Draft Conservation Advice for the *River Murray downstream of the Darling River, and associated aquatic and floodplain systems* Ecological Community

Under the EPBC Act, the Threatened Species Scientific Committee (TSSC) must invite comments on whether or not a nominated ecological community (EC), which has been prioritised for assessment, is eligible for listing and under which threat category. The TSSC and Department are also seeking comments on this *Draft Conservation Advice* which is prioritised for assessment by 29 November 2024. The draft document also includes a description of the EC, key threats, and draft key actions to stop decline and support recovery for the EC**.**

The purpose of this consultation document is to elicit updated and additional information to better understand the threatened status of the ecological community and help inform its future conservation.

This *Draft Conservation Advice*, containing a preliminary listing assessment, should be considered **tentative** at this stage, as it is likely to be updated as a result of responses to this consultation process and the input of further scientific information and analysis.

Historical Notes – 2013 Listing and Conservation Advice: This *Draft Conservation Advice* is based on a previous listing assessment of the same ecological community that was listed as Critically Endangered on 5 August 2013 (then named: *River Murray and associated wetlands, floodplains and groundwater systems—from the junction with the Darling River to the Sea*). This listing remained in place for four months before a motion for its disallowance was passed on 11 December 2013 during the next sitting period of Parliament following its approval for listing.

The *2013 Conservation Advice* (with listing assessment) was developed over several years and overseen by the independent Threatened Species Scientific Committee—with input from: over 100 experts; a review of over 400 papers and reports; the outcomes of two technical workshops (published on the Department's website); and consultation with a range of industry, government, First Nations, and other community stakeholders.

Current Assessment – October 2023 – November 2024: The ecological community was nominated for listing again in 2023 and was deemed a priority by the TSSC and the Minister for the Environment, for the assessment period starting October 2023.

This Draft Conservation Advice (i.e. August 2024) used the 2013 version as a foundation, with updates based on the range of scientific data and other information that has arisen in the intervening decade or so. **Updates** have progressed prior to this public consultation period **but, in some sections, are not yet fully comprehensive and we await the release of upcoming Murray-Darling Basin Plan technical reports, due to be released soon.** Therefore, throughout this Draft document there are text boxes with Questions/ Comments for your consideration, as part of the consultation process. These include seeking your assistance with identifying further relevant data and information, to help the Committee reach a final assessment outcome and Conservation Advice for the Minister to approve.

This document forms the *Draft Conservation Advice*, including a preliminary listing assessment, for the ecological community (EC), *River Murray downstream of the Darling River, and associated aquatic and floodplain systems* (in brief, *River Murray—Darling to Sea*, or RMDS). It aims to provide a foundational guide for protection, conservation and recovery actions, and further planning, including threat abatement.

Big Bend, Murray River South Australia © Ben Goode

The *River Murray—Darling to Sea EC* occurs on Country (the traditional lands and sea) of several First Nations Peoples in South Australia, NSW and Victoria—including the Ngarrindjeri, Peramangk, the First Nations of the South East (southern Coorong), First Peoples of the River Murray and Mallee, Barkindji, Latje Latje, and Kureinji.

We acknowledge all of these First Nations Peoples' culture and continuing link to the ecological community and the Country (including land, waterways and sea) it inhabits.

Note: The Threatened Species Scientific Committee and the Department would appreciate input related to the significance of the Ecological Community occurring on First Nations' Country. This includes information that could be appropriately acknowledged and incorporated within the final *Conservation Advice*.

In addition, First Nations' advice on the draft description, threats, threat impacts, and conservation actions, is sought. It is acknowledged that the Committee has a short statutory timeframe to provide its advice and for this *Conservation Advice* to be drafted.

Significant consultation occurred with the Ngarrindjeri for preparation of the 2013 *Conservation Advice* and further consultation with relevant groups is underway for the 2024 *Conservation Advice*. Importantly, the Board of the *Murray Lower Darling River Indigenous Nations* (MLDRN) has been briefed and their valuable input sought.

Proposed Conservation Status

The *River Murray downstream of the Darling River, and associated aquatic and floodplain systems* Ecological Community is proposed to be listed in the **Critically Endangered** category of the Threatened Ecological Communities List under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act).

A preliminary assessment has determined that the ecological community is likely to be eligible for listing as 'Critically Endangered' under Criteria 3 and 4, and potentially as 'Endangered' under Criterion 5 of the EPBC Regulations. A draft assessment of the regulated Criteria is at Section 0.

The main factors that make this nationally unique ecological community likely to be eligible for listing as threatened in the Critically Endangered category result from combined and long-term impacts from multiple threats (historic and current) that have resulted in:

- widespread declines or losses (including local extinctions) of many key ecologically functional species or taxonomic groups throughout various components of the *River Murray—Darling to Sea* EC, combined with their significant and at times catastrophic recruitment failure
- a reduction in community integrity, as evidenced by reductions in biodiversity across a range of taxonomic groups and habitats; significant disruption of key ecological, hydrological, and geo-physical processes; and, conditions that favour invasive species (alien and pest), and
- restoration of the biota and processes is unlikely in the immediate future, especially without further efforts to prevent and limit threats and support recovery.

Ecological communities can also be listed as threatened under State and Territory legislation. At the time of this *Draft Conservation Advice,* there are no comparable ecological communities listed under State or Territory legislation. However, there are some State listed aquatic threatened ecological communities that overlap with parts of the NSW and Victorian sections of the RMDS EC. Also, three internationally recognised Ramsar wetlands within the South Australian section of the *River Murray—Darling to Sea* EC. This EC also provides seasonal habitat for a range of migratory birds listed under national environment law and international agreements. More information is at Section 5.

Draft Conservation Advice for the *River Murray downstream of the Darling River, and associated aquatic and floodplain systems* Ecological Community

About this document

This *Conservation Advice* describes the ecological community and where it can be found (Section 1) and outlines information to assist in identifying the ecological community and important occurrences of it (Section 0). Pending further information, it also intends to provide a brief, draft description of certain key aspects of the ecological community's cultural significance for First Nations Peoples (Section 3).

In line with the requirements of section 266B of the EPBC Act, it sets out the grounds on which the ecological community is eligible to be listed as threatened (Section 0); outlines the main threat factors that cause it to be eligible for listing (Section 4); and provides information about what could appropriately be done to stop its decline and/or support its recovery (Section).

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1 Ecological community name and description

1.1 Name

The name of the ecological community (EC) is *River Murray downstream of the Darling River, and associated aquatic and floodplain systems*.

This EC was nominated in 2023 and placed on the 2023 Finalised Priority Assessment List as *River Murray and associated wetlands, floodplains and groundwater systems, from the junction with the Darling River to the sea.*

The *River Murray and associated wetlands, floodplains and groundwater systems, from the junction with the Darling River to the sea* threatened ecological community was previously listed as Critically Endangered under the EPBC Act, from 5 August 2013. However, the Legislative Instrument for inclusion on the list of threatened ecological communities was disallowed on 11 December 2013.

Abbreviated names for the EC, as used throughout this draft document are:

"*River Murray—Darling to Sea*" or "RMDS".

1.2 Description of the ecological community and the area in nature it inhabits

Overview

The EPBC Act defines an ecological community as "an assemblage of native species that inhabit a particular area in nature". This section describes the species assemblages and areas in nature that comprises the ecological community (EC).

The *River Murray—Darling to Sea* EC consists of the native flora, fauna, and other organisms associated with, and dependent upon, the River Murray lowland river-floodplain system, below the river's confluence with the Darling River, downstream to the sea, inclusive.

This landscape-scale ecological community is formed by an interconnected series of 'keystone sub-communities' and associated 'sub-ecosystems', that together form one major 'keystone-type ecosystem'—a concept that is beneficial for understanding, conserving, and managing disturbed landscapes (Mouquet et al. 2012; Locky 2016; Yang et al. 2020; Sacco et al. 2023). The loss of the keystone sub-communities may lead to loss of local species diversity and, importantly, also erode broader regional biodiversity and ecosystem functions (Mouquet et al. 2012; Yang et al. 2020). Therefore, the RMDS is associated with a complex aquatic/terrestrial' keystone-type ecosystem', whose interconnected components include: the river channel, lakes, and estuaries; associated tributaries and streams; floodplain wetlands and woodlands, associated islands; and groundwater.

In a national context, the ecological community represents a 'one-of-a-kind' keystone ecosystem and is different from other river systems, including the parent rivers, due to its complex features, habitat heterogeneity, and high levels of biodiversity (Walker 2006; TSSC 2010, 2011, 2013). It encompasses one of the most nationally unique and biodiverse sections of the Murray-Darling Basin river system, and includes the system's terminus (TSSC 2010). Important

distinguishing features that contribute to its biodiversity, ecological, and functional uniqueness in the national context are:

- it incorporates the terminus of the Murray-Darling Basin (MDB)
- it is the only portion of the MDB (i.e. Australia's largest river system), where the water is a mixture from both the Murray and Darling rivers, which confers different water composition, chemistry, and quality, and which in turn influences the biota
- the waters of the River Murray downstream of the Darling junction contain greater dissolved carbonate concentrations than most upstream waters in the MDB, potentially due to the marine-origin limestone, marl deposits, and groundwater inputs that characterise this landscape (e.g. Cartwright 2010; Mosley & Leydon 2023)
- while there are several streams and creeks that flow into the region of the ecological community, there are no 'major' tributaries within the EC—with the exception of the Darling Anabranch, when flowing; major tributaries, as sources of water, sediments, and biota, may significantly influence abiotic and biotic attributes and enhance resilience (e.g. Rice et al. 2008; Dye 2010; Milner et al. 2019; Consoli et al. 2022).
- the floodplain understorey, of both *Eucalyptus largiflorens* (black box) and *E. camaldulensis* (river red gum) woodlands and forests, is compositionally different compared to that upstream of the Darling River confluence (Smith & Smith 1990)
- long-term monitoring and other studies found phytoplankton, zooplankton, and macroinvertebrate assemblages are compositionally distinctive (i.e. with a discrete zonation) in the River Murray downstream of the Darling junction, i.e. compared to those upstream in the parent rivers (e.g. Sullivan, 1990; Shiel, 1990; Bennison and Suter, 1990; Paul et al. 2018; Furst et al. 2019; Dittmann et al. 2021)
- the ecological community incorporates the full suite of diadromous fish species that occur in the MDB and, for several other fish species, the ecological community represents a large portion of their MDB distribution range (e.g. Hammer & Walker 2004; Hammer et al. 2009, 2012; Wedderburn et al. 2017; Bice et al. 2018a)
- the ecological community is nationally significant for bird fauna, providing habitat, feeding grounds, and refuge for a high diversity of resident and migratory waterbird species of national and/or international significance (e.g. Paton et al. 2018).

This complex threatened ecological community aligns with several ecosystem functional groups (EFGs) as per the IUCN Global Ecosystem Typology 2.0 (see Table 1).

More information to assist in identifying occurrences of the ecological community is provided in Section 0. Because of past loss or degradation of biodiversity and associated habitat, not all extant occurrences of the ecological community are in a completely natural state. Section 0 provides information to identify which areas or patches of native vegetation are still the ecological community and retain sufficient conservation values to be considered a matter of national environmental significance and which are too degraded.

Table 1: Ecosystem Functional Group by realms and biomes as they relate to the River Murray—Darling to Sea EC (i.e. as per IUCN Global Ecosystem Typology 2.0).

Code	Biome	Code	Ecosystem Functional Group
Realm: Subterranean-Freshwater			
SF2	Subterranean freshwater biome	SF2.2	Groundwater*
Realm: Freshwater			
F1	Rivers and streams biome	F1.2	Permanent lowland rivers
		F1.5	Seasonal lowland rivers
		F1.6	Episodic arid rivers
		F1.7	Large lowland rivers
F2	Lakes biome	F2.1	Large permanent freshwater lake
		F2.2	Small permanent freshwater lake
		F2.3	Seasonal freshwater lake
Realm: Terrestrial-Freshwater			
TF1	Palustrine wetlands biome	TF1.3	Permanent marshes
		TF1.4	Seasonal floodplain marshes
		TF1.5	Episodic arid floodplains
Realm: Freshwater-Marine			
FM1	Semi-confined transitional waters	FM1.3	Intermittently closed and open lakes and
Realm: Marine-Freshwater-Terrestrial			
MFT1	Brackish tidal biome	MFT1.3	Coastal saltmarshes and reedbeds

*Note, Groundwater within the RMDS EC may be saline at times, and the IUCN typology only recognises subterranean freshwater.

1.2.1 Description of the area in nature inhabited by the ecological community

GEOGRAPHIC LOCATION

The *River Murray—Darling to Sea* EC occurs within the Murray-Darling Basin (MDB; Murrundi—the Ngarrindjeri name for the MDB) in southeast Australia. The MDB forms the broader 'catchment' for this nationally unique ecological community. The River Murray channel, below the confluence with the Darling River, is the main artery of the ecological community—linking riverine environments along its course, including riparian zones, floodplain woodlands, islands, streams, wetlands, lakes, and the estuaries at the river's mouth (e.g. MDBC, 2006a). There are also groundwater connections.

The length of the River Murray below its confluence with the Darling River is about 828 km (Geoscience Australia, 2023). The bulk of the River Murray's linear extent associated with the EC occurs within South Australia (approx. 655 km or 79%). Of this, 11 km are shared with Victoria, where the SA/VIC border is misaligned; along this stretch, the mid-line of the river forms the border between SA and Victoria (Geoscience Australia, 2023). Approximately 174 km (21%) of the linear extent of the River Murray within the EC occurs in NSW; noting that, the NSW border is delineated by the river's southern bank rather than by the middle of the river (Geoscience Australia, 2023).

BIOREGIONALISATION AND NRM

The ecological community spans six Interim Biogeographic Regionalisation of Australia (IBRA) Version 7 bioregions and 11 IBRA subregions (Appendix A, Table A1). It occurs mainly within the bioregions of the Murray Darling Depression and Riverina, and within smaller areas of the Kanmantoo, Naracoorte Coastal Plain, Darling Riverine Plains and Flinders Lofty Block. It also occurs within the Natural Resource Management (NRM) regions of South Australian Murray

Darling Basin (SA), Adelaide and Mount Lofty Ranges (SA), Northern and Yorke (SA), South East (SA), Western (NSW) and Mallee (VIC).

BOUNDARIES

Boundaries and buffer zones for the RMDS are outlined in Table 2. Boundaries for the RMDS EC are typically mappable and indicate where the EC 'definitely' occurs or 'is 'likely to' occur. In brief, the RMDS:

- incorporates and is bounded downstream by the terminus of the MDB system—the Coorong, Lower Lakes and Murray Mouth (CLLMM), and includes several coastal lakes which may serve as refugia for the ecological community (e.g. McNeil et al. 2013)
- any associated tributaries, including streams of the Eastern Mount Lofty Ranges, Lake Victoria, and a section of the Darling Anabranch, with lateral boundaries 100 m from the edge or the 1956 flood line, whichever is greater
- has a broad floodplain (i.e. lateral) boundary which is formed by the 1956 flood line (TSSC 20010), and
- has an upstream boundary at the confluence between the Murray and Darling rivers, which is near Lock 10 (TSSC 2010).

BUFFER ZONES

Buffer zones are widely used as an approach to protect and manage sensitive ecological areas (Boyd 2001). In the context of the RMDS EC, a buffer zone is a contiguous area directly adjacent to an area of the ecological community but is not part of the ecological community itself. These zones serve an important role in protecting the integrity of the RMDS, however they are not considered to be a part of the ecological community, itself. Buffer zones often overlap with an ecotone—an area of transition between two different habitats or ecosystems (Winning 1997). As such, their recognition by land managers, and incorporation into conservation actions, helps to minimise external threats and support recovery of these vulnerable areas. The benefits of buffer zones to aquatic ecosystems are many and wide-ranging (Newton 2012).

Groundwater forms part of the ecological community's habitat and an integral component of the hydrological processes supporting it; any groundwater connections with the RMDS have a buffer zone of at least 5000 metres (e.g. DEW 2020a).

See Section 2.4 for how buffer zones are important to the survival of the ecological community and Section 5.4 for specific buffer requirements to avoid impacts and manage threats.

PHYSICAL ENVIRONMENT

Due to the complexity of this large, landscape-scale ecological community, the environment in which it occurs can be divided longitudinally into six bio-geographical sections, or sub-units, along the River Murray channel—summary at Table 3 (adapted from TSSC 2010, 2013). The divisions are based on the internal physiography (i.e. features related to geomorphology, hydrology, biodiversity) of each section.

Table 2: Boundaries of the *River Murray—Darling to Sea* Ecological Community (TSSC 2010).

Boundary	Description	
Upstream Limit	Confluence with Darling River/near Lock 10 [A practical upper boundary, given differences in biodiversity, habitats, and water chemistry/quality in this region of the Murray (e.g. Walker 2006)].	
Downstream Limit	Mouth of the River Murray - including the Coorong Lagoons and associated sand dune systems, peninsulas, and islands [The position of the Murray Mouth may change – naturally or from dredging].	
General Lateral Boundary	1956 Flood line [A practical lateral boundary (unless otherwise specified) – from ecological, hydrological, and geomorphic perspectives (TSSC 2009). The line is well mapped and used at State level (e.g. defines a practical management unit and planning boundary in SA (e.g. DEWNR 2012), and a limit for horticulture].	
Groundwater	Groundwater feeding directly into the EC (+ lateral buffer of ≥5,000 m)	
Other Boundaries (i.e. for water bodies that flow into, adjoin, or otherwise influence the RMDS EC)		**Lateral Boundary**
Lower Darling Anabranch	Lower Darling Anabranch from the junction with the River Murray to Glen Esk [Glen Esk is considered to be the upstream influence of Lock 9. This constitutes approximately 25 km of the Anabranch. This stretch is also considered an important geo-chemical influence on water quality and a potential refuge habitat (Nias 2002; TSSC 2010) to the EC.]	100 m or 1956 Flood line (whichever greater)
Lake Victoria	Lake Victoria and its input/output streams, Frenchman's Creek and Rufus River. [This natural lake was annexed in the late 1920s to provide a reliable water supply for the development of the Lower Murray region in SA, and to mitigate and augment flood peaks].	100 m or 1956 Flood line (whichever greater)
Wetlands Streams	Any stream or tributary upstream of Mannum, between Lock 1 and Lock 10, that connects the River Murray with wetlands.	1956 Flood line
Streams of Eastern Mt Lofty Ranges	Streams of the Eastern Mount Lofty or the Marne-Saunders Prescribed Water Resources Areas (PWRA) [Note: Longitudinal boundary is that of the PWRA for each stream (SAMDBNRM Board 2010a, 2010b)].	100 m from edges
Salt Creek	Salt Creek – entire length [Includes headwater spring; funnels surface water from SED into Coorong South Lagoon; drives export of material from the South to the North Lagoon (Paton 2010; Mosley et al. 2017; Gibbs et al. 2018).]	100 m from edges
Lower Lakes	Lake Alexandrina and Lake Albert, islands, and riparian vegetation.	100 m from edges
Coastal Lakes south of Coorong	Coastal Lakes between Coorong South Lagoon and Kingston, SA. [These costal lakes are important refuge sites and may boost resilience of the lower EC; they may also be potential sites from which to recolonise certain species into the EC, should they be lost/extirpated. Lakes include: Lake Cantara North & South; Brine Shrimp; Coxiella; Paranki Lagoon, and Teilaka].	100 m from edges

Table 3: Main bio-geographical sections (sub-units) of the *River Murray—Darling to Sea* EC (TSSC 2010). (Note, includes any streams connecting to the River Murray in these sub-units).

Name of	Location	Description
Top Valley	From the Darling River junction (Lock 10, near Wentworth, NSW) to Overland Corner (Lock 3, SA), and also including Locks 9, 8, 7, 6, 5 and 4.	In this Section, the river meanders westward over a 10–20 km wide floodplain, with extensive wetlands and woodland, and with an associated high biodiversity. The section includes two important Ramsar-listed wetland complexes, the Riverland and Banrock Station. In particular, the Chowilla Anabranch and Lindsay-Mullaroo systems in this section constitute permanently flowing habitat critical to fish refuge and recruitment. This section also contains the Lower Darling Anabranch and Lake Victoria.
Murray George	From Overland Corner to Mannum.	Here, the river's course is realigned southward and the floodplain is constrained to 4–5 km, within a 30 m deep limestone gorge. The section includes three weirs, at Lock 3, 2 and 1, and the Marne and Saunders rivers enter this section from the Eastern Mount Lofty Ranges in SA.
Lower Swamplands	From Mannum, past Murray Bridge and Tailem Bend to Wellington.	In this Section, the river flows through areas that formerly had extensive riparian swamps, but are now reclaimed for agriculture (or shacks) and protected by levees planted with willows (*Salix* spp.). Reedy Creek flows into this section and there are no in-channel weirs.
Eastern Mount Lofty Ranges Watershed	Eastern Mount Lofty Ranges PWRA and Marne-Saunders PWRA.	This section incorporates the perennial and ephemeral streams within the region defined by the Prescribed Water Resources Areas (PRAs) for the Eastern Mount Lofty Ranges and the Marne-Saunders.
Lower Lakes Section	The sit between Wellington and the Coorong.	Here, there is a shallow 'freshwater' lake system with marginal wetlands and adjacent ephemeral saline ponds—Lake Alexandrina and Lake Albert. The Lower Lakes are isolated from the Murray Mouth and Coorong by a system of five barrages (Goolwa, Mundoo, Boundary Creek, Ewe, and Tauwitchere) which connect the various islands in the southern section of Lake Alexandrina.
Murray Mouth and Coorong	Terminus of the River Murray (and the end-of-system for the entire MDB). The Coorong stretches for 100 km and consists of two permanently inundated coastal saline lagoons.	This section represents the estuarine component of the River Murray (and MDB). The Murray Mouth ranges from a partially mixed to a salt-wedge (stratified) estuary, with salinities 'typically' lower than sea water. The Coorong is considered a 'reverse estuary', with salinities higher than seawater. It is comprised of the North (hypermarine) and South (hypersaline) lagoons. This section also includes associated islands and coastal sand dune systems, and several ephemeral coastal lakes to the south of the South Lagoon. Historically, prior to drainage, these lakes formed part of the South Lagoon during periods of high flow or high water (see England 1993). This section also includes Salt Creek, which drains into the South Lagoon.

CLIMATE

Key Points on Climatic Context of the RMDS EC

- The EC has an underlying Mediterranean-type climate (i.e. hot dry summers, cool wet winters)
- Long-term climate trends for the EC are masked by natural variability and interdecadal cycles, with overarching climate change trends/impacts (i.e. warming and drying, plus extreme events)
- Climate change is likely to lead to increased evapotranspiration, seasonal rainfall changes and more severe droughts throughout the MDB, which on balance, is likely to reduce water availability to the EC into the future
- Water-temperature tends to correspond to seasonal air temperature (average surface water range 7–30°C) and is increasing under climate change
- Smaller more frequent floods (induced by rainfall and runoff) and larger less frequent floods are critical to maintaining the RMDS, but this is shifting with climate change (on top of water regulation)

The climate of the RMDS EC is heavily influenced by the prevailing climate of the entire Murray-Darling Basin (MDB), particularly that of the Southern Basin. Climate of the MDB is characterised by extremely variable annual rainfall, leading to variable river flows; this includes, at times, large floods and widespread droughts. Long-term trends in the climate across the RMDS are masked by interdecadal cycles (e.g. the 'wet' 1950s and the 'dry' 2000-2010). The variable and unpredictable nature of climate in the MDB is further exacerbated by the impacts of climate change, including an unpredictable and increasing occurrence of extreme events (Dowdy et al. 2019). Overall, the MDB has warmed by around a degree since 1910, with more warm days, fewer cold days, and greater evapotranspiration (Whetton & Chiew 2021; Zhang et al. 2024).

Occurring across a semi-arid region, the ecological community historically had a more pronounced seasonal pattern of winter-dominant rainfall in the south, including the Eastern Mount Lofty Ranges (Young 2001; MDBA 2010b; SAMDBNRM Board 2010a). Spring and summer together may receive up to half of the annual total rainfall (Schwerdtfeger and Grace 2009). However, there is strong agreement that climate change has resulted in a long-term trend of warming and drying over the region of the RMDS, with increased potential for extreme events and severe wildfire (Lawrence et al. 2022). This was particularly evidenced by the Millennium Drought (1997-2010). Overall, the pattern and seasonality of rainfall has changed (Evans et al. 2016; Peterson et al. 2021; Lawrence et al. 2022).

