Technical information supporting the 2023 River Murray flow-dependent fish populations environmental trend and condition report card

Department for Environment and Water
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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 and expert advice provided by George Giatas from the South Australian Research Development Instutite (SARDI).

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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 flow-dependent fish populations report card. The reliability of information sources used in the report card is also described.

The River Murray flow-dependent fish populations 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 Flow-dependent fish

Freshwater fish assemblages in the Murray–Darling Basin, Australia, have species-specific life history strategies that influence their response to hydrological conditions and cues (Balcombe et al. 2006; Baugartner et al. 2014; Stocks et al. 2020). In the lower River Murray, historic flow regimes have been altered by changes in climatic conditions, upstream extraction and diversion of water, and river regulation through the impoundment of water within weirs (Maheshwari et al. 1995; Bice et al. 2017; BOM 2020). These changes in flow regimes have had pronounced impacts on fish assemblages (Wedderburn et al. 2017), and led to significant population declines and the extinction of fish species associated with lotic (fast flowing, average cross-sectional water movement of >0.3 metres per second) habitats with hydraulic complexity, such as eddies (Bice et al. 2017).

Two iconic fish species in the Murray–Darling Basin that occur in the South Australian (SA) River Murray are the Murray cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua*). The Murray cod and golden perch are both riverine species associated large woody debris in lotic habitats (Bice et al. 2017). In the lower River Murray, elevated flow during spring and summer, either in-channel or overbank, are beneficial to the recruitment of Murray cod and golden perch (Ye et al. 2022). Although both Murray cod and golden perch recruitment is benefited by elevated flows during spring and summer, there are distinct differences between the life history strategies of these flow-dependent species.

Murray cod are a large-bodied (commonly >1.2 m in length) and long-lived (up to 47 years) fish that are slow to sexually mature (four to six years) and highly fecund (Koehn et al. 2020). In the lower River Murray, Murray cod move moderate distances (10s km) upstream from their home location in winter–spring to spawn (Leigh and Zampatti 2013). Spawning occurs between October and December and is cued by warming water temperatures (Ingram et al. 2022) rather than hydrological conditions (Ye et al. 2022). Murray cod are nest-spawners, meaning they adhere their eggs to hard substrates, such as logs, rocks and clay surfaces (Koehn et al. 2020). Following spawning, adult Murray cod rapidly return to their home sites (Koehn et al. 2009). Once eggs hatch, larvae drift downstream (Humphries 2005). Lotic reaches of river, even at mesohabitat scales (1–10 km), are hypothesised to be beneficial to Murray cod recruitment by facilitating the drift of larvae to slackwaters (area of still water that is unaffected by river flow) (Gibbs et al. 2020) where food resources are likely to concentrate (Humphries et al. 2020). The importance of lotic river reaches with hydraulic complexity is highlighted by the regular recruitment of Murray cod in the lotic Chowilla Anabranch during the Millennium Drought (1996–2010), when recruitment in the lentic (slow-flowing) main channel of the SA River Murray was negligible (Zampatti et al. 2014).

Golden perch are a medium- to large-bodied (commonly >400 mm) and long-lived (up to 26 years) fish that reach sexual maturity at an intermediate age (four years for females and two years for males) and are highly fecund (Mallen-Cooper and Stuart 2003; Koehn et al. 2020). Spawning for golden perch is cued by warming water temperatures and increased flow (Mallen-Cooper and Stuart 2003; Zampatti and Leigh 2013; Zampatti et al. 2015). Successful golden perch recruitment requires connectivity over large spatial scales (>100 km) to enable bi-directional movements of adults, eggs/larvae and juveniles (Zampatti et al. 2015; Zampatti et al. 2018). The large distances of movement and dispersal of golden perch early life stages, juveniles and adults means that population age structures in the SA River Murray are influenced by local and upstream (lower Darling River and mid-River Murray) spawning events (Zampatti et al. 2015).

This report card evaluates the population age structures of Murray cod and golden perch in the SA River Murray, and provides an understanding of whether flow has supported successful recruitment events.

2 Methods

2.1 Indicator

The indicator used for the SA River Murray flow-dependent fish report card is population age structure of Murray cod and golden perch. Ecological targets for Murray cod and golden perch have been set based on population age structures in the *Long-term environmental watering plan for the South Australian River Murray water resource plan area* (DEW 2020a) (Table 2.1).

Table 2.1. Recruitment and population age structure based ecological targets for Murray cod and golden perch in the long-term environmental watering plan for the South Australian River Murray water resource plan area (DEW 2020a).

Species	Ecological target
Murray cod	Population age structure includes recent recruits (includes fish <2 years old), sub-adults and adults in **9** of the last 10 years.
Golden perch	Population age structure includes young-of-the-year (YOY), sub-adults and adults in **8** of the last 10 years.

2.2 Data sources

2.2.1 Murray cod

Assessment of trend and condition of Murray cod was based on total length data collated from the following sources:

- Primary Industries and Regions South Australia (PIRSA) and Commonwealth Environmental Water Office (CEWO) Native Fish Monitoring Program;
- Murray–Darling Basin Authority (MDBA) Murray River Fishway Assessment Program Lock 1-3;
- 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);
- CEWO Lower River Murray Monitoring, Evaluation and Research (MER) Category 1 (condition monitoring)
- CEWO Lower River Murray MER Category 3 (targeted YOY monitoring)
- The Living Murray (TLM) Chowilla Condition Monitoring program;
- SA Riverland Floodplain Integrated Infrastructure Program (SARFIIP) Pike Condition Monitoring program;
- SARFIIP Katarapko Condition Monitoring program;
- MDBA Chowilla Murray cod targeted monitoring program;
- MDBA Murray–Darling Basin Fish Survey; and

- Australian Research Development Corporation Murray cod angler surveys.

2.2.2 Golden perch

Assessment of trend and condition of golden perch was based on age data collated from the following sources:

- CEWO STIM program;
- CEWO Lower River Murray LTIM program Category 1 (mandatory indicators with standard protocols);
- CEWO Lower River Murray LTIM program Category 3 (targeted hypothesis-driven monitoring);
- CEWO Lower River Murray MER Category 1 (condition monitoring);
- CEWO Lower River Murray MER Category 3 (targeted YOY monitoring);
- TLM Chowilla Condition Monitoring program;
- SARFIIP Pike Condition Monitoring program;
- SARFIIP Katarapko Condition Monitoring program; and
- MDBA/Native Fish Strategy Intervention Monitoring at Katarapko.

2.3 Data collection

2.3.1 Murray cod

A total of 1,439 Murray cod were captured throughout the Lower River Murray from 2002–03 to 2020–21. All Murray cod were captured in SA or within 5 km of the SA border in New South Wales. Murray cod were primarily captured over the floodplain geomorphic zone (985 records) and secondarily over the gorge geomorphic zone (454 records) of the SA River Murray (Figure 2.1). Nine of the data sources captured and measured over 30 Murray cod individuals (Table 2.2). The methods used by these nine 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. (2019), LTIM (Cat 1 and 3) in Ye et al. (2020) and CEWO MER (Cat 1 and 3) in Ye et al. (2022) (*Note: CEWO MER is an extension of the sampling undertaken as part of LTIM*). Murray cod were captured in the main channel of the River Murray and its associated anabranches primarily using electrofishing and secondarily drum nets (not used since 2012) (Table 2.2). Electrofishing targeted habitats used by Murray cod in the Chowilla Targeted Monitoring and CEWO LTIM and MER Cat 3 programs. Murray cod captured were measured for total length (TL) (±1 mm) and released after processing.

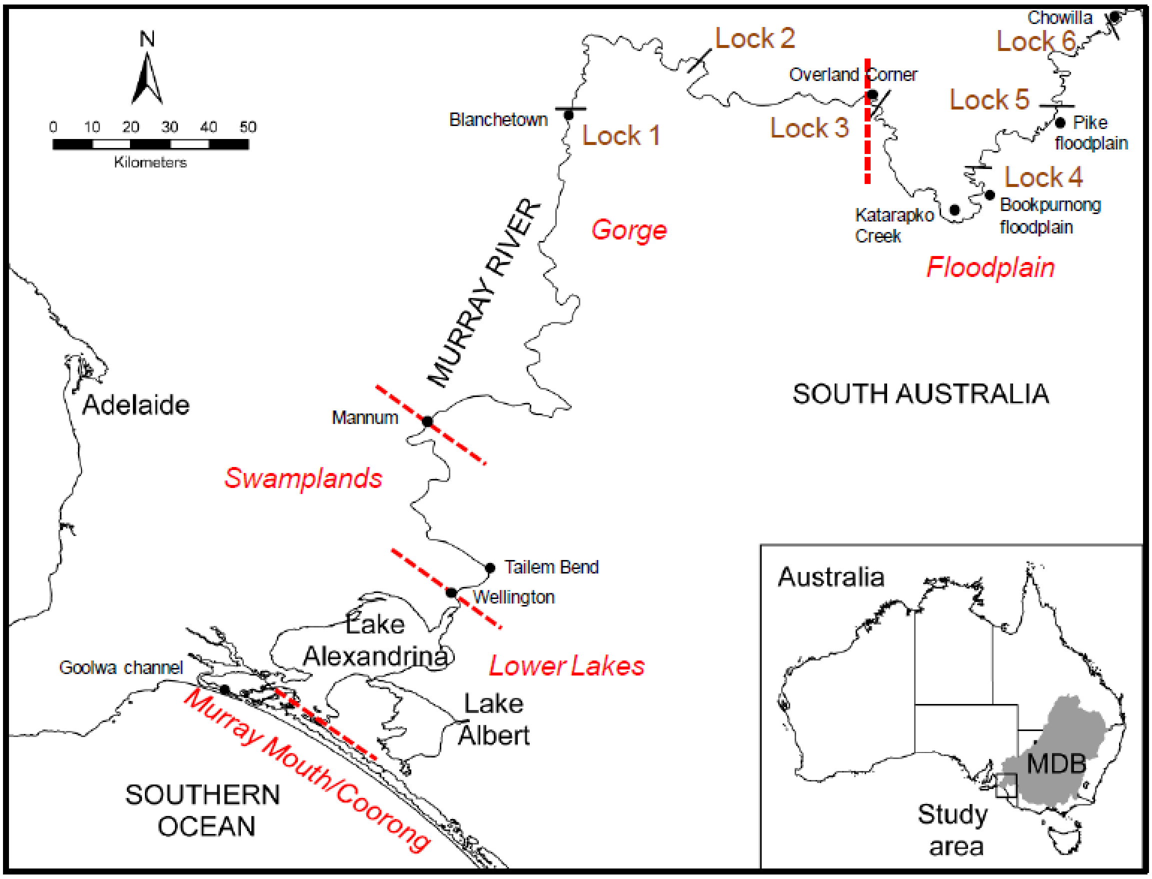


Figure 2.1. The lower River Murray, South Australia, showing four geomorphic regions and six locks and weirs (Ye et al. 2014).

Table 2.2. The number of Murray cod captured per water year for each data source (see Section 2.2) that contributed more than 30 individuals to the overall dataset. Fish were sampled in the gorge (G) and floodplain (FP) geomorphic zones of the South Australian River Murray.

	Murray Fishway Assessment	Native Fish Monitoring Program	CEWO LTIM Cat 1	CEWO LTIM Cat 3	CEWO MER Cat 1	CEWO MER Cat 3 (early juveniles)	CEWO MER Cat 3 (YOY targeted)	TLM Chowilla Condition Monitoring	MDBA Chowilla Targeted Monitoring
Year	**G**	**FP & G**	**G**	**FP***	**G**	**FP & G**	**FP & G**	**FP**	**FP**
2002–03	10								
2003–04	13								
2004–05	9	11						6	
2005–06		83						10	
2006–07	12	12						10	
2007–08	8	2						11	
2008–09	8							16	
2009–10	7	4						9	
2010–11	68	28						6	
2011–12	7	4						8	
2012–13	10	3						6	
2013–14								29	32
2014–15			11	20				9	
2015–16			16	28				12	50
2016–17			8					3	15
2017–18			14	21				17	33
2018–19			18	17				13	27
2019–20					59	103	48	24	36
2020–21					25	160	64	32	41

*one individual captured in the gorge geomorphic zone

2.3.2 Golden perch

A total of 2,144 golden perch were captured throughout the lower River Murray from 2004–05 to 2020–21. All golden perch were captured in SA or within 5 km of the SA border in New South Wales. The majority of records were captured in the floodplain geomorphic zone (1,431 records) and secondarily from the gorge geomorphic zone (706 records), with one recorded from the swamp geomorphic zone (Figure 2.1).

Electrofishing was conducted across all data sources to capture golden perch (Wilson et al. 2014; Ye et al. 2016; Fredberg et al. 2019; Ye et al. 2020; Ye et al. 2022), while fyke nets were also used for Katarapko Intervention Monitoring (Wilson et al. 2013) (Table 2.3). Captured golden perch were aged using otoliths (ear stones) as length measures do not accurately reflect the age of individuals in the Murray–Darling Basin (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 in Table 2.3.

Table 2.3. The number of golden perch captured per water year from each data source (see Section 2.2). Golden perch were sampled in the gorge (G) and floodplain geomorphic (FP) 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.

	CEWO STIM	CEWO MER CAT1	CEWO MER Cat 3	CEWO LTIM Cat 1	CEWO LTIM Cat 3	TLM Chowilla Condition Monitoring	Katarapko Intervention Monitoring	Katarapko Condition Monitoring	Pike Condition Monitoring
Year	**FP & G**	**G**	**FP & G**	**G**	**FP & G**	**FP**	**FP**	**FP**	**FP**
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			
2019–20		80	39			32			
2020–21		52	39			35		24	21

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 flow-dependent fish recruitment in the SA River Murray. 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 a likelihood estimate of the trend in the time series data assessed.

Trend analysis was undertaken in R Studio (R version 4.2.1, R Core Team 2022) using a Bayesian generalised linear 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 presence of YOY/recent recruits within the annual population age structures of Murray cod and golden perch. A model was developed and run for each species. 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. Outcomes from the trend assessment were aligned with the categories used for report cards (Table 2.4).

Table 2.4. 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 flow-dependent fish in the SA River Murray was based upon the population age structures of Murray cod and golden perch using the methodology developed in DEW (2020b). Criteria to assess condition of Murray cod (Table 2.5) and golden perch (Table 2.6) were based on the number of years that YOY/recent recruits, sub-adults and adults were present within the annual population age structures over the past decade. The condition of the fish species in poorest condition was used to represent overall condition of flow-dependent fish for the report card.

Table 2.5. 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 means 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 **<7** of the last 10 years.

Table 2.6. 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.

2.4.3 Reliability

The reliability of data to assess the trend and condition of SA River Murray flow-dependent fish (based on population age structure) 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 in to 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 flow-dependent fish.

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 Murray estuary 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

3.1 Trend

The trend in the presence of recent recruits/YOY in the annual age population structure differed greatly between Murray cod and golden perch. The presence of recent recruits in the annual population age structure of Murray cod between 2002–03 and 2020–21 was virtually certain (100% likelihood) to be getting better (Figure 3.1). In contrast, the presence of YOY in the annual population age structure of golden perch between 2004–05 and 2020–21 was about as likely as not (64%) to be improving, and therefore, is considered to be stable (Figure 3.2). As the overall trend of flow-dependent fish population age structure for the report card is representative of the poorest performing species, population age structures for flow-dependent fish in the SA River Murray were classed as **stable**.

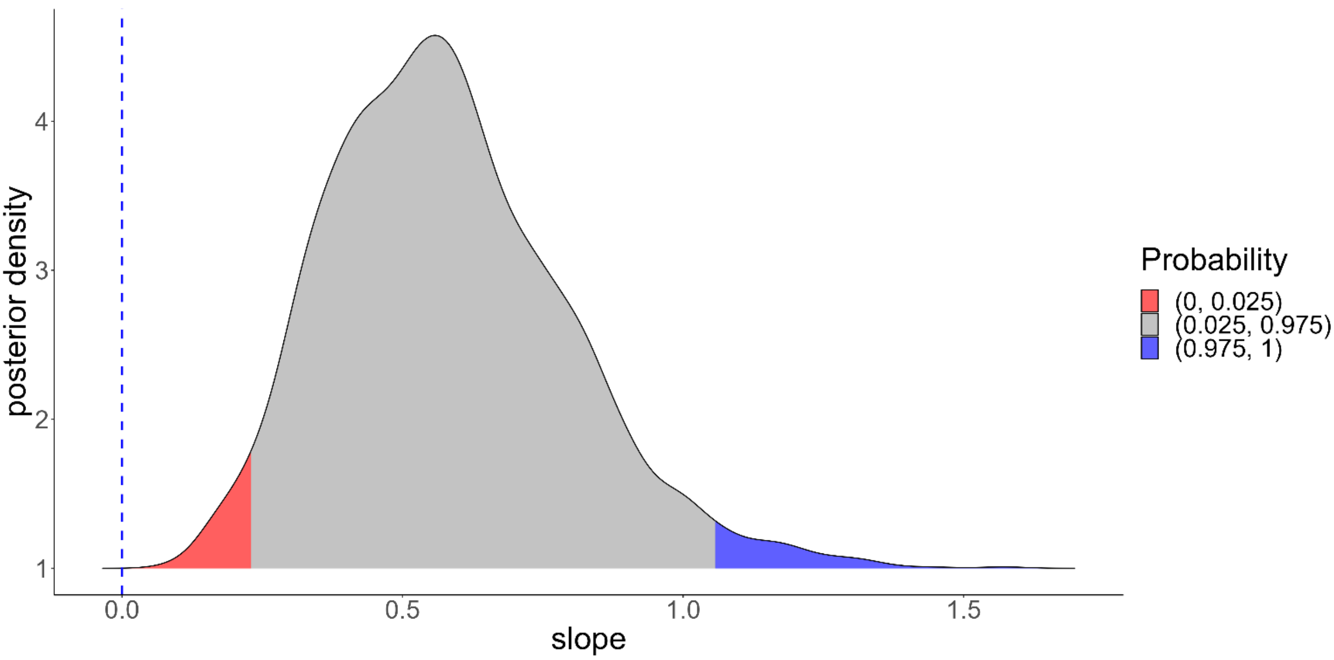


Figure 3.1. Estimated values for the slope generated from Bayesian modelling for the presence of recent recruits within the annual population structure of Murray cod from 2002–03 to 2020–21. Posterior density values with a slope >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

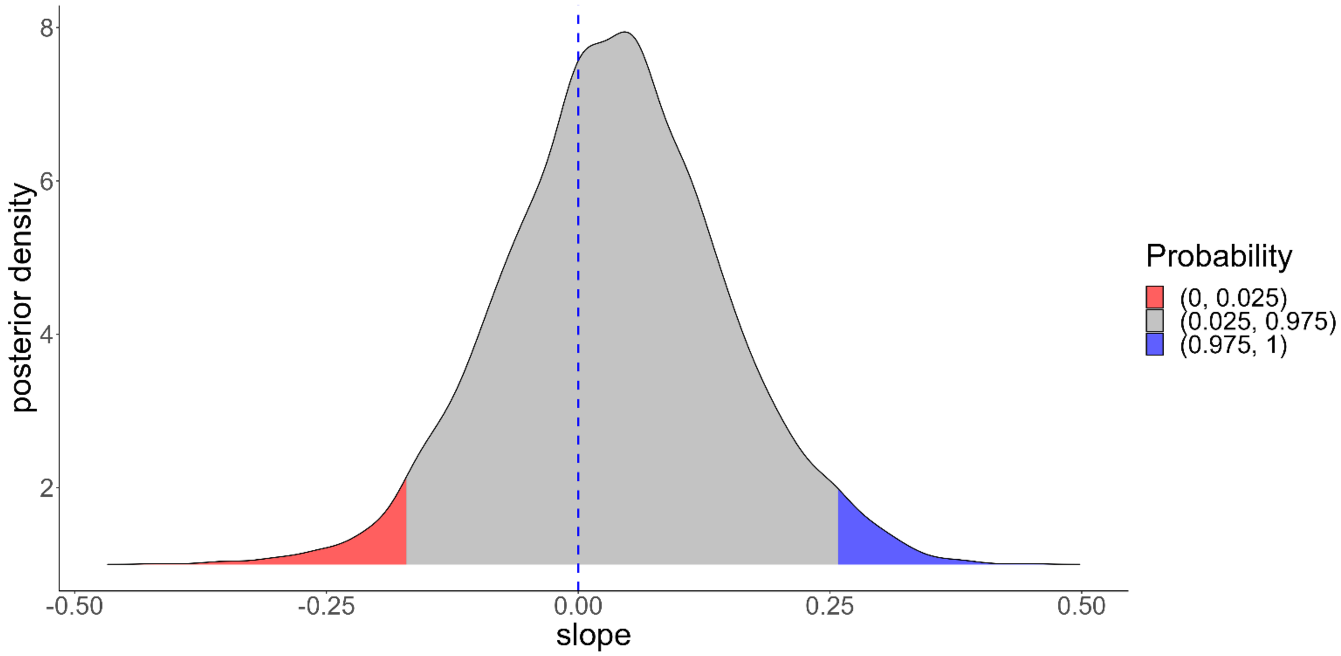


Figure 3.2. Estimated values for the slope generated from Bayesian modelling for the presence of recent recruits within the annual population structure of golden perch from 2004–05 to 2020–21. Posterior density values with a slope >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

3.2 Condition

The population condition of Murray cod and golden perch differed greatly. The condition of the Murray cod population was classed as good with recent recruits, sub-adults and adults present in the annual population age structure in nine of the past 10 years (Table 3.1; Figure 3.3). The condition of the golden perch population was classed as poor with YOY, sub-adults and adults present in the annual population age structure in four of the past 10 years (Table 3.2; Figure 3.4). As the overall condition of flow-dependent fish for the report card is representative of the species in the poorest condition, flow-dependent fish population condition in the SA River Murray was classed as **poor**.

Table 3.1. 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 2020–21.

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

Year	# of individuals captured	Recent recruits	Sub-adults	Adults
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
2019–20	278	Present	Present	Present
2020–21	339	Present	Present	Present

Table 3.2. Presence/absence of young-of-the-year (<1 year old), sub-adults (1-3 years old) and adults (>3 years old) in the population age structure of golden perch from 2004–05 to 2020–21.

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	Present	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	170	Absent	Present	Present
2015–16	188	Absent	Present	Present
2016–17	83	Absent	Present	Present
2017–18	214	Absent	Present	Present
2018–19	161	Absent	Present	Present
2019–20	151	Absent	Present	Present
2020–21	171	Present	Present	Present

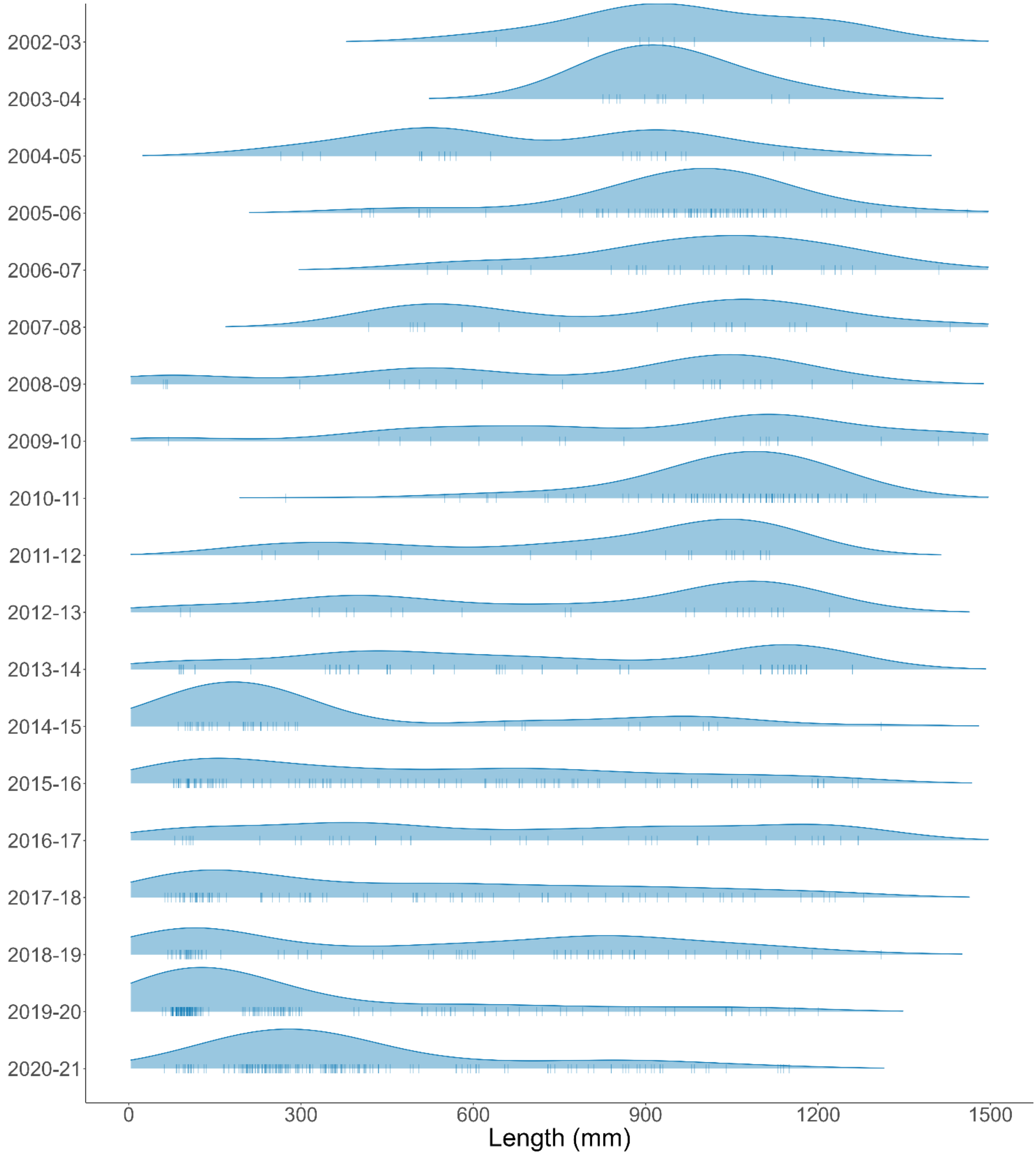


Figure 3.3. Density plot of Murray cod total length (mm) from 2002–03 to 2020–21 in the South Australian River Murray. Total lengths (mm) of individual fish in each water year are marked by |. Markers have been jittered to prevent overlap of individual fish with similar total lengths. Monitoring datasets that targeted juvenile fish have been removed from this plot. Note: recent recruits are <200 mm and include fish <2 years old, sub-adults are 200-600 mm and adults >600 mm.

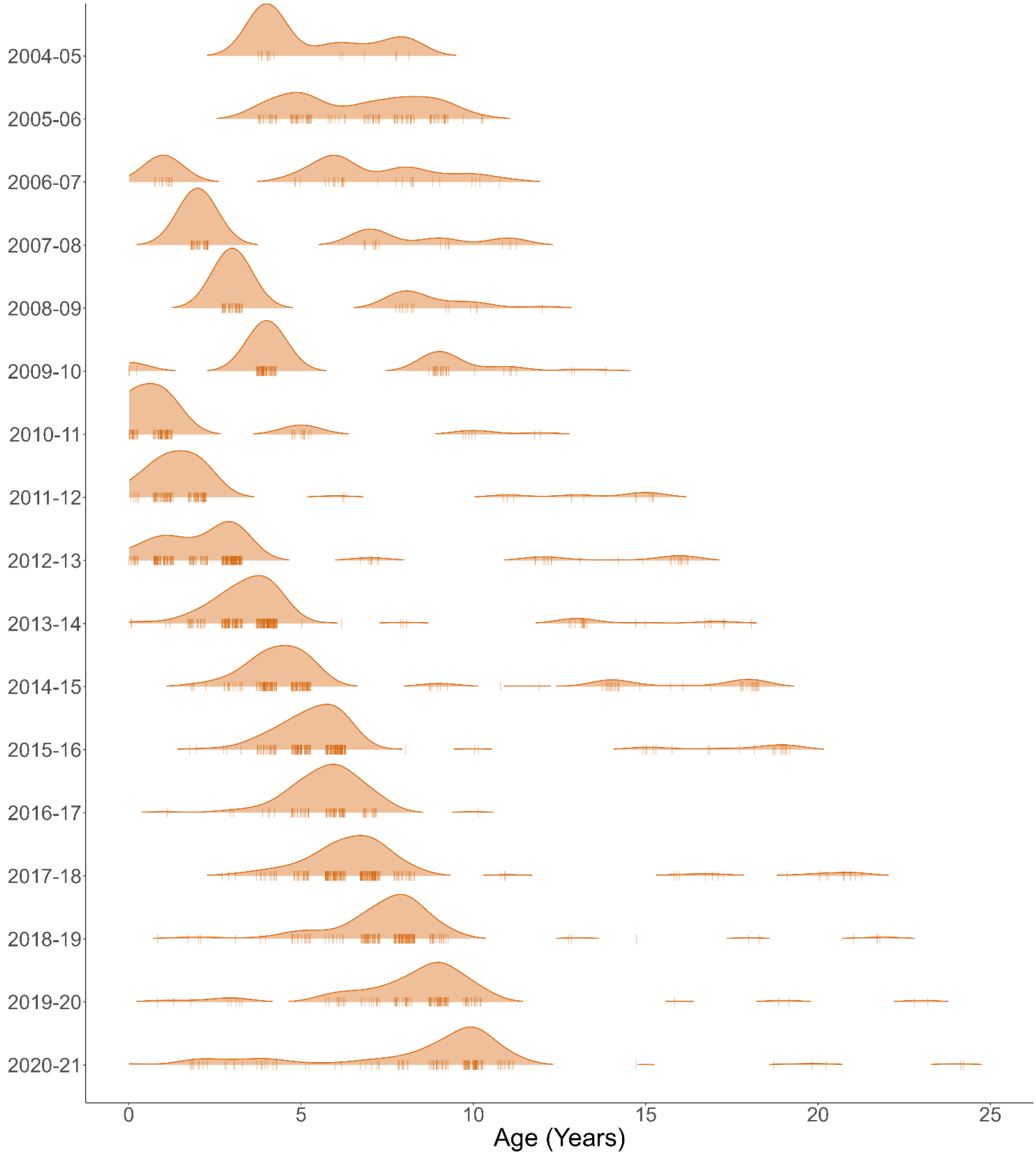


Figure 3.4. Density plot of golden perch age (years) from 2004–05 to 2020–21 in the South Australian River Murray. Ages of individual fish in each water year are marked by |. Markers have been jittered to prevent overlap of individual fish with the same age. Note: YOY are <1 year of age, sub-adults are 1-3 years old and adults >3 years old.

3.3 Reliability

The data reliability rating was classed as fair for Murray cod and good for golden perch. Justification for the data reliability ratings for Murray cod and golden perch are provided in Table 3.3 and Table 3.4, respectively. As the report card reflects the poorest data reliability rating across assessed species, the overall reliability score for this report card is **fair**.

Table 3.3. Reliability of data to assess trend and condition of the Murray cod population age structure. Reliability was scored based on the response to standardised questions on methods and the representativeness and repetition of sampling. 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.** Data collection is appropriate in determining the presence of YOY, sub-adults and adults in the annual population age structure.	2
Standard methods	Has the same method been used over the sampling program?	**Partially**. Murray cod were captured primarily using electrofishing and secondarily drum nets. Drum nets have not been used since 2012.	1
Representativeness			
Space	Has sampling been conducted across the spatial extent of the SA River Murray with equal effort?	**Partially.** 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 2020–21, and therefore includes years of monitoring over a wide range of hydrological conditions.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Partially**. 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 trend and condition.	2
Final score			**9**
Information reliability			**Fair**

Table 3.4. Reliability of data to assess trend and condition of the golden perch population age structure. Reliability was scored based on the response to standardised questions on methods and the representativeness and repetition of sampling. 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.** Data collection is appropriate in determining the presence of YOY, sub-adults and adults in the annual population age structure.	**2**
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 SA River Murray with equal effort?	**Partially.** Golden perch have been sampled throughout the SA River Murray, 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 2020–21, and therefore includes years of monitoring over a wide range of hydrological conditions.	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Partially**. 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 2020–21 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 trend and condition.	**2**
Final score			**10**
Information reliability			**Good**

4 Discussion

4.1 Trend and condition

Flow-dependent fish in the SA River Murray were determined to be in **poor condition** and **stable**. However, there were contrasting results between the two fish species assessed, with Murray cod determined to be in good condition and getting better, while golden perch were in poor condition and stable.

4.1.1 Murray cod

The Murray cod population was considered to be in good condition, with recent recruit, sub-adults and adults recorded in nine of the 10 years from 2011–12 to 2020–21. Collated Murray cod data from across SA River Murray found that since 2014–15 that there has been an improvement in diversity of the length-frequency distribution, attributed to increased recruitment. Monitoring of Murray cod in the main SA River Murray channel conducted since 2013 found continual improvement in population age structures and recorded large recruitment events in 2018–19 and 2019–20 (Ye et al. 2022). Similarly, long-term monitoring in the Chowilla Anabranch found recruitment to have continually improved from 2014 to 2020 (Fredberg et al. 2022). The diverse length-frequency distribution of Murray cod in 2020–21 reflects a healthier population age structure of the Murray cod population that is likely to have resilience to future events of environmental stress (Ye et al. 2022).

Improvement in population age structure of Murray cod in the SA River Murray has been hypothesised to be in response to elevated spring–summer flows, either in-channel or overbank, that has increased the extent of lotic habitat (Ye et al. 2022). Such flow characteristics may improve population condition of Murray cod by (Ye et al. 2022):

- increasing available spawning habitat
- improving body condition, and
- enhancing recruitment.

Spatial and temporal scales of elevated flows may influence recruitment of Murray cod in the SA River Murray. Murray cod are capable of recruiting over mesohabitat scales (1–10 km) (Leigh and Zampatti 2011), and therefore, even small improvements in the extent of lotic and hydraulically diverse habitat may be beneficial. Strong recruitment events, however, are positively associated with elevated flows and widespread (10s–100s km) improvement in lotic and hydraulically diverse habitat (Ye and Zampatti 2007). Timing may also be an important factor in the recruitment of Murray cod. Elevated flows in early spring that coincide with the spawning season may be associated with strong recruitment, whereas, elevated flows after the spawning season may result in negligible recruitment (Ye et al. 2022).

The hydrological requirements hypothesised to improve population condition and recruitment of Murray cod in the SA River Murray corroborate the findings of Stuart et al. (2019), who assessed how flow regimes influenced Murray cod populations in an anabranch of the mid-Murray. Stuart et al. (2019) found Murray cod abundances to be enhanced by (1) annual spring spawning and recruitment flows that do not have rapid water level recession, (2) hydraulic complexity and (3) annual base winter connection flows.

4.1.2 Golden perch

The golden perch age population structure is characteristic of a population with low resilience. Golden perch age structure diversity is low (Ye et al. 2022), with few individuals in younger cohorts and the vast majority of individuals being adults aged between seven and 11 years. Young-of-the year golden perch were recorded in

2020–21 for the first time since 2013–14, however, this recruitment event had negligible influence (two individuals recorded) on the overall population age structure. In 2020–21, 15% of the golden perch sampled were between the ages of two and four years, suggesting there were successful recruitment events in 2016–17, 2017–18 and 2018–19 (Ye at el. 2022).

Sampling of golden perch over nearly the past two decades has identified strong recruitment events in 1996–97, 2000–01, 2005–06, 2009–10, 2010–11 and 2011–12. Golden perch recruited in events prior to 2009–10 now only represent a very small (<5%) proportion of individuals in the 2020–21 population age structure.

The abundances of golden perch captured in the SA River Murray are likely to have varied significantly over the past 20 years. Long-term monitoring of fish assemblages at Chowilla found abundances of golden perch to be low during the Millennium Drought (1996–2010); high during high flows from 2011 to 2013, and low from 2014 to 2020 (Fredberg et al. 2021). Standardised sampling within the main channel of the SA River Murray also observed golden perch abundances to have declined from 2015 to 2020 (Ye et al. 2022). The decline in abundance is attributed to a lack of strong recruitment events for nearly a decade, mortality (natural and fishing) and/or the upstream emigration of adult fish, with large-scale movements most extensive during overbank flows (i.e. 2016–17) (Zampatti et al. 2018).

As population dynamics of golden perch are influenced at very large spatial scales, inclusive of the lower Darling River and mid-River Murray, spawning and recruitment events are not necessarily associated with the flow regimes experienced in the SA River Murray. Zampatti et al. (2018) studied the natal origins of golden perch in the lower River Murray in 2016. During the study, golden perch captured were from three predominant cohorts, having spawned in 1996–97, 2009–10 and 2010–11. The study found all individuals in the 1996–97 cohort to have spawned in the lower River Murray, while individuals that recruited in 2009–10 and 2010–11 were from the lower Murray and Darling River. Moreover, the natal origins of larval and YOY golden perch captured in the SA River Murray in 2020–21 were from spawning events in the mid-Murray (Ye et al. 2022).

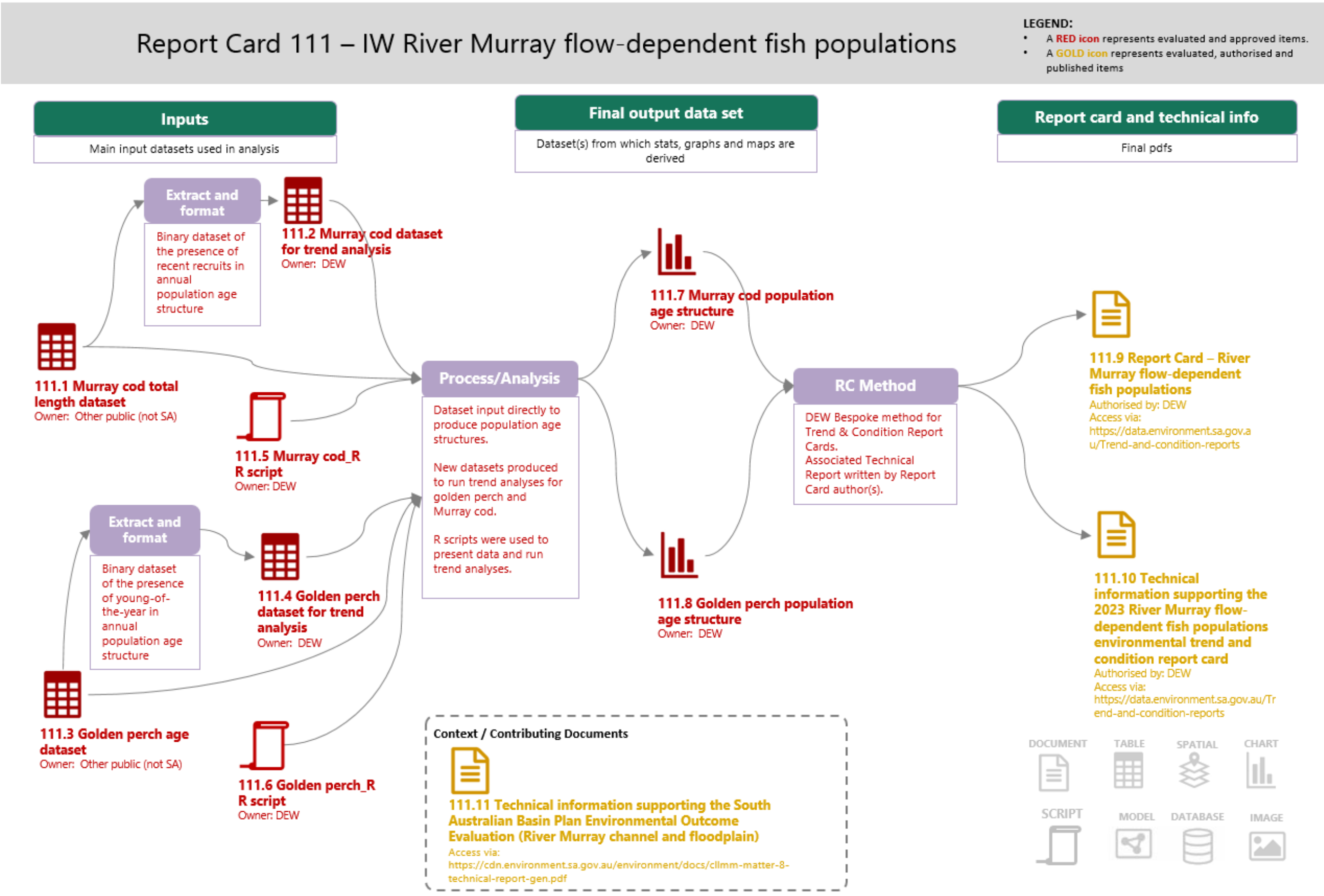
Years of golden perch distinct cohorts and recruitment in the SA River Murray are associated with elevated in-channel (>20,000 ML/day) and overbank flows (>40,000 ML/day) (Zampatti & Leigh 2013a, b; Wilson et al. 2014; Ye et al. 2022). Therefore, to promote golden perch spawning and recruitment in the SA River Murray, it is likely that elevated (>20,000 ML/day) in-channel and overbank flows in spring–summer need to be restored (Ye et al. 2022). Flows to SA of >20,000 ML/day restores lotic habitats to large reaches of the SA River Murray (Bice et al. 2017), and cue spawning and enable bi-directional movements of adult, eggs/larvae and juvenile golden perch, which is critical to their recruitment and population resilience (Zampatti et al. 2015; Zampatti et al. 2018).

5 Conclusion

Flow-dependent fish in the SA River Murray were determined to be in **poor condition** and **stable**. The two flow-dependent fish species assessed had contrasting results, with Murray cod determine to be in good condition and getting better, while golden perch were in poor condition and remaining stable. These contrasting results are due to differences in the spatial scales of lotic habitat required for spawning and recruitment events, with Murray cod able to recruit in lotic habitats at mesohabitat scales (1–10 km), while golden perch require lotic habitats at megahabitat scales (>100 km). Both flow-dependent fish species would benefit from elevated (>20,000 ML/day) in-channel and overbank flows in spring–summer that restore lotic conditions to large reaches of the SA River Murray.

6 Appendices

A. Managing environmental knowledge flow chart for River Murray flow-dependent fish



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