could not be separated. Although it could not be deduced that rainfall influenced river red gum condition in this assessment, Doody et al. (2014) determined that while rainfall had little influence on NDVI of river red gums on the Chowilla floodplain in November 2010 prior to flood, continued rainfall in December 2010 during the flood peak very likely increased NDVI of trees in the outer floodplain. As such, it is possible that periods of high rainfall contributed to the improvements in river red gum condition recorded during the monitoring program.

### 8.7.3 Elevated within-channel flows

Improved within-channel flows since the adoption of the Basin Plan that were driven by widespread rainfall/run-off in the upper catchments and supported by the delivery of water for the environment (Figure 2-3) may have helped to limit the deterioration of river red gum condition during inter-flood dry phases by elevating river heights and improving hydrological connectivity between river banks, wetlands and riparian zones. Improved within-channel flows may have improved river red gum condition in 2010/11 prior to the high (unregulated) flood event and may have helped to limit declines in condition during inter-flood dry periods. Significant improvement in river red gum condition prior to the adoption of the Basin Plan (between 2009/10 and 2010/11), which may be attributed to reduction in sample size (-45% for the Channel PEA and -30% for the Floodplain PEA), rainfall and greater within-channel flows as data collected was completed prior to flood. It is likely that greater within-channel flows contributed significantly to this result as Wallace et al. (2019) identified improvement in river red gum condition over all 14 assessment areas that were surveyed on the Chowilla floodplain in August/November 2009 and again in July 2010. As July 2010 occurred prior to high rainfall and flood, it is likely that greater within-channel flows contributed to this improvement. Higher within-channel flows were also determined by Doody et al. (2014) to be critical to the survival of river red gums adjacent to the river channel on the Chowilla floodplain during the Millennium Drought.

### 8.7.4 Managed floodplain inundations

Managed inundation of the floodplain through pumping, weir pool raising and operation of the Chowilla regulator has helped to deliver water, including water for the environment, to river red gums on the floodplain. Although the spatial scale of managed floodplain inundations is limited compared to high (unregulated) flood events, it is recognised that river red gums with access to water for the environment during inter-flood dry phases are likely to be in better condition than non-managed trees (Denny et al. 2019), which may have improved their response to high (unregulated) flows.

Pumping of water for the environment to creeks and wetlands on the Chowilla floodplain during inter-flood dry phases at annual return interval of 1 in 2 to 2 in 3 years was found to maintain or improve the condition of river red gums dependent upon their condition prior to the commencement of watering (Wallace et al. 2020). Trees that commenced in poor or moderate condition were recorded to improve their condition, while those initially in good condition had their condition largely maintained (Wallace et al. 2020). Similarly, on the Katarapko floodplain, river red gums that had received water for the environment via pumping were found to be in better condition during inter-flood dry phases than trees that only received water from high (unregulated) flows (2010/11 and 2016/17) and a series of smaller follow-on unregulated flows (2011/12 and 2012/13) (Denny et al. 2019).

Weir pool raising and operation of the Chowilla regulator that were supported by the delivery of water for the environment increased river and anabranch heights. As river red gum condition is particularly sensitive to changes in river height (Doody et al. 2014), it is likely that these events positively contributed to the maintenance or improvement in the condition of river red gums. Raises of Lock 6 coupled with operation of the Chowilla regulator inundated 2,142 ha in 2014/15, 535 ha in 2015/16, 7,653 ha in 2016/17 (prior to flood) and 2,250 ha in 2018/19 (Nicol et al. 2020). Moreover, since the adoption of the Basin Plan, there were four consecutive years, from 2015 to 2018, of weir raises at Lock 5 that ranged in height from 0.37 to 0.48 m, however, these events would have had negligible out-of-channel influence on the Chowilla floodplain. Therefore, the operation of the Chowilla regulator since the adoption of the Basin Plan is likely to have had some influence on the improvements in condition of river red gums during inter-flood dry phases, but the magnitude of influence is unknown.

## 8.8 Actions to achieve environmental outcomes

Delivery of water for the environment, where feasible, is an important management tool to improve the condition and resilience of floodplain tree populations (Wallace et al. 2020). The conceptual model of stress recovery for floodplain eucalypts (see Wallace et al. 2020) summarises how the condition of floodplain eucalypts transition with respect to the duration of dry phases or conversely the frequency and duration of inundation or watering. This model demonstrates the value of the delivery of water for the environment during inter-flood dry phases to reduce the proportion of trees declining to poor or very poor condition (Denny et al. 2019). The provision of water for the environment when availability is high may help to increase the proportion of trees in good condition, so that they are able to tolerate a decline in condition during dry periods when the availability of water for the environment is low (Wallace et al. 2020). Trees in better condition have short recovery periods, while trees in moderate condition are able to be restored to good condition in 3 years if inundated or watered during that period (Wallace et al. 2020).

While the TCI conceptual model (Wallace et al. 2020) interprets resilience of floodplain trees based on crown condition, visual assessment of the crown alone may not be fully representative of a tree's metabolic state and ultimate resilience (Doody and Overton 2012; Wallace et al. 2020). Therefore, where site-specific knowledge of tree condition trajectory is lacking or uncertain, measurement of soil total water potential (a direct measure of the biological availability of water in the unsaturated zone) and/or physiological measurements of stress such as transpiration, pre-dawn shoot water potentials and the proportion of sapwood in stems may be used to ascertain how trees at a given site may respond to watering (Doody and Overton 2012; Wallace et al. 2020).

The frequency and spatial extent of managed floodplain inundations, and therefore our ability to support floodplain tree condition, will increase in future years with the completion of floodplain infrastructure in 2020, such as the regulators on the Pike and Katarapko floodplains. Operation of regulators on the Chowilla, Pike and Katarapko floodplains in conjunction with raising of Locks 4, 5 and 6 and the delivery of water for the environment will increase the extent of manageable floodplain between Lock 3 and the South Australian border (Nicol et al. 2015). Pumping, irrigation, and groundwater management (e.g. lowering to reverse groundwater gradients and generate low salinity lenses, injection of low salinity water to generate low salinity lenses) can further support floodplain trees that are located within reaches and at elevations beyond the influence of weir raising and the regulators or that trigger management thresholds (i.e. >10% of viable floodplain trees in a standardised transect have TCI scores ≤8).