HYDROLOGY

Key points on Hydrology of the RMDS EC

- Historically hydrology is fed by winter-spring rainfall (and snow-melt)
- RMDS occurs in a semi-arid zone, with relatively low run-off and high evaporation
- Long-term average discharge of River Murray estimated as 12 600 GL (CSIRO 2008; Local discharge is typically low and highly variable)
- Limited tributaries; strong influence from mid-Murray, with typically lower but intermittent influence from Darling River
- Smaller more frequent floods (induced by rainfall and runoff) are critical to ecology
- Groundwater recharge is important to the EC, and in particular the Coorong's South Lagoon
- Seasonal hydrological cycles are being impacted by climate change
- Regulated by 10 locks (built 1022-1935) and 5 barrages near Mouth (built 1935-1940)
- Since 2008

The River Murray system is fed mainly by winter-spring rainfall and snow-melt (Jacobs 1990; Hart et al. 2020). Water is carried from a wet, high rainfall zone in the southeast, westerly through a semi-arid zone that contributes comparatively little run-off (Zhang et al. 2024). Most of the rainfall is evaporated from the land surface or transpired by vegetation. An exception is the region of River Murray above Albury, NSW, which has a 500 mm annual rainfall isohyet (BoM 2024); this is the source of most of the surface water in the ecological community (Walker 1986, 2006).

DISCHARGE

The Murray's annual discharge is highly variable and generally low compared with rivers of similar catchment areas (Jacobs, 1990). The long-term annual average natural flow in the River Murray is around 12 600 GL (CSIRO 2008), with flows as low as 3000 GL or less in dry years, and up to 57 000 GL in very wet years (Jacobs 1990; MDBC 2003 in MDBC 2006a; *MDBA update to come*).

FLOW

The area of the River Murray that the ecological community inhabits has no 'major' tributaries, and its hydrographic behaviour is usually determined by flows from the middle and upper River Murray rather than from the Darling River (CSIRO, 2008). In an average year, the Darling contributes only about 10 % of water in the Murray (Eastburn 1990); although, in years where strong flood events occur the Darling does deliver significant flow.

The ecological community is unique within the MDB in this respect, i.e. historically (pre-regulation) the area it inhabits received both relatively regular, but relatively small volume flows from the Murray and relatively infrequent and unpredictable, but large, flows from the Darling. This multi-year mixed flow regime has been, and continues to be, an important contributor to the unique ecology of the ecological community's biota.

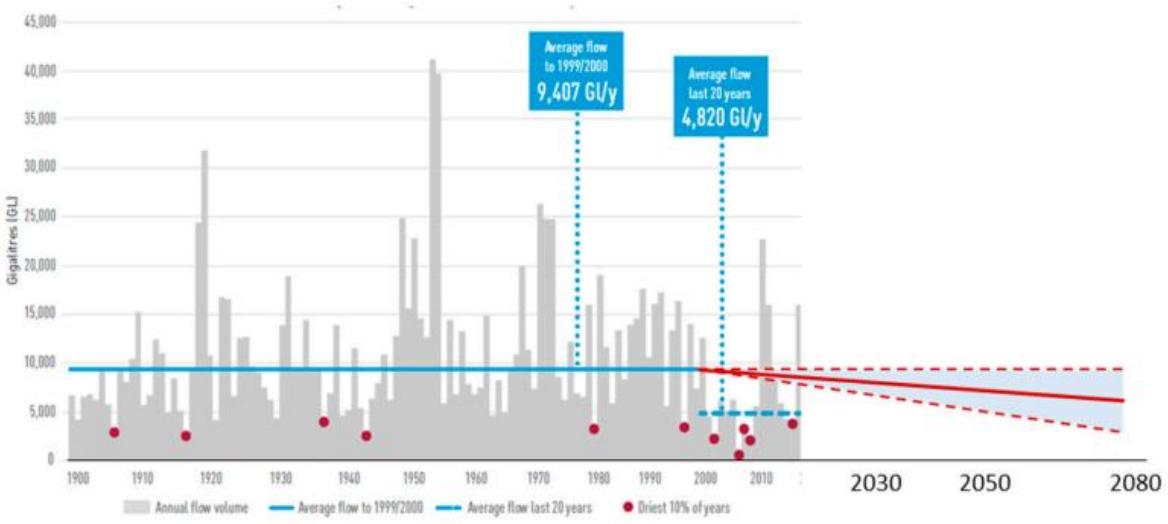

Figure 1: Annual time series of stream flows to the Murray River, showing the high inter-annual and multiyear variability, with projected changes in annual average streamflow under 2 °C global average warming (RCP8.5) climate change. Projections are for the median, 10th, and 90th percentile results from hydrological modelling of climate change from 42 CMIP GCM (Prosser et al. 2021; DEWLP, BoM, CSIRO, University of Melbourne 2021). (*MDBA update to come*)

The Murray's highly variable flow regime includes an unpredictable pattern of highs and lows. Over the past 100 years or so, there have been significant changes in climate, with dry and wet periods at decadal scales, and a series of significant droughts and floods (Zhang et al. 2024; see Figure 1). In the latter part of the 20th Century, river flow was dominated by low flows (<5000 ML/day) owing to intensive regulation (Walker & Thoms 1993; Maheshwari et al. 1995). Since 2001, there has been a significant reduction in stream flow due to a decline in cool season (April to October) rainfall, which is partly attributed to climate change (Zhang et al. 2024).

The waters of the River Murray are managed for various uses, including irrigation, industry, communities, the environment, and meeting South Australia's flow entitlement. The various flow components are determined by demand and water availability, amongst other factors (Figure 2).

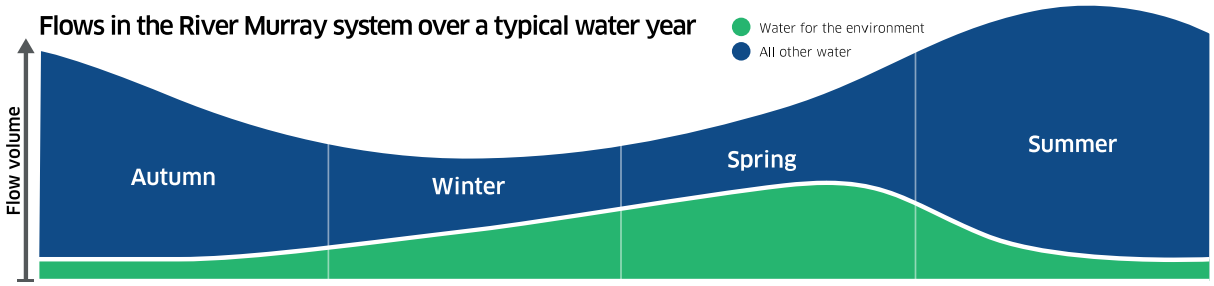

Figure 2: Indicative water flow management throughout the seasons across a typical year (source MDBA 2024).

During the irrigation season, the regulated flow released from Lake Hume to the Murray is about 25 000 ML/day. In winter, when water is being stored, this is reduced to about 1200 ML/day (Mackay & Eastburn 1990; *MDBA update to come*). Moderate to high flows (i.e. >20 000 ML/day) are little affected by regulation because the river overflows the weirs. Ecologically, the most significant changes to the natural flow pattern have been the reduction in the frequency of low to moderate in-channel flows (e.g. 5000 to 20 000 ML/day) (TSSC 2010).

Flows to the Lower Lakes and Coorong

The water regime of the Lower Lakes and Coorong is primarily dependent on inflows from the River Murray, with minor contributions from other sources such as the eastern Mount Lofty Ranges, upper south-east drainage network, and groundwater; this is moderated by evaporation, operation of the barrages, and tidal forces (Gibbs et al. 2018). In turn, the duration, timing, and frequency of inundation greatly influence the availability of habitat, presence of biodiversity, and ecological functionality (Phillips & Muller 2006).

Most freshwater input to the Coorong occurs through the barrages in the North Lagoon which combined with Southern Ocean tides, results in the system acting as an inverse estuary. The North Lagoon is a 'hypermarine' estuary, while the South Lagoon is a 'hypersaline' estuary (TSSC 2009). The South Lagoon receives smaller volumes of fresh to brackish water from the network of drains culminating at Salt Creek (Gibbs et al. 2018). Historically, excess water from the south-east flowed north-west to the South Lagoon—via groundwater to Morella Basin and Salt Creek, and via surface waters along the ephemeral coastal lakes. These sources had a significant effect on the water chemistry of the South Lagoon (Coleman in press). However, due to extensive

drainage works from the 1860s, this input transitioned to just negligible flows along Salt Creek by the late-1940s (England, 1993). Since 2006, efforts have restored a small portion of these historical flows (Gibbs et al. 2018).

INFLUENCE OF THE DARLING RIVER

The *River Murray—Darling to Sea* EC has been influenced over time by flows from the Darling River (in particular, the Lower Darling—*Baaka* River, LDR), despite it contributing only about 10% of the long-term mean discharge (Maheshwari et al 1995). The Darling is typically highly turbid owing to colloidal clays (Walker 2006), while the Murray is typically much clearer. The mixing of these two water bodies over paleo-history has influenced the biota and geo-chemistry, which are uniquely different from those of the parent rivers (Walker 2006; TSSC 2010).

Since around 2000, the hydrology of the LDR has been transformed from a naturally near-perennial flowing system to an intermittent one (Stuart & Sharpe 2022). This has resulted from increased water abstraction, prolonged periods of drought, and climate change. The significant hydrological change has placed immense pressure on biota, particularly native fish populations, as evidenced by the catastrophic 2018–2019 fish kills (AAS 2019; Vertessy et al. 2019; Stocks et al. 2022; Stuart & Sharpe 2022). This has important flow-on effects to the EC.

RIVER REGULATION

The River Murray is highly regulated. Ten weir and lock structures or 'locks' (from Lock 1 at Blanchetown, SA to Lock 10 near Wentworth, NSW) and various levees and off-stream regulators are used along the length of the ecological community (Table 4). The locks were built progressively between 1922 and 1935 and have resulted in this stretch of the Murray becoming a series of stable weir pools.

Table 4: Locks and Weirs along RMDS EC (Lock 1–10) and State of occurrence and operator.

Lock & Weir	Location	River distance from Murray Mouth (km)	Distance from last Lock (km)	Elevation at Full Supply Level (m)	Typical head distance (m)	Year	State op.
1	Blanchetown	274	-	3.3	2.5	1922	SA
2	Waikerie	362	88	6.1	2.8	1928	SA
3	Overland Corner	431	69	9.8	3.7	1925	SA
4	Bookpurnong	516	85	13.2	3.4	1929	SA
5	Renmark	562	46	16.3	3.1	1927	SA
6	Murtho	620	58	19.2	2.9	1930	SA
7	Rufus River	697	77	22.1	2.8	1934	SA
8	Wangumma	726	29	24.6	2.5	1935	SA
9	Kulnine	765	39	27.4	2.8	1926	SA
10	Wentworth	825	60	30.8	3.4	1929	NSW
11	Mildura	878	53	34.4	3.7	1927	VIC

The weirs have little effect on through-flow but exert a major influence on water-level variability in the channel and on connectivity with floodplain wetlands and woodlands (Walker 2001; Walker 2006; Hart et al. 2020). Consequently, the river channel associated with the ecological community has progressively developed a stepped gradient, with deposition of sediments above each weir and erosion downstream (Thoms and Walker 1992; Walker and Thoms 1993). Such changes have resulted in the infilling of deeper pools and scour holes, which combined with extensive removal of snags and erosion, have led to simplification of habitat diversity in the river channel (MDBC 2006a).

In addition to the ten locks, construction of five barrages (and two further locks) at the Murray Mouth (i.e. Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere) occurred between 1935 and 1940 (Sim and Muller 2004). South Australia was concerned with the Lower Lakes being brackish when flow in the Murray was insufficient (in the face of upstream diversions) to meet evaporation losses from the Lakes (Jacobs, 1990) and prevent seawater intrusion (Chiew et al. 2020). The barrages were aimed at preventing ocean intrusions and allowing local landholders to further utilise the fresh lake water for irrigation.

MURRAY MOUTH

During periods of high flow, the morphology of the river mouth is dominated by fluvial processes (Bourman & Harvey 1983). During periods of low flow, marine processes dominate, and a flood tide delta develops inside the river mouth. This delta can develop to the extent that the mouth becomes severely restricted by sand deposits (Goode & Harvey 2009). Water extraction related to development and agriculture across the MDB has reduced flow through the Murray Mouth, and the barrages have reduced the volume of water passing into and out of the mouth under the influence of ocean tides (Jacobs 1990; DEW 2023b). Models suggest that the end-system flow of the MDB has been reduced by an estimated 61% in the last 100 years by water regulation upstream, leading to a situation in which water ceases to flow at the mouth of the River Murray 40% of the time (CSIRO 2008; *MDBA update to come*).

The Murray Mouth closed completely for the first time on record in April 1981, after there was no flow through the barrages for 196 days; dredging was required to re-connect the river to the sea (Bourman & Harvey 1983; Goode & Harvey 2009; DEW 2023b). During the 1982–83 drought, there was no flow past the barrages for a year and a half, which was much longer than the period of zero flow prior to its closure in 1981, yet the mouth did not close. This demonstrates that sea and tidal conditions, and prevailing winds also play an important part in keeping the Murray Mouth open. A continuous barrage release of about 2 GL per day is needed to assist in maintaining an open Mouth; much larger volumes are required to produce a scouring effect to remove sand build-up (Bourman et al. 2018).

During the Millennium Drought, dredges were used from 2002 to 2010 continuously to keep the Murray Mouth open (Paton 2010). Two dredges also operated from January 2015 to October 2022, ceasing due to the 2022/23 floods. Operations, using one larger dredge, recommenced in November 2023 and continued to at least August 2024 (DEW 2024a).

GROUNDWATER

Currently, groundwater accounts for about 13% of total water use in the MDB, with an increasing trend in depth to water table (Rojas et al. 2022). Groundwater in the region of the ecological community originates from a geological basin known as the Murray Groundwater Basin. This basin has three main aquifer systems: the Renmark Group (confined aquifer of Eocene age), the Murray Group Limestone aquifer (Oligo-Miocene age), and the Pilocene Sands

unconfined aquifer (Barnett 2015). These aquifers are mainly recharged in the high rainfall areas toward the basin margins, with groundwater flowing under low hydraulic gradients along extended flow paths before discharging to the River Murray, either by upward leakage from confined aquifers or direct hydraulic connection from the water table aquifers (Barnett 2015).

Groundwater salinities generally increase downgradient from the recharge areas where they are below 1000 mg/L (Barnett 2015). Where groundwater discharges to the river, salinities are often over 20 000 mg/L which can add significant salt loads. The aquifers of the Murray Groundwater Basin are relatively thin and do not drain directly to the sea, therefore filling rapidly in geologic terms (2000–3000 years) (Schwerdtfeger and Grace 2009; MDBA 2010b). This geology, combined with changed groundwater tables associated with clearing, irrigation, and weirs, has led to extensive salinisation of the riverine floodplains in the region of the ecological community which can be problematic for salt-sensitive biota (Young 2001). In effect, the salt is stored in the floodplain soil rather than being flushed out to sea.

Groundwater makes a significant contribution to the baseflow of many of the Eastern Mount Lofty Ranges streams that form part of the ecological community, i.e. these are 'groundwater dependent' systems (SAMDBNRM Board 2010a). Groundwater inflows are also ecologically significant to the Coorong. The almost continuous soaks along both sides of the Coorong provide drinking water to birds, as well as breeding and refugia sites for fish during drought conditions. Relatively fresh groundwater is an important water source for river red gums on the Chowilla floodplains (Thorburn & Walker 1993) and locally elevated groundwater (i.e. due to weirs) can impact the water regime of nearby wetlands (Lloyd et al. 1994).

There are likely stygofauna assemblages associated with groundwater in the ecological community, however knowledge remains limited (Van Laarhoven & Van der Wielen 2012; Goonan et al. 2015; Sacco et al. 2022). Stygofauna are (typically blind) animals that live in dark underground waters, such as aquifers; they are generally small aquatic invertebrates, like crustaceans, worms, snails, and insects, and occasionally fish. These organisms are crucial to oxygenic aquifers, contribute various ecosystem services (e.g. water quality, hydrological flow, etc.), and are highly vulnerable to disturbance (Goonan et al. 2015; Becher et al. 2022; Hose et al. 2022).

Consultation Questions on the location, physical environment, climate, and hydrology of the RMDS Ecological Community:

- Do you have any feedback regarding this section, including the boundaries and groundwater buffer zones of the RMDS EC, as provided?
- More recent data and trend analysis will be available and will be incorporated when Murray-Darling Basin Plan reports are released soon. In addition to that, do you have any information, diagrams, analyses, or publications that may be relevant, and up-to-date, especially for the climate and hydrology components of this section? If so, could you please provide this with your response.
- Please note that 'climate change' impacts, river regulation and changes in hydrology will be considered further under the Threats and Criteria assessment sections.

1.2.2 Description of the assemblage of species

Overviews of the major components of the microbiota, plants (flora) and animals (fauna) that form the native assemblages of the ecological community are provided in the sections below, along with appropriate reference sources. Further species lists for some taxonomic groups are provided in Appendix B. More comprehensive species lists and related survey information for these and other flora and fauna taxa that are likely to occur within the ecological community may be found in: MDBC (1990, veg. only); Foulkes & Gillen (2000); Brandle (2002); Moise & Milne (2010); Stewart et al. (2010, Murray River Valley); Nicol (2012, veg. only); Smith & Kenny 2005 (veg. only); Smith & Smith 2014 (veg. only); Mosley et al. 2018, CLLMM only).

VEGETATION (FLORA)

Overview of Vegetation Sections

- **Floodplain to channel vegetation**
  - Floodplain & riparian
  - Wetland
  - Aquatic riparian and channel
- **Eastern Mount Lofty Ranges**
  - Floodplain, riparian & aquatic vegetation
- **Coorong and Lower Lakes vegetation**
  - Coastal shrubland of the Coorong and dunes
  - Riparian
  - Aquatic
    - Coorong
    - Lower Lakes

Floodplain to channel vegetation

Floodplain and riparian vegetation

Although there are well over 300 native plant species recorded on the River Murray floodplain (Newall et al. 2009; Gehrig & Nicol 2010), the overstorey vegetation is typically dominated by two tree species:

- *Eucalyptus camaldulensis* (river red gum), which may occur in several forms (Bren 1990; McDonald et al. 2009), such as: extensive forests in more frequently flooded areas; smaller, 'river red gum swamps'; sparse woodland; or a fringing band of trees along the river banks and foreshores. The latter two forms are most commonly represented within the ecological community.

- *Eucalyptus largiflorens* (black box), which forms woodlands on the higher, outer parts of the floodplain of the RMDS, but is rarely dominant (Smith & Smith 1990).

- *Acacia stenophylla* (river cooba) is another important canopy species in some areas on the floodplain of the EC.

The understorey, shrub layer, and ground layer vegetation of the ecological community exhibits considerable variation, both along the river and across the floodplain, depending on varying habitat types. Floodplain terrestrial habitats generally range from forest and woodland, through to shrubland, herbland, and grassland areas. Detailed information on river red gum and black box understorey vegetation is provided at Appendix B, Table B1.

The understorey of the river red gum zone is generally herbaceous, with chenopods (saltbushes) also typical and intergrading with *Duma florulenta* (syn. *Muehlenbeckia florulenta*; tangled lignum) shrubland. Common ground layer species include *Cyperus gymnocaulos* (spiny flat-sedge), *Setaria jubiflora* (warrego grass), *Senecio cunninghamii* (branching groundsel) and *Enchylaena tomentosa* (ruby saltbush, shrubby form) (Nicol 2012; Smith & Smith 2014; Kilsby & Steggles 2015; Nicol et al. 2020).

Black box woodland typically occurs on higher areas of the floodplain and has a lower and more open canopy than river red gum. The understorey in a black box woodland is generally shrubby, with three plant families dominating the ground layer: grasses (Poaceae), daisies (Asteraceae) and saltbushes (Chenopodiaceae). Some common species include river cooba, lignum, *Atriplex rhagodioides* (river saltbush) and *Disphyma crassifolium* ssp. *clavellatum* (rounded noon-flower) (Nicol 2012; Smith & Smith 2014; Kilsby & Steggles 2015). Dryland floodplain habitats periodically become aquatic systems depending on flow magnitude and duration, and their elevation (DEH 2010; Holland et al. 2013; Smith & Smith 2014; Kilby & Steggles 2015; Nicol et al. 2020, 2021, 2023).

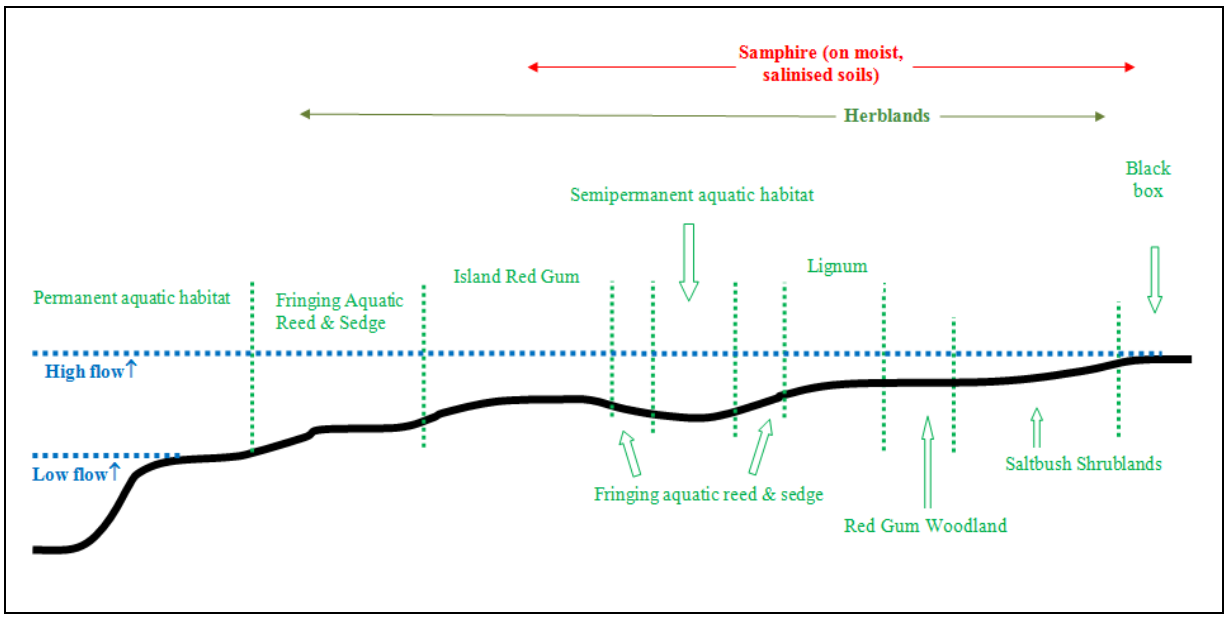

Figure 3: Conceptual model of habitat types and hydrological regime for the Riverland Ramsar site, broadest floodplain areas within the ecological community (Lance Lloyd in TSSC 2011).

The landscape of the Riverland Ramsar site (i.e. Chowilla floodplain) provides a good example of the variation in floodplain vegetation in the ecological community. The major vegetation types on the floodplain form three main categories: terrestrial (woodland, shrubland and ground layer), edge/emergent (i.e. 'riparian), and submerged. Figure 3 provides a conceptual diagram of these key vegetation components and Table 5 provides an indicative list. Further information and a list of species is provided at Appendix B, Table B1.

Black box and river red gum are considered keystone species for riverine ecology at the Riverland Ramsar site, although other trees or tall shrubs occur here also, such as river cooba, *Melaleuca* spp., *Myoporum* spp. (boobialla) and *Callitris preissii* (Murray pine). Vegetation of the islands in this region are also biodiverse and key habitats (Gehrig & Nicol 2010; see Appendix B, Table B1), hence areas on islands dominated by native vegetation are an important part of the ecological community.

Table 5: Indicative floodplain and riparian vegetation types of the Riverland Ramsar site/ Chowilla Floodplain Icon Site (DEH 2010; Nicol et al. 2020, 2021, 2023).

Vegetation Type	Species-complex
Terrestrial (no permanent inundation)	**Black box** (*Eucalyptus largiflorens*) woodland with either ephemeral forb/grass, chenopod shrubland (e.g. *Atriplex*, *Sclerolaena* spp.) or pigface (e.g. *Disphyma crassifolium* typical in the understorey, and at times lignum (*Duma florulenta)*
	River red gum (*Eucalyptus camaldulensis*) forest and/or woodland with a low open understorey of either shrubs (e.g. *Duma florulenta*, *Enchylaena tomentosa*, *Chenopodium nitrariaceum*, *Eremophila divaricata*), forbs, sedge and grass, or floating freshwater herbland species
	Lignum (*Duma florulenta*) shrubland with possibly sparse river red gum, black box and river cooba (*Acacia stenophylla*), and/or an understorey of herbland, grassland or chenopod species
	Chenopod shrubland (medium to low height) *Atriplex rhagodioides* (river saltbush), *Atriplex* spp., (saltbush), *Sclerolaena brachyptera* (short-wing saltbush), *S. divaricata* (tangled copperburr), *S. stelligera* (star copperburr), *Tecticornia triandra* (desert glasswort), *T. pergranulata* (black-seeded samphire), *Halosarcia* spp. (samphires)
	Herbland *Calocephalus sonderi* (pale beauty-heads), *Disphyma crassifolium* (round-leaf pigface), *Lepidium* spp. (peppercress)
	Grassland *Vulpia* spp. (fescue), *Sporobolus mitchellii* (river couch)
	Bare soil – devoid of vegetation (16% of sites in 2021)
Edge/emergent (intermittently to permanently inundated wetlands, creeks and billabongs)	**Fringing vegetation** – particularly common reed *(Phragmites australis*), spiny sedge (*Cyperus gymnocaulos*), cumbungi (*Typha domingensis*) and bulrush (*Typha orientalis)*.
Submerged (perennially to permanently inundated wetlands)	**Fully aquatic species** – red milfoil (*Myriophyllum verrucosum*), ribbonweed (*Vallisneria australis*).

Although broader than the RMDS EC, an extensive list of vascular plant species surveyed from 1990-2003 in the Murraylands and Riverland regions, is provided by Jennings et al. (2009), with a more recent list in Nicol et al. (2022) for the Chowilla Floodplain.

Wetland vegetation

Wetlands fringing the river historically contained dense expansive and permanent stands of macrophytes. Ephemeral wetlands and swamps associated with the ecological community are frequently characterised by native perennial shrubs such as lignum, and chenopods such as

Atriplex nummularia (old-man saltbush) and *Enchylaena tomentosa var tomentosa* (ruby saltbush) (Sainty and Jacobs 1990; Gehrig & Nicol 2010: and see Appendix B, Table B1).

Where water levels fall sufficiently to allow light penetration, aquatic/semi-aquatic plants such as species of *Marsilea* (nardoo), *Pilularia* (pillwort), *Glossostigma* (glosso), as well as *Eleocharis acuta* (common spike rush), *Leptochloa fusca* (beetle grass), *Cyperus* (sedge) and *Alisma* (water plantain) colonise, usually completing their life cycle on the drying mud (Sainty and Jacobs 1990; and see Appendix B, Table B1). Free floating species of *Azolla* (mosquito fern) and Lemnaceae (duckweed) are also common, as is *Ceratophyllum* spp. (hornwort).

Alongside the Murray channel components of the ecological community, floodplain wetlands are generally subject to controlled flows. Free-floating and emergent aquatic plants benefit more from this regulated system, i.e. compared to the submerged aquatics. Only perennial wetlands near the Murray channel allow the growth of some submerged aquatics, e.g. *Ceratophyllum* spp. (hornwort), *Potamogeton crispus, Vallisneria australis*, *Myriophyllum* spp. (Sainty & Jacobs 1990; Walker 2006; Grehig & Nicol 2010).

Aquatic riparian and channel vegetation

In its now highly regulated form, the River Murray channel and fringes are currently a series of weir pools separated by river sections with lower average velocities and less fluctuation in depth. Still-water plants that thrive in soft sediments and prefer to be constantly, but only partially, submerged have proliferated since weir construction; this being influenced by increased sedimentation and impoundment (Sainty & Jacobs 1990; Walker et al. 1994; Blanch 1997; Jacobs in Young et al. 2001; Walker 2006).

Walker et al. (1994) found a broad correlation between the composition of the plant assemblages and the distance below a weir (hence the amplitude of water level fluctuation). Downstream of each weir, where water levels change rapidly and the sediments are unstable, there is little permanent vegetation. In contrast, the middle reaches of weir pools are fringed by dense stands of *Phragmites australis* (common reed) and *Typha domingensis* (cumbungi), while further downstream, where water levels are held steady by the next weir, dense stands of non-native willows (*Salix* spp.) often overhang the water (Schulze & Walker 1997). The weir pools also encourage a persistent presence of species that lay across the surface, such as *Cotula coronopifolia* (water buttons), *Azolla rubra* (red azolla), *Lemna disperma* (common duckweed), *Vallisneria australis* (ribbonweed) and *Cycngeton procerum* (water ribbon) (Blanch 1997; Australian Virtual Herbarium, accessed 18/04/2024).

Emergent species such as *Phragmites australis* (common reed) and *Typha* spp. (cumbungi or bulrush) tend to occur in the uppermost 0.5 m, and rooted species like *Myriophyllum* (milfoil) occur down to about 2 m (Walker et al. 1994). Species less tolerant of variable flow, such as *Persicaria decipiens* (slender knotweed), have increased in abundance where water levels are held constant for extended periods (Jacobs in Young et al. 2001). *Cyperus gymnocaulos* (spiny sedge) and *Paspalidium jubiflorum* (Warrego summer grass) are tolerant of full exposure so may occur high on the river-bank (Young et al. 2001; Smith & Smith 2014).

Eastern Mount Lofty Ranges floodplain, riparian, and aquatic vegetation

The Mount Lofty Ranges have a recent history of intensive land use, including urban development, agriculture, forestry, with some mining, and have been extensively cleared (Mitchell 1983; Paton et al. 2004). The natural (i.e. remnant) habitat of the mountainsides of the Eastern Mount Lofty Ranges (EMLR) is woodland of eucalypt tree species (e.g. river red gum, *E. paludicola, E. obliqua*, *E. baxteri, E. fasciulosa* (pink gum), *E. cosmophylla* (cup gum)) mixed with

Acacia pycnantha (golden wattle) trees on the lower slopes, all with an undergrowth of shrubs and herbs (Davies 1992; Bonifacio et al. 2016). There are hundreds of plant species across the EMLR and these can be categorised into three broad groupings, with ten functional types (see Vanlaarhoven & van der Wielen 2012). Noting that only native dominated vegetation forms part of the RMDS ecological community, the three broad groups are:

- terrestrial species associated with waterways and wetlands (i.e. riparian) - many are annual herbaceous species and a large proportion of exotic weeds such as grasses and clovers that are often associated with watercourses
- amphibious species that require or tolerate the presence of surface water at some stage of their life cycle - e.g. various species of *Cyperus, Elatine*, *Eleocharis, Eucalyptus, Glossostigma*, , *Isolepis*, *Juncus, Lemna, Leptospermum, Melaleuca, Myriophyllum, Nymphoides, Persicaria*, and
- submerged species that require extended periods of free surface water - various species of *Azolla, Bolboschoenus, Chara, Lepilaena, Nitella, Phragmites, Potamogeton, Triglochin procera, Typha, Vallisneria.*

Coorong and Lower Lakes vegetation

The vegetation types of the Coorong and Lower Lakes are well documented in the area's natural histories, including Noye (1975), Gilbertson & Foale (1970), and Mosley et al. (2018). In addition, online databases such as the Australian Virtual Herbarium and citizen science platforms such as iNaturalist hold much related information on plant species in this region. See also Appendix B, Table B1.

Coastal shrubland of the Coorong and dunes

Occurring on the coastal dunes of the Younghusband Peninsula, rolling spinifex (*Spinifex hirsutus*) is significant in establishing the fore-dunes and other mobile dunes (i.e. on the seaward side of the Coorong) (Paton, 2010). Secondary colonisers include rushes (e.g. *Ficinia nodosa,* knobby club-rush), creeping succulents (e.g. *Carpobrotus* spp., native pigface), and scattered shrubs. On protected slopes of the dunes there is a moderately dense coastal scrub, typically 2–3 m tall; typical species in these areas are listed in Table 6. Many of these coastal dune plants produce fleshy fruits that are consumed and dispersed by frugivorous birds (mainly over summer, see Table 6). The parasitic species *Amyema melaleucae* (tea-tree mistletoe) colonises melaleucas, particularly *Melaleuca halmaturorum* (South Australian swamp paperbark), in the Coorong and has fleshy fruits that attract birds for dispersal.

Over the last six decades, the vegetation on the Younghusband Peninsula has become more extensive, as the site recovers from being used for grazing prior to the area being declared a national park (Da Silva et al. 2024).

The shorelines of the Coorong include extensive sandy beaches, muddy bays, and samphire shrublands. The Coorong's samphire-dominated coastal saltmarshes are of unique value compared to many others around Australia, and form part of another EPBC Act listed EC (see Section 5). This is due to them experiencing a comparative delay in the effects of sea-level rise—

Table 6: 'Indicative' vegetation prominent in coastal dune areas around the Coorong, including Young Husband and Narrung peninsulas (after Paton 2010; Jellinek et al. 2018; Coleman & Coleman 2024). *Fleshy-fruited species often consumed by frugivorous birds.

Dune Plant Species	Common Name
Acacia longifolia subsp. *sophorae*	coastal wattle*
Acaena nova-zealandiae	bidgee-widgee
Adriana quadripartita	coast bitter-bush
Allocasuarina verticillata	drooping sheoak
Alyxia buxifolia	sea box
Amyema melaleucae	tea-tree mistletoe
Carpobrotus rossii	karkalla
Carpobrotus spp.	native pigface
Clematis microphylla	small-leaved clematis
Dianella brevicaulis	native flax-lily
Eucalyptus diversifolia subsp. diversifolia	coastal white mallee
Exocarpa syrticola	coast cherry
Ficinia nodosa	knobby club-rush
Kunzea pomifera	muntrie
Leucophyta brownii	cushion bush
Leucopogon parviflorus	coast beard-heath*
Melaleuca halmaturorum	SA swamp paperbark
Melaleuca landceolata	moonah
Muehlenbeckia gunnii	coastal lignum
Myoporum insulare	common boobialla*
Olearia axillaris	coast daisy-bush
Ozothamnus turbinatus	coast everlasting
Pimelea serpyllifolia subsp. seryllifolia	thyme rice flower
Nitraria billardierei	nitre-bush
Rhagodia candolleana	seaberry saltbush*
Spinifex hirsutus	rolling spinifex
Sporobolus virginicus	salt couch
Tecticornia arbuscula	shrubby samphire
Tecticornia pruinosa	waxy samphire
Tetragonia implexicoma	bower spinach*

a result of tidal restriction at the mouth and the length of the lagoons (although some dieback is still occurring) (Coleman et al. 2017; Coleman & Coleman 2024).

Samphires known to be around the Coorong and/or Lower Lakes include (Phillips & Muller 2006; Nicol et al. 2018; AVH accessed 18/4/2024; Appendix B, Table B1):

- *Tecticornia arbuscala* (shrubby samphire), *T. pergranulata* (black-seed samphire), *T. indica* (brown headed samphire), *T. syncarpa* (fused or bracelet samphire), *T. halocnemoides* (grey samphire), *T. lepidosperma* (sea beans or white-seed samphire)
- *Salicornia quinqueflora* (bearded glasswort), *S. blackiana* (big-headed glasswort), and
- *Suaeda australis* (Austral seablite; note, in irrigated areas this is sometimes known as a salinity indicator plant, 'redweed').

The riparian vegetation around the Coorong and Lower Lakes is characterised by saline tolerant species, with localised areas of emergent freshwater species (e.g. cumbungi, common reed) where fresh groundwater discharges occur along the shoreline. For example, around the Coorong in low-lying areas of the swales, there are dense patches of sedgeland, consisting of *Lepidosperma gladiatum* (coast sword-sedge), and creeping carpets of *Kunzea pomifera* (muntries), and on the broader flats there is often a band of *Gahnia filum* (smooth cutting-grass) with tussocks of *Austrostipa stipoides* (coast spear-grass) that are displaced by halophytic plants, mainly samphires, next to the lagoon (Paton 2010; Jellinek et al. 2018).

Swampy areas of the Coorong and Lakes, such as drainage lines and depressions, support *Gahnia filum* (vulnerable) and *G. trifida* (endangered), which form sedgeland systems recognised as 'threatened' in South Australia (Phillips & Muller, 2006). The former prefers more saline areas, and the latter fresher creek habitats. Samphire vegetation and dense lignum shrublands also occur adjacent to the lakes, with scattered *Melaleuca halmaturorum* (swamp paperbark) woodlands also occurring around the lakes and islands (Gehrig & Nicol 2010).

Along both sides of the Coorong and in the dunes, there are a number of freshwater soaks that hold great cultural significance and also provide unique fresh–brackish habitats for unusual vegetation types. These often include a mix of terrestrial and aquatic plants, or species not found elsewhere in the Coorong (due to salinity stress); importantly, they provide water and food to wildlife (Young 1981).

Coorong and Lower Lakes aquatic vegetation

Aquatic vegetation (macrophytes), both submergent and emergent, are known to cool and clean water, reduce sediment-water interactions, and remove excess nutrients from the water column. These plants are also key habitat or food sources for many of native fish (particularly juveniles) and wetland birds (Merrick et al. 2003). Knowledge of the diversity of macrophytes within the ecological community is regarded as more limited than for terrestrial plants, and there are relatively fewer voucher specimens (Gehrig & Nicol 2010; Coleman in press). In turn, this has limited an understanding of baseline conditions (particularly pre-regulation) and hindered a detailed knowledge of the current state of aquatic vegetation—particularly in relation to rare species and reproductive material (F. Coleman pers. comm).

Aquatic vegetation of the Coorong

Historically, macrophytes (water plants) were recorded as a prominent feature of the Coorong. By the 1980s, *Ruppia* spp. (widgeon or tassel grass), *Althenia* spp. (syn. *Lepilaena*. long-fruit

water-mat) and *Lamprothamnium papulosum* (foxtailed stonewort) were still common (Geddes, 1987; Gehrig & Nicol 2010; Paton, 2010), but did not cover the large portion of deeper sediments they had prior to about 1978 (Coleman in press). Other species in the South Lagoon included *Acetabularia peniculus* (balloon-tops) and a range of other charophytes (calcifying macroalgae), filamentous green algae, and water felts; those of the North Lagoon included *Zostera mulleri* (seagrass) and (Geddes & Hall 1990; Phillips & Muller 2006; Gehrig & Nicol 2010; Paton 2010; Appendix B, Table B1).

The two main species of *Ruppia,* including *R. megacarpa* (large-fruit tassel) and *R. tuberosa* (tuberous tassel) historically provided a critical role in the food chain of the Coorong, particularly for waders, ducks, and other water birds, including migratory shorebirds (Nicol 2005a, b; Rogers and Paton 2009a, b). *Ruppia tuberosa* is still recognised as a keystone species in the Coorong (Asanopoulos & Waycott 2020). However, *Ruppia megacarpa and R. polycarpa* plants have not been officially recorded in the Coorong since the mid-1990s (Nicol 2005; Phillips & Muller 2006; Nicol et al. 2018; Waycott et al. 2022); although it has recently been found that some *R. megacarpa* seeds persist (Lewis et al. 2022).

The once dominant submerged aquatic macrophyte community of the Coorong central and South Lagoon (often referred to as 'southern Coorong') is currently recognised as a 'mixed' sub-community featuring, but not confined to, *Ruppia tuberosa* and *Althenia cylindrocarpa* (Asanopoulos & Waycott 2020; Waycott & Lewis 2022). Recovery of the 'Ruppia Community' since the Millennium Drought has been limited and variable, and the South Lagoon has switched to a system dominated by filamentous green algae and frequent phytoplankton blooms due to eutrophication (Collier et al. 2017; Brookes et al. 2018; Asanopoulos & Waycott 2020; Waycott et al. 2022; Lewis et al. 2022).

Aquatic vegetation of the Lower Lakes

Although historical evidence suggests Lakes Alexandrina and Albert once contained extensive macrophyte cover (e.g. Sturt 1833 p. 163), the open waters of the lakes are now generally devoid of plants, possibly due to wave action, depth, and increased turbidity (Gehrig & Nicol, 2010). Rather, submergent and amphibious plants are generally restricted to fringing wetlands, sheltered bays, the Goolwa Channel and the lower reaches of Currency Creek and the Finniss River. Examples include *Vallisneria australis*, *Myriophyllum* spp., *Ruppia* spp. and *Lepilaena cylindrocarpa*, cumbungi and common reed (Gehrig & Nicol 2010). Further examples are provided in Appendix B, Table B1.

Some aquatic plants, such as *Typha domingensis* (cumbungi or narrow-leaf bulrush) and *Phragmites australis* (common reed), have thrived in the still, turbid and relatively constant water levels of the lakes post barrage construction, whereas plants that require more variable water regimes or greater water clarity, are now be restricted to peripheral wetlands or tributaries.

Questions on Flora (Vegetation) species:

- This section of the *Draft Conservation Advice* aims to provide an indicative description of 'characteristic' plant species, within different components of the RMDS, with further species provided in Appendix B and/or through citations of existing references. However, do you know of other characteristic plants occurring within the RMDS EC that are not highlighted? If so, can you please provide details and reference sources to the Committee.
- Please provide any suggestions to clarify the vegetation description for the various components/habitat types.
- Can you comment on the currency of the inferences being made about the plants and vegetation in the description (i.e. are there more recent sources to incorporate)?

MICRO-BIOTA

Overview of Micro-Biota Section

- **Viruses, Bacteria, Fungi and Oomycetes**
- **Cyanobacteria**
- **Phytoplankton**
- **Zooplankton**

Overall, the composition and condition of planktonic assemblages underpin aquatic food webs across the range of aquatic habitats within the ecological community (e.g. Leterme et al. 2018).

Viruses, Bacteria, Fungi and Oomycetes

Viruses (femtoplankton), bacteria (picoplankton), fungi, and oomycetes serve vital roles in riverine and estuarine ecosystems, particularly in the decomposition of organic matter, nutrient cycling, and microbial food web processes (Janssen & Walker 1999; Young, 2001; Peduzzi & Luef 2008; Wuzbacher et al. 2011; Masigol et al. 2019). They can also be pathogens, causing disease in a range of aquatic organisms (e.g. Sarowar). Viruses, bacteria and fungi are commonly found on suspended particles (i.e. particulate organic matter), where they are often most abundant (Peduzzi & Leuf 2008; Leterme et al. 2018). In the Coorong, the salinity gradient has been shown to be a major driver of the distribution and composition of virus and bacteria sub-communities (Schapira et al. 2009; Leterme et al. 2018).

Recent research has highlighted the potential of water self-purification associated with virus-pathogen bacteria dynamics for water quality improvement (Chen et al. 2023). These micro-organisms have been little studied to date in the ecological community, despite their vulnerability to environmental and anthropogenic stressors (van Rossum et al. 2018). Such stressors could potentially lead to changes in species composition, abundance, and distribution, and therefore disruptions to ecosystem function.

Cyanobacteria

Cyanobacteria, also part of the picoplankton, are commonly known as blue-green algae. However, they are not a true alga, but rather, a photosynthetic bacteria. They form thick scum in clumps or filaments, and can often form significant surface blooms, which may be toxic to fauna (Leterme et al. 2018). Examples within the ecological community include various species of: *Anabaena*, *Nodularia*, *Microcystis*, *Cylindrospermopsis*, and *Oscillatoria* (Leterme et al. 2018).

Phytoplankton

Phytoplankton are typically single-celled (sometimes colonial) photosynthetic bacteria and protists that drive primary production and aquatic food chains. Major groups that occur in the freshwater River Murray and estuarine Coorong (i.e. the ecological community), are (Sullivan 1990; Young 2001; Nayar & Loo 2009; Aldridge et al. 2012a; Leterme et al. 2018):

- diatoms (with a siliceous cell wall), e.g. *Synedra, Nitzschia, Atheya, Rhizosolenia,* centrics, *Aulacoseira* (filaments), *Asterionella* (colonies)
- flagellates (independent movement by flagella), e.g. *Synura, Euglena, Trachelomonas, Cryptomonas, Rhodomonas*, and
- green algae (single cells to filamentous colonies of 'true' alga), e.g. *Ankistrodesmus*, *Planctonema, Scenedesmus.*

Surveys of the River Murray from 1980–1985 reported more than 150 algal taxa representing most freshwater classes, with 14 of these abundant (Sullivan 1990). More recently, surveys within the CLLMM region have collectively identified 185 phytoplankton species in 140 different genera, with 131 different taxa in the Coorong, alone (Leterme et al. 2018). The diversity and composition of the phytoplankton changes with season and with varying hydrological conditions, such as before and after drought (Sullivan 1990; Aldridge et al. 2012a; Leterme et al. 2018). In the Coorong, salinity is a major driver of phytoplankton biomass and species composition, with chlorophytes dominating fresh to low-brackish conditions, diatoms and dinoflagellates dominating higher salinities, and a transitory euryhaline population that comprises species found throughout the Coorong, irrespective of season and salinity (Jendyk et al. 2014; Leterme et al. 2015).

Historical analysis of phytoplankton distributions along the River Murray indicates there were four distinct regions based on species assemblages, of which one was the South Australian River Murray, including from the Darling River downstream to the mouth (Sullivan 1990), which equates to the ecological community.

Zooplankton (micro-invertebrate animals)

Zooplankton are microscopic animals inhabiting the water-column and littoral regions of aquatic environments (Leterme et al. 2018). Zooplankters graze and control resident phytoplankton and bacterial assemblages, and in turn are a primary food source for macroinvertebrates and fish (particularly larval fish) (Wedderburn et al. 2013; Leterme et al. 2018). Within the River Murray system, there are a high number of species (>500 species), although species diversity and population densities are much less in the main river channel than in the floodplain wetlands and billabongs (Shiel 1990, 2002; Leterme et al. 2018). For example, despite some endemism, most of the rotifers, copepods, and cladocerans are cosmopolitan species, widely distributed across Australia (Shiel et al. 1998; Shiel & Tan 2013; Furst et al. 2019).

Rotifers are the most diverse group of the River Murray (>250 species) although only about 10 species are widespread (Shiel et al. 1998; Leterme et al. 2018). On the floodplain, zooplankton communities of ephemeral pools tend to be distinct from those of permanent pools, such as billabongs (Shiel et al. 1998). In the fresh waters of the ecological community, major zooplankton components are (Shiel et al. 1982; Shiel 1990; Sheil 2010; Shiel & Tan 2013; Leterme et al. 2018):

- single-celled Protista (protozoans, e.g. the ciliate Coleps),

- Rotifera (rotifers, e.g. *Brachionus falcatus, B. novaezealandiae, Filinia australiensis*), and micro-crustaceans such as:
    - Copepoda (copepods, e.g. *Boeckella triarticulata*, *Boeckella* spp., *Calamoecia* spp.)
    - Cladocera (cladocerans or water fleas, e.g. *Daphnia lumholtzi*, *Bosmina meridionalis*)
    - Ostracoda (ostracods or seed shrimps)
    - juveniles of shrimps (*Caridina* spp., *Paratya australiensis*) and the prawn *Macrobrachium australiense*, and
- juveniles of other aquatic invertebrates (e.g. snails, worms, insects, etc.).

Within the ecological community (i.e. below the Murray-Darling confluence) there is a mixed zooplankton assemblage dominated by rotifers, with fewer cladocerans and copepods (Walker et al. 2009; Shiel 2010). The composition and dynamics of zooplankton reflect contributions from headwater rivers, mainly the Murray and its tributaries (i.e. reservoir/lake-like open water assemblage), with seasonal inputs from the relatively unimpounded Darling River (i.e. riverine assemblage) (Shiel et al. 1982; Neilson et al. 2005; Shiel 2010; Shiel & Aldridge 2011). The less regulated Darling River contributes a warm-temperate, rotifer-dominated riverine plankton (Walker et al. 2009).

Rotifers tend to dominate in waters of low 'age' (i.e. short retention time storages) and microcrustaceans (such as copepods, cladocerans and ostracods) tend to appear in waters of greater 'age' (i.e. long retention time storages such as lakes, dams, weirs and locks) (Leterme et al. 2018). This also is reflective of their respective life cycles, with rotifers reproducing in days and microcrustaceans in weeks (Leterme et al. 2018).

The zooplankton of Lake Alexandrina is typically dominated by freshwater copepods, cladocerans and rotifers, and is typically structured by turbidity (Geddes 1984; Shiel & Aldridge 2011). Conversely, of the 200 taxa recorded from the Coorong, Murray Mouth and adjacent ephemeral saline lakes, many species are halotolerant and microcrustaceans tend to dominate (De Deckker & Geddes 1980; Shiel & Tan 2013; Leterme et al. 2018). The composition of zooplankton in this region is largely determined by system hydrology (including regulation) and water chemistry, with species diversity typically inversely related to salinity (Shiel & Tan 2013; Furst et al. 2019; Dittmann et al. 2022).

For example, during the large floods at the end of the Millennium Drought (2010-11), a riverine assemblage dominated by rotifers replaced the microcrustacean-dominated estuarine assemblage at the Murray Mouth and North Lagoon (Shiel & Tan 2013). Conversely, during the prolonged low or no-flow conditions of the Millennium Drought, the zooplankton community became increasingly dominated by marine/estuarine species (Shiel & Aldridge 2011; Furst et al. 2019).

FAUNA (ANIMALS)

Overview of Fauna Section

- **Terrestrial invertebrates**
- **Aquatic Invertebrates**
  - Aquatic Macroinvertebrates
    - Freshwater
    - Estuarine
  - Aquatic Insects
  - Mussels and Snails
  - Crayfish
- **Vertebrates**
  - Fish
  - Amphibians & Reptiles
  - Birds
  - Mammals

Terrestrial invertebrates

In contrast to the aquatic invertebrates that are confined almost entirely to the freshwater and estuarine biomes of the ecological community, terrestrial invertebrates of the floodplain can be found in a wide variety of habitats, from soil and litter through to living on/in plants and animals (Jennings et al. 2009). Their distribution is significantly influenced by inundation patterns and flood history (e.g. Ballinger et al 2007; Ramy & Richardson 2017). For example, the upper reaches of the floodplain tend to be dominated by strictly terrestrial and rapidly developing aquatic invertebrates, while lower reaches are dominated by wetland taxa with desiccation resistant life-history stages (e.g. Reese & Batzer 2007).

Terrestrial invertebrates are also essential to ecosystem function of this riverine-floodplain ecological community, for example: serving as bioenergetic links between aquatic and riparian/floodplain food webs; decomposing and recycling organic matter; aerating soils; pollinating plants; and, as parasites (Jennings et al. 2009; Ramey & Richardson 2017).

Examples of terrestrial invertebrates that occur within the ecological community include: platyhelminthes (flat worms), nematodes (round worms), annelids (segmented worms), molluscs (snails and slugs), crustaceans (e.g. slaters, land-hoppers), myriapods (millipedes and centipedes), arachnids (spiders and scorpions), acari (mites and ticks), and a wide variety of ants and insects (both native and introduced) (see Jennings et al. 2009).

Aquatic Macroinvertebrates

Aquatic macroinvertebrates are a significant component of the ecological community, with specific freshwater or estuarine assemblages. They occur in three main habitats: benthic—living mainly on the sediments, pelagic—living mainly in the water column, and littoral—living at the edges of lakes and streams, typically among vegetation. Open waters support zooplankton, but it is along the littoral edges that most macroinvertebrate biodiversity exists (Walker et al. 2009, 2018). Macroinvertebrates are a taxonomically and functionally diverse group (Dittmann et al. 2018; Walker et al. 2018). Ecosystem functions they confer range from contributing to food webs (i.e. as detritivores, suspension feeders, grazers, predators, and prey) and nutrient recycling, to bioturbation of sediments and engineering of biogenic habitat (Dittmann et al. 2018).

Taxonomic diversity of macroinvertebrates recorded within the ecological community, includes:

- the main river channel– 450 taxa, entire length River Murray (Bennison & Suter 1990)
- floodplain-wetlands– 200-280 taxa (Williams 1980; Boulton & Lloyd 1991; Walker et al. 2009; Stewart et al. 2010)
- Murray Mouth, Coorong– 60 taxa (Dittmann et al. 2006, 2018)
- Lower Lakes– >140 taxa (Walker et al. 2009, 2018, 2022), and
- Eastern Mount Lofty ranges streams, including pools & riffle habitats– 350 taxa (Walker et al. 2009).

Freshwater macroinvertebrates - general

The deep sediments of the river channel are sparsely populated by macroinvertebrates, mainly by annelid worms and chironomids, while there is a wide diversity found in riparian and floodplain-wetland areas, including the Lower Lakes, for example: macro-crustaceans, corixids (Micronecta), midge larvae, and oligochaetes (Bennison & Suter 1990; Walker et al. 2009, 2018). Macro-crustaceans include: prawns (Palmonidae e.g. *Macrobrachium australiensis*), shrimps (Atyidae e.g. *Parataya australiensis*), amphipods (Chiltoniidae, Corophidae, Eusiridae), isopods (Janiridae, Scyphacidae), crabs (Hymenosomatidae e.g. *Amarinus lacustris*), and the yabby (Parastacidae, *Cherax destructor*) (Walker et al. 2018)

Analysis of macroinvertebrates recorded from 74 sites along the Murray floodplain identified six Macroinvertebrate Groups associated with varying habitat/environmental characteristics (see Table 7). Stewart et al. (2010) provides characteristic/indicator taxa for each group (based on relative abundance). They found that while many taxa may occur in many sites (i.e. more than one group), their abundance varies, and this was the discriminatory factor in the groupings.

In the many streams of the Eastern Mount Lofty Ranges (EMLR), pool-edge habitats harbour species like those found in the River Murray, while the riffles (which typically do not occur in the Murray) support *Simulium ornatipes* (blackfly larvae), hydrobiid snails, oligochaetes, and amphipods such as *Austrochiltonia australis*; and, aquatic snails of the Pomatiopsidae are known only from Salt Creek in the EMLR (Walker et al. 2009).

Freshwater macroinvertebrates of the Lower Lakes are dominated by insect taxa (>97 species), particularly chironomids (midge larvae; 26 taxa), with at least 15 species of beetle, 13 of Haemiptera, and 13 caddisfly taxa (Walker et al. 2018). About a third of taxa (>45 species) are non-insect (e.g. sponges (e.g. *Eunapius fragilis*), cnidarians (e.g. *Hydra*, *Cordylophora*), platyhelminths, nemerteans *(Prostoma* spp. – possibly introduced), nematodes (e.g. *Eutobrilus heptapapillatus*), leeches, worms, mites, molluscs, and crustaceans) (Walker et al. 1992, 2018). Macro-crustaceans include amphipods, isopods and decapods; amphipods tend to numerically dominate the crustacean assemblage of both Lakes, although isopods and decapods are rarely collected from Lake Albert (Walker et al. 2018). Most species recorded in the Lower Lakes also live upstream in the main channel of the River Murray (Walker et al. 2009).

Estuarine macroinvertebrates - general

In the estuarine region of the Murray Mouth and Coorong, the mudflat regions of which form critical bird feeding habitat, bristleworms (Annelida) and crustaceans (e.g. amphipods, shrimp, crabs, ostracods) are the most numerous in species, followed by insects and molluscs (Dittman et al. 2018, 2022). The majority of these species (50) occur near the Mouth, with fewer in the North Lagoon (40) and the least in the South Lagoon (22) (Dittmann et al. 2018). Common crabs

Table 7: Six Macroinvertebrate Groups and their predictor environmental variables—from a Murray River Valley floodplain survey in spring 2003, with samples taken from 74 sites revealing 53,335 specimens representing over 280 taxa (Stewart et al. 2010). [Number of taxa given is: 'total' across all sites in Group, and '(at 5 or more sites)'].

Group	Taxa	No. sites & Habitat/environment types	Wetland examples
1	118 (36)	15 sites; Wetlands with significant/continuous exchange with main river; good macrophyte cover	Tailem Bend Swamp; Younghusband Wetland; Devlin's Pound Wetland
2	136 (52)	21 sites; Sites typically with flowing relatively clear water, good connection and exchange with main river (often anabranch connections); highest coverage of snags;	Boat Creek; Pike River; Katarapko Creek; The Splash; Stanley Oxbow
3	57 (11)	7 sites; Non-channel wetlands; large shallow lagoons but with good exchange with main river; low silt and shade	Yacanto Lagoon; Punyelroo; Wachtels Lagoon; Yarra Lagoon
4	87 (27)	12 sites; Non-channel wetlands; high number of temporary wetlands (and many disconnected), slightly saline, fine sediment and silt cover	Lake Woolpoolool; Morgan Lagoons; Lake Merreti; Ross Lagoon; Overland Corner Wetland (permanent)
5	117 (17)	8 sites; Non-channel wetlands; typically very small wetlands, high macrophyte cover but low snags; high shade from trees or dense macrophyte cover; lowest DO saturation (less light)	Nil Nil Wetland; mouths of Burra Creek & Marne River; Moorundie Wetland; Boat Creek Wetland
6	27 (3)	11 sites; All sites disconnected from main river and saline or hypersaline; highest alkalinity & dissolved oxygen saturation; lowest macrophytes; little shade; this was the most different group to the other five groups.	The most different Group; Bookmark Creek; Mobilong Swamp; Cadell Wetland

along the Mouth and Coorong shorelines include *Amarinus laevis*, *Paragrapsus gaimardii*, and *Helograpsus haswellianus* (Brandle 2002; Dittmann et al. 2019).

Distribution and abundance of macroinvertebrates are strongly influenced by salinity and dissolved oxygen (Geddes 1987; Dittmann et al. 2018, 2022). The five most abundant taxa recorded during long-term monitoring (2004-2016) were amphipods, polychaetes (e.g. *Capitella capitata*, *Simplisetia aequisetis*), bivalves (e.g. *Arthritica helmsi*) and chironomid larvae (Dittmann et al. 2018).

The endemic *Parartemia zietzianna* (brine shrimp) occurs in the winter-filled ephemeral saline wetlands adjacent to the Coorong lagoons (De Deckker & Geddes 1980; Geddes 1987). During the Millennium Drought this brine shrimp established resident populations in the South Lagoon of the Coorong, where they flourished in the extreme high salinities for several years and were often the only macroinvertebrate (Geddes et al. 2016).

The colonial surpulid polychaete *Ficopomatus enigmaticus* (Australian tubeworm) occurs throughout the Murray Mouth and the North Lagoon of the Coorong, where it builds pronounced

reef structures; these are typically 50 cm to 1 m in diameter and occur in areas less exposed to wave action (Dittmann et al. 2018). These reefs create habitat for other organisms (e.g. *Limnoperna* sp., mytilid mussel; *Alpheus richardsoni*, snapping shrimp; *Amarinus laevis*, small crab; amphipods; tanaids; nemerteans, barnacles, other polychaetes). Species numbers and individual densities of associated macroinvertebrates are higher in/on reefs than adjacent sediments, with effects site-specific and highly variable between years (Dittmann et al. 2018).

For further information on macroinvertebrates that occur, or are likely to occur, within the ecological community, comprehensive species lists can be found in Brandle (2002), Walker et al. (2009, 2018), Moise & Milne (2010), and Dittman et al. (2018). An identification guide to aquatic invertebrates of South Australia (Wade et al. 2004) is also a useful reference, as is this visual guide (https://cdn.environment.sa.gov.au/landscape/images/2023-Macro-GUIDE.pdf) by the Murraylands and Riverland Landscape Board of South Australia.

Aquatic insects

Insects are the most diverse group of freshwater macroinvertebrates within the ecological community (Walker et al. 2009, 2018; Jennings et al. 2009). Most aquatic forms are the immature stage of species with airborne adults, for example: Odonta (dragonflies, damselflies), Ephemeroptera (mayflies), Trichoptera (caddisflies). There are also aquatic adults, particularly among the Coleoptera (beetles) and Hemiptera (bugs)—with the latter common in still waters, such as Coroxidae (waterboatmen) in the water column and Gerridae (water striders) at the surface (Jennings et al. 2009). Dipterans are the most diverse insect group, with these dominated by the Chironimidae (non-biting midge flies); saline ephemeral wetlands attract brine flies (Ephydridae) and midges (Walker et al. 2009, 2018).

A five-year survey of the River Murray in the early 1980s recorded 439 taxa of aquatic macroinvertebrates, with 368 being insects—of these, 66% were unknown or known only from aerial adult life stages rather than aquatic larval stages (Bennison and Suter 1990).

Plecoptera (stoneflies) favour cool, flowing water and are rarely found in the River Murray, with the exception of *Dinotoperla,* which occurs in fast-flowing anabranches at Chowilla; in addition, four species of stonefly occur in the Eastern Mount Lofty streams, including two that are endemic to South Australia, *Dinotoperla evansi* and *Riekoperloa naso* (Jennings et al. 2009).

Surveying the River Murray, Bennison & Suter (1990) found that the trend in insect dominance over non-insect groups progressively decreased downstream at around Swan Hill in Victoria, with a clear increase in the crustacean populations downstream of Lock 9 (i.e. within the ecological community). Of the five zones of macroinvertebrates identified in their survey, two, Zone 4 and 5, overlap entirely with the ecological community.

Aquatic insects serve an important role in flood succession dynamics in wetlands, with early flood assemblages often including *Agraptocorixa eurynome* (coroxid), midges, and the alien snail *Physa acuta.* Late flood assemblages in permanently connected wetlands often include *Cladotanytarsus* (midge) and *Paratya australiensis* (shrimp) (Walker et al. 2009, 2018).

Freshwater Mussels (Mollusca) and Snails (Gastropoda)

Freshwater mussels provide a range of ecological functions such as water purification (biofiltration), nutrient cycling and storage, and food and habitat for other biota (Vaughn 2018). There are two main freshwater mussels in the Murray-Darling Basin, both of the family Hyriidae, *Alathyria jacksoni* (Murray-Darling river mussel), which is endemic to the MDB, and *Velesunio ambiguus* (floodplain mussel) (Walker 1981; Walker et al. 2018; Sheldon et al. 2020). Both are

culturally important for First Nations peoples living along the River Murray (Walker et al. 2009). These two species are also the main two freshwater mussels within the ecological community. *A. jacksoni* is adapted for big river environments, such as the littoral areas of faster-flowing channel reaches of the Murray and its larger tributaries; it is currently (2024) under assessment for threatened status under the EPBC Act. The larger of the two species, *V. ambiguus* is typical of billabongs, lakes, creeks, small streams and often occurs in weir-pools (Walker 1990; Walker et al. 2001, 2014; Ponder et al. 2023).

A third species, a smaller orb-shell mussel *Corbicula australis* (family Cyrenidae) is common in Lake Alexandrina, along with the floodplain mussel (Walker et al. 2018). Both these species also occur upstream in wetlands and slow-flowing sections of the River Murray (Walker 1981; Walker et al. 2009).

Eighteen species of native aquatic snails have been recorded from the region of the ecological community (i.e. Lower Murray), but most now have very patchy distributions or have disappeared entirely (Walker et al. 2009 and references therein). As of the mid-1990s, the only native gastropods taxa that are common within the RMDS are the freshwater limpets, Ancylidae(Botting 1995 in Ponder & Walker 2003). The most common gastropod species in the RMDS at present, are two introduced species—the European aquarium snail (*Physa acuta*) and the New Zealand mudsnail (*Potamopyrgus antipodarum*). (See also Section 6, Criterion 3).

Crayfish

Crayfish (Parastacidae) are an important element of Australia's native freshwater fauna. The River Murray is inhabited by two native freshwater crayfish—the relatively small *Cherax destructor* (yabbie), which is distributed widely in south-eastern Australia, and the larger *Euastacus armatus* (Murray crayfish), which is restricted to the River Murray and its tributaries (Geddes, 1990; Whiterod & Zukowski 2019). *E. armatus* is currently (2024) under assessment for threatened status under the EPBC Act. While yabbies remain relatively common, the Murray crayfish is extirpated from the River Murray downstream of Mildura (Lock 11); i.e. within the entire ecological community (Geddes 1990; Newall et al. 2009) and the species is considered extinct in South Australia, with no records since the 1980s (Walker et al. 2009).

Vertebrates

Fish

Over 50 species of native fish (freshwater and diadromous) and 11 species of introduced fish species have been recorded within the entire Murray-Darling Basin (MDBA 2020; Lintermans 2023). Notwithstanding marine dependent visitors and strays, at least 55 species of fish have been recorded within the region of the ecological community, of which 47 are native and eight are introduced invasive species (Hammer and Walker 2004; Smith & Hammer 2006; Ye and Hammer 2009; Wedderburn and Suitor 2012; Bice et al. 2018). Thirteen of the ecological community's native fish species are recognised as threatened under national and/or State legislation, including five as locally extinct (Table 8; Appendix B, Table B2).

The fish fauna of the RMDS is predominantly temperate/subtropical species endemic to south-eastern Australia. The majority are freshwater forms, including the keystone species *Maccullochella peelii* (Murray cod), with nine species that are diadromous, and further nine that are solely estuarine (Bice et al. 2018; see Appendix B, Table B2). The region of the ecological community forms a considerable portion of the Murray-Darling Basin range for at least 14 species (Ye & Hammer 2009; Table 8), with several species also occurring in nearby coastal systems (Bice et al. 2018; Table 9). Of note is that at least three marine-estuarine opportunist

Table 8: Aspects of fish diversity across the broader region of the ecological community. *

Component	Numbers of species	Taxa**	References
Ecological community region	at least 47 freshwater, estuarine, & diadromous species, including: 39 native, 9 alien species	at least 19 species of conservation significance, with at least four species locally extinct	Hammer & Walker 2004; Ye & Hammer 2009; Wedderburn & Suitor 2012.
EC forms a significant portion of MDB range for	at least 5 species + 9 diadromous species (see below)	*Mogurnda adspersa* *Nannoperca obscura* *Philypnodon macrostomus* *Pseudogobius olorum* *Tasmanogobius lasti*	Ye & Hammer 2009
Diadromous species (migrate between fresh and saltwater habitats over life-cycle)	9 species	*Anguilla australis; A. reinhardtii* *Galaxias brevipinnis; G. maculatus* *G. truttaceus;* *Geotria australis* *Macquaria colonorum* *Mordacia mordax* *Pseudaphritis urvillii*	Ye & Hammer 2009; Bice 2010.
Best represented families in EC		Percichthyidae (cods, pygmy perches) Eleotridae (gudgeons) Galaxiidae (galaxiids) Atherinidae (hardyheads)	Ye & Hammer 2009
Euryhaline species (broad salt tolerance)	3 species	*Atherinosoma microstoma* *Pseudogobius olorum* *Tasmanogobius lasti*	Ye & Hammer 2009
Eastern Mount Lofty Ranges	historically up to 30 spp. 14 spp. from 24 sites in April 2023 16 native species in 2004	nationally threatened - *Nannoperca obscura*	Conallin & Hammer 2003; Hammer 2004; McNeil & Hammer 2007
River Murray wetland	2004-2007: 74 sites, 18 native freshwater, 5 estuarine, 5 alien species; 2003-2012, 40 sites, 28 native & 5 alien species		Smith et al. 2009; Wedderburn & Suitor 2012
Riverland Ramsar site Chowilla floodplain/ wetland complex	up to 16 native & 4 alien species in 2009; 10 native & 4 alien species in 2021		Newall et al., 2009; DEH 2010; Fredburg et al. 2022
Coorong	at least 26 species common up to 93 spp. (incl. Murray Estuary)	small-bodied fish (associated with submerged vegetation); large-bodied fish	Noell et al. 2009; Paton 2010; Bice et al. 2018
Murray Estuary	at least 78 species, including 34 marine visitor		MDBC 2006c; Higham et al. 2002
Lower Lakes	up to 45 native species; (18 native & 4 alien species in 2001-03 survey)	nationally threatened species *Nannoperca obscura; Craterocephalus fluviatilis*	Wedderburn & Hammer 2003; Bice et al. 2018

* Marine irregular visitor/stray species not included.

****** Common names for fish taxa are provided in Appendix B, Table B2.

Table 9: Functional guild classification of fish species recorded in the CLLMM—determined by expert workshop using the approach of Potter et al. (2015) in Bice et al. (2018).

Functional fish guild	No. Spp.	Lifestyle/Habitat
Freshwater (straggler)	14 native 8 alien	Mainly restricted to freshwater; low tolerance to elevated salinity; Golden perch common & widespread in Lower Lakes; 6 species of conservation significance
Freshwater estuarine opportunist	3	Freshwater species that commonly use the estuary; e.g. bony herring, Australian smelt, flat-headed gudgeon
Anadromous	2	Adult life in marine habitat; upstream migration into freshwater to spawn; e.g. two lamprey species
Catadromous	2	Adult life in freshwater habitat; migrate downstream to spawn in sea, where larvae develop; e.g. eel, congolli
Semi-catadromous	3	Adult life in freshwater habitat but downstream spawning migration ends in estuary to breed; e.g. estuary perch, common galaxias; (Australian bass is from one record in 2017 & likely translocated illegally)
Solely estuarine	6	Reproduction is confined to estuarine habitats; e.g. black bream, small mouth hardyhead
Estuarine & marine	3	May form discrete self-sustaining populations in both estuarine and marine habitats; e.g. bridled & lagoon goby
Marine-estuarine opportunist	15	Marine species that enter estuary regularly & abundant; may use as nursery; several species of commercial importance; CLLMM plays important role in regional population dynamics; e.g. greenback flounder, mulloway, sandy sprat
Marine straggler	48	Marine species that enter estuaries sporadically and in low numbers (but can form 50% of fish in CLLMM); stenohaline – can't tolerate high salinity; CLLMM role in regional population dynamics is not significant.

species are considered important components of the RMDS, as their presence is integral to the Coorong foodweb and contributes to the regional population (Bice et al. 2018 & references therein; Appendix B, Table B2).

Bice et al. (2018) recognised nine 'estuarine use functional guilds' (EUFG) of fish occurring in the Coorong (Murray Estuary, North and South Lagoons) and Lower Lakes (Lake Albert, and Lake

Alexandrina and the lowland stream reaches/terminal wetlands of the Eastern Mount Lofty Ranges tributaries). The guilds are based on life history and spawning environments, Table 9.

The diversity of fish species varies across the ecological community (and see Table 8), for example:

- Historically, up to 30 native species of fish have been recorded in streams of the Eastern Mount Lofty Ranges (McNeil & Hammer 2007). However, only 16 native species, including the nationally endangered (and now locally extinct) *Nannoperca obscura* (Yarra pygmy perch), were recorded in 2003 (Hammer 2004; Table 8).
- In 2021, 14 species of fish (10 native, 4 non-native) were recorded within the Chowilla Anabranch and floodplain system, which constitutes the largest area of undeveloped floodplain and wetland within the ecological community (Fredburg et al. 2022; Table 8). This area also includes the Riverland Ramsar site (which includes Lake Woolpolool), for which the character description reports 16 native fish species and 4 alien species (Newell et al. 2009).
- Up to 104 fish species (with about half of marine origin and only irregular visitors) have been found in various surveys downstream of Lock 1, including the Coorong lagoons and the Murray Estuary (93 spp.), with relative richness of fish species shifting from high to low along the increasing salinity gradient, and the Lower Lakes (45 spp.) (Higham et al. 2002; Noell et al. 2009; Bice 2010; Bice et al. 2018; Table 8 & 9).

Amphibians and reptiles

The River Murray corridor (or valley)—i.e. the main river channel and its floodplains, billabongs, and wetlands, lies on the intersection of two major climatic and zoogeographic regions, the temperate southeast and the arid centre. This contributes to a relatively high biodiversity of amphibians and reptiles occurring within the ecological community, as it provides the only natural permanent water in the broader arid region. Therefore, the RMDS supports species that would otherwise be unable to live in the region. This includes wetlands specialists and arboreal species that need the large trees of floodplain woodlands and forests, such as river red gum and black box.

At least twelve species of Anura (frogs) are known from the broader region of the RMDS (Table 10). Most are conventional pond breeders using overflow areas adjacent to billabongs and wetlands as breeding sites (usually in spring) (Hutchinson 2009). *Limnodynastes dumerilii* (eastern banjo) and *Neobatrachus pictus* (Mallee spadefoot) are burrowing species that can live up to a meter below ground, waiting for the next flood event to breed (Scott 2001). Frogs are major contributors to ecosystem functions (e.g. nutrient cycling, decomposition) and ecosystem structure (bioturbation, burrowing) (Hocking & Babbit 2014). While frogs are opportunistic carnivores, tadpoles feed on vegetation and sediments, but will also opportunistically prey on insects (Antis 2007).

Nine of the twelve frog species have been recorded from the Riverland Ramsar site and the Chowilla–Lindsay/Wallpolla Icon site, which represent the most biodiverse areas of floodplain-wetlands in the ecological community (Hutchinson 2009; Stewart et al. 2010). This includes the threatened (EPBC Act) *Litoria raniformis* (southern bell frog) and two species, *Crinia parinsignifera* and *Limnodynastes fletcheri*, that occur nowhere else in South Australia. Three species are tree dwelling *Litoria* species (see Table 10). Eight of the twelve frog species have been recorded from the Coorong, Lower Lakes and Murray Mouth (CLLMM) region of the RMDS, of which *Crinia signifera* (common eastern froglet) is the most common (Mason & Turner 2018).

Table 10: Frogs known or likely to occur in the RMDS ecological community (after Bird & Armstrong 1990; Butcher et al. 2009; Hutchinson 2009; Newall et al 2009; Stewart et al. 2010; Tyler & Walker 2011; Mason & Turner 2018; Vörös et al. 2023).

Common Name	Taxonomic Name	Recorded in CLMM
HYLIDAE		
Brown tree frog	*Litoria ewingii*	√
Peron's tree frog	*Litoria peronii*	√
Mount Lofty Ranges/ South Australian tree frog	*Litoria calliscelis*	
Southern bell (growling grass/ golden bell) frog*	*Litoria raniformis major*	√
MYOBATRACHIDAE		
Barking marsh/ long-thumbed frog	*Limnodynastes fletcheri*	√
Bibron's/brown toadlet#	*Pseudophryne bibronii*	
Common eastern froglet	*Crinia signifera*	√
Eastern banjo/Pobblebonk/ Bull frog	*Limnodynastes dumerilii*	√
Eastern sing-bearing/ Murray Valley froglet	*Crinia parinsignifera*	
Mallee spadefoot/ painted frog	*Neobatrachus pictus*	√
Spotted grass frog	*Limnodynastes tasmaniensis*	√
Sudell's/trilling frog	*Neobatrachus sudellae*	

**Listed as Vulnerable under EPBC Act; #listed as Rare under SA National Parks and Wildlife Act.*

Of note is that *Litoria ewingii*, the brown tree frog (known for its characteristic whistling call), was only recently reassessed as three species, with *Litoria calliscelis* occurring in the Mount Lofty Ranges (thus the RMDS) and Fleurieu Peninsula (Parkin et al. 2024). Additionally, the threatened southern bell frog was recently assessed to be two sub-species, *L. r. raniformis* for the northern lineage and *L. r. major* for the southern lineage (Vörös et al. 2023).

At least 49 reptile species have been recorded from the South Australian River Murray floodplains from combined surveys and museum records, with approximately half considered to have affinities to specific habitat types such as wetlands, floodplains, and fringing woodlands (Bird & Armstrong 1990; Scott 2001; Brandle 2002; MDBC 2006b, c; Hutchinson 2009; Newall et al. 2009; Stewart et al. 2010; Scott et al. 2022). Of these, at least 35 species have been observed at Chowilla (Bird & Armstrong 1990). In particular, three species of turtle, two water skinks, a goanna, and two snake species are reliant on these critical riverine habitats for their survival in the region (Stewart et al. 2010; Van Dyke et al. 2019; Table 11). For example, the wetland specialist *Eulamprus quoyii* (eastern water skink) is strongly associated with the riparian zones of streams and wetlands.

Some of the most common reptiles on the River Murray floodplain are: *Morethia boulenger* (common snake-eye skink), *Christinus marmoratus* (marbled gecko), *Menetia greyii* (dwarf skink), *Tiliqua rugosa* (sleepy lizard), and *Egernia striolata* (eastern tree skink) (Stewart et al. 2010). *Notechis scutatus* (eastern tiger snake), and to a lesser extent *Pseudechis porphyriacus* (red-bellied black snake), have suffered drastic population declines along the more arid sections of the River Murray (Bird & Armstrong 1990; Eckert 2000 in Hutchinson 2009). Both are wetland specialists and anurophagous (aka batrachophagous) snakes, feeding predominately on frogs (Hutchinson 2009). *Morelia spilota* (carpet python) utilise two significant microhabitats in the River Murray floodplain corridor—large fallen limbs and hollow tree trunks, and rocky hollows and overhangs along the limestone cliffs (Hutchinson 2009).

Denesonia devisi (De Vis' banded snake) has recently been discovered for the first time in SA—four adults at Chowilla, with one of them observed biting into a large southern bell frog (Scott et al. 2022). This discovery represents a range extension for this species, which mainly eats frogs and is typically associated with floodplains and riparian systems that receive significant seasonal inundation (Wilson & Swan 2021; Scott et al. 2022). This discovery takes the number of reptile species on the floodplain of the RMDS to at least 50.

Table 11: Reptile families and associated number of species recorded during the 2002–04 and earlier surveys of the Murray River Valley (i.e. floodplain) (Stewart et al. 2010). Key species of reptiles reliant on riverine floodplain/wetland habitat are also listed. Note, *Morelia spiota* (carpet python) was not found during the 2002–04 survey, and *Denesonia devisi* (De Vis' banded snake) was recently discovered in the MRV in 2021 (Scott et al. 2022). SA-CS=conservation status in SA.

Family	Common name	No. Species	Key species reliant on riverine habitat	Common name	SA-CS
Agamidae	dragon	4			
Chelidae	turtle	3	• *Chelodina expansa* • *Chelodina longicollis* • *Emydura macquarii*	• broad-shelled turtle • long-necked turtle • Murray River turtle (or, short-necked turtle)	V
Elapidae	snake	4	• *Notechis scutatus* • *Pseudechis prophyriacus* • *Morelia spiota* • *Denesonia devisi*	• eastern tiger snake • red-bellied black snake • carpet python • De Vis' banded snake	R
Gekkonidae	gecko	8			
Scincidae	skink / lizard	16	• *Eulamprus quoyii* • *Egernia striolata*	• eastern water skink • eastern tree skink	
Typhlopidae	blind snake	2			
Varanidae	goanna	2	• *Varanus varius*	• tree goanna	R

Birds

The River Murray runs through semi-arid South Australia and ends in a more temperate region adjacent to the Mount Lofty Ranges, and this provides for a diverse range of bird species with areas of relatively high species diversity (Stewart et al. 2010; Table 12). Within the ecological community, these diverse bird assemblages that include both terrestrial and waterbird species, from a range of wetland, woodland, shrubland, grassland, and coastal habitats, some of which are endemic to the region (DEH, 2010; Paton et al. 2009a, 2018; Wassens et al. 2021). For example, birds such as parrots and raptors nest along the river corridor, typically in large river red gums, including rare species such as *Lophoictinia isura* (square-tailed kite) and *Haliaeetus leucogaster* (white-bellied sea-eagle), and the nationally threatened *Polytelis anthopeplus monarchoides* (eastern regent parrot) (MDBC 2003a).

Table 12: Bird species diversity from surveys and reviews within the broader region of the ecological community.

Survey region	Number of Species	Reference
Murray-Darling Basin	• 95 waterbird species • >100 waterbird species	Scott 1997 Wassens et al. 2021
Murray-Darling Basin	• 108 woodland species	McGuinness et al. 2010; Mott et al. 2020
8 wetlands: Lake Carlet (nr Mannum) to Clover Lake (nr SA border) 1992–93	• 41 species waterbirds • large breeding colony of Silver Gull	Suter et al. 1995
River Murray floodplain in SA (defined by 1956 flood line & SA border to Murray Bridge)	• 174 species from 53 families (of 229 species known for area BDBSA*); includes woodland & waterbirds, & 28 species with conservation status in SA#	Stewart et al. 2010 [and summarises previous survey records]
Chowilla Floodplain	• 134 (of 170 recorded previously); 30 breeding species	Carpenter 1990
Chowilla Floodplain and nearby regions	• 165 native (wetland, migratory, mallee-dependent)	Newall et al. 2009: DEH 2010
Lake Woolpolool	• >60 waterbirds (including 2 wetland raptors)	Jensen et al. 2000 in Newall et al. 2009
Banrock Station Wetland Complex	• 61 wetland associated species (resident & transient) • up to 191 species in 20 years of monitoring (wetland, floodplain, mallee spp.); 32 waterbird spp. in 2019-20	Butcher et al. 2009 Field & Turenq 2014; Field 2020
Coorong – January 2000–2009 Coorong – January 2000–2015 Coorong – January 2023	• up to 71 waterbirds (40 species present every year; 17 most years; 14 rarely) • up to 82 spp. (35 present every year; 5 in all but one year; 33 with >100 birds) • 49 spp. (31 below long-term median abundance (LTMA))	Paton 2010 Paton et al. 2018 Paton et al. 2023
Lower Lakes – January 2009–2015 Lower Lakes – Jan. 2023	• 72 species (33 species present in all years, with 22 species at >100 birds) • 48 spp. (16 spp. below LTMA)	Paton et al. 2018 Paton et al. 2023

*BDBSA=Biological Survey Databases of South Australia; # SA *National Parks and Wildlife Act 1972.*

For birds that are known to occur, or are likely to occur, within the ecological community, extensive species lists are provided in Scott (1997), Brandle (2002), Butcher et al. (2009), Newall et al. (2009), DEH (2010), Paton (2010), Stewart et al. (2010), and Paton et al. (2018). For species with conservation significance, see Appendix D.

Bird diversity

Various surveys highlight the diversity of birds found within the ecological community, see Table 12. The highest numbers have been recorded along the River Murray floodplain corridor, including Chowilla and nearby regions (see Newall et al. 2009, McGuinnes et al. 2010, Stewart et al. 2010, Paton et al. 2018, Mott et al. 2020 for species lists and associated habitat information). Many of the species recorded were found to be generalists occupying a range of vegetations types, while others had a closer association with the river or wetlands. Species richness of birds was found to be highest in vegetation with high structural complexity, such as forest and woodland with dense understory (Stewart et al. 2010).

Floodplain and woodland birds

Stewart et al. (2010) identified six broad groups of bird species and particular structural floristic associations on the SA Murray floodplain (Table 13). Woodland and forest habitats of the floodplain (i.e. the ecological community) are considered important complementary habitats for woodland birds in the broader semi-arid landscape. Within South Australia, some species have a limited range that is largely centred on the eucalypt habitat of the Murray floodplain corridor, for example: *Entomyzon cyanotis* (blue-faced honeyeater), *Philemon citreogularis* (little friarbird), *Plectorhyncha lanceolata* (striped honeyeater), *Polytelis anthopeplus* (regent parrot), and *Polytelis alexandrae* (princess parrot) (Stewart et al. 2010). In addition, lignum shrublands along the River Murray corridor are likely to greatly increase habitat available to small birds that require cover, such as fairy wrens (*Malurus* spp.).

Waterbirds

Waterbirds rely on wetlands and the riparian zone and are generally highly mobile (DEWNR 2012). They are a key component of the bird fauna of the ecological community. Waterbird biodiversity is high in the three Ramsar wetlands of international importance that occur within the RMDS: the Coorong, Lower Lakes and Murray Mouth (CLLMM); Banrock Station Wetland Complex; and Riverland (see Table 12). Wetlands are valuable to waterbirds as breeding habitat and as a rich food source driven by productivity peaks following inundation after a dry period (Suter et al. 1993, 1995; Scott 1997; Paton et al. 2009b, 2018).

The high diversity of waterbirds recorded at Lake Woolpolool (Table 12) is indicative of the ecological community having a significant proportion of the aquatic avian fauna when compared to the entire Murray-Darling Basin. Broad groups of waterbirds include (Butcher et al. 2009; Paton et al. 2018):

- Anatidae (ducks, geese, swans)
- Ardeidae (egrets, herons)
- Charadriidae (plovers, dotterels)
- Laridae (gulls, terns)
- Pelecanidae (pelican)
- Phalacrocoracidae (cormorants)
- Threskiornithidae (ibis, spoonbills)
- Podicipedidae (grebes)
- Rallidae (crakes, rails)
- Recurvirostridae (avocets, stilts)
- Scolopacidae (sandpipers, stints)

Table 13: Floodplain bird assemblages determined from analysis of data from the 2003–04 survey of the South Australian River Murray Valley (note, all waterbirds, migratory, highly mobile species or birds at < 4 sites were removed from this analysis). Note, species may occur in more than one group (Stewart et al. 2010).

Bird Assemblage Group (salinity/understory)	No. Spp. / (Sites)	'Indicator' and example species
1/Birds of taller river red gum and black box woodlands & forests (least saline; lignum, Phragmites; bottlebrush, chenopod shrubs)	61 (59)	crimson rosella; white-plumed honeyeater; striated pardalote; dusky wood swallow
2/Birds of degraded river red gum woodlands & forests of southern River Murray (low-medium salinity; lignum, Phragmites, ruby saltbush, river saltbush)	43 (17)	superb fairy-wren; little grassbird; new holland honeyeater; high proportion of feral species
3/Birds of northern black box woodlands & lignum shrublands (low-medium salinity; typically open shrubland; river saltbush, spreading emubush, ruby saltbush)	61 (32)	weebill; chestnut-rumped thornbill; little friarbird; striped honeyeater
4/Birds of the highly saline Chowilla floodplain shrublands (very high salinity; open lignum shrubland)	13 (3)	hooded robin; blue bonnet; chestnut-rumped thornbill; red-capped robin; southern whiteface
5/Birds of highly saline lignum shrublands (50% low salinity, 50% medium to extreme high salinity; typical open shrubland & some adjacent to woodland)	44 (14)	white-fronted chat; Australian magpie; crested pigeon; pied butcherbird; variegated fairy-wren
6/Birds of black box and river coobah woodlands with open understoreys (low & high salinity; open shrubland dominated by round-leaf pigface & ruby saltbush)	26 (9)	indicator species; similar species to Group 3; crested pigeon, crimson rosella; weebill; common bronzewing

Waterbird breeding

The three Ramsar sites within the ecological community are particularly important for bird breeding, including colonial nesting bird species (Table 14). For example, Lake Merreti (Riverland Ramsar site), has the largest bird colonies and in a year when there is a large flood, these can number over 1,000 nests of up to six breeding species which are dominated by two ibis species (Newall et al. 2009; DEH 2010; Table 14). Another Ramsar site, the Coorong, represents the only regular historic breeding location in South Australia for *Pelecanus conspicillatus* (Australian pelican) (i.e. 'Pelican Islands' & Seagull Island) and other bird species use the islands of the Coorong's South Lagoon to breed (Paton 2010; Paton & Paton 2021; Table 14). Similarly, the Lower Lakes are an important breeding area for at least eight colonial nesting species (Paton & Paton 2021; Table 14).

Table 14: Waterbird breeding observations at Ramsar sites within the ecological community (Butcher et al. 2009; Newall et al. 2009; DEH 2010; Paton et al. 2018; Paton & Paton 2022).

Colonial Nesting Waterbird Breeding		**Non-colonial Waterbird Breeding**	
Scientific Name	**Common Name**	**Scientific Name**	**Common Name**
Riverland			
Threskiornis moluccus	Australian white ibis	*Stictonetta naevosa*	freckled duck
Threskiornis spinicollis	straw-necked ibis	*Recurvirostra novaehollandiae*	red-necked avocet
		Erythrogonys cinctus	red-kneed dotterel
Banrock Station Wetland Complex			
		Tadorna tadornoides	Australian shelduck
		Chenonetta jubata	Australian wood duck
		Cygnus atratus	black swan
		Anas gracilis	grey teal
		Biziura lobata	musk duck
Coorong (islands and lagoons) & Murray Mouth			
Chroicocephalus novaehollandiae	silver gull	*Anas castanea*	chestnut teal
Hydroprogne caspia	caspian tern	*Cygnus atratus*	black swan
Pelecanus conspicillatus	Australian pelican	*Haematopus longirostris*	pied oystercatcher
Thalasseus bergii	greater crested tern		
Sternula nereis nereis	fairy tern		
Lower Lakes			
Anhinga novaehollandiae	Australian darter	*Anas gracilis*	grey teal
Microcarbo melanoleucos	little pied cormorant	*Cygnus atratus*	black swan
Phalacrocorax carbo	great cormorant	*Fulica atra*	Eurasian coot
Phalacrocorax sulcirostris	little black cormorant	*Porphyrio porphyrio*	purple swamphen
Phalacrocorax varius	pied cormorant		
Platalea regia	royal spoonbill		
Threskiornis moluccus	Australian white		
Threskiornis spinicollis	straw-necked ibis		

Waterbird feeding

In the CLLMM component of the ecological community, three main foraging groups have been identified for waterbirds—invertebrate foragers, (mainly) aquatic plant feeders; and a fish-eating group (Paton 2010; Paton et al. 2018; see Appendix B, Table B3). Long-term surveys have shown that more fish-eating waterbirds use the Lower Lakes (approx. double), while the use of both the Coorong and Lower Lakes by waterfowl is fairly even (Paton et al. 2018, 2023; see Appendix B, Table B3). Invertebrate foragers (mainly shorebirds and waders) feed by wading in shallow water around the shoreline, with the depth of water in which they forage in determined by relative leg length (Paton et al. 2018).

Surveys have also shown a range of terrestrial birds with foraging niches in the Coorong, with frugivores making up the largest proportion (~50%), insectivores around a third (~33%) and smaller proportions of nectivores and granivores (Paton 2010; see Appendix B, Table B4):

Migratory birds

Significant components of the ecological community are also habitat for many nomadic and/or migratory waterbirds when inland wetlands dry, or during times of drought in central and eastern Australia, as well as for nomadic bush-birds during summer. In particular, the Lower Lakes is a critical site for migratory birds, supporting an estimated 30% of the migratory shorebirds summering in Australia, of which many species are listed under international agreements with Japan, China, and Korea (Paton 2010; Paton et al. 2018; Appendix B, Table B5).

The Coorong also supports large numbers of small migratory birds, in addition to non-migratory waders, piscivorous birds, and waterfowl, with more than 80 species recorded over long-term surveys (Paton et al. 2018, 2022; Appendix B, Table B5). Importantly, there are large number of shorebirds (e.g. sandpipers, stints, plovers, stilts, avocets) that use the saline wetlands of the Coorong but not the freshwater wetlands of the Lower Lakes (Paton et al. 2018).

Mammals

Historic loss

The broader Riverland and Murraylands of South Australia were once home to around 70 species of native mammals: two monotremes, 39 marsupials, 11 rodents and 18 bats (Carthew & Reardon 2009). However, the mammal fauna of the Murray River valley floodplain has been heavily impacted by habitat clearing, change and degradation due to the high use of this area since European settlement, in addition to predation by feral cats and foxes (Foulkes & Gillen 2000; Brandle 2002); the species composition has altered dramatically, with losses including 75% of dasyurids, 50% of macropods and rodents, and all peramelids and potoroids (Carthew & Reardon 2009). Species lists of extant mammals are provided in Carthew & Reardon (2009) and Stewart et al. (2010).

Further south, several mammals recorded at the Coorong and Lower Lakes in the 19th Century no longer remain (i.e. extinct or extirpated, e.g. toolache wallaby and numbat, respectively), with native mammal species now limited to the southern Coorong and adjacent coastal shrubland (Paton 2010). Surveys in 1982 and 2002 of the Murray Mouth reserves recorded only four native mammal species (Brandle 2002).

Monotremes

One monotreme, *Tachyglossus aculeatus* (short-beaked echidna), occurs within the ecological community (Table 15). *Ornithorhynchus anatinus* (platypus) has been extirpated in South Australia for decades, and therefore within the ecological community. There are current plans to

reintroduce it to the Torrens River in Adelaide (Zukowski & Whiterod 2022)—i.e. outside of the RMDS.

Placental mammals and marsupials

Surveys of the River Murray Valley floodplain over 2002-04 (and earlier), recorded 24 native mammals and 12 non-native mammals (Stewart et al. 2010, see Table 15). The most commonly detected species were non-natives, with native species having low species richness, apart from bats (10 species). The sites that supported more than three native mammal species were all in river red gum woodlands, which also had a good cover of lignum, or reeds and sedges, in the understory. Fifteen native mammal species once known to have occurred along the River Murray Valley are now extinct in the region (Stewart et al. 2010).

Table 15: Mammal species known to occur, or likely to occur, within the ecological community (Brandle 2002; Carthew & Reardon 2009; Newall et al. 2009; Stewart et al. 2010).

Mammal Group	Species
MONOTREMES	
Echidna (1)	*Tachyglossus aculeatus* (short-beaked echidna) (Note: *Ornithorhynchus anatinus* (platypus) is extinct in the EC & SA)
PLACENTAL MAMMALS	
Bats (~18)	See Appendix B, Table B3 for full list. Dominant/common species are: *Chalinolobus gouldii* (Gould's wattle bat); *Nyctophilus geoffroyi* (lesser long-eared bat); *Vespadelus vulturnus* (little forest bat); *Austronomus australis* (white-striped free-tailed bat); *Ozimops planiceps* (southern free-tailed bat)
Native rodents (3)	*Hydromys chrysogaster* (native water rat); *Pseudomys bolami* (Bolam's mouse); *Rattus lutreolus* (Australian swamp rat)
MARSUPIALS	
Dasyurids (3)	*Sminthopsis crassicaudata* (fat-tailed dunnart); *S. murina* (common dunart); *Planigale gilesi* (Giles' planigale)
Possums/ Gliders (3)	*Cercartetus concinnus* (western pygmy-possum); *Trichosurus vulpecular* (common brushtail possum); *Acrobates pygmaeus* (feathertail glider)
Macropods (3)	*Macropus fuliginosus* (western grey kangaroo); *Macropus rufus* (red kangaroo); *Macropus robustus* (euro)
Other (1)*	*Lasiorhinus latifrons* (southern hairy-nosed wombat)

*One koala (*Phascolarctos cinereus*) observed during survey but listed as an introduced species (Stewart et al. 2010).

Survey records confirm that bats are the most diverse group of mammals within the South Australian River Murray floodplain (i.e. the ecological community), with at least 18 species of microchiropteran bats (microbats) from four families recorded (Carthew & Reardon 2009; Armstrong et al. 2019, 2020a, b; Appendix B, Table B6). This is likely due to the availability of roosting habitat, foraging habitat/prey, and drinking water (Blakey et al. 2018). The most common native mammal (and bat) species in a 2002-04 survey was *Vespadelus vulturnus* (little forest bat) (Carthew & Reardon 2009), while a more recent survey, the citizen science Mega bat survey of 2017-19, found *Chalinolobus gouldii* (Gould's wattle bat) to be the most abundant bat species in the Riverland and Murrayland (Armstrong et al. 2019, 2020a, b).

Highest mammal diversity habitat

At least 20 native mammal species have been recorded in the Chowilla floodplain-wetland complex, including the Riverland Ramsar site (Carthew & Reardon 2009; Newall et al. 2009; DEH 2010), which is likely to be the most diverse area of native mammals within the ecological community (Table 15). For example, the Chowilla area is identified as containing the greatest diversity of bats found anywhere in South Australia (Brandle & Bird 1990; Carthew & Reardon 2009; Armstrong et al. 2019, 2020).

Consultation Questions on Fauna (Animal) and Micro-biota species:

- This *Conservation Advice* aims to provide an indicative description of animal and micro-biota species, with further species lists provided through citations of existing references. However, please provide any suggestions (with sources) to clarify the species assemblage.
- Can you identify more recent survey or monitoring data to those used thus far in this draft *Conservation Advice*? If so, could you please provide a reference or source.
- Do you know of other 'characteristic' animal and micro-biota species occurring within the RMDS EC that are not highlighted in this draft *Conservation Advice*. If so, can you please provide details and reference sources to the Committee.

1.2.3 Functionally important species within the ecological community

KEYSTONE SPECIES AND ECOSYSTEM ENGINEERS

Keystone-type species play a critical role in maintaining the structure, composition and function of a particular ecological community—they can affect many other organisms, determine the types and numbers of various other species, and influence ecosystem processes.

A keystone species is one that has a disproportionately large effect on its environment and community relative to its abundance or biomass; they can be predators, prey/hosts, or habitat modifiers (Stiling 1999). The concept was originally proposed by Paine (1966, 1969) who defined a keystone as a species whose activities greatly modify "the composition and physical appearance" of its ecological community. While originally having a trophic focus, the ecological concept expanded, with the two hallmarks of keystone species commonly accepted as (e.g. Mills et al. 1993):

- their presence is crucial in maintaining the organisation and diversity of their ecological community, and
- these species are 'exceptional', relative to the rest of the community, in their importance.

In addition to the physical environment and broader community, characteristics of a species can affect its status as a keystone species, for example: trophic position (top predator versus primary producer; connectivity (number of direct links to other species); strength of its interactions with other species (Ebenman & Jonsson 2005).

'Ecosystem engineers' are a particular type of keystone species; they are species that modify and modulate the physical environment and its resources, and thus may create, maintain, and change habitats and resources (Jones et al. 1994; Wright and Jones 2006). 'Autogenic engineers' change the environment via their own physical structure (e.g. corals, trees) and 'allogenic' engineers

(typically fauna) change the environment by transforming living or non-living materials from one physical state to another (Jones et al. 1994).

Of note, Ellison (2019) presents the case for the use and focus on 'foundation' species (or group of functionally similar taxa), as first introduced by Dayton (1972). He defines a foundation species as one that—dominates an assemblage numerically and in size (biomass), determines the diversity of associated taxa through non-trophic interactions, and modulates fluxes of nutrients and energy at multiple control points in the ecosystem it defines. However, for the purposes of the current assessment, the more straightforward concept of keystone species, including ecosystem engineers, is used.

Removal, addition, or changes in local populations of keystone species or ecosystem engineers can have significant impacts on the functioning of ecological and ecosystem processes, predatory relationships, and overall long-term stability and resilience of the ecological community. Owing to the interdependences among species in ecological communities, the loss of one keystone-type species can trigger a cascade of secondary extinctions which may destabilise and threatened the functionality of the ecological community (e.g. Ebenman & Johnsson 2005).

Ecosystem engineers provide resilience to the broader ecosystem through the foundational physical ecosystem engineering functions and structure they provide, combined with their trophic interactions. For example, two significant ecosystem engineers within the ecological community are the long-lived eucalypt trees, river red gum and black box. In addition to their leaves, bark, flowers, and seeds providing an important food source to a range of organisms (Robertson et al. 2001), the dead leaves, branches and bark accumulating on the ground can affect rainfall throughfall, rates of evaporation, and local hydrology, as well as providing microbial and invertebrate habitat. Therefore, they are critical to nutrient and energy cycling and contribute substantial amounts of carbon to terrestrial and aquatic food webs. In addition, their branches and hollows provide shelter and nesting habitat for a range of birds, marsupials, and other animals.

In aquatic habitats, these same trees can form debris dams and ponds, reduce erosion and flow rates, provide habitat for fish, and influence sediment accumulation (Colloff & Baldwin 2010; Tonkin et al. 2020, 2022). Their roots provide substrate stabilisation and habitat for mammals and reptiles, and can alter local topography and water infiltration. Their canopy alters microclimate, affecting shade, shelter, temperature, and humidity, as well as mitigating erosive effects of wind and rainfall (Colloff and Baldwin 2010). Resilience of the system is also strengthened by a positive feedback loop linking soil carbon content to soil moisture and vegetation condition (Colloff & Baldwin 2010).

Where disturbance (particularly anthropogenic) constrains growth of these keystone species/ecosystem engineers, or where age structure is skewed towards younger individuals, ecological performance or function within the ecological community is likely to be compromised. In terms of ecosystem function, measurements of these eucalypts as ecosystem engineers relating to age structure, recruitment, and condition may represent useful surrogates for the assessment of resilience and relative 'health' of the ecological community (Colloff & Baldwin 2010). For example, in some areas, river red gum along the River Murray have shown signs of reduced frequency and extent of flowering events, likely due to decreased flood frequency (Colloff & Baldwin 2010; Jensen 2011a; Lamontagnew et al. 2012). This would have cascading trophic effects and implications for the seed bank and future recruitment.

Further examples of eco-physiological effects (such as on key functional/keystone species) in natural ecosystems associated with changes to alternative states is provided in Table 16. Such processes and changes are acutely relevant to the ecological community and are related to the threats outlined in Section 4 and the assessment of Criterion 3 in Section 6.

A table of functionally important species (or suites of species/taxon groups) indicative of the *River Murray – Darling to Sea* ecological community is provided at Table 17. This table provides further detail on the functional roles and ecological characteristics and requirements of these species, many of which are keystone species or ecosystem engineers.

Table 16: Examples of biogeochemical processes, drivers and parameters relating to eco-physiological effects in natural ecosystems, such as the ecological community, associated with changes to alternative stable states (modified from Colloff & Baldwin 2010 & references therein).

Process	Driver	Parameter	Eco-physiological effect	System/state change
changes in flood regime	water diversions, climate change	water	succession of terrestrial plants	reduction in wetland area - permanent terrestrial grasslands and woodlands
reduced soil water infiltration	overgrazing; crusting; reduced macropores*	water	reduced water uptake by plant roots	rangelands to semi-desert
eutrophication & algal blooms	runoff from agriculture	nutrients	shifts in decomposition	clear to turbid lakes/rivers, reduced aquatic biodiversity
dryland salinity	vegetation clearance	salt	osmotic disruption	woodland to chenopod shrubland
hypoxia	runoff with high labile carbon content	oxygen	inhibition of aerobic respiration	productive to unproductive estuaries
acid sulfate sediments	drying, oxidisation of pyrite, re-wetting	pH	direct cell and tissue damage	lake/river and forest degradation
changes in fire regime	grazing intensity and reduced fire frequency	temperature	succession of terrestrial shrubs	grassland to shrubland

*****In soil, macropores are defined as cavities that are larger than 75 μm. Macropores increase the hydraulics of soil, allowing water to infiltrate and drain quickly, and shallow groundwater to move relatively rapidly via lateral flow.

Table 17: Functionally Important Species/Taxon Groups indicative of the *River Murray—Darling to Sea* Ecological Community.

Taxon	Functional Role	Ecological Characteristics/Requirements	References
Flora			
River red gum *Eucalyptus camaldulensis*	• perennial, single stemmed, large-boled, medium to tall tree up to 45 m • provides feeding & shelter habitat for a wide variety of fauna, e.g. mammals, birds, reptiles, invertebrates • contributes to instream production and habitat structure (e.g. debris, ponds, snags, leaf litter; biofilms) • contributes to nutrient recycling • contributes to soil-water balance on floodplain	• relatively long lived - up to 950 years. • prefers close proximity to permanent fresh water • high water demand (limited stomatal control if soil deficit); survival dependent on water availability (e.g. have extensive roots and can depend on groundwater if < 40 dSm-1) • environmental water requirements (flooding): Duration 1-4 months, <2 y; Timing spring-early summer; Frequency 1-4 y; Max. interval 5-7 y • inundation > 2-4 y likely to cause tree death • seed production, germination and recruitment promoted by flooding (e.g. summer watering reinforces bud set, flowering & germination during peak seed rain from aerial seed banks) • flood duration of 4–7 months for seed germination	White et al. 2000; George et al., 2005; Jensen et al., 2007; Jensen 2008; Newall et al., 2009; Roberts & Marston 2011; Rogers and Ralph 2011 (and references therein); Doody et al. 2014, 2015, 2023; Kilsby & Steggles 2015; Overton et al. 2018; DEW 2020c, 2023b, 2024; Stoltefaut et al. 2024.
Black box *Eucalyptus largiflorens*	• single stemmed tree up to 20 m (becomes twisted under drier conditions) • provides habitat & shelter for a range of fauna, e.g. mammals, reptiles, insects • contributes to nutrient recycling • contributes to soil-water balance on floodplain	• generally, marks outer limits of larger floods and higher levels on floodplain • more drought tolerant than river red gum, but survival dependent on water • prefers areas that are intermittently flooded, supplemented by other water sources (rainfall, groundwater) • groundwater a potential alternative water source (depending on salinity, < 40 dSm-1) • flooding requirements: 1 year in 7–10 y, 2-3 y in succession every 30 years (timing not critical) • flooding duration needed 2–4 months for reproduction, longer may compromise reproduction and vigour • cannot take anoxia during prolonged flooding	Jensen et al., 2007; George et al., 2005; Newall et al., 2009; Rogers and Ralph, 2011 (and references therein); Jensen, 2011a; Roberts & Marston 2011; AWE 2015; Gehrig & Frahn 2015; Kilsby & Steggles 2015; McGuiness et al. 2018; Overton et al. 2018; DEW 2020c, 2023b, 2024; Gibbs et al. 2020; Doody et al. 2021, 2023; Stoltefaut et al. 2024.

Taxon	Functional Role	Ecological Characteristics/Requirements	References
		• summer or winter (May-July) water to reinforce bud set & flowering (depending on phenological cycle) • distribution represents recruitment episodes in response to historic natural flood events • susceptible to disease if stressed (e.g. mistletoe) • seedlings susceptible to flooding stress	
River Cooba *Acacia stenophylla*	• perennial tree to height of 13 m • provides habitat & shelter for a range of fauna, e.g. mammals, reptiles, insects • contributes to nutrient recycling • contributes to soil-water balance on floodplain	• regarded as drought and flood tolerant • often occurs between river red gum and black box • survival limited in salinity > 15 dSm-1 • flooding increases likelihood of germination	Roberts & Marston 2011; Rogers and Ralph, 2011.
Swamp Paperbark *Melaleuca halmaturorum*	• in Coorong region, nesting habitat for birds	• occurs along margins of wetlands • can live for 100 years • at risk from flooding as seedlings drown; survival increases if mature trees flower, set and drop seed in spring as water recedes	Paton, 2010; Paton et al. 2018.
Tangled lignum *Duma florulenta*	• important nesting habitat for water birds • shelter & refuge for Murray cod & other large- bodied fish • shelter & refuge for juvenile fish and turtles when flooded • habitat for invertebrates • shelter for terrestrial fauna (birds, mammals, reptiles) • protects eucalypt seedlings from grazers • critical role in soil water (evaporation) balance • role in salt-water balance on floodplain (i.e. helps keep saline groundwater levels down)	• long-lived, perennial shrub, 1-3 m height & persistent rootstock 2-3 m deep • tangled woody stems remain bare until wetted when shoots, leaves & flowers rapidly form • prefers higher flood frequency zones than low • reliant on flooding to reproduce vegetatively and sexually from seed (i.e. a prerequisite)* • seed germination cued by flooding, soil moisture & fluctuating temperature (seeds buoyant for 5-28* days); seeds can ripen & disperse in 12 days; no persistent seed-bank (seeds not viable for extended periods) • flowers in spring (from winter rains) or a few weeks after flooding	Craig et al. 1991; Capon 2005; Chong & Walker, 2005; Jensen et al. 2006 and references therein; Overton & Doody 2007; Jensen 2008; Capon et al. 2009; Roberts & Marston 2011; Rogers & Ralph 2011; Jensen et al. 2011b; Freestone et al. 2017; Jensen & Walker 2017; DEW 2023a; Mokany et al. 2024 * Jensen pers. comm.

Taxon	Functional Role	Ecological Characteristics/Requirements	References
		• germination influenced by temperature, with rates highest & fastest between 15 and 30° C • spring growing season; clone emergence coincides with high moisture soil through autumn & winter* • on EC floodplain where flooding to < 60 cm depth occurs for 45-115 days per year • relatively salt and drought tolerant but growth limited at high salinities • dies under prolonged flood conditions (> 1 yr) • prefers flood frequency of 1-3 (max. 3-10) years and timing important; flood duration important for germination (~1-3 months) • floods important for dispersal and genetic diversity	
Emergent macrophytes e.g. *Phragmites australis* (CR) (common reed) *Typha* spp. (C) (cumbungi)	• habitats/refuges for littoral fauna and flora • contributes to productivity via promoting detritus and biofilms • maintains and improves water quality (nutrient control) • erosion control and flood abatement	• CR occurs in fluctuating or static water levels to 4 m; C prefers stable water levels to 2 m • flood and dry tolerant (C less so at 4 months) • flowering in summer/ full height autumn • peak below-ground biomass winter • brackish/saline tolerant	Blanch et al. 1999; Rogers & Ralph 2011; Brookes et al. 2018; Jellinek et al. 2018; Nicol et al. 2018, 2020, 2021, 2023.
Reeds (basket weaving) *Cyperus gymnocaulos* (spiny flat sedge)	• coarse leaves used by Ngarrindjeri weavers for nets, basketry, etc.	• occurs along river and lake margins, in areas prone to frequent flooding • hardy, tolerant of drying	Blanch et al. 1999; Coleman et al. 2017; Jellinek et al. 2018; Nicol et al. 2018, 2020, 2021, 2023.
Widgeon/Tassel grass *Ruppia megacarpa* (RM) *Ruppia tuberosa* (RT) "Ruppia Community'	• provide habitat & shelter (e.g. for small fish & invertebrates) • primary producers in the Coorong • leaves, seeds & turions provide vital food for fish & waterbirds (e.g. swans, ducks) • contribute to carbon & nutrient recycling, & a major source of detritus	• require relatively high light levels e.g. RM restricted to water < 2 m deep & RT < 1 m deep • sensitive to desiccation and do not grow in water < 0.3 m deep (due mainly to wind disturbance) • RM - perennial; brackish to hypersaline, preferred salinity range 5-46 ppt, depth < 1-2m	Phillips & Muller 2006; Paton 2010; Paton 2010; Whipp 2010 (and references therein); Nicol et al. 2018, 2020, 2021, 2023; Asanopoulos & Waycott

Taxon	Functional Role	Ecological Characteristics/Requirements	References
	• provide substrate for algal growth and fish egg deposition	• RT - annual (often in ephemeral saline wetlands); exclusively hypersaline, preferred salinity range 40-80 ppt, depth 0.3-1 m • RM regenerates from seeds or asexual propagules (turions)	2022; Lewis et al. 2022; Waycott & Lewis 2022.
Phytoplankton	• primary producers in aquatic food chains	• over 150 taxa recorded • typically 'lake' type composition during summer-autumn low flows • some forms (e.g. Cyanobacteria) can develop blooms in warm, nutrient-rich water (e.g. Lake Alexandrina)	Sullivan 1990; Young et al. 2001; Aldridge et al. 2012a; Leterme et al. 2018.
Fauna			
Zooplankton	• secondary producers in aquatic food chains primary food source for larval fish	• over 180 taxa recorded • some species unique to system • a mixed assemblage derived from the Darling riverine zooplankton (rotifer dominated) and the middle Murray (crustacean dominated) • estuarine taxa in Coorong	Shiel 1990; Shiel & Aldridge 2011; Leterme et al. 2018.
Macroinvertebrates	• multiple functional groups - e.g. shredders, grazers, gatherers, filterers, predators • influence nutrient cycling, primary production, decomposition and translocation of materials • important link between primary producers, detrital deposits, and higher trophic levels in aquatic food webs • important source of food for fish (+ larvae) • good environmental indicators	• approximately 440 taxa recorded • include crayfish, shrimps, freshwater mussels, snails, insects, worms and many other forms	MDBC 2008b; Walker et al. 2009, 2018; Davies et al. 2010; Geddes et al. 2016; Dittmann et al. 2018, 2019; Le et al. 2021
River mussel (RM) *Alathyria jacksoni* and **Floodplain mussel** (FM)	• filter feeders • filter phytoplankton and organic matter from the water • accumulate chemical pollutants including heavy metals, pesticides	• RM - flowing water; strong burrower; intolerant of hypoxia and dehydration (most abundant in strong currents such as river bends) • FM - still and slow-flowing water including weir pools and river margins, floodplain wetlands;	Walker 1981, 1998, 2006, 2017; Walker et al. 2001, 2009, 2014, 2018; Rogers & Ralph 2011; Sheldon et al. 2014, 2020; Graf et al. 2015;

Taxon	Functional Role	Ecological Characteristics/Requirements	References
Velesunio ambiguus	• shells provide important substrate for algae, insect larvae and other macroinvertebrates; attracts fish • food for large-bodied fish, including Murray cod • can contribute to stabilisation and oxygenation of bottom substrate • formerly key food resource for Ngarrindjeri people (hence middens along river-banks)	weak burrower; tolerant of hypoxia and dehydration • critical temperature for growth and activity is > 12° C for RM & FM • larvae (glochidia) are parasites on fish • adult aestivation: No RM; Yes FM • lifespan of decades provides stability to aquatic habitats	Vaughn 2018; Whiterod & Zukowski 2019; Brower et al. 2023; Humphries 2023; Wright et al. 2023
Aquatic snails e.g. *Notopala shanleyi*	• grazers, feeding on biofilms - scrape plants, surfaces and sediments with toothy radulae (some filter feed) • prey to crayfish, fish, amphibians, birds	• native fauna (18 species) much reduced by regional extinctions; some introduced species now common	Walker 2006; Walker et al. 2009, 2018; Holmes et al. 2013; FSC 2015; DISRD 2018; Ponder et al. 2023
Crayfish *Euastacus armatus* (EA – Murray crayfish) *Cherax destructor* (CD - yabby)	• generalist predators, scavengers, detritivores, and at times filter-feeders, of anything edible	• EA large, up to 3 kg and 50 cm; slow growing, long lived (28 y for maximum size, up to 50 y) • EA prefers faster-flowing cool water habitats of main channel, clay banks, woody debris, deep holes, boulders • low dispersal ability; small home range • EA tolerates temperatures up to 27°C; intolerant of low DO • EA optimal temperature for tail flipping 18° C • EA matures at 4 y males; 6–10 y females; low fecundity (200–2000 eggs); high mortality prior to maturity (~ 50%) • CD (yabbie) prefers slow, warm water - common in weir pools and wetlands • CD small, ≤ 250 g	Geddes 1990; Walker 2006; Gilligan et al. 2007; McKinnon 1995 in Walker et al. 2009, 2018; Furse & Coughran 2011a, b, c; FSC 2013; Soffels et al. 2015; Noel & Fulton 2017; Whiterod & Zukowski 2017, 2019; Whiterod et al. 2018; Forbes et al. 2019; Laurence et al. 2022; Zukowski et al. 2024

Taxon	Functional Role	Ecological Characteristics/Requirements	References
Freshwater catfish *Tandanus tandanus*	• medium to large benthic (bottom) feeder (now largely replaced by carp) • males build (and guard) elaborate nest on bottom substrate	• max. 90 cm & 6.8 kg; usual 30–50 cm & < 2 kg • max. age 12 y; sexual maturity 2–5 y • prefers habitat structure - submerged vegetation, woody debris, undercut banks (unknown in Lower Lakes) • spawn spring/summer 20–24° C • juveniles often in backwater habitats • no long-distance movements/migrations	Clunie & Koehn 2001; Lintermans 2007, 2023; Hammer et al. 2009; Bice 2010 ;Wilson et al. 2014 ; Kostner et al. 2015 ; Ye et al. 2015 ; Burndred et al. 2017.
Silver perch *Bidyanus bidyanus*	• large-bodied fish, omnivore	• highly migratory (adults spawning related, up to 517 km; juveniles dispersal related) • flow a trigger for spawning	Reynolds, 1983; Mallen-Cooper & Stuart (2003); Lintermans, 2007, 2023; Tonkin et al. 2017, 2019; Kostner et al. 2020; Michie et al. 2020.
Murray cod *Macculochella peelii*	• large bodied: max 1.8 m, 113.6 kg; typically < 20 kg • long lived: max. 114 y, usually < 48 y • powerful apex predator (adults - fish & crustaceans, occasionally larger prey; larvae - zooplankton & aquatic insects)	• slow to mature 4–6 y; low fecundity • cover-oriented at all life-stages (snags, rocks) • prefers fast-flowing mesohabitats • diet: ~ 45% fish, also crustaceans (eg. yabby) • floods/freshes not needed to trigger spawning; but gain significant benefits from increased flow which improves larval survivorship • annual spawning triggered by rising temperature (15–23.5° C) & day length (October/November) • large upstream migration prior to spawning (after, rapid return to same area/snag) • yolk-sac/early larvae at risk from raised salinity	Harris & Rowland, 1996; Koehn, 1996; Humphries et al., 1999; Ye et al., 2000; Rowland, 2005; Ebner, 2006: Koehn & Harrington, 2006; Baumgartner, 2007; Lintermans, 2007, 2023; Ye and Zampatti, 2007; Bice, 2010; Ye et al. 2010, 2012, 2022, 2023; Leigh & Zampatti 2011; Zampatti et al. 2011a,b; Zampatti 2012; Vilizzi et al. 2014; Giri & Hall 2015; Mallen-Cooper & Zampatti 2018, 2020; Kaminskas 2021; Stuart et al. 2021; Fredberg et al. 2022; DEW 2023a; Humphries 2023; Fanson et al. 2024; Schilling et al. 2024.

Taxon	Functional Role	Ecological Characteristics/Requirements	References
Congolli *Pseudaphritis urvillii*	• estuarine/freshwater species - in channel, terminal wetlands, lowland streams • opportunistic benthic carnivore • diadromous species (catadromous)	• migrates upstream (up to 215 km) • highest adult female abundance in freshwater; males in coastal/estuarine zones • moves downstream to estuaries to spawn in autumn/winter • prefers habitat with soft silt or sand in which can bury, or lots of instream vegetation cover • opportunistic benthic carnivore	Bice et al. 2007, 2017b, 2018a, b; 2020, 2021, 2023; DEH 2008; Bice 2010; Hortle 1978 in Zampatti et al. 2011a, b; Ye et al. 2012; Reinfelds et al. 2013; Mallen-Cooper & Zampatti 2018; Bice 2023.
Lampreys *Geotria australis/ Mordacia mordax*	• diadromous species (anadromous)	• lives mostly in sea but migrates into freshwater to breed	Zampatti et al. 2011a, b; Bice et al. 2017b, 2018a, 2021; Mallen-Cooper & Zampatti 2018.
Assemblage small-bodied fish (various species) e.g. Murray hardyhead *Craterocephalus fluviatilis* Yarra pygmy perch *Nannoperca obscura* Small mouth hardyhead *Atherinosoma microstoma*	• wetland ecological specialists—dependent on macrophytes and low flows • convert resources at base of food chain (plant detritus, epiphytes, zooplankton, insect larve, etc.) • important prey items for higher trophic levels, particularly large-bodied fishes and piscivorous birds • graze zooplankton and invertebrates	• dependent on macrophytes for habitat – reproduction, shelter, and feeding • short-lived (< 2 y) • freshwater species, with MH adults tolerant of saline waters (adults can survive > 90 ppt; larvae, 30 ppt) • wide range of spawning strategies, including main channel generalists, wetland specialist and low flow specialists—with most species falling into more than one of these categories • MH – spawn spring-summer (Sept. to March); lays eggs on submerged vegetation • SPSG – spawn summer (above 20 C); eggs on firm substrates & guarded by male	Lloyd & Walker 1986; Humphries et al. 1999; Hammer 2004; McNeil et al. 2007; Hammer et al. 2009; Bice 2010; McNeil et al. 2011; Wedderburn et al. 2012, 2014, 2017, 2019, 2020, 2022, 2023; Humphries & Walker 2013 ; Saddlier et al. 2013 ; Attard et al. 2016; Cole et al. 2016: Koehn et al. 2017, 2020; Lovett 2019; Whiterod 2019; Whiterod et al. 2019, 2021; Brauer & Beheregaray 2020; Theile et al. 2020; Stoessel et al. 2020; Beheregaray et al. 2021; Zukowski et al. 2021 ; Buckley et al. 2023; Lintermans 2023;

Taxon	Functional Role	Ecological Characteristics/Requirements	References
			Wedderburn & Bailey 2024
Freshwater turtle *Chelidina expansa* (CE) *Chelodina longicollis* (CL) *Emydura macquarii* (EM)	• multiple functional groups • nutrient recycling • ME specialist predator (decapod crustaceans) • CL opportunistic carnivore (invertebrates, small fish) • EM -opportunistic omnivore (algae, carrion, invertebrates)	• habitats include channels and billabongs (EM), swamps, slow-moving rivers and streams (CL), and turbid water e.g. river bottom (CE) • CL and EM spring mating, hatch summer/autumn; ME less abundant, autumn mating, hatch summer • Australian freshwater turtles are slow growing and mature at around 10 y; they can live up to 75 years • Nest sites are usually in the open, between 2 and 40 metres from the water's edge (EM) • Up to 30 eggs per nest (EM)	CSIRO, 2004; Hutchinson, 2009; Howard et al. 2016; Cann & Sadler 2017; Van Dyke et al. 2019 (& references therein)
Black swan *Cygnus atratus*	• top-order consumer; dispersal of aquatic flora and fauna (via seeds, dormant eggs, etc.)	• nesting - ground, floating or island nesting	Paton et al. 2009a, b; Rogers & Ralph, 2011; Paton et al. 2018.
Pelican *Pelecanus conspicillatus*	• top-order consumer; dispersal of aquatic flora and fauna (via seeds, dormant eggs, etc.)	• nesting - ground, floating or island	Paton et al. 2009a, b; Rogers & Ralph 2011; Paton et al. 2018, 2022.
Colonial Nesting Water Birds e.g. Ibis	• top-order consumer; dispersal of aquatic flora and fauna (via seeds, dormant eggs, etc.)	• nesting - live tree, shrubs or reed	Paton et al. 2009a, b; Rogers & Ralph 2011; Paton et al. 2018, 2022.
Migratory Water Birds e.g. *Calidris* species, *Numenius madagascarensis*	• top-order consumer; dispersal of aquatic flora and fauna (via seeds, dormant eggs, etc.)	• nesting - live tree, shrubs, reed, ground, floating or island	Paton et al. 2009a, b; Rogers & Ralph 2011; Paton et al. 2018, 2022.

Consultation Questions on the functionally important species

- Do you have any feedback or further relevant source-information for this section, including other functionally important species that should be highlighted? If so, please provide details and reference sources in your response.

Table 18: Examples of ecological processes that generally operate within aquatic ecosystems and apply to the ecological community (modified from DSE 2005; Rogers & Ralph 2011).

Process Categories	Key Processes or attribute
Energy and nutrient dynamics	• primary production • nutrient cycling e.g. N, P • carbon cycling • decomposition • oxidation-reduction
Processes which maintain animal and plant populations	• survival/ mortality • reproduction and recruitment • dispersal or migration (recolonisation) • spawning or pollination • regeneration (recovery after disturbance) • access to refuge (i.e. from predators, drought or flood) • dormancy (encystment); seed/egg banks
Species interactions	• herbivory or detritivory • predation • competition for resources • mutualism (symbiosis) • parasitism • diseases and pathogens • succession
Geomorphologic and fluvial processes	• sediment regime (erosion, transport, deposition, turbidity) • acid sulfate soil formation • boundary effects (e.g. areas of low velocity) • connectivity • salt transport • nutrient transport
Hydrological regime	• flow regime—frequency, magnitude, duration, timing (+seasonality), time since last flooding (return period)) • water depth (and level) persistence (variable/stable) • climate (e.g. temperature) • groundwater—surface water connections • water balance—water inflow, evaporation, water outflow • residence time • infiltration and soil moisture content • water quality (e.g. salinity, algal blooms, etc.) • boundary effects (e.g. stratification from thermoclines or haloclines; mouth closure) • mixing—wind, stratification breakdown

1.2.4 Key biological and ecological processes

In general, the relevant biology and ecology of species assemblages within the ecological community are influenced by five main drivers. These combine to shape the diversity, dynamics, and distribution of plants and animals and their habitats in this complex riverine-floodplain system (e.g. Bayley 1995; Walker 2006; Goode and Harvey 2009; Walker et al. 2009; Rogers and Ralph 2011). The five main drivers are:

- Hydrology— temporal and spatial variability of flows and water levels (see Section 1.2)
- Connectivity— between the river and its floodplain woodlands and wetlands, and between the river and the sea
- Transport of particless—sediments, nutrients, and carbon (i.e. influencing productivity and water chemistry)
- Salinity—i.e. as influenced by groundwater and surface hydrology, and
- Regional climate.

Biota within the ecological community have basic requirements for survival, growth and reproduction that are related to preferred habitats, and water regimes and trophic linkages (Walker et al. 1995; Rogers and Ralph 2011). These requirements, and the underlying ecological processes, are also subject to disturbances through river regulation and other anthropogenic effects. Ecosystems and biota have some inherent degree of resilience to cope with such disturbances, but there are limits that, once exceeded, may change the ecological character of the community.

Table 18 provides an overview of the ecological processes that generally operate in aquatic ecosystems and key elements of the biology and ecology of the ecological community, as influenced by the main drivers (with the exception of climate), are elaborated below, in addition to in Table 17.

FLOW AND CONNECTIVITY

The transport-transformation model

River ecosystems are governed by their flow regimes (i.e. hydrology), and the effects of flow are so pervasive that it has been called the 'Maestro', or 'Master' variable, in river ecology (Walker et al. 1995; Young 2001). Flow influences virtually all features of the riverine environment, including the character of the sediment, the shape of the channel and the lay of the land, and the transport of sediment, salt and nutrients. It also determines the kinds of animals and plants that are present, their dispersal and dynamics, and governs hydraulic connections between the channel and the floodplain wetlands, shrublands and woodlands.

A simple model of a floodplain river ecosystem is at Figure 4 (Walker 2010). The channel is shown as a strong vector, representing its role in *transport* of water and matter, and as a corridor for dispersal of aquatic and riparian plants and animals. On the floodplain, matter from the river is deposited in wetlands and woodlands to undergo *transformation*, whereby it is stored, broken down and reassembled as the bodies of new organisms. As decomposition and production are more complex processes than those involved in transport, there often are more ecological niches and correspondingly more biodiversity in floodplain environments, including aquatic, terrestrial and amphibious species.

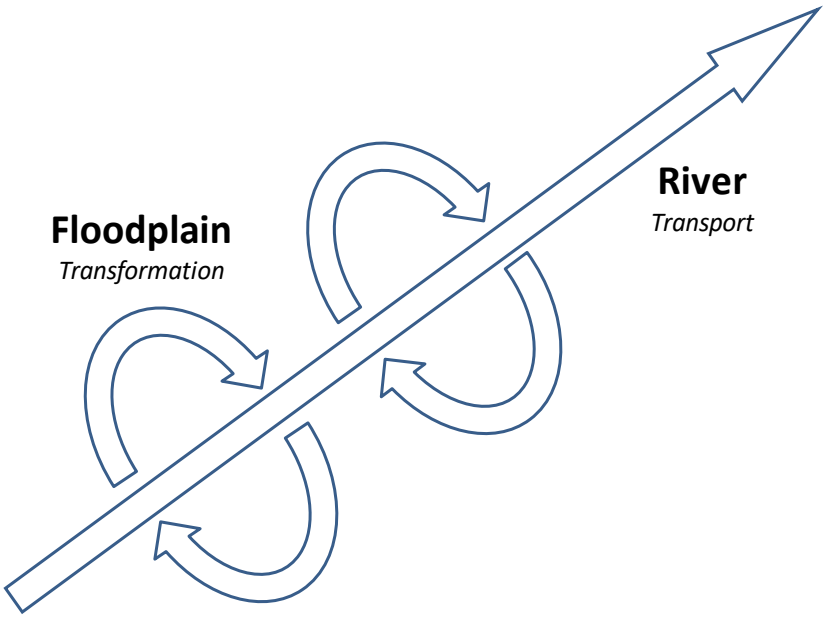

Figure 4: The 'transport' and 'transformation' functions of a floodplain river (Walker 2010).

The transport-transformation model emphasises the integrity of rivers and floodplains and the necessity for hydrological 'connectivity'. It portrays the channel as a conduit and corridor, and the floodplain as a site for key biological processes, and it highlights the channel's role in connecting the elements of the system. In a regulated river, where overbank flows are limited, channel functions are promoted, the floodplain is isolated, processes are constrained and biodiversity declines (e.g. Walker 2006).

Connectivity is the opposite of fragmentation, and refers to connections along the channel, between the channel and floodplain, as well as throughout the drainage network. Connectivity is a prerequisite for a healthy floodplain-river ecosystem. Aquatic connections between the channel and the floodplain may include anabranches, flood runners and ephemeral, seasonal and permanent backwaters, billabongs and lakes (Sheldon and Walker 1998). The floodplain as a whole is, by definition, dependent on flows in the river, and the fauna and flora of the channel also depend on access to floodplain habitats.

Wetting and drying cycles

In the River Murray, as in most dryland rivers, the pattern of flow (the flow regime) is highly variable (Young 2001). The hydrograph shows erratic sequences of flood and drought, and a high degree of variability between years and decades, although the natural pattern has been modified by diversions and regulation (e.g. Maheshwari et al. 1995). The propensity for river flows to vary widely is reflected in the life cycles of many native species that are opportunistic, tolerant and capable of rapid dispersal. The effects of regulation, however, have reduced flow variability within and between years for the RMDS, and generally favoured introduced species, with regular, seasonal life cycles, over native species.

The river channel, unlike most floodplain habitats, is characterised by strong currents, unstable sediments, a shallow photic zone, and other conditions that represent a harsh environment for many organisms. The littoral[1] zone, at the channel edge, supports a narrow band of emergent and submerged plants that forms a refuge for many animals and is often a place of high

[1] Littoral ('edge') relates to the zone at the margins of a river, lake or other waterbody.

biodiversity (Walker et al. 1992; Walker et al. 2009). The distribution of aquatic/emergent plants is influenced by the frequency of flooding and exposure (Walker et al. 1994), and this zone was much less developed (or absent) prior to river regulation (Blanch et al. 2000).

Many wetlands in semi-arid Australia are adapted to intermittent periods of wetting and drying (Passfield et al. 2008) and the wetting-drying sequence is also important for habitats within the river channel component of the ecological community. Primarily, changes in the water level in the channel affect the growth of biofilms[2] that provide food for fish, and for snails and other grazing invertebrates (Walker 2001).

In a natural system, the wetting and drying cycles are driven by ephemeral stream inflow or floodplain flooding (Passfield et al. 2008). Wetting and drying cycles influence temporal surface water and groundwater interactions, and these changes can determine the accumulation of salt in a wetland (Passfield et al. 2008). Within floodplain systems, the interaction between temperature and flow also contributes to the structuring of biotic communities (Tockner et al. 2000).

Wetting and drying model

In general, floodplain wetlands occur along a water-availability gradient that governs the zones where particular plant and animal species may occur (Brock 1994). Zones of a wetland may range from fully terrestrial land that has wet and dry phases but is dry most of the time, through to an edge zone (littoral) characterised by fluctuating water levels, and potentially to a fully submerged zone where inundation is effectively permanent.

According to the 'wetting and drying' model of Brock and Casanova (1997), plants occupying the upper edge of a wetland are regarded as 'terrestrial', those on the lower edge are 'submerged' and plants located between those zones are referred to as 'amphibious'. These are further classified into 'functional groups' on the basis of wetting and drying cycles (see Table 19). Species less tolerant of waterlogging are limited to the upper, drier sections of the moisture gradient whilst species that require full inundation are limited to the submerged zone. The area between is occupied by amphibious species that can cope with variable wet and dry conditions. Amphibious plants can be classified into two broad groups (Brock and Casanova 1997):

- *Fluctuation tolerators* that cope with changes in water level without any major change in their growth or habit. Examples include upright sedges and grasses that can have their roots and lower shoots submerged on occasion but their upper shoots nearly always emerge above the surface water level, and
- *Fluctuation responders* that can change their patterns of growth or habit when water is present. An example is species of *Myriophyllum* (water milfoil) that changes its leaf shape depending on whether or not shoots are submerged or not.

Variable water levels have special significance for the riverine littoral community. Aquatic and semi-aquatic plants along the river margins of the Murray are confined to a band whose width varies with the magnitude of seasonal water-level changes (Walker et al. 1994).

[2] Biofilm - a layer of living microorganism including algae, fungi and bacteria, in a polysaccharide matrix coating submerged gravel, rocks, plant, leaves, wood, etc. (also called epilithon, Aufwuchs, epiphyton, periphyton).

Table 19: The wetting and drying model (Brock & Casanova, 1997), with classification of Australian wetland plants based on responses to wetting and drying patterns (Source: Brock and Casanova, 1997; Casanova and Brock, 2000 in Rogers & Ralph, 2011).

Primary Category	Secondary Category	Description
Terrestrial	Dry species	Species which germinate, grow and reproduce where there is no surface water and the water table is below the soil surface
Terrestrial	Damp species	Species which germinate, grow and reproduce on saturated soil
Amphibious fluctuation-tolerators	Emergent species	Species which germinate in damp or flooded conditions, tolerate variation in water level, and grow with their basal portions under water and reproduce out of the water
Amphibious fluctuation-tolerators	Low growing species	Species which germinate in damp or flooded conditions, tolerate variation in water level, are low-growing and tolerate complete submersion when water levels rise
Amphibious fluctuation-responders	Morphologically plastic species	Species which germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and have morphological plasticity (e.g. heterophylly) in response to water level variation
Amphibious fluctuation-responders	Species with floating leaves	Species which germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and have floating leaves when inundated
Submerged	Submerged	Species which germinate, grow, and reproduce underwater

In general, an increase in flooding (including frequency, depth, extent, duration, variability) may encourage competitive submerged and amphibious species and decrease species richness, whereas the opposite conditions (i.e. more permanently dry) may encourage weedy terrestrial species, with a concomitant decrease in species richness of amphibious and submerged species (Brock and Casanova 1997).

Further information on hydrological processes that underpin the riverine, wetland, and floodplain components of the ecological community, and the biological adaptations to flow and wetting and drying cycles of the various plants and animals that inhabit them is provided by Mackay & Eastburn (1990), Boulton & Brock (1999), Young (2001), Jennings (2009), and Paton (2010).

The 'Flood Pulse Concept' (FPC)

The floodplain component of the ecological community is part of the river-floodplain ecosystem that is regularly flooded and dried, and could be considered to be a type of wetland (Bayley 1995). Floodplains are characterised by two phases, wet and dry, interspersed by floods and drought; each phase with a dominant biota (Colloff & Baldwin 2010). Thus, riverine floodplains

are expanding and contracting systems (at both the over and below bankfull scales) and are often fragmented.

Connectivity, the connection between the floodplain and river, is of critical importance and supports a myriad of ecological functions and interactions (Goode & Harvey 2009). The floodplain flora and fauna depend on the river for dispersal and replenishment, and in turn, the riverine biota depend on the floodplain for food, nurseries, and refuges (Walker 2001).

A useful general model for the lowland floodplain reaches of large rivers, such as for the ecological community, is that of the *Flood Pulse Concept* (FPC) which recognises the importance of lateral linkages between the river and floodplain and consequent exchange of water, organic material, nutrients, and organisms (Junk et al. 1989; Robertson et al. 1999; Tockner et al. 2000; Junk & Wantzen 2004; see also Figure 4). The FPC is based on overbank inundation driven by floods and is considered to be the key ecological determinant of river-floodplain system function (Junk et al. 1989; Robertson et al. 1999).

According to the FPC, biota respond to characteristics of the flood pulse, including flood timing, magnitude, duration, and rate of rise and fall (Junk & Wantzen 2004; Rogers & Ralph 2011). The flood pulse enhances biological productivity (e.g. through exchange of nutrients) and maintains diversity in the system (Bayley 1995). The 'moving littoral' zone during flooding also provides excellent nursery grounds for fish and optimal environments for many invertebrates, especially those associated with macrophytes (Bayley 1995). Many fish species anticipate these conditions by spawning before or during the period of water rise. Thus, lateral connectivity directly determines the diversity patterns of many taxonomic groups (Tockner et al. 1999 in Junk & Wantzen 2004).

For floodplain wetlands, floods and dry periods can be both beneficial and detrimental to the performance of biota, depending on their extent. For example, flood pulses can introduce high levels of productivity from the floodplain into the channel environment, or open up space or new habitats, or alternatively, act as detrimental perturbations—thereby reducing the physiological function of some biota (Odum et al. 1979 in Rogers and Ralph 2011; Tockner et al. 2000).

Many floodplain organisms have a 'physiological and phenological[3] window of susceptibility' to the benefits and disturbances of the flooding (Junk & Wantzen 2004). The timing decides whether an organism can profit from the flood-borne resources or apply survival strategies. Importantly, when river water inundates the floodplain or retreats from the floodplain, various key processes occur (see Table 20).

Floodplain and wetland vegetation and fauna exhibit varying degrees of adaptation to flooding and/or drought, and knowledge remains limited regarding specific water requirements of much of the freshwater biota. Common survival strategies for systems with highly variable and less predictable flood pulses include (Williams 1985; Tockner et al. 2000):

- flexible life cycles
- rapid development and early reproduction
- high fecundity
- short life spans

[3] Phenological - relating to periodic biological or behavioural phenomena such as flowering, breeding, migration, especially in relation to climate or other environmental factors (Park, 2007).

- production of resistant seeds or dormant eggs
- retreat to refugia; or the formation of metapopulations (e.g. some species of insects).

For example, snails and certain crustaceans (e.g. cladocerans and ostracods) are abundant in floodplain wetlands and have evolved strategies to take advantage of the 'boom and bust' cycles that are characteristic of this environment. However, regulation has tended to stabilise flow and water level within the ecological community and decreased the frequency of overbank flows (Walker 1991). Small floods (e.g. return period less than seven years) have been almost eliminated, but there is insufficient storage to check large floods (Walker 1991). The book by Rogers and Ralph (2011) provides a useful synthesis of available biological and ecological knowledge for key flora and fauna in freshwater floodplain wetlands.

Table 20: Key processes that occur simultaneously during river water inundation or consequent retreat on the floodplain (after Junk and Wantzen, 2004 & references therein).

River inundates the floodplain - via overspill or floodplain channels	Water level falls on the floodplain
• ***reset*** - pre-flood thermal and chemical heterogeneity[4] between main channel and floodplain water bodies temporarily resets	• ***disperse*** - water stored in the floodplain with any dissolved and suspended matter enters the parent river or lake
• ***recharge*** - considerable inputs of mainstream water-bound substances (dissolved and suspended, organic and inorganic) flush into the floodplain	• ***dry*** - the aquatic/terrestrial transition zone (ATTZ) dries out and becomes colonised by terrestrial organisms
• ***recycle*** - terrestrial habitats are flooded, large amounts of biomass decays and large amounts of inorganic matter deposited during the terrestrial phase are mobilised by the overlying water	• ***detach*** - fringing vegetation in the once-submerged littoral or riparian zone becomes isolated, removing an important habitat and/or food source for many aquatic organisms
• ***renew*** - aquatic organisms are flushed or migrate into the floodplain or emerge/hatch from resting stages	• ***disconnect*** - large amounts of water-borne organic carbon become stranded and incorporated in the terrestrial food webs
• ***respond*** - terrestrial organisms migrate into non-flooded habitats or show adaptations to flooding	• ***differentiate*** - aquatic organisms move to permanent water bodies or show adaptations to periodic drought
• ***re-enter*** - terrestrial carbon and floodplain products from the canopy of the floodplain woodland/forest, such as terrestrial invertebrates, fruits and seeds, are incorporated into aquatic food webs	• ***dissociate*** - permanent water bodies become increasingly isolated from the parent river or lake and develop specific physical and chemical characteristics and specific species assemblages

[4] Heterogeneity relates to variety or diversity, or lack of uniformity, of aspects of the environment (Park, 2007).

PRODUCTIVITY AND TROPHIC LINKAGES

The *Flood Pulse Concept* (FPC) implies that biological production in the ecological community is enhanced through a variety of processes during the flooding cycle (Bayley 1995). Nutrient and energy pathways are complex in riverine-floodplain ecosystems and depend on both biological and geo-chemical processes. For example, during flooding, high primary production rates can occur, as nutrients previously mineralised during the preceding dry phase are dissolved and additional nutrients dissolved in the flood waters or associated with suspended sediment are also brought in from the main river (Bayley 1995). Therefore, for floodplain habitats of the ecological community, primary production is closely related to the hydrological regime, and changes to flood frequency, seasonal timing, and duration can have marked impacts on patterns of production (Brinston 1990 in Robertson et al. 1999, 2001). In addition, catchment vegetation, particularly in the riparian zone, contributes carbon and regulates in-stream primary production through reducing incident light and lowering water temperatures (Gregory et al. 1991).

Central to productivity are riverine food webs, which are formed from a myriad of food chains—the feeding relationship between organisms at different trophic levels. The lowest trophic level is that of the primary producers—plants and algae that convert solar energy, carbon and nutrients into organic matter. Animals then consume or break down this organic material:

- in the open water, zooplankton are the most important grazers, including rotifers (Rotifera), copepods (Copepoda), and 'water fleas' (Cladocera)
- in the littoral zone, important invertebrate grazers include insect larvae, aquatic snails (Gastropoda), and beetles (e.g. Curculionidae, weevils), and important vertebrate grazers include tadpoles and waterbirds (Boulton and Brock 1999).

In turn, grazers are generally preyed upon by fauna at higher trophic levels—the littoral and nektonic predators, such as diving beetles (Dytiscidae), dragonfly larvae (*Odonata*), fish, frogs, and waterbirds.

Importantly, size-selective predation underpins the 'trophic cascade' concept[5], which is based on the expected sequence of changes in abundance of prey and predators or plants and herbivores due to biological interactions (Boulton and Brock 1999). For example, if an important predator (such as an apex predator at the highest trophic level in a food web) is removed from the community, then the abundance of their prey increases; if that prey species usually grazes on certain plants, then these plants are similarly impacted—possibly to the point where the grazer can no longer be supported (Estes et al. 2001).

Bacteria, the smallest and most abundant organism in aquatic ecosystems, live on and in the river-bed, as well as suspended in the water-column where they can also take up dissolved carbon (Young 2001). Bacteria are an extremely important food source and recognised as a vital link between detritus and higher consumers in aquatic food chains (Young 2001); for example, dead organic matter is recycled into the food web by bacteria and fungi. Biofilms of microorganisms coating organic matter on the bottom or other substrates (such as gum leaves) also provide nutritious energy-rich food for grazing invertebrates (Boulton and Brock 1999).

[5] Example of trophic cascade concept: When fish-eating (piscivorous) fish are reduced, their prey – zooplankton-eating (zooplanktivorous) fish should increase. In turn, their predation on herbivorous zooplankton would lead to an increase in phytoplankton. Ultimately, available nutrients decrease as they are taken up by the algae.

Food webs in freshwaters can be supported by bottom detritus and/or from primary production in the pelagic[6] zone. Food webs in large floodplain rivers can also be influenced by terrestrial input and organic matter derived laterally from the floodplain (i.e. the FPC). Flow and its interaction with geomorphology control organic carbon fluxes in rivers. In general, riparian sources dominate organic carbon pools in catchment streams (exceptions occur where cover is absent, in-stream gross primary production is more than 1 $gCm^{-2}day^{-1}$, and ratios of production to respiration are greater than 1) as demonstrated by the comparisons in Table 21. For example, the major floodplain overstorey species, river red gum and black box, generate a large annual biomass of leaf litter, around 2500 g m^{-2} and 600 g m^{-2} respectively, which is a major source of organic matter to the system (Wallace 2009).

Flood release and export of dissolved organic carbon (DOC) from the floodplain may be substantial relative to in-stream production in river channels, while sediments deposited on floodplains during large floods represent a substantial sink of riverine particulate organic matter (POC) (Robertson et al. 1999, see Table D4). Bacteria are responsible for rapid decomposition of DOC and POC in floodplain wetlands (Table 21). Importantly, river regulation and disturbance to the catchment have resulted in decreased inputs of floodplain carbon, and domination by algal production in the river channel (Robertson et al. 1999; Walker 2006).

Table 21: Sources and comparative amounts of organic carbon on riverine floodplains (Robertson et al. 1999).

Aspect of organic carbon/production	Amount
Floodplain primary production by river red gum forests	~600 gC m^{-2} $year^{-1}$
Total primary production by aquatic macrophytes in floodplain wetlands	>2500 gC m^{-2} $year^{-1}$
Total primary production by aquatic biofilms in floodplain wetlands	>620 gC m^{-2} $year^{-1}$
Large pools of particulate organic carbon (POC) as floodplain litter	>500 gC m^{-2}
POC on floodplain as coarse woody debris	~6 kgC m^{-2}
Floods may release dissolved organic carbon (DOC) from leaf litter	50 gDOC m^{-2}
Sink of riverine POC onto floodplain by large floods	up to 280 gC m^{-2}
Decomposition of DOC and POC by bacteria in floodplain wetlands (i.e. sediment respiration and methanogenesis)	both processes ~1 gC m^{-2} day^{-1}

SALINITY

Salinity is another important driver influencing aquatic ecology. The region of the ecological community has been flooded by rising sea levels over the last 20 million years, and the regional groundwater contains large quantities of relictual salt. The salt entered the surface water slowly, until the rate of accession was greatly increased by clearing of vegetation and irrigation (Miles and Kirk 2005). The River Murray channel, a major component of the ecological community, also provides the only natural conduit to flush salt from the entire Murray-Darling Basin through to

[6] pelagic - in open water, within the water-column of a waterbody (cf. benthic which relates to the bottom).

the sea (Evans et al. 1990). The quantity of salt transported by the river in South Australia is estimated to be about two million tonnes (MDBA 2010).

Levels of salinity in riverine, floodplain, wetland, and groundwater environments of the ecological community are largely influenced by flow, although the retention of salt in floodplain soils has been increased through the hydraulic effects of the weirs (e.g. Walker 2006). If the river level drops suddenly after an overbank flood, high levels of salt can be entrained and passed down-river. Many of the temporary wetlands in the ecological community can become saline after flooding (Suter et al. 1993), with terminal wetlands that are seldom flushed most at risk from salinisation (Hart et al. 1990).

The native flora and fauna of the ecological community have evolved under conditions where salinity fluctuated widely. Before impoundment, the river would sometimes contract to a series of pools during very dry seasons, with salinities up to 6 g/L, and seawater would move some 100 km upstream (Mackay et al. 1988 in Williams and Williams 1991). Consequently, animals and plants in the ecological community often display varying levels of tolerance to elevated salinity, particularly in the adult phase. Some of the fish species move between the sea, estuary, and freshwater habitats and have at least moderate salinity tolerance (Williams and Williams 1991).

Plants and animals typically have a range of physiological mechanisms and adaptations to maintain the necessary balance of water and ions in cells and tissues. These abilities determine the level of sensitivity to salinity changes, with high increases in salinity being lethal to most freshwater plants and animals. For example, certain groups of insects and molluscs are particularly sensitive to small increases in salinity (Hart et al. 1991). In general, the juvenile stages of both animals and plants are less tolerant of salinity than the corresponding adults; this means that the range of salinities where adult organisms occur is not a reliable indication of the range where self-sustaining, reproducing populations of those organisms can persist.

A review of salt sensitivity of Australian freshwater biota (including microbes, plants, and a range of invertebrate and vertebrate taxa) found that biological effects are likely to occur in river, stream, and wetland ecosystems if salinity (total soluble salts) is increased to around 1 g/L (Heart et al. 1991 and references therein). This review also found that:

- freshwater macrophytes are not generally adapted to survive major fluctuations of salinity and water level, and many species of riparian plants are salt sensitive with adverse effects often apparent at salinities above 2 g/L (Hart et al. 1991)[7]
- osmoregulatory mechanisms of most freshwater invertebrates fail when animals are exposed to solutions containing salts in excess of 9 g/L—however most also experience significant deleterious effects on physiology, biochemistry, and behaviour at far lower salt concentrations (Hart et al. 1991).

Therefore, in general, most freshwater organisms live at salinities < 1 g/L. Some species 'drop out' above this level, and there is a further loss of biodiversity at about 3 g/L and again at about 10 g/L (Hart et al. 1991). As an example of conditions in important components of the ecological community, from 1978 to 1991, salinities of up to 21 g/L were recorded in tributaries which receive drainage from irrigation areas (i.e. which concentrate salt from rising groundwater),

[7] A salinity of 3 g/L is often regarded as the upper limit for fresh water (Williams 1987 in Hart et al. 1991; AWRC 1987 in Hart et al. 1991).

while salinity in the river itself rarely exceeded 1.2 g/L (Mackay et al. 1988 in Williams and Williams 1991).

Given the above, it is clear that salinity plays a major role in structuring aquatic communities and influencing survival of aquatic biota and rates of many ecological process, such as organic matter decomposition and productivity (Boulton and Brock 1999). For example, salinity was found to be the main determinant of species composition within the dominant phytoplankton group of the ecological community (Tibby and Reid 2005 in Walker 2006). Concomitantly, changes in salinity may have indirect effects on the invertebrates (particularly zooplankton) that graze diatoms. The significance of salinity in ordering macroinvertebrate assemblages in the ecological community has also been well demonstrated by the results of the national AUSRIVAS (Australian River Assessment System) bio-assessment program (Suter et al. 1993).

Alternatively, some species are only found in saline water, for example certain species of insect larvae (e.g. caddis fly, midge), water beetle (e.g. *Laccobius zietzi*), segmented worm (e.g. *Paranais litorali*), and water snail (*Coxiella*). Though they support fewer species in total, saline streams can be important for maintaining genetic diversity. Along with estuarine regions, these can be significant habitats for biodiversity conservation within the region of the ecological community. For example, saline wetlands can, at times, provide important refuges and food sources for waterbirds (Suter et al. 1993).

Up until the 1980s, salinity and water level were the two key drivers in the ecology of the Coorong lagoons (Paton, 2010). Salinities typically increase along the Coorong from north to south, and vary seasonally and annually depending on flows to the Murray Mouth. Some example records from this period include:

- North Lagoon: 20–80 g/L from 1981–83 (Geddes and Butler 1984); 5–35 g/L in 1987 (Geddes 1987)
- South Lagoon: up to 80–120+ g/L (same studies as above).

Aquatic invertebrates and fish are influenced by this salinity gradient, with species richness declining progressively as salinity increases (Paton 2010 and references therein). Most estuarine species can tolerate salinities up to about 5–60g/L. Only a few species can tolerate higher salinities (i.e. hypersaline conditions), for example: *Capitella* (polychaete), *Salinator* (gastropod), dipteran larvae such as *Tanytarsus barbitarsis* (chironomid or midge) and *Ephydrella* sp. (brine fly), *Haloniscus searlei* (isopod), *Diacypris compacta* (ostracod) and small mouthed hardyhead.

Importantly, while many faunal species are able to shift their distribution moderately quickly in response to changes in salinity and water levels (unless prevented by infrastructure), most aquatic plants do not have this capacity (Paton 2010). Submerged and emergent aquatic plants provide important habitat for a range of invertebrates and fish and food for waterbirds. The response of aquatic plants to salinity and water level changes is particularly critical to the ecological health of the Coorong component of the ecological community (e.g. Paton 2010).

RESILIENCE VIA DORMANCY AND REFUGIA

Resilience is the capacity of an ecosystem to resist disturbance, maintain core functions, and recover to some form of equilibrium state afterwards (Colloff and Baldwin 2010 and references therein). Many aquatic species are adapted to cope with the natural variability of flow and climate, with some species more tolerant and resilient than others. For example, many aquatic plant species have a long-lived seed bank that can cope with periods of dryness and successive

wetting-drying cycles, which allows species to re-establish after dry periods (Brock 1994, 1998). Similarly, aquatic animals may exhibit several strategies, such as:

- drought-resistant stages in the life-cycle, such as dormant eggs (Newton & Mitchell 1999)
- a physiological capacity for diapause[8] (Boulton and Lloyd 1992; Brock et al. 2003)
- adopting highly mobile strategies that enable the tracking of scarce resources (e.g. waterbirds).

For example, many floodplain snails are capable of aestivation[9] (Walker 1998). Dormant aquatic plant seeds (or vegetative propagules) and eggs of zooplankton (e.g. rotifers, ostracods, cladocerans, copepods) exist in substantial numbers in temporary wetland sediments, and seed and egg banks have been shown to be long-lived (Williams 1985; Newton & Mitchell 1999 and references therein; Neilson et al. 2000; Brock et al. 2003 and references therein). These dormant stages provide not only refuge from drying but also a means of maintaining genetic, phenotypic, species and community diversity (Brock et al. 2003 and references therein). As such, many species of zooplankton, other invertebrates, and aquatic plants recover after the disturbance of drying by means of specific patterns of dormancy, dormancy breakage (e.g. staged hatching or germination), re-establishment, and reproduction.

Multiple generations in egg and seed banks, and complexity of environmental cues for dormancy breakage (e.g. diapause versus quiescence, see Newton & Mitchell 1999), facilitate ecological community recovery on flooding of a temporary wetland following a drying event. However, this capacity can become compromised, as changes to the water regime will select for different components of the ecological community, and thus modify future seed/egg bank replenishment. For example, more permanent flooding (i.e. loss of drying) removes one of the cues necessary to trigger hatching of some zooplankton species, and long-term loss of flooding can result in the loss of viability of eggs, which in turn leads to a loss of biodiversity (Neilsen et al. 2000; Brock et al. 2003).

Disturbed environments often favour opportunistic species that recover rapidly through vegetative (plants) or r-selected (animals) growth, indicating low resilience at the community scale and high resilience at the species scale (Hughes 1990 in Walker et al. 1994). Thus, the effects of water regime alterations on the survival and composition of seed and egg banks has important implications for the composition and functionality of the RMDS ecological community. Maintaining a variety of hydrological patterns and wetland types across the landscape will enhance system resilience and biodiversity (at both the genetic and species levels).

Species may also seek refuge from disturbance if suitable areas exist nearby (i.e. refugia[10]) and recolonise their previous habitat once the disturbance has passed. Refuges (or refugia) are sites that are secure from one or more disturbances. They support populations of plants and animals while unable to live elsewhere in the surrounding landscape; they are a source of colonists for the wider landscape once a disturbance is past (e.g. Robson et al. 2008).

[8] Diapause is a period of dormancy in insects and other invertebrates during which growth or development is suspended (Park, 2007).

[9] Aestivation is a state of animal dormancy characterised by inactivity and lowered metabolic rate. It assists the animal to avoid damage from high temperatures or the risk of desiccation.

[10] Refugia - A refuge (pl. refuges or refugia) is a shelter from predators or disturbance of some kind.

Access to refugia contributes to the resilience of the RMDS ecological community. The availability of refuges depend on the nature, scale, and timing of a disturbance. It will also vary from species to species, depending on various factors including life history traits and the extent of dependence on an aquatic environment. For example, refuges are critical to the recovery of macroinvertebrates from drought and drying of streams, including the use of sheltering (e.g. below cobbles, in debris, or among macrophytes) or by penetrating the hyporheic[11] zone (Boulton 2003 and references therein). Yabbies may take refuge in burrows beneath the wetland during the inter-flood dry period (Williams 1985). In general, two types of places provide refuge for a wide range of plants and animals (and see Table 22 for specific refuges for different organisms):

- places where the natural water regime is maintained, and
- places where natural water-riparian zone interactions are maintained.

The number of viable refuges that survive a disturbance governs the rate and success of recovery for the various components of the ecological community (e.g. Robson et al. 2008).

Table 22: Examples of specific refuges for different aquatic organisms (source: Robson et al. 2008).

Plants	Algae	dry stones, dry biofilm, dry leaf packs, perennial pools
	Macrophytes	soil where seed banks reside
	Trees and riparian vegetation	areas of remnant vegetation with a suitable flow regime, protected from livestock and associated weed infestation and disease
Animals	Invertebrates	perennial pools or flowing sections, moist leaf litter, hyporheic zone, backwaters, spaces between stable stones, sediment with egg banks, riparian vegetation
	Fish	perennial pools, sections of perennial flow in non-perennial rivers and streams, slackwaters
	Frogs	perennial streams and wetlands, drainage ditches, farm dams
	Reptiles	spaces undercut in river-banks, deep perennial pools, floodplain swamps, leaf litter
	Birds	perennial wetlands and rivers, dams, sewage farms

Consultation Questions on the key biological and ecological processes

- Do you have any feedback or further information on relevant biological and ecological processes related to the RMDS ecological community?
- Are there any other relevant functional biology and ecology processes or other elements you think are important to highlight in this section?
- Please provide citations for any supporting evidence or relevant references you may have.

[11] Hyporheic zone is the saturated sediment environment below a stream that exchanges water, nutrients, and fauna with surface flowing waters.

2 Identifying areas of the ecological community

Section 1.2 (and Appendices A and B) describes the species assemblage comprising the ecological community and the particular area in nature that it inhabits (as well as key ecological processes). This section provides additional information to assist with the identification of the RMDS ecological community and important areas of it.

2.1 Key diagnostic characteristics

The RMDS ecological community is defined as the assemblage of native species inhabiting a particular area in nature as described in Sections 1.1 and 1.2 and referenced information therein. This ecological community is most clearly defined by its area in nature and associated hydrology, with a large diversity of mostly aquatic or semi-aquatic species organised around several biogeographical sub-units and associated sub-communities. The following key diagnostic characteristics represent a summary of the main features of the RMDS EC (i.e. across the sub-units), including further information on boundaries and key hydrology. They serve to assist with determining whether the ecological community is present at a particular time and place.

2.1.1 Location and landscape

- The ecological community inhabits more than 830 river-kilometres of the River Murray from near Wentworth NSW (Lock 10) to Goolwa SA (Coorong and Murray Mouth); it is formed by two dissimilar rivers, the Darling from the north and the Murray from the east, and its ecological character combines features of both.
- The ecological community lies on the intersection of two major climatic and zoogeographic regions, the temperate southeast and the arid centre, which contributes to its high biodiversity (Jennings 2009).
- The riverine component where the ecological community occurs can be divided into six bio-geographical sub-units along the length of the main channel are highly connected:
    - *Top Valley Section* (Wentworth to Overland Corner), with the river meandering westward over a 10–20 km wide floodplain, with extensive wetlands and woodlands
    - *Murray Gorge Section* (Overland Corner to Mannum), where the river's course is realigned southward and the floodplain is constrained to 4–5 km, within a 30 m deep limestone gorge
    - *Lower Swamplands* Section (Mannum to Wellington), with the river flowing through areas that formerly had extensive riparian swamps, now reclaimed for agriculture and protected by levees
    - *Eastern Mount Lofty Ranges Watershed*, including the perennial and ephemeral streams
    - *Lower Lakes Section* including Lakes Alexandrina and Lake Albert, and
    - *Coorong and Murray Mouth*, the estuarine terminus of the River Murray and the entire Murray-Darling Basin.
- The ecological community also occurs on the islands and coastal dune systems within the Murray Mouth complex, and natural components of islands within the Lower Lakes, River Murray channel, and in associated floodplain-wetland complexes.

- The ecological community occurs within the coastal lakes that occur between the South Lagoon of the Coorong and Kingston in South Australia, including (but not restricted to): Lake Cantara North and South, Brine Shrimp, Coxiella, Paranki Lagoon, and Teilaka.

2.1.2 Boundaries

The main boundaries for the RMDS ecological community are (and see Tables 2 and 3):

- The upstream boundary of the RMDS EC is at Lock 10, near the confluence of the Murray and Darling rivers (i.e. where the waters of the two rivers begin to mix).
- The downstream boundary is at the Murray Mouth and the Coorong lagoons, and includes associated sand dune systems, peninsulas, and islands.
- The general lateral boundary envelope for the RMDS EC is the 1956 flood line.
- Permanent and episodic streams and tributaries that flow into or adjoin the River Murray:
    - Eastern Mount Lofty Ranges (EMLR) Section—for individual permanent and episodic streams/tributaries that enter the Murray via the Eastern Mount Lofty Ranges or the Marne-Saunders Prescribed Water Resources Areas (SAMDBNRM Board 2010a, 2010b), the longitudinal boundary is that of the Prescribed Water Area for each.
    - Salt Creek (entire length) which intermittently funnels surface water into the South Lagoon of the Coorong.
    - Lower Darling Anabranch—from the junction with the River Murray to the upstream influence of Lock 9, which occurs at around Glen Esk and is approximately 25 km from the Murray River.
    - Other streams/tributaries that connect the River Murray channel with wetlands upstream of Mannum (i.e. those occurring between Lock 1 and Lock 10).
    - Lake Victoria (located in south-western NSW) and its input/output streams, Frenchman's Creek and Rufus River. Note: the lateral boundary for Lake Victoria is the 1956 flood line.
    - For the Darling Anabranch and other streams or tributaries, as included above, the lateral boundary is the 1956 flood line, or, 100 m on either side from the 'typical' edge of the stream—whichever of these two measures is the greater.

2.1.3 Key hydrology

- Flow is a driver variable that sustains all natural physical and biological processes in the ecological community, including keeping the mouth of the river open and determining wetting and drying cycles and overbank flows on the floodplain. There is not a simple relationship between flow (discharge) and water levels, as the latter are affected by the weirs (locks) and barrages.
- Hydrological connectivity, driven by flow, is central for maintaining the ecological community in a healthy functioning state. There are three main dimensions for operational connectivity:
    - vertically (groundwater/surface water)
    - longitudinally (along river to sea, including an open river mouth), and
    - laterally (across banks, wetlands, and floodplain).

- It is recognised that the flow regime for the ecological community, including overbank flows and hydraulic connectivity, is highly and permanently modified by the 10 weirs (locks) on the channel and five barrages on Lake Alexandrina that have been in place since 1922-1940. Flow is also modified by about 200 km of riverbank levees, numerous off-stream wetland regulators, and temporary weirs (e.g. The Narrows, Clayton Bay (this was removed in 2011), Currency Creek.
- Groundwater from aquifers can contribute significantly to baseflow in many of the associated streams and wetlands that form part of the habitat for the ecological community, including those that may feed directly into the River Murray.
- Although pre-regulation is a more natural benchmark state (reference condition), a useful reference condition for the ecological community may be the periods of 'good' flows (i.e. small, medium, overbank) in the early 1970s or earlier (i.e. prior to the establishment of common carp) (TSSC 2010).

2.1.4 Biota that is the RMDS EC

- The geomorphic diversity within the environment of the RMDS ecological community is reflected in diverse aquatic and terrestrial habitats, and correspondingly high levels of biodiversity and keystone biota (see Section 1.2.2).
- A range of vegetation types is present, which intergrade and are variable and dynamic depending on wet and dry cycles, including: woodland-forest, shrubland, herbland, grassland, riparian and submerged aquatic. Some species may not be visible or suffer significant dieback during prolonged drought but may be retained in the seedbank or resprout foliage when flooded.
- The canopy of the floodplain and riparian vegetation of the ecological community is generally dominated by two tree species, *Eucalyptus camaldulensis* (river red gum), typically along the river-banks and foreshore, and *Eucalyptus largiflorens* (black box), typically on the outer or higher parts of the floodplain. Dead hollow-bearing individuals of these trees are considered to be part of the RMDS EC.
- There is considerable variation in the understorey, shrub layer, and ground layer along the river and across the floodplain, with over 300 plant species.
- Emergent, free-floating, and submerged aquatic plants (macrophytes) in the river channel, estuaries, lakes, and other wetlands include a variety of species as outlined in Section 1.2.2 and Appendix B, Table B1.
- The submerged aquatic macrophyte community of the Coorong features *Ruppia*, *Althenia* and *Lamprothamnium*.
- The phytoplankton of the River Murray component of the ecological community forms one of four distinct compositional and distributional zones defined for the River Murray.

- The ecological community has a mixed assemblage of zooplankton derived from the Darling, which has a typical lotic[12] assemblage dominated by rotifers, and the Murray, which has a lentic[13] assemblage dominated by microcrustaceans typical of impoundments and wetlands.
- The ecological community has been found to have the most diverse region of macroinvertebrate fauna within the entire River Murray, with a distinctive zonation present.
- A diverse fish fauna, of which about three quarters are native freshwater species, with the remainder showing a strong marine/estuarine influence (including diadromous species), particularly near the river mouth.
- There is an abundant and diverse bird fauna within the ecological community—both wetland and woodland assemblages. Colonial nesting water birds are an important component of the wetland complexes within the ecological community, which also provide seasonal habitat for many migratory birds listed under international agreements.
- Additional information on plants and animals in the RMDS ecological community is at Section 1.2.2 and Appendix B

2.1.5 Exclusions

- Existing infrastructure, land already permanently replaced with crops or exotic pasture or plantations (i.e. at the time of listing), and human settlements, are typically modified or degraded beyond restoration and do not form part of the RMDS ecological community. This includes built infrastructure such as that related to dwellings, sheds, bridges, and existing roads.
- Importantly, however, areas of the ecological community altered by 'official' river regulatory structures, while not part of the 'natural' ecological community historically, are considered to be part of it if they are consistent with the key diagnostic characteristics at Section 2.1 and condition thresholds at Section 2.2.

Questions on the key diagnostic characteristics

- Do you have any feedback on any aspect of the key diagnostic characteristics?

2.2 Condition thresholds

National listing focuses legal protection on areas of the ecological community that are the most functional, relatively natural, and in comparatively good condition. Protecting these areas is vital for the long-term persistence of the ecological community and its ecological functions. These areas are identified through the description (Section 1) and key diagnostic characteristics (Section 2.1), and sometimes additionally though minimum Condition Thresholds. Therefore, in order to be protected as a Matter of National Environmental Significance (MNES), areas of the ecological community must meet both:

[12] *Lotic* - relating to flowing waters such as rivers and streams.

[13] *Lentic* - relating to standing or non-flowing body of water such as a lake or swamp.

- The 'description' (Section 1), as also summarised in the key diagnostic characteristics (i.e. Section 2.1) **AND**

- at least the minimum Condition Thresholds (where applicable).

Condition thresholds provide guidance for when a threatened ecological community retain sufficient parts of the assemblage and conservation values to be considered an MNES under national environment law (currently the EPBC Act). This then allows for the referral, assessment, approval, and compliance provisions of the national environment law to be focussed on the most valuable elements of Australia's natural environment, while heavily degraded or heavily modified elements are excluded.

Importantly, any exclusions resulting from condition thresholds may still retain important natural values, and although they would not be part of the national listed ecological community, they should not be excluded from recovery or rehabilitation actions. Suitable recovery and management actions (e.g. environmental watering) may improve these areas to the point that they may be regarded as part of the EPBC Act threatened ecological community, again.

However, in applying 'minimum condition thresholds' it is important to recognise that the *River Murray—Darling to Sea* ecological community:

- is strongly influenced by seasonal and inter-annual variation in rainfall, run-off, temperature, regulation, and extraction
- that wetting and drying cycles are particularly important to the ecology and productivity of the system, and these cycles will be impacted by climate change events and trends, and
- that components of the system are permanently wet, while others are episodically wet (e.g. some wetlands and parts of the floodplain) or mostly dry (e.g. coastal dune vegetation, island vegetation, some parts of the floodplain vegetation, particularly close to the 1956 flood line boundary).

The RMDS ecological community has been heavily disturbed in the past, for example by clearing floodplain vegetation, regulation of water flow, and the introduction of invasive species. In some cases, the natural assets have been permanently replaced by agriculture or urban infrastructure, and such areas on the floodplain do not form part of the ecological community.

Importantly, aquatic ecosystems are dynamic, and there may be strong potential to recover or rehabilitate aquatic and floodplain components of the RMDS ecological community, even if heavily degraded (as an example, by employing translocations in the case of local extinction of a species, or, by management of exposed acid sulfate soils).

Due to the highly variable nature of this complex landscape-scale, connected riverine-floodplain ecological community, the presence of long-term regulatory infrastructure, and the potential for a degree of rehabilitation (albeit variable), minimum Condition Thresholds are **not** recommended for the *River Murray—Darling to Sea* ecological community.

However, an exception occurs with terrestrial vegetation, which includes vegetation on the floodplain, adjacent to wetlands, dunes, associated islands, and in some cases, the riparian strip. For these areas, the ecological community **is present** if native vegetation is 'dominant' in the canopy and ground vegetation layers (where present), as per Table 22x.

Table 22x: Minimum Condition Thresholds which indicate in which areas of native vegetation that are not inundated with water.

MINIMUM CONDITION THRESHOLDS for RMDS EC	
If at a particular place and time, a patch of native vegetation comprising the RMDS EC is present within the specified boundaries from Section 1 (and Table 2), and it is in areas other than those currently inundated with water, then the minimum condition thresholds specified below apply. ***This is relevant within the following areas:***	
Riparian & Floodplain zones	Any vegetation on the floodplain within the 1956 flood line boundary. Any vegetation adjacent to the inundated areas of the River Murray, Lower Lakes, Coorong Lagoons, or 'southern' coastal lakes within the boundary of the RMDS EC. Any riparian vegetation adjacent to the Eastern Mount Lofty Ranges streams, the Darling Anabranch, and Lake Victoria and its tributaries within a 100 m strip from the 'typical' edge and on both sides of a stream, **OR**, from the edge of Lake Victoria, **OR**, to the 1956 flood line—whichever is the greater.
On Islands or Dunes	Any vegetation on islands or dunes within the boundaries or according to the description of the EC.
Minimum Condition Thresholds *One or both of the following two sets of minimum Condition Thresholds apply:*	
1) At least 50% Native Canopy and/or Understory/Ground Vegetation Cover	
A tree or shrub canopy is present with 50% or more of the crown cover from **native species** *[Note: crown cover is the percentage cover of an area within the vertical projection of the periphery of crowns. In this case, crowns are treated as 'opaque'.]* **And/ Or** at least 50% of the perennial understorey or ground vegetation cover is comprised of native species (including small or immature trees, shrubs, and herbaceous plants, with a life-cycle of more than two growing seasons) **OR**	
2) At least 25% Understory/Ground Native Vegetation Cover plus Large/Mature Trees	
A canopy of large/mature trees (i.e. with hollows and/or more than 40 cm diameter at breast height) is present (typically red gum and/or black box) at a density of 5 or more per hectare (including stags with hollows) **AND** at least 25% of the perennial vegetation understorey or ground vegetation cover is comprised of native species (including small or immature trees, shrubs, and herbaceous plants with a life-cycle of more than two growing seasons)	

Where condition is variable and the condition of the total area determined to be the ecological community falls below the minimum thresholds, the largest area (or areas) that meet the minimum Condition Thresholds within the total area should be identified. This may result in multiple protected occurrences of the ecological community being identified within the original area where condition is being assessed.

Restored (including revegetated or replanted) sites or areas of regrowth are not excluded from the listed ecological community as long as the patch or occurrence meets the description and Condition Thresholds.

2.2.1 Additional considerations

When determining whether or not the above Condition Thresholds apply, the timing and search effort of surveys of the vegetation is an important consideration. Samplin of areas to determine proportion of vegetation cover should be based upon an accepted methodology and appropriate plot/transect/quadrat size.

Native vegetation can be variable in appearance throughout the year and between years, depending on drought/rain cycles. Some areas may have native or exotic species of vegetation present all year round in the ground layer, while in other areas there may be a seasonal component—for example, with only spring/summer flowering evident. Thus, the timing of surveys should consider the detectability of mid- and ground-layer native species at different times of their life cycle, or their potential recovery after recent disturbances (natural or anthropogenic) to the ecological community.

Ideally, surveys should be conducted in more than one season to maximise the chance of detecting all species present. In years of low rainfall and/or flow, assessors should recognise that many species may not be detected or may be defoliated. In these situations, it is preferable that surveys are carried out over more than one year and in a reasonable timeframe after disturbance.

When determining 'significant impact' upon the ecological community, it is also important to consider influences and impacts pertaining to the surrounding catchment areas, regardless of the cover of native vegetation. These adjacent catchment areas are critical for connectivity and a buffer against significant impacts on aspects critical to the ecological community's integrity and functioning, for example, maintaining adequate flows and groundwater levels, or minimising pollution or invasive species.

It is recognised that the main river channel in the natural area of the ecological community is highly regulated and has been for many decades (i.e. since 1920s) and that the system is now composed of a series of weir pools influenced by regulated and natural flows. It is also accepted that the ecological community is altered from its original, more natural condition due to this regulation and therefore using pre-European or pre-regulation condition as a reference state is not always practical or desirable, given the influence of these regulatory structures on the ecology of the system (TSSC 2010).

Consultation Questions on 'Condition Thresholds'

- Are the Condition Thresholds appropriate for this ecological community? If not, please suggest and justify any alternatives.

2.3 Habitat important or critical to the survival of the ecological community

Of critical importance to the survival of the ecological community is a flow regime (surface and groundwater) adequate to ensure connectivity and ecological function between the riverine and floodplain wetland components, and connectivity between the river and the adjacent ocean (MDBA 2010 b, c, 2012; TSSC 2010, 2011). Notwithstanding this, the ecological community can still be present should 'cease-to-flow' or desiccation of aquatic components occur.

Habitat that is considered important or critical to the survival of the ecological community consists of all of the areas that meet the description (as per Section 1) within the boundaries of the RMDS EC (and taking into account any buffer zones), in addition to meeting the Condition Thresholds in vegetated components. The reference to vegetated components here, includes those parts of the floodplain, riparian zone, Coorong dunes, etc., when they are not inundated and in a relatively good condition. Of the vegetated areas that meet the description, those that also meet the Condition Thresholds are most likely to retain the highest natural abundance and diversity of flora and fauna, the most intact structure and ecological function (integrity), and therefore have the highest chance of persisting in the long-term (viability and resilience).

Apart from areas where Condition Thresholds apply, in general, habitats or areas critical or important to the survival of the *River Murray—Darling to Sea* ecological community include:

- the riverine and associated floodplain area of the River Murray bounded by the 1956 flood line downstream of the Darling River and including the Coorong, Lower Lakes, and Murray Mouth estuary (i.e. as described in Table 2)
- the streams within the Eastern Mount Lofty Ranges and the Marne-Saunders Prescribed Water Resources Areas.
- areas where there is evidence of recruitment of keystone/ecosystem engineer native species or the presence of a range of age cohorts are critical
- areas providing connectivity between the floodplain and channels and where there are adequate wetting and drying cycles on connected floodplain and wetland habitats are critical
- good faunal habitat is critical as indicated, for example, by areas containing colonial waterbird nesting sites, waterbird foraging habitat, large trees for resources and breeding, cover, refuge, contribution to movement corridors
- areas of high species richness are critical, as shown by the variety and proportion of native flora and the diversity of fauna species present
- patches that are in areas where unique or localised variants/aspects of the ecological community are critical
- areas providing for unimpeded movement of fish, including diadromous species, for migrations, spawning, or recruitment are critical
- areas where there are healthy populations of key functional species are critical and any populations of listed threatened species are important
- areas of minimal weeds and feral animals, or where these can be managed easily are important

- as a specific example, the area of the Chowilla floodplain, including wetlands and islands, is considered especially critical to the survival of the RMDS EC, due to its role in recruitment and dispersal for a wide range of taxa (e.g. fish, frogs, turtles) and for its potential 'refuge' values; it also represents the largest area of floodplain woