Technical information supporting the 2023 River Murray floodplain trees condition environmental trend and condition report card

Department for Environment and Water
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Government of South Australia
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Acknowledgement of Country

We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past and present. We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country. We also pay our respects to the cultural authority of Aboriginal and Torres Strait Islander people and their nations in South Australia, as well as those across Australia.

Acknowledgements

This document was prepared by Gareth Oerman (DEW). Rebecca Quin (DEW) provided principal oversight throughout and technical review of this report. We greatly appreciate the data, expert advice and review provided by Todd Wallace. Improvements were made to this report and associated report card based on reviews by Michelle Denny (DEW).

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Summary

The 2023 release of South Australia's environmental trend and condition report cards summarises our understanding of the current condition of the South Australian environment, and how it is changing over time.

This document describes the indicators, information sources, analysis methods and results used to develop this report and the associated 2023 River Murray floodplain trees condition report card. The reliability of information sources used in the report card is also described.

The River Murray floodplain trees condition report card sits within the report card Biodiversity theme and Inland waters sub-theme. Report cards are published by the Department for Environment and Water and can be accessed at www.environment.sa.gov.au.

1 Introduction

1.1 Environmental trend and condition reporting in SA

The Minister for Climate, Environment and Water under the *Landscape South Australia Act 2019* is required to 'monitor, evaluate and audit the state and condition of the State's natural resources, coasts and seas; and to report on the state and condition of the State's natural resources, coasts and seas' (9(1(a-b)). Environmental trend and condition report cards are produced as the primary means for the Minister to undertake this reporting. Trend and condition report cards are also a key input into the State of the Environment Report for South Australia, which must be prepared under the *Environment Protection Act 1993*. This Act states that the State of the Environment Report must:

- include an assessment of the condition of the major environmental resources of South Australia (112(3(a))), and
- include a specific assessment of the state of the River Murray, especially taking into account the Objectives for a Healthy River Murray under the *River Murray Act 2003* (112(3(ab))), and
- identify significant trends in environmental quality based on an analysis of indicators of environmental quality (112(3(b))).

1.2 Purpose and benefits of SA's trend and condition report cards

South Australia's environmental trend and condition report cards focus on the state's priority environmental assets and the pressures that impact on these assets. The report cards present information on trend, condition, and information reliability in a succinct visual summary.

The full suite of report cards captures patterns in trend and condition, generally at a state scale, and gives insight to changes in a particular asset over time. They also highlight gaps in our knowledge on priority assets that prevent us from assessing trend and condition and might impede our ability to make evidence-based decisions.

Although both trend and condition are considered important, the report cards give particular emphasis to trend. Trend shows how the environment has responded to past drivers, decisions, and actions, and is what we seek to influence through future decisions and actions.

The benefits of trend and condition report cards include to:

- provide insight into our environment by tracking its change over time
- interpret complex information in a simple and accessible format
- provide a transparent and open evidence base for decision-making
- provide consistent messages on the trend and condition of the environment in South Australia
- highlight critical knowledge gaps in our understanding of South Australia's environment
- support alignment of environmental reporting, ensuring we 'do once, use many times'.

Environmental trend and condition report cards are designed to align with and inform state of the environment reporting at both the South Australian and national level. The format, design and accessibly of the report cards has been reviewed and improved with each release.

1.3 Floodplain trees

The woodlands of the South Australian (SA) River Murray floodplain support and maintain the productivity and health of the River Murray system by performing essential ecosystem functions, including the sequestration and generation of carbon and nutrients (Francis & Sheldon 2002; Smith & Reid 2013; Gibbs et al. 2022), and the provision of habitat for a suite of flora and fauna (Jansen & Robertson 2005; Rogers & Paton 2008; Kilsby & Steggles 2015; McGinness et al. 2010; McGinness et al. 2018; Moore 2020). Two tree species dominate the woodlands of the SA River Murray floodplain; river red gum (*Eucalyptus camaldulensis* ssp. *camaldulensis*) and black box (*E. largiflorens*) (Kilsby & Steggles 2015).

The river red gum is a medium–large (up to 42 m) and single-stemmed tree that is an iconic species in the Murray–Darling Basin due to its ecological, cultural, recreational and economic value (MDBC 2003; SASCC 2018a). River red gums grow along watercourses, on floodplains and in the woodlands and forests of the Murray–Darling Basin (SASCC 2018a). In the SA River Murray, riparian and lower floodplain habitats that are subject to flooding are dominated by river red gum woodland and forest (George et al. 2005; Kilsby & Steggles 2015).

Black box is a medium sized (up to 20 m high) and single-stemmed tree that is distributed over the Murray–Darling Basin (SASCC 2018b). It grows in woodland between lignum and river red gum dominated communities at lower elevation (more frequently inundated) and mallee woodlands on the highland (never inundated) (Rogers & Paton 2008; Kilsby & Steggles 2015). Black box are therefore more drought tolerant than river red gums, and occur in areas with comparatively long inter-flood periods and/or lower soil water availability (Kirby et al. 2013; Kilsby & Steggles 2015).

Trees require water for photosynthesis (generation of energy) and transpiration (loss of water through openings in plant tissue that creates a negative pressure, enabling the plant to uptake water and nutrients from soil moisture) to enable respiration (use of energy for plant growth). Floodplain trees access water by transpiring 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 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 (groundwater seepage above the water table that fills soil pores via capillary action) (Mensforth et al. 1994; Thorburn & Walker 1994; Doody et al. 2009; Holland et al. 2011; Roberts & Marston 2011).

The condition of river red gums and black box has been in long-term decline over the Murray–Darling Basin (Doody et al. 2014; Doody et al. 2015; Overton et al. 2018), associated with increased groundwater level, soil salinity and reduced wetland connectivity and flooding frequency (Overton et al. 2006; Wen et al. 2009). The drivers of these stressors that reduce biologically available soil water for floodplain trees are drought, river regulation, river water extraction, irrigation drainage, grazing and land clearance (Overton et al. 2006; Doody et al. 2014; Doody et al. 2015; Overton et al. 2018).

The condition of floodplain trees is important, as it impacts their ability to withstand and recover from events of stress, such as drought (Wallace et al. 2020). For example, a tree in good condition, should be able to withstand a short dry period with minimal loss of condition and respond positively to watering. Whereas a tree in poor condition is likely to lose condition under dry conditions and require multiple successive watering events to achieve good condition (Wallace et al. 2020). The water requirements to sustain river red gums and black box in the SA River Murray, as described in Kilsby & Steggles (2015), are presented in Table 1.1.

This report card evaluates the condition of floodplain trees in the SA River Murray, which provides insight into their ability to withstand and recover from future events of stress.

Table 1.1. Environmental water requirements for river red gums and black box on the South Australian River Murray floodplain (Kilsby & Steggles 2015).

Species	Duration	Timing	Frequency	Maximum interval	Condition description
River red gum	1–4 months; <2 years	Spring–early summer	1–4 years	5–7 years	Condition improves with greater duration and frequency of inundation (within preferred range). Inundation durations greater than 2–4 years are 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 rainfall); if conditions are favourable this could be longer.
Black box	1–6 months; <13 months	Spring–summer	3–7 years	8 years (in some cases possibly longer)	Black box peak seed production occurs in summer; flowering times may vary been sites. Vigorous crown and flowering associated with inundation of 3–6 months, although others note reduced vigour >4 months. Acute stress noted in trees inundated >13 months.

2 Methods

2.1 Indicator

The indicator used for the SA River Murray floodplain trees condition report card is the Tree Condition Index (TCI), which scores the condition of trees. Scores range from 0; a non-viable tree, to 14; a tree in excellent condition with a higher degree of resilience (Wallace et al. 2020).

Ecological objectives and targets for river red gum and black box populations are described in the updated South Australian River Murray Long Term Watering Plan (DEW 2020a) and are presented in Table 2.1 for the Channel (inundated by flows of 10,000–40,000 ML/day at the South Australian border [QSA]) and Floodplain (inundated by flows of 40,000–80,000 ML/day QSA) priority environmental assets (PEAs).

This report card only considered tree condition data collected on the Chowilla, Pike and Katarapko floodplains, due to negligible data collection elsewhere on the SA floodplain and discrepancies in methodologies. Across the Chowilla, Pike and Katarapko floodplains, all tree data available were used in the assessment, irrespective of whether they occur within or outside of the Channel and Floodplain PEAs, to represent the spatial extent of these floodplains as best as possible.

The ecological target of *>70% of all trees have a TCI score ≥10* (from DEW 2020a) is used in this report card to evaluate changes in the percentage of floodplain trees in good (TCI 10–12) or excellent (TCI 13–14) condition.

Table 2.1. Ecological objective and target for river red gums and black box in the SA River Murray (DEW 2020a).

Species	Ecological objective	Ecological target
River red gum	Throughout the length of the Channel Priority Environmental Asset (PEA) (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	In standardised transects spanning the elevation gradient in the target zone, >70% of all trees have a Tree Condition Index (TCI) score ≥10.
	Maintain a viable, functioning river red gum population within the Floodplain PEA (inundated by flows of 40,000–80,000 ML/day QSA)	In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all trees have a TCI score ≥10.
Black box	Maintain a viable, functioning black box population within the Floodplain PEA	In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all trees have a TCI score of ≥10.

2.2 Data sources

Data were sourced on the Chowilla floodplain as part of The Living Murray (TLM) program. Data for the Pike and Katarapko floodplains were collected by the Department for Environment and Water (DEW) as part of its ongoing responsibilities for effective use and management of water for the environment in South Australia.

2.3 Data collection

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 is visually assessed. The crown cover and crown density of each tree is allocated a score from 0 to 7 and these two scores are summed (Table 2.2). The Tree Condition Index (TCI) score is the sum of the crown cover and crown density scores, and therefore ranges 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 (see

Table 2.3, Wallace et al. 2020). The annual numbers of individual river red gums and black box assessed over each floodplain (Chowilla, Pike and Katarapko) from 2008 to 2022 are shown in

Table 2.4. Data collected in 2022 occurred prior to widespread overbank flooding.

Table 2.2. 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 2.3. Score system for Tree Condition Index (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
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 dry period with minimal loss of condition

Table 2.4. The number of river red gums (RRG) and black box (BB) assessed each year over Chowilla, Pike and Katarapko floodplains from 2008 to 2022. Data collected in 2022 occurred prior to widespread overbank flooding.

Year	Chowilla		Pike		Katarapko		Total		
	RRG	BB	RRG	BB	RRG	BB	RRG	BB	Total
2008	2,274	262	231	385			2,505	647	3,152
2009	2,773	584					2,773	584	3,357
2010	1,151	172	229	443			1,380	615	1,995
2011	1,072	90	164	358			1,236	448	1,684
2012	1,493	412					1,493	412	1,905
2013	1,718	739					1,718	739	2,457
2015	2,889	1,786	231	328	238	375	3,358	2,489	5,847
2016	1,372	501			240	375	1,612	876	2,488
2017	1,389	502	76	481			1,465	983	2,448
2018	1,276	591	76	481	553	1,088	1,905	2,160	4,065
2019	1,423	591			564	1,094	1,987	1,685	3,672
2020	1,707	1,400	135	512	827	1,229	2,669	3,141	5,810
2021	679	756	422	879	842	1,283	1,943	2,918	4,861
2022	1,819	1,882	476	960	797	1,343	3,092	4,185	7,277
Grand Total	23,035	10,268	2040	4827	4061	6787	29,136	21,882	51,018

2.4 Methods to assign trend, condition and reliablity

2.4.1 Trend

A Bayesian modelling approach was used to assess trend in the data collected for floodplain trees. This modelling approach was used as it provides more information surrounding the results and allows for a 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.

Trend analyses for river red gums and black box were undertaken in R Studio (R version 4.2.1, R Core Team 2022) using a Bayesian Generalised Linear Mixed Model (using the stan-glm function in the rstanarm package, Goodrich et al. (2020), 4,000 runs) with a binomial family. Models aimed to determine the likelihood of trend (either positive or negative) in the proportion of trees in good or excellent condition (TCI ≥10) for a given year over the assessment period (2008–2022). 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. Slope (trend) was estimated from the posterior distribution resulting from the Bayesian analysis. Trend direction was assessed using calculated probability (as per McBride 2019). A graduated scale was used to describe outcomes. Outcomes from the trend assessment were aligned with the categories used for report cards (Table 2.5).

Table 2.5. 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 to +100%	Getting better
Extremely likely increase	>+95 to +99%	
Very likely increase	>+90 to +95%	
Likely increase	>+66 to +90%	
About as likely as not	-66 to +66%	Stable
Likely decrease	<-66 to -90%	Getting worse
Very likely decrease	<-90 to -95%	
Extremely likely decrease	<-95 to -99%	
Virtually certain decrease	<-99 to -100%	

2.4.2 Condition

The condition of floodplain trees in the SA River Murray floodplain was assigned based on the condition of the tree species, river red gum or black box, that was in the poorest condition. The condition the river red gum and black box populations in the SA River Murray floodplain was assessed based on the percentages of viable trees that had TCI scores of ≥10 and 2–8. Therefore, the condition of each floodplain tree species was assessed against a target condition (TCI ≥10) and management threshold (TCI = 8) as per Wallace and Whittle (2014). Trees that receive a condition (TCI) score ≥10 are considered to be in good to excellent condition and are expected to be able to withstand a short dry period with minimal loss of condition (

Table 2.3). Trees that receive a condition (TCI) score of 2–8 are expected to respond positively to watering but may require back-to-back watering events to attain good condition, particularly if left un-watered for another year (

Table 2.3) (Wallace et al. 2020). The proportion of trees scoring 2–8 is used as a management threshold that guides annual decisions regarding delivery of water for the environment. The percentage of viable trees in the TCI score ranges of 2–8 and ≥10 were compared against Table 2.6 to determine a population condition rating for the report card. The condition ratings in Table 2.6 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 2.6. Assessment of river red gum and black box population condition based upon the percentage of viable trees 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	>0% to <10%	≥70%
Fair	10 to <25%	≥70%
Poor	>25%	<70%

2.4.3 Reliability

The reliability of data to assess the trend and condition of SA River Murray floodplain trees was scored based upon the method devised by Battisti et al. (2014) with modifications to improve its applicability to 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 2.7 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 2.8.

Table 2.7. Scoring system for the reliability of data used to assess and analyse trend and condition for River Murray floodplain trees.

Methods	Question	Scoring system		
		Yes	Partially	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 SA River Murray channel and floodplain 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 2.8. Conversion of the final score (0–12) of data reliability to an information reliability rating that ranges from poor to excellent for report cards.

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

2.5 Data transparency

Data transparency for this report card is represented in Appendix A.

3 Results

The percentage of river red gums with a TCI score ≥10 increased from 12.1% in 2008 to 67.5% in 2022 (Figure 3.1). The observed increase was variable over the assessment period, and included notable increases from 2008 to 2010 and 2016 to 2018. The density plot of annual distributions of TCI scores of river red gums show that condition was typically poor in 2008 and 2009 before improving in 2010 (Figure 3.2). The distributions of TCI scores remained relatively stable from 2011 to 2016, improved markedly in 2017 and again stabilised from 2018 to 2022.

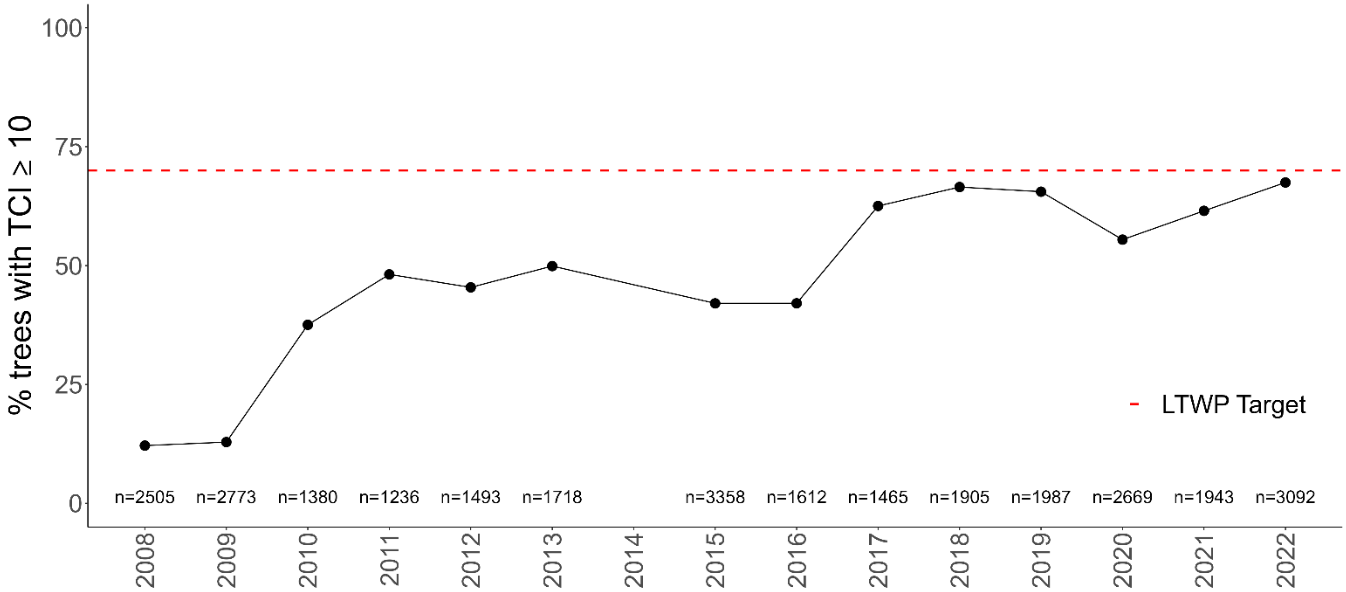


Figure 3.1. Percentage (%) of river red gums with TCI scores ≥10 over the Chowilla, Pike and Katarapko floodplains from 2008 to 2022. LTWP = Long Term Watering Plan (for the South Australian River Murray (DEW 2020a)).

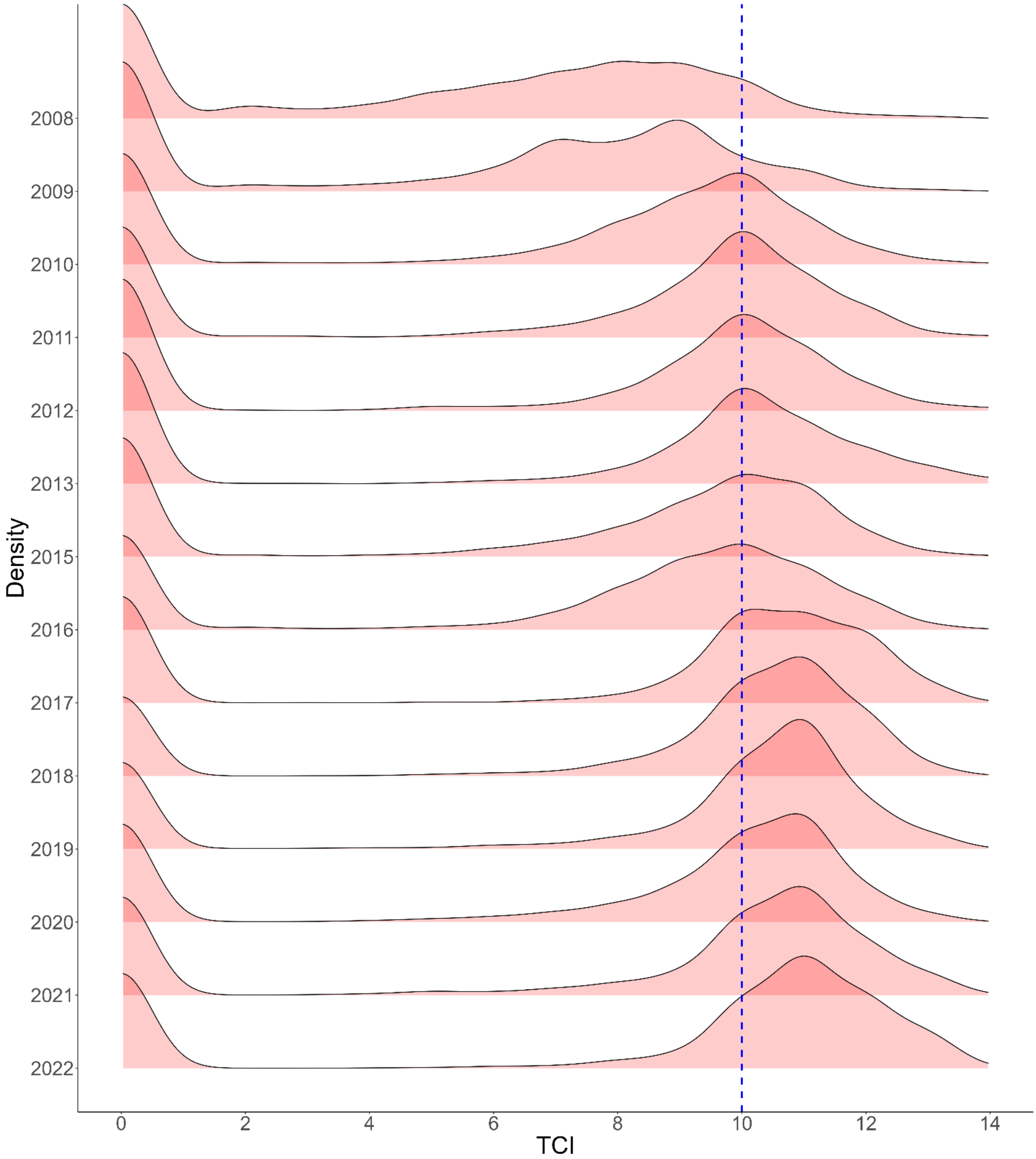


Figure 3.2. Density distribution of TCI scores for river red gums on the Chowilla, Pike and Katarapko floodplains between 2008 and 2022.

The percentage of black box with a TCI score ≥10 increased from 6.3% in 2008 to 55.2% in 2022 (Figure 3.3). The observed increase was variable over the assessment period, and included notable increases from 2008 to 2012 and 2016 to 2019. The density plot of annual distributions of TCI scores of black box show that condition continually improved from 2008 to 2012, progressively declined from 2012 to 2016, improved from 2016 to 2019, and slightly declined from 2019 to 2022.

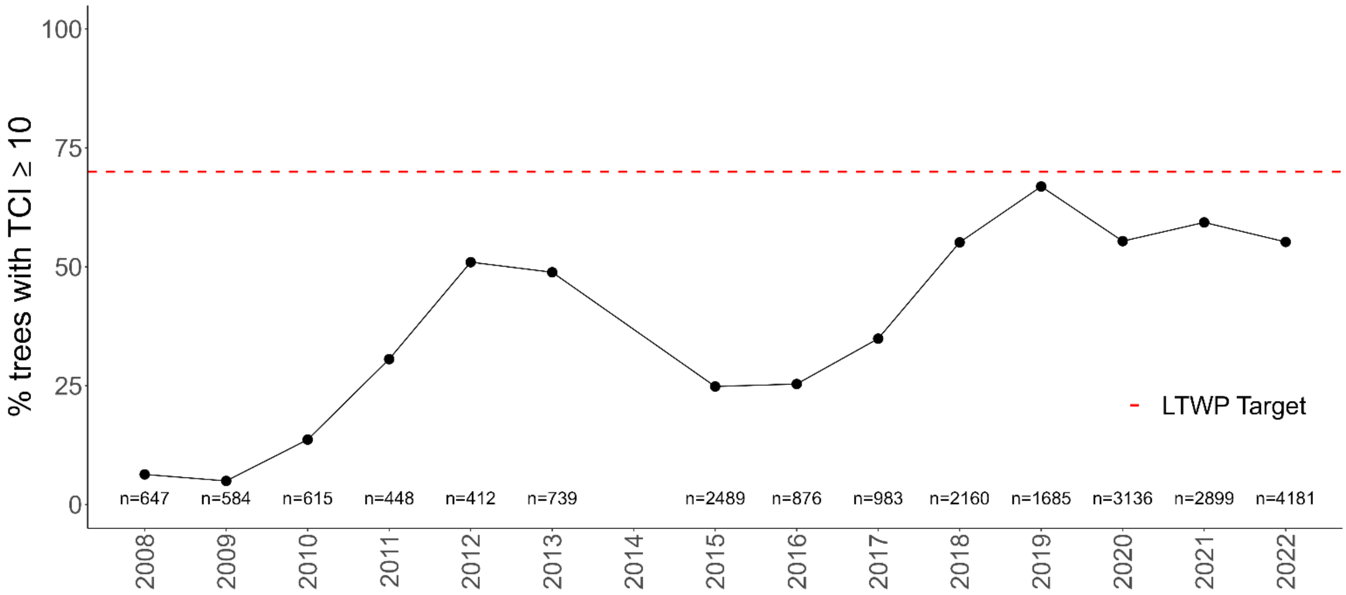


Figure 3.3. Percentage (%) of black box with TCI scores ≥10 over the Chowilla, Pike and Katarapko floodplains from 2008 to 2022. LTWP = Long Term Watering Plan (for the South Australian River Murray (DEW 2020a)).

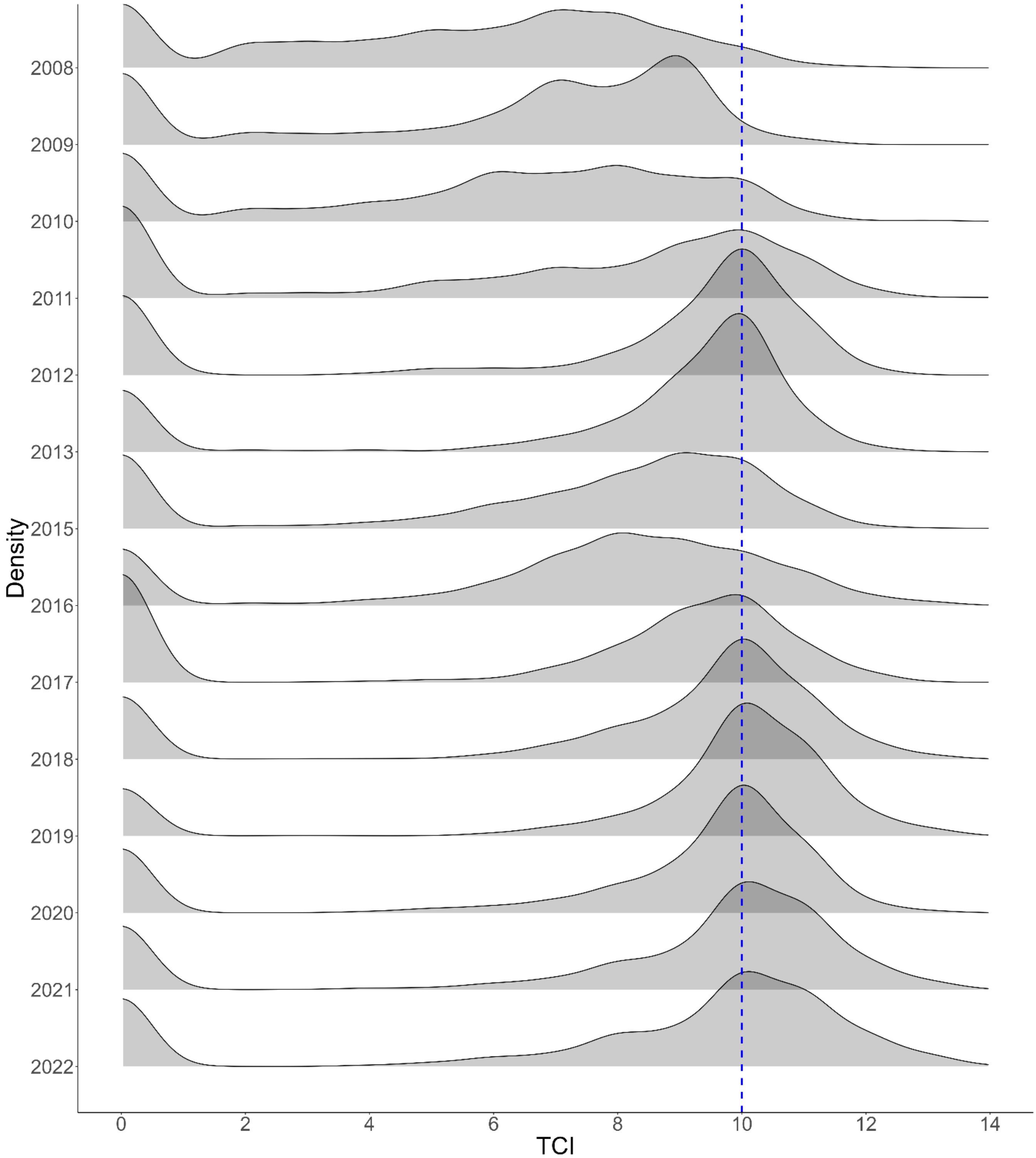


Figure 3.4. Density distribution of TCI scores for black box on the Chowilla, Pike and Katarapko floodplains between 2008 and 2022.

3.1 Trend

It is virtually certain (100%) that the proportions of river red gums and black box with TCI scores of ≥10 over the Chowilla, Pike and Katarapko floodplains have increased from 2008 to 2022 (Figure 3.5, Figure 3.6). Therefore, the proportion of river red gums and black box in good or excellent condition is **getting better**.

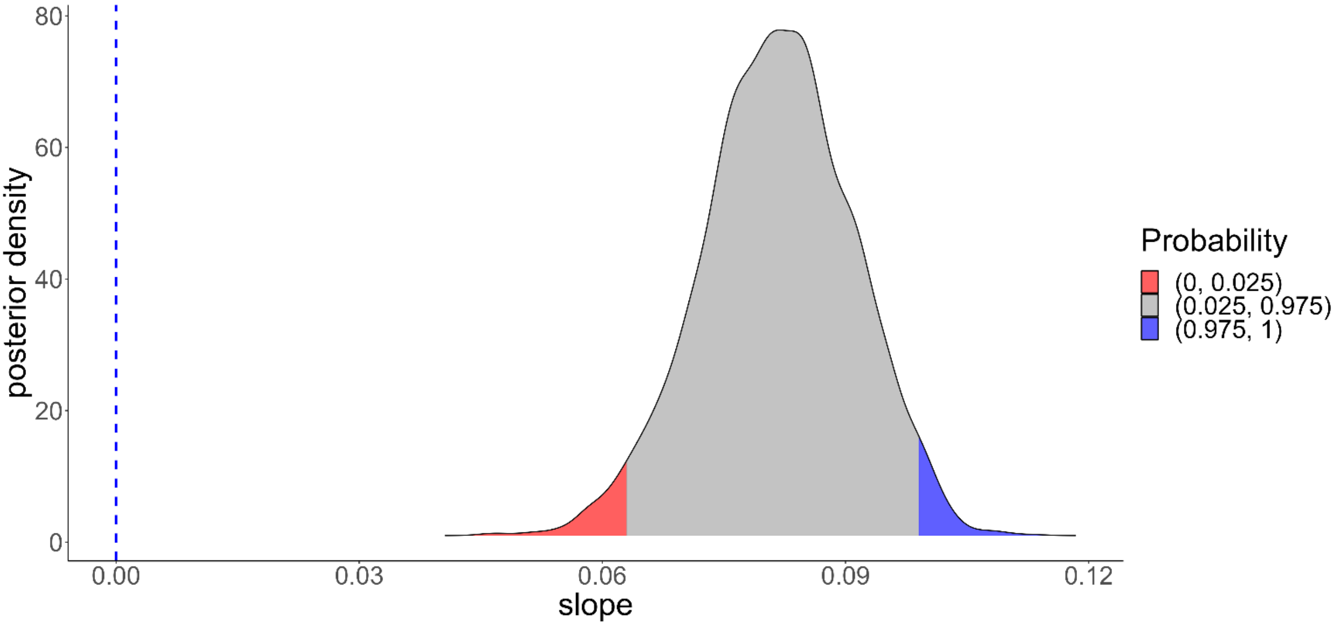


Figure 3.5. Estimated values for the slope generated from Bayesian modelling for river red gum in good or excellent conditions (TCI score ≥10) over the Chowilla, Pike and Katarapko floodplains from 2008 to 2022. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

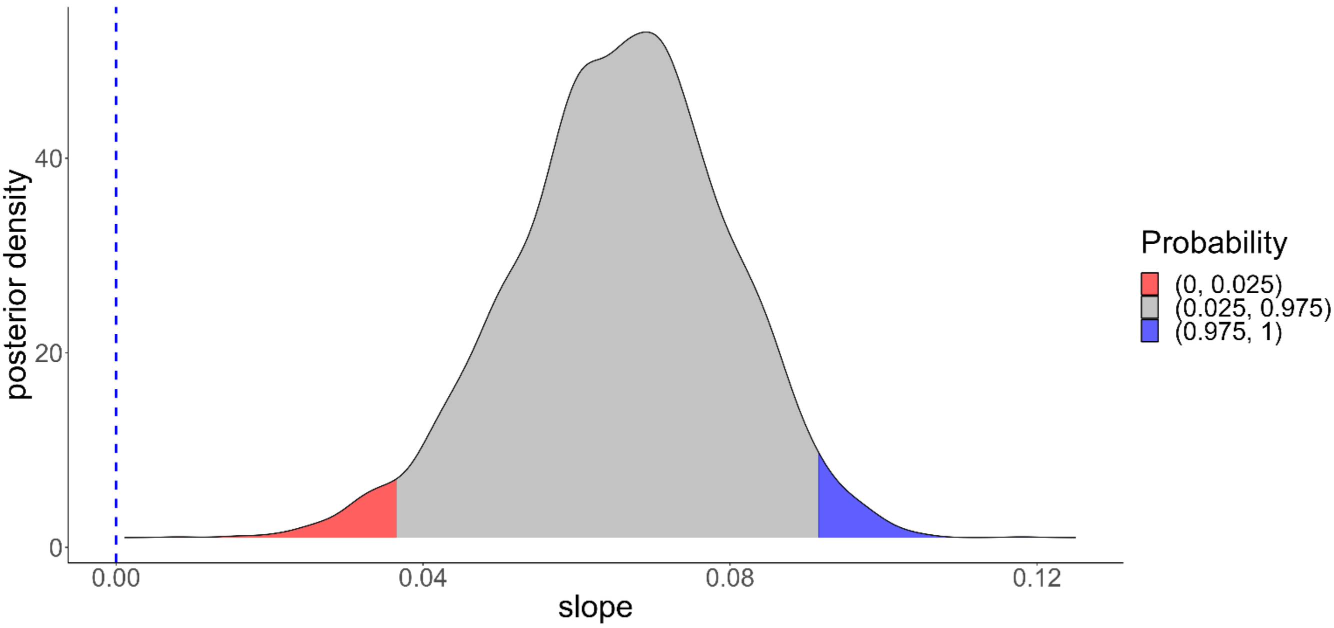


Figure 3.6. Estimated values for the slope generated from Bayesian modelling for black box in good or excellent conditions (TCI score ≥10) over the Chowilla, Pike and Katarapko floodplains from 2008 to 2022. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

3.2 Condition

In 2022, a total of 2,279 viable river red gums and 3,319 viable black box were scored using the TCI method on the Chowilla, Pike and Katarapko floodplains. Overall, 4.1% (n=94) of the scored river red gums had TCI scores of 2–8 and 91.5% had TCI scores ≥10. Black box had 19.3% (n=641) of scored trees with TCI scores of 2–8 and 69.6% (n=2312) of trees had TCI scores ≥10. Therefore, river red gums met the criteria (as per Table 3.1) to be in good condition, while black box were in poor condition. As the overall condition of floodplain trees for the report card is representative of the species in the poorest condition, floodplain trees condition for the report card was classed as **poor**.

Table 3.1. The population condition of the sampled river red gum and black box population on the Chowilla, Pike and Katarapko floodplains in 2022. Data in 2022 were collected prior to widespread overbank flooding. The condition assessment was based upon the percentage of viable trees that had TCI scores of 2–8 and ≥10.

Species	TCI Score		Total no. of viable trees	Condition
	2–8	≥10		
River red gum	4.1% (n=94)	91.5% (n=2,086)	2,279	Good
Black box	19.3% (n=641)	69.6% (n=2,312)	3,319	Poor

3.3 Reliability

The data reliability rating was classed as poor for river red gum and black box. Justification for the data reliability rating for river red gum and black box is provided in

Table 3.2 and Table 3.3, respectively. The overall data reliability rating for this report card is **poor**.

Only viable trees were used in the trend and condition assessments for river red gum and black box, and therefore, this report card has not analysed tree death over the assessment period.

Table 3.2. Reliability of data to assess river red gum condition. The metrics of methods, representativeness and repetition were scored against their response to the metric question. Answers were scored 2 points – Yes, 1 point – Partially, 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 Long Term Watering Plan 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 River Murray channel and floodplain 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, trees from Chowilla comprised 79% of the database.	**0**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Partially**. Tree condition data were recorded annually since 2008, with the exception of 2014. However, there were fluctuations in sample size between years, with three-fold fluctuations.	**1**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Partially**. There are differences in the inaugural year of monitoring between trees sampled on the Pike, Katarapko and Chowilla floodplains. Additional sites were allocated to monitoring programs as they progressed. Sites were re-visited between years for each monitoring program.	**1**
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Yes**. Tree condition data were recorded annually since 2008, with the exception of 2014.	**2**
Final score			**8**
Information reliability			**Poor**

Table 3.3. Reliability of data to assess black box condition. The metrics of methods, representativeness and repetition were scored against their response to the metric question. Answers were scored 2 points – Yes, 1 point – Partially, 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 Long Term Watering Plan 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 River Murray channel and floodplain 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?	**Partially.** Tree condition data were recorded annually since 2008, with the exception of 2014. However, there were fluctuations in sample size between years, with eight-fold fluctuations.	**1**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Partially**. 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 2008, with the exception of 2014.	**2**
Final score			**8**
Information reliability			**Poor**

4 Discussion

4.1 Trend and condition

The condition of River Murray floodplain trees in SA was determined to be **poor** and **getting better** in areas where water for the environment has been delivered. However, there were contrasting results in the condition of the two floodplain tree species assessed, with river red gums determined to be in good condition, while black box were in poor condition. The results from this assessment should be treated with caution, as tree death was not assessed, and only viable trees from the Chowilla, Pike and Katarapko floodplains were used in the analysis. These floodplains are actively managed with targeted water delivery and therefore tree condition at these sites may not necessarily be representative of the River Murray broader floodplain in South Australia.

4.2 Trend

The hydrological drivers that contributed to the improvement in the condition of river red gums and black box on the Chowilla, Pike and Katarapko floodplains are not separated and quantified in this assessment. The primary and secondary hydrological drivers that are expected to have influenced the condition of river red gums and black box are shown in Table 4.1. High unregulated flows (see section 4.2.1) are considered a primary hydrological driver of condition for river red gums and black box. In the years between high unregulated flows, rainfall (see section 4.2.2), managed floodplain inundations (see section 4.2.3) and elevated within-channel flows (see section 4.2.4) may have also had an influence on the condition of river red gums and black box.

Table 4.1. Primary and secondary hydrological drivers influencing the condition of river red gums and black box on the Chowilla, Pike and Katarapko floodplains.

Factor	River red gum	Black box
Primary	High (unregulated) flows	High (unregulated) flows Rainfall
Secondary	Rainfall Managed floodplain inundations Elevated within-channel flows	Managed floodplain inundations

4.2.1 High (unregulated) flows

High unregulated flows have significant influence on the condition of river red gums and black box, with trees that are inundated more recently and frequently found to be in better health (Taylor et al. 1996; Overton et al. 2006; Doody et al. 2014; Moxham et al. 2018; Overton et al. 2018; Denny et al. 2019; Wallace et al. 2020). In this study, an improvement in the percentage of river red gums and black box in good or excellent condition on the Chowilla, Pike and Katarapko floodplains occurred in the years following the 2010–11, 2011–12 and 2016–17 high flows that peaked at 94, 60 and 94 GL/day QSA, respectively. These findings support those by Doody et al. (2014), Denny et al. (2019) and Wallace (2022a,b,c) whom found notable improvement in the condition of floodplain trees across the Chowilla, Pike and Katarapko floodplains following the 2010–11 and 2016–17 high unregulated flows.

4.2.2 Rainfall

Rainfall is a water source for floodplain trees and periods of high rainfall may improve their condition. High rainfall may be particularly beneficial for black box that are distributed at higher elevations on the floodplain 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 & Steggles 2015). The influence of high rainfall events on river red gum and black box condition could not be determined in this assessment due to the confounding effects of changes in sampling effort and frequency, and high unregulated flows. Despite this, other studies assessing floodplain trees condition over the SA River Murray floodplain observed improvement following high rainfall events. Doody et al. (2014) identified that the greenness index of river red gums on the outer Chowilla floodplain very likely increased in response to very high rainfall (140 mm) in December 2010 that coincided with the flood peak, although high rainfall from August to October (monthly totals up to 52 mm) had little influence on the greenness index in November 2010 prior to the flood. Similarly, black box on the SA River Murray floodplain were observed to reduce water stress (Doody et al. 2021) and improve in condition following rainfall events (Jensen & Walker 2017).

4.2.3 Managed floodplain inundations

Managed inundation of the floodplain through pumping, irrigation, weir pool raising and operation of the Chowilla, Pike and Katarapko environmental regulators has delivered water to river red gums and black box on the floodplain. The spatial extent of managed floodplain inundations is limited in comparison to high (unregulated) flows and flood, however, the provision of water during inter-flood dry phases helps to maintain or improve the condition of river red gums and black box. Numerous studies across the SA River Murray have demonstrated the benefits of managed floodplain inundations:

- Gehrig & Frahn (2015) observed that irrigated black box on the Mataranka Floodplain, Riverland, had greater condition than unwatered black box, either improving in condition when unwatered trees remained stable or maintaining condition when unwatered trees were deteriorating.
- Jensen & Walker (2017) found that the canopy condition, growth rates and reproductive outputs of river red gums and black box were significantly higher at watered than non-watered sites in the Riverland region of the Murray Valley.
- Denny et al. (2019) identified that river red gums and black box on the Katarapko floodplain that received water via pumping during an inter-flood dry phase were likely to be in better condition than trees that had not received additional water.
- Wallace et al. (2020) found that watering trees via pumping and inundating floodplains using environmental regulators helped to maintain or improve the condition of river red gums and black box on the Chowilla floodplain.

The ability of river managers to inundate the major floodplains in South Australia has improved with the construction of environmental regulators at Chowilla in 2014 and at Pike and Katarapko in 2020. The operation of these regulators in conjunction with raising of Locks 4, 5 and 6 and targeted water delivery has increased the extent of manageable floodplain between Lock 3 and the SA border (Nicol et al. 2015). The Chowilla environmental regulator has been operated on four occasions since construction in 2014, with inundation areas ranging from 535 to 7,653 ha (Nicol et al. 2021). The Pike and Katarapko environmental regulators were both operated in 2020 and 2021. Inundation extents at Pike were 495 ha in 2020 and 990 ha in 2021, and at Katarapko were 480 ha in 2020 and 796 ha in 2021 (M. Denny, personal communication, 3 February 2022).

4.2.4 Elevated within-channel flows

The lower elevation distribution of river red gums means that elevated within-channel flows (<35 GL/day) can influence soil water availability through lateral bank recharge. Within-channel flows have improved since the end of the Millennium Drought (1996–2010) (DEW 2020b). This 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 the river, wetlands and riparian zones. River red gums significantly improved in condition from 2008 to 2010. This result could be a result of changes in sample size and location, rainfall and elevated within-channel flows. Wallace (2022) identified improvement in the percentage of river red gums with TCI ≥10 at 18 of 19 transects on the Chowilla floodplain assessed in June 2009, August 2009 and July 2010. As each of these sampling events occurred prior to the high rainfall and flood of 2010–11, it is likely that greater within-channel flows contributed to this result. In addition, Doody et al. (2014) identified higher within-channel flows during summer months as critical to the survival of river red gums on the Chowilla floodplain during the Millennium Drought (1996–2010).

4.3 Condition

In 2022, black box were assessed to be in poor condition and river red gums in good condition, despite long-term improvement in the condition of both floodplain tree species. This discrepancy in the condition of floodplain tree species is due to their relative locations on the floodplain that influence their access to water, including via managed inundations. River red gums grow along water courses and on floodplains, with approximately 75% of river red gum woodland located below the 80 GL/day flow to South Australia (QSA) flow band. In comparison, approximately one third of black box woodland is located below the 80 GL/day flow band (Kilsby & Steggles 2015). This discrepancy in the distribution of the two floodplain tree species means that:

- elevated within-channel flows have significantly greater influence on river red gums than black box,
- river red gums are more likely to experience inundation via high (unregulated) flows
- river red gums are more likely to be inundated for longer durations when high (unregulated) flows occur, and
- river red gums are more likely to experience targeted water management through release or changes in storage operations.

The poor condition of black box on the Chowilla, Pike and Katarapko floodplains is reflective of its condition across the Murray–Darling Basin, where drought, river regulation and extraction, irrigation drainage, grazing and land clearance have contributed to reducing biologically available soil water (Overton et al. 2006; Doody et al. 2015; Doody et al. 2015; Overton et al. 2018).

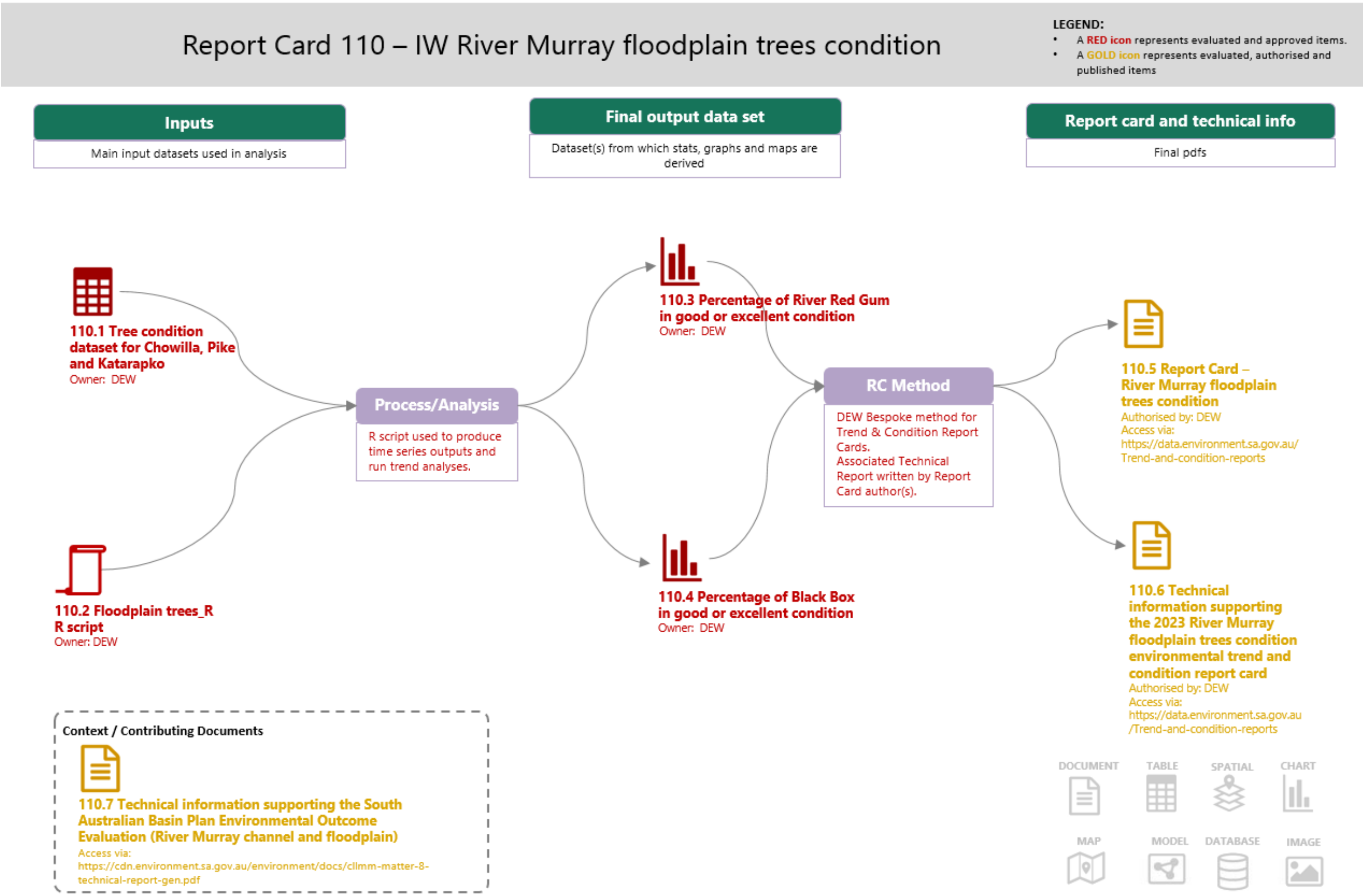
The good condition of river red gum on the Chowilla, Pike and Katarapko floodplains can likely be attributed to the provision of water via high (unregulated) flows, elevated within-channel flows and managed floodplain inundations as described in Section 4.2. Delivery of water via managed floodplain inundations is strategic, with sites nominated for targeted water delivery if >10% of viable trees have TCI scores ≤8. By delivering water to sites that exceed the management threshold, environmental managers can avoid long recovery times and intensive water management regimes, and recover trees to good condition that can withstand stress with minor loss in condition (Wallace et al. 2020).

5 Conclusion

River Murray floodplain trees in SA were determined to be in **poor condition** and **getting better** in areas where water for the environment has been delivered. There were contrasting results in the condition of the two floodplain tree species assessed, with river red gums determined to be in good condition, while black box were in poor condition. The condition of both floodplain trees was considered to be improving due to high (unregulated) flows, elevated within-channel flows and greater rainfall since the end of the Millennium Drought, and the provision of water during inter-flood dry phases via managed floodplain inundations. The results from this assessment should be treated with caution, as tree death was not assessed, and only viable trees from the Chowilla, Pike and Katarapko floodplains were used in the analysis. Therefore, the results are not expected to be reflective of the trend and condition of floodplain trees across the SA River Murray.

6 Appendices

A. Managing environmental knowledge chart for River Murray floodplain trees condition



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