## 8.9 Conclusion

The proportion of river red gums in good or excellent condition across the Chowilla, Pike and Katarapko floodplains in the Channel and Floodplain PEAs increased from 2007/08 to 2018/19. The delivery of water for the environment, since the adoption of the Basin Plan has helped to improve flow conditions, which has:

- increased flows within the channel, increasing river water levels and improving hydrological connectivity between habitats – this helped to limit the deterioration of river red gum condition between periods of floodplain inundation
- enabled floodplains to be inundated via operation of infrastructure which may have –
    - maintained the condition, and increased resilience, of trees which improves the response of trees to future flooding events
    - supported a small increase in the area of inundation, with more trees receiving water.

Key messages:

- Overall, the proportion of trees in good or excellent condition within the Pike, Katarapko and Chowilla floodplains increased between 2007/08 and 2018/19.
- Delivery of water, including water for the environment, has been important in supporting river red gum condition during inter-flood dry phases.

- High (unregulated) flow events were likely a key driver of temporal improvements in the condition of the river red gums population since the adoption of the Basin Plan. These events are needed more frequently to support the resilience of the river red gum population, particularly those that are outside of management influence.
- Full implementation of the Basin Plan, including addressing current water delivery constraints, is required to achieve greater frequency, duration and magnitude of overbank flows along the SA River Murray, which may lead to improvements in river red gum condition.
- It is important to note that data derived for the assessment of river red gum condition are from sites where there has been targeted water delivery of water for the environment, thus the results are likely not to be representative of the broader asset.

# 9 Black box condition

## 9.1 Introduction

Black box (*Eucalyptus largiflorens*) is a medium-sized (up to 20 m high) and single-stemmed tree that is distributed over eastern South Australia, Victoria, New South Wales and Queensland. Black box woodland has the second most extensive coverage of any vegetation community on the floodplain in South Australia (Kilsby and Steggles 2015). These woodlands generate organic matter that, when inundated, results in the mobilisation of water soluble dissolved organic carbon and nutrients that can provide vital resources for the aquatic food web (Gibbs et al. 2020).

Black box are more drought tolerant than river red gums, and therefore tend to occur in areas with comparatively long inter-flood periods and/or lower soil water availability (Kirby et al. 2013; Kilsby and Steggles 2015). Sources of soil water transpired by floodplain trees, including black box, include (i) rainfall events of sufficient magnitude to generate vertical infiltration (Baldwin et al. 2011), (ii) vertical infiltration and lateral movement of floodwaters from temporary waterbodies, (iii) lateral movement of surface water from permanent waterbodies (bank recharge) (Holland et al. 2006) and, (iv) low salinity groundwater accessed from the capillary fringe (Mensforth et al. 1994; Thorburn and Walker 1994; Doody et al. 2009; Holland et al. 2011; Roberts and Marston 2011).

The condition of black box on the floodplain has declined over the Murray–Darling Basin since the 1980s (Overton et al. 2018). Causes of black box decline include drought, river regulation, river water extraction, irrigation drainage, grazing and land clearance (Overton et al. 2006a; Overton et al. 2018). These drivers of decline have decreased the depth to the watertable, increased soil salinity and reduced the frequency of flooding (Overton et al. 2006a). Black box in poor condition are associated with saline groundwater (>40 $mS.cm^{-1}$), infrequent flooding (less frequent than one in 10 years) and shallow groundwater (<4 m) (Taylor et al. 1996). Likewise, black box in good condition are associated with fresher groundwater, more frequent flooding and deeper groundwater (Taylor et al. 1996).

Floodplains in south-eastern Australia comprise large and continuous remnants of native vegetation, and therefore, are of great importance for the conservation of wildlife (McGinness et al. 2010; McGinness et al. 2018). The flora community in black box woodland differ from those in river red gum woodland forest (Kilsby and Steggles 2015), and in turn, fauna communities also differ between these habitats (Rogers and Paton 2008). As black box woodland is an ecotone between lignum and river red gum dominated communities at lower (more frequently inundated) areas, and mallee woodlands on the highland (never inundated), they support the highest species richness of terrestrial birds for a floodplain vegetation community (Rogers and Paton 2008). Furthermore, black box woodlands following flood are more productive than mallee habitats (McGinness et al. 2010; McGinness et al. 2018), and therefore, may be important habitat at a landscape scale for fauna.

## 9.2 Ecological objective, target and environmental outcomes

The ecological objective and target for black box populations in the Floodplain PEA are described in Table 9-1. The condition of black box is scored using the Tree Condition Index (Wallace et al. 2020), with a score of ≥10 reflective of a tree in good or excellent condition.

**Table 9-1. Ecological objective and target for black box in the SA River Murray Floodplain PEA (DEWNR 2015)**

| Characteristic | Description |
|---|---|
| Ecological objective | Maintain a viable, functioning Black Box population within the Floodplain PEA |
| Ecological target | In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all trees have a Tree Condition Index (TCI) Score of ≥10. |

The expected environmental outcomes for the black box tree condition in 2019, 2029 and 2042 were determined by expert elicitation with key experts (Table 9-2). Over time, it is expected that the percentage of trees with a TCI score of ≥10 will be increase, however, the confidence of this prediction attenuates with time (Figure 9-1). In 2019, it is expected that 35% of black box will have a TCI of ≥10.

**Table 9-2. Expected environmental outcomes for the percentage of black box in good or excellent condition (TCI score ≥10) in 2019, 2029 and 2042.**

| Year | Expected outcome |
|---|---|
| 2019 | 35% (80% confidence range of 23-45%) of black box will have a TCI score of ≥10. |
| 2029 | 46% (80% confidence range of 16-68%) of black box will have a TCI score of ≥10. |
| 2042 | 52% (80% confidence range of 24-73%) of black box will have a TCI score of ≥10. |

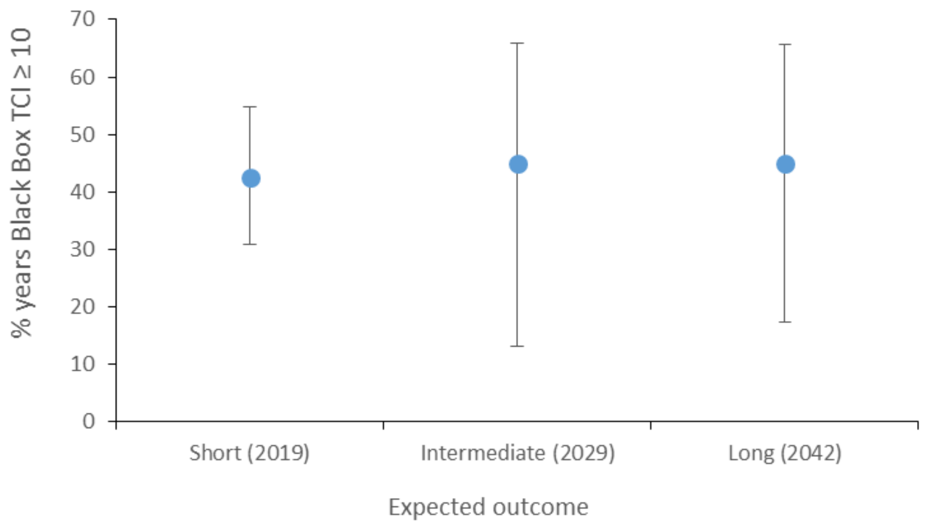


**Figure 9-1. Expected environmental outcomes for the percentage of black box in good or excellent condition (TCI score ≥10) in 2019, 2029 and 2042.**

## 9.3 Data source

Tree condition data were sourced from the Biological Database of South Australia (BDBSA). To reduce location confounding factors in black box TCI scores, the database were subset to data collected across the Chowilla, Pike and Katarapko floodplains, where annual collection of data were most consistent.

The River Murray Floodplain Inundation Model (RiM-FIM) developed by Overton et al. (2006b) was used to subset records of black box tree condition to trees located in the Floodplain PEA (40-80,000 $ML.day^{-1}$) extent of the Chowilla, Pike and Katarapko floodplains. Black box in flow bands <40,000 $ML.day^{-1}$ or >80,000 $ML.day^{-1}$ were excluded from analyses.

Tree condition data collected on the Chowilla floodplain were collected as part of the Living Murray (TLM) program and data for the Pike and Katarapko floodplains were collected as part of the South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP) and the Riverine Recovery Project.

## 9.4 Method

Tree condition data were collected using the standardised TLM tree condition method (Souter et al. 2010). Trees assessed using the TLM method are arranged in transects. At each transect, the condition of 30 trees with a diameter at breast height of ≥10 cm are visually assessed. The crown cover and density of each tree is allocated a score from 0 to 7 and these 2 scores are summed (Table 9-3). The Tree Condition Index (TCI) score is the sum of the crown cover and density scores, and therefore range from 0 to 14. A TCI score of 0 is interpreted as a non-viable tree and a score of 14 is reflective of a tree in excellent condition with a high degree of resilience (Table 9-4) (Wallace et al. 2020). The number of individual black box assessed at each site (Chowilla, Pike, Katarapko) in the Floodplain PEA for each water year are shown in Table 9-5.

**Table 9-3. Categories for reporting crown extent (CE) and crown density (CD) (adapted from Souter et al. 2010).**

| Score | Description | Percentage of CE / CD |
|---|---|---|
| 0 | None | 0% |
| 1 | Minimal | 1-10% |
| 2 | Sparse | 11-20% |
| 3 | Sparse-Medium | 21-40% |
| 4 | Medium | 41-60% |
| 5 | Medium-Major | 61-80% |
| 6 | Major | 81-90% |
| 7 | Maximum | 91-100% |

**Table 9-4. Score system for TCI and corresponding condition description (Wallace et al. 2020).**

| TCI score | Condition | Description |
|---|---|---|
| 0 | Non-viable | Tree may be dead or very near to the critical point of loss. A small proportion of trees may respond to delivery of water, but are likely to be in a precarious position i.e. response may not be sustained and tree may not recover |
| 2-4 | Very poor | Tree viable but in very poor condition and in a precarious position i.e. continuation of dry conditions is likely to lead to death. Trees with low TCI scores |

| TCI score | Condition | Description |
|---|---|---|
| | | have a slow response. A single watering may stabilise condition. Multiple, back to back watering will be required to achieve 'good' condition |
| 5-7 | Poor | Most trees would be expected to respond positively to watering. Inundation may stabilise condition or result in an improvement. Trees may be at the edge of the resilience period, i.e. continuation of dry conditions is likely to lead to a marked loss of condition. Multiple, back to back watering is likely to be required to achieve 'good' condition |
| 8-9 | Moderate | Most trees with TCI scores ≥8 would be expected to respond positively to watering and increase to the next condition class |
| 10-12 | Good | Trees are expected to have a moderate degree of resilience and should be able to withstand a short dry period with minimal loss of condition |
| 13-14 | Excellent | Trees are expected to have a high degree of resilience and should be able to withstand a short period with minimal loss of condition |

**Table 9-5. The number of individual black box assessed each year in the Floodplain PEA conducted on the Chowilla, Pike and Katarapko floodplains.**

| Year | Chowilla | Pike | Katarapko | Total |
|---|---|---|---|---|
| 2008/09 | 138 | 64 | | 202 |
| 2009/10 | 113 | | | 113 |
| 2010/11 | 50 | | | 50 |
| 2011/12 | 57 | | | 57 |
| 2012/13 | 193 | | | 193 |
| 2013/14 | 268 | | | 268 |
| 2014/15 | 333 | 45 | | 378 |
| 2015/16 | 333 | | 164 | 497 |
| 2016/17 | 221 | 150 | 164 | 535 |
| 2017/18 | 193 | 151 | 446 | 790 |
| 2018/19 | 252 | 151 | 433 | 836 |
| **Grand Total** | **2151** | **1207** | **561** | **3919** |

### 9.4.1 Trend assessment

The approach to assess trend using a Bayesian Generalised Mixed Model is discussed in section 3.2.1. Trend for the black box ecological objective was assessed based upon the proportion of trees in good or excellent condition (TCI ≥10) for a given year over the assessment period, from 2008/09 to 2018/19. Individual trees were treated as an independent data points for the analysis, with a 1 allocated to trees with a TCI ≥10 and a 0 allocated to trees with a TCI ≤9, resulting in a binary dataset. Time step (years since the commencement of the assessment period) was included as a random effect and transect was included as a fixed effect within the model to account for the difference in spatial location of trees. A binomial family was fitted to the Bayesian Generalised Linear Mixed Model.

### 9.4.2 Condition

The condition of the black box population in 2019 was assessed based on the percentage of viable trees in the <80,000 $ML.day^{-1}$ QSA flow band that had TCI scores of ≥10 and 2–8. Therefore, the condition of the black box population were assessed against a target condition (TCI ≥10) and management threshold (TCI = 8) as per Wallace and Whittle (2014). The percentage of trees within the black box population that had TCI scores of ≥10 and 2–8 provide an understanding of the percentage of trees that are in good or excellent condition (TCI≥10) that should be able to withstand a short dry period with minimal loss of condition (Table 8-5), and the percentage of trees that require multiple back to back watering events to attain good condition or may do so if un-watered for another year (TCI 2–8) (Table 8-5) (Wallace et al. 2020a). The percentage of viable trees in the TCI score ranges of 2–8 and ≥10 were compared against Table 8-7 to determine a population condition rating for the South Australian River Murray Report Cards. The condition ratings in Table 8-7 read as consecutive criteria that must all be satisfied to meet the requirements of that condition class. For example, for a population to be in 'very good' condition, no viable trees can have a TCI score of 2–8 and ≥70% of trees must have a TCI score ≥10. If one of these criteria is not satisfied, then the population is assessed against the next highest population condition rating (i.e. 'good') until all criteria are met.

**Table 9-6. Assessment of black box population condition based upon the percentage of viable trees in the <80,000 $ML.day^{-1}$ QSA flow band that had TCI scores of 2–8 and ≥10. The percentage of trees must meet the criteria for each TCI score range for a given population condition class to be considered to be of that condition class. If one or more criteria are not met then the population is assessed against the next highest condition class until all criteria are met.**

| Population Condition Class | TCI score | |
|---|---|---|
| | 2–8 | ≥10 |
| Very good | 0% | ≥70% |
| Good | 1–9% | ≥70% |
| Fair | 25–10% | ≥70% |
| Poor | <25% | <70% |

### 9.4.3 Information reliability

The information reliability assessment for the black box evaluation was conducted as per section 3.2.2.

## 9.5 Limitations of assessment

The ability to assess change in the condition of the black box population, and therefore assess the achievement of the expected environmental outcomes and evaluate progression towards the LTWP target are influenced by site scale management actions that impact condition at localised scales. For example, activities related to the delivery of water for the environment (e.g. weir pool raising, pumping and the use of regulators) deliver water to higher elevations than otherwise would be possible without such interventions. Trees that have received water for the environment may be in better condition than trees that have only been inundated by high discharge events (Denny et al. 2019; Wallace et al. 2020a).

Over time, the condition of black box that occur within and adjacent to areas inundated by operation of the Pike and Katarapko environmental regulators may change depending on the frequency and duration of inundation events and any consequential effects on the local shallow groundwater systems. Construction of the regulators at Pike and Katarapko were completed in 2020, whilst the Chowilla environmental regulator has been operational since 2014, with use in 2014/15, 2015/16, 2016/17 (before flood peak) and in 2018/19 (Nicol et al. 2020). The delivery of water for the environment by pumping to individual wetland basins has occurred on all 3 floodplains over the assessment period, with provisions of water for the environment lowest on the Pike floodplain and greatest on the Chowilla floodplain.

Weir raisings carried out at Lock 5 during the assessment period were not of sufficient magnitude to inundate any black box transects in the floodplain asset at Chowilla floodplain. Raising of Lock 6 were only undertaken in conjunction with operation of the Chowilla regulation, which inundated black box transects on the floodplain. There were no weir pool raisings at Lock 3 or 4 that would have inundated the black box transects at Katarapko or Pike Floodplains, over the assessment period.

All tree condition data used in this assessment were collected in the valley floodplain reach (border to Overland Corner) which receives lower rainfall and is subject to different groundwater conditions compared with the gorge reach (Overland corner to Wellington). There was highly unequal sampling between the 3 floodplains and over time within the assessment period (Table 9-5).

Therefore, the results of this assessment should not be used to infer the condition of black box over the entirety of the SA River Murray Floodplain PEA.

## 9.6 Results

### 9.6.1 Environmental outcome assessment

The percentage of trees with a TCI score ≥10 increased from 10% in 2008/09 to 65% in 2018/19. The observed increase was non-linear and variable over the assessment period. Increases in the percentage of trees with a TCI score ≥10 were recorded between 2009/10 and 2011/12 and again between 2016/17 and 2018/19, with declines occurred in the intervening periods (Figure 9-2). The density plot for annual distribution of TCI scores for black box (Figure 9-3) follow the same trends as recorded for the percentage of trees with a TCI score ≥10.

The expected environmental outcome for black box condition in the Floodplain PEA in 2019 was exceeded. In 2018/19, 65% of black box in 2018/19 had a TCI score ≥10, and therefore, the expected environmental outcome of 35% with a TCI score ≥10 was exceeded. As at 2019, progression towards the LTWP target has been made (despite the target not being met in any year of the assessment period), with the percentage of trees with a TCI score of ≥ 10 nearing the target threshold of 70% of trees.

Caution should be taken when interpreting results for the assessment of the expected environmental outcome in 2019 and the progression towards the LTWP target due to variations in sample size, location of sampling and site specific management actions (see section 9.5).

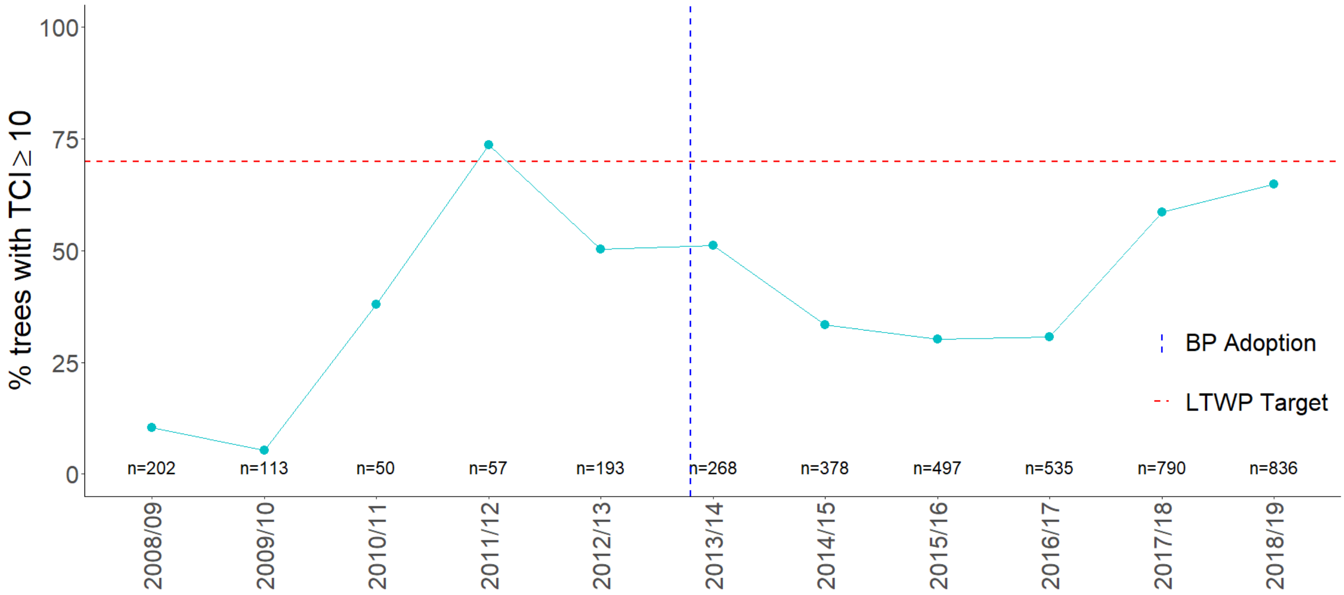


**Figure 9-2. Percentage (%) of black box in good or excellent condition (TCI score ≥10) in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains from 2008/09 to 2018/19. Sample size (n) is provided above the x axis for the corresponding water year.**

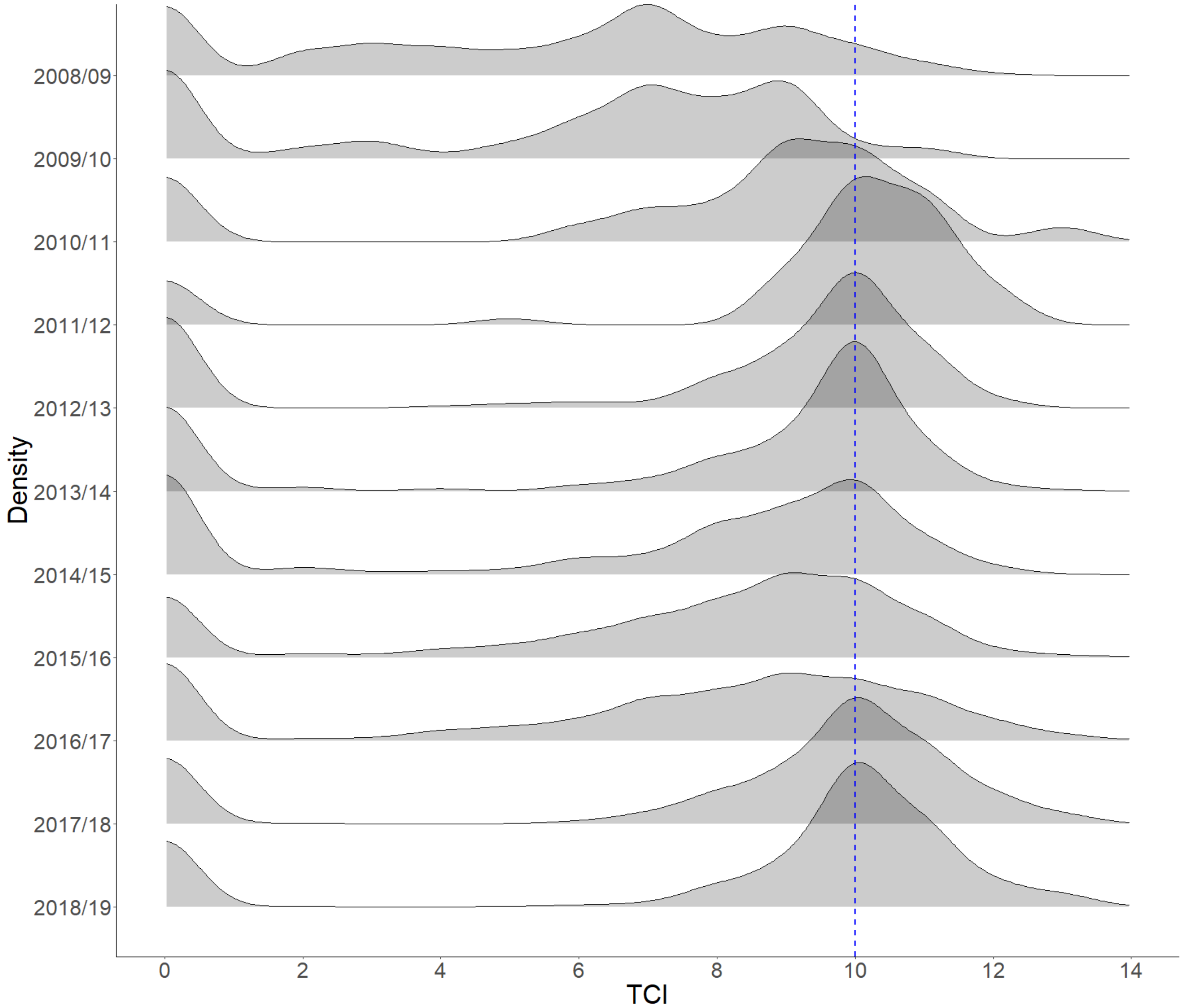


**Figure 9-3. Distribution of TCI scores for black box in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains from 2008/09 to 2018/19.**

### 9.6.2 Trend

It is virtually certain (100%) that the proportion of black box with a TCI score of ≥10 in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains has increased between 2008/09 and 2018/19 (Figure 9-4). Therefore, the proportion of black box in good or excellent condition is **getting better**.

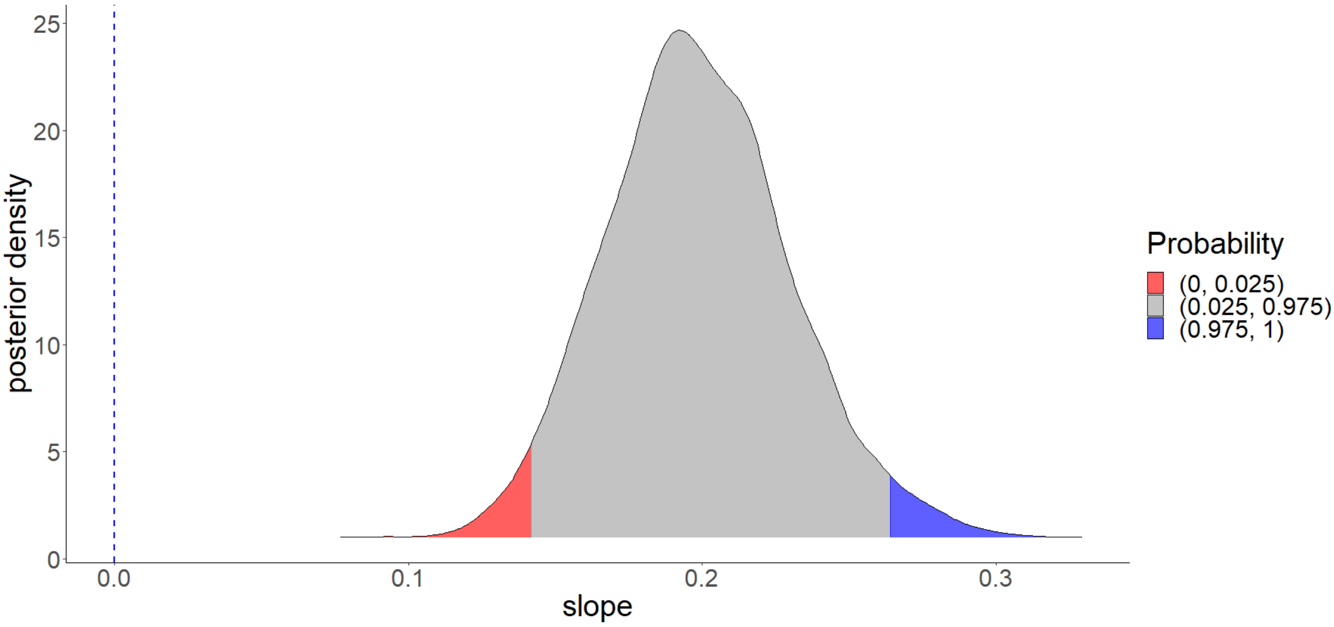


**Figure 9-4. Estimated values for the slope generated from Bayesian modelling for black box in good or excellent condition (TCI score ≥10) in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains from 2008/09 to 2018/19. As all posterior density values have a slope >0, there is a 100% likelihood that the proportion of black box in good or excellent condition has increased.**

### 9.6.3 Condition

In 2018/19, a total of 683 viable black box in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains (Table 9-7) were scored using the TCI. Overall, 8.3% (n=57) of trees had TCI scores of 2–8 and 79.5% (n=543) of trees had TCI scores ≥10. Therefore, the population of black box in 2018/19 met the criteria as per Table 8-7 to be classed as **good**.

**Table 9-7. The percentage of viable trees in the sampled black box population in 2018/19 in the Floodplain PEA extent of the Chowilla, Pike and Katarapko floodplains that had TCI scores of 2–8 and ≥10.**

| TCI scores | | Total no. viable trees |
|---|---|---|
| **2–8** | **≥10** | |
| 8.3% (n=57) | 79.5% (n=543) | 683 |

### 9.6.4 Information reliability

The information reliability rating for black box was **fair** (final score of 9). Justification for the scoring of black box data reliability is provided in Table 9-8.

**Table 9-8. Reliability of black box data to assess the black box condition expected environmental outcome. The metrics of methods, representativeness and repetition are scored against their response to the metric question. Answers are scored 2 points – Yes, 1 point – Somewhat, 0 points – No.**

| **Methods** | **Question** | **Answer and justification** | **Score** |
|---|---|---|---|
| Methods used | Are the methods used appropriate to gather the information required for evaluation? | **Yes**. The LTWP target and expected outcomes were established upon data collected using the TCI method. | **2** |
| Standard methods | Has the same method been used over the sampling program? | **Yes**. Tree condition data were collected using the standardised The Living Murray tree condition method. | **2** |
| **Representativeness** | | | |
| Space | Has sampling been conducted across the spatial extent of the PEA with equal effort? | **No.** Only data from Chowilla, Pike and Katarapko floodplains were analysed. The protocol for establishing transects at other managed wetlands excluded dead (defoliated) trees from inclusion within transects. Consequently, these non-standardised transects were not compared to standardised transects which include defoliated trees at the time of transect establishment. | **0** |
| Time | Has the duration of sampling been sufficient to represent change over the assessment period? | **Yes.** Tree condition data was available for each year following Basin Plan adoption (2012/13 – 2018/19) and for years prior to Basin Plan adoption (2008/09 – 2011/12). | **2** |
| **Repetition** | | | |
| Space | Has sampling been conducted at the same sites over the assessment period? | **Somewhat**. There are differences in the inaugural year of monitoring between trees sampled on the Pike, Katarapko and Chowilla floodplains. Furthermore, additional transects were allocated to monitoring programs as they progressed. Some transects were re-visited annually following their establishment. | **1** |
| Time | Has the frequency of sampling been sufficient to represent change over the assessment period? | **Yes.** Tree condition data were recorded annually since Basin Plan adoption and baseline data exists. | **2** |
| **Final score** | | | **9** |
| **Information reliability** | | | **Fair** |

## 9.7 Evaluation

The trend assessment determined that the proportion of black box in good or excellent condition across the Chowilla, Pike and Katarapko floodplains in the Floodplain PEA increased from 2008/09 to 2018/19, with results compared across individual transects between years. However, the results of this assessment should be treated with caution, as changes in sample size and location of trees sampled may have confounded the results.

Over the assessment period, marked improvement in the condition of the black box population were recorded in 2010/11, 2011/12 and 2017/18. Improvement in the condition of the black box population in 2010/11 may have been in response to a 50% reduction in sample size, as data collection were completed in July prior to very high rainfall (monthly totals >90mm) and the high (unregulated) flow event. Further improvement in the condition of the black box population in 2011/12 were likely associated with the 2010/11 high (unregulated) flow event that peaked at ~94,000 $ML.day^{-1}$. The condition of the black box population declined from 2011/12 to 2016/17, in response to an absence of high (unregulated) flow events and low rainfall (except for 2014). As data collected in 2016/17 were completed before exceptionally high rainfall in September 2016 and flood inundation (peaked at ~94,000 $ML.day^{-1}$), improvement in the condition of the black box population were not recorded until 2017/18. The improved condition of the black box population was maintained in 2018/19, despite exceedingly low rainfall, possibly due to a three-fold increase in sampling effort on the Katarapko floodplain. However, in part, this result may also reflect that trees have a moderate degree of resilience, and are able to withstand short-dry periods with minimal loss of condition (Wallace et al. 2020).

The improvement in black box condition of the Chowilla, Pike and Katarapko floodplains over the assessment period, from (2008/09 to 2018/19, were primarily influenced by high (unregulated) flow events (see section 9.7.1) and rainfall (see section 9.7.2). Managed floodplain inundations supported by water for the environment (see section 9.7.3) may also have had an influence on black box condition, however, the effect was not separated in this assessment.

### 9.7.1 High (unregulated) flow events

Flood history is an important factor that influences the condition of black box populations, with trees inundated more recently and frequently found to be in better health (Taylor et al. 1996; Overton et al. 2006a; Moxham et al. 2018; Overton et al. 2018; Denny et al. 2019). While trends in the condition of black box solely inundated by high (unregulated) flow events (i.e. did not receive water through managed floodplain inundations) were not assessed as a component of this study, the high (unregulated) flow events in 2010/11 and 2016/17 were associated with an improvement in the condition of the black box population over the Chowilla, Pike and Katarapko floodplains. In the water year following the high (unregulated) flow events, there were higher proportions of trees in good or excellent condition and much lower proportions trees in poor and very poor condition. These results are reflective of the results from Denny et al. (2019), who assessed the condition of black box on the Katarapko floodplain over 3 time points (2015, 2016 and 2018). A high (unregulated) flow event also occurred in 2011/12 (peaked at ~60,000 $ML.day^{-1}$) and inundated black box that were sampled in 2012/13. The condition of black box in 2012/13 declined from 2011/12, despite the 2011/12 high (unregulated) flow event, likely due to a three-fold increase in sampling effort. However, the response of individual trees inundated from the 2011/12 high (unregulated) flow event is not known due to the pooling of data. Therefore, it is likely that high (unregulated) flow events were a key driver of temporal improvements in the condition of the black box populations across the Chowilla, Pike and Katarapko floodplains since the adoption of the Basin Plan.

### 9.7.2 Rainfall

The influence of high rainfall on black box condition in this assessment could not be determined due to the confounding effects of changes in sampling effort, frequency of sampling and overbank flood. High rainfall events at Renmark where >90mm fell in a given month were between December 2010 and February 2011 and in February

2014 and September 2016 (Figure 9-5). As data collected in both 2010/11 and 2016/17 were completed prior to both the high rainfall and high (unregulated) flow events in each water year, the relative contribution of rainfall to the improvement in the condition of black box recorded in 2011/12 and 2017/18 cannot be separated from the influence of overbank flooding and changes in sample size. The influence of the high rainfall event in February 2014 also could not be determined as trees were not subsequently sampled until March 2015. Although the influence of rainfall could not be determined in this assessment, Jensen (2017) identified improvement in the condition of black box in the Riverland following periods of above-average rainfall at sites that were and were not watered with water for the environment. Volumes of rainfall required to enhance black box condition may be inferred from black box that were drip irrigated during drier months, with watering of 40–100 $mm.month^{-1}$ found to be most optimal for promoting growth flushes in black box trees (Gehrig and Frahn 2015). It is therefore possible that periods of high rainfall contributed to the improved condition of black box since the adoption of the Basin Plan.

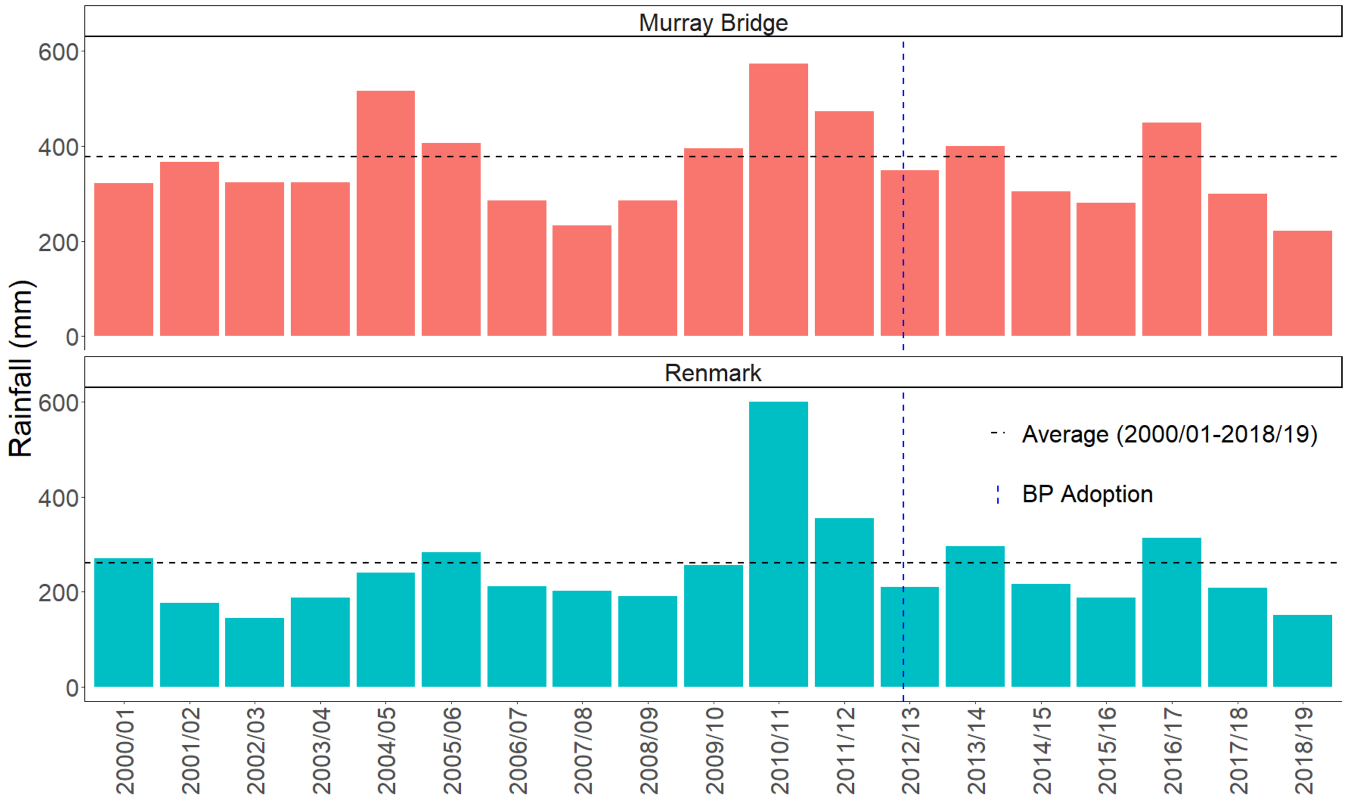


**Figure 9-5. Rainfall recorded at Murray Bridge (station no. 02451) and Renmark (station no. 24003) from 2000/01 to 2018/19.**

### 9.7.3 Managed floodplain inundation

Managed inundation of the floodplain through pumping, irrigation, and operation of the Chowilla regulator has helped to deliver water, including water for the environment, to black box on the floodplain. Although the spatial scale of managed floodplain inundations is limited with compared to high (unregulated) flow events, it is recognised that black box that have been watered are likely to be in better condition than non-managed trees (Gehrig and Frahn 2015; Jensen 2017; Denny et al. 2019). For example, black box at wetlands that were delivered water for the environment via pumping during inter-flood periods were observed to be better than trees that did not receive water for the environment (Jensen 2017; Denny et al. 2019). However, the magnitude of difference in condition between trees that received water for the environment during inter-flood periods (watered) and those that do not (un-watered) may reduce in surveys conducted shortly after high (unregulated) flow events. Such responses are likely to be highly site specific, and strongly influenced by local factors such as groundwater depth and salinity, soil type, soil water availability and prevailing tree condition. Whether watered trees continued to be in better condition than non-watered trees following the unregulated flood in 2016/17 has not been determined in this assessment due to pooling of all scores. The influence of maintaining trees in comparatively good condition during inter-flood periods on habitat value for woodland dependent fauna and biogeochemical processes is a key factor that is currently poorly understood.

## 9.8 Actions to achieve environmental outcomes

Delivery of water for the environment, where feasible, is an important management tool to improve the condition and resilience of floodplain tree populations (Wallace et al. 2020). The conceptual model of stress recovery for floodplain eucalypts (see Wallace et al. 2020) summarises how the condition of floodplain eucalypts transition with respect to the duration of dry phases or conversely the frequency and duration of inundation or watering. This model demonstrates the value of the provision of water for the environment during inter-flood dry phases to reduce the proportion of trees declining to poor or very poor condition (Denny et al. 2019) that are subsequently very difficult to recover (Wallace et al. 2020). The provision of water for the environment when availability is high may help to increase the proportion of trees in good condition, so that they are able to tolerate a decline in condition during dry periods when environmental water availability is low (Wallace et al. 2020). Trees in better condition have short recovery periods, while trees in moderate condition are able to be restored to good condition in 3 years if inundated or watered during that period (Wallace et al. 2020).

While the TCI conceptual model (Wallace et al. 2020) interprets resilience of floodplain trees based on canopy condition, visual assessment of the canopy alone may not be fully representative of a tree’s metabolic state and ultimate resilience (Doody and Overton 2012; Wallace et al. 2020). Therefore, where site-specific knowledge of tree condition trajectory is lacking or uncertain, physiological measurements of stress such as transpiration, soil water potential, pre-dawn shoot water potentials and the proportion of sapwood in stems may be used to ascertain how trees at a given site may respond to watering (Doody and Overton 2012; Wallace et al. 2020).

The frequency and spatial extent of managed floodplain inundations, and therefore our ability to support floodplain tree condition, will increase in future years as construction of regulators on the Pike and Katarapko floodplains were completed in 2020. Operation of regulators on the Chowilla, Pike and Katarapko floodplains in conjunction with raising of Locks 4, 5 and 6 and the delivery of environmental water will increase the extent of manageable floodplain between Lock 3 and the South Australian border (Nicol et al. 2015). Pumping and irrigation can further support floodplain trees that are located at elevations beyond the influence of weir raising and the environmental regulators or that trigger management thresholds (i.e. >10% of viable floodplain trees in a standardised transect have TCI scores ≤8).

## 9.9 Conclusion

The proportion of black box in good or excellent condition across the Chowilla, Pike and Katarapko floodplains in the Channel and Floodplain PEAs increased from 2008/09 to 2018/19. The delivery of water for the environment in addition to managed floodplain inundations since the adoption of the Basin Plan has helped to:

- maintain the condition and increased resilience of trees, which improves the response of trees to future flooding events
- support a small increase in the area of inundation, with more trees receiving water.

Key messages:

- Overall, the proportion of trees in good or excellent condition within the Pike, Katarapko and Chowilla floodplains increased between 2008/09 and 2018/19.
- High (unregulated) flow events were likely a key driver of temporal improvements in the condition of the black box population since the adoption of the Basin Plan. These events are needed more frequently to support the resilience of the black box population, particularly those that are outside of management influence.
- Full implementation of the Basin Plan, including addressing current water delivery constraints, is required to achieve greater frequency, duration and magnitude of overbank flows along the SA River Murray, which may lead to improvements in black box condition
- It is important to note that data derived for the assessment of black box condition are from sites where there has been targeted water delivery of water for the environment, thus the results are likely not to be representative of the broader asset.

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**Red gum**

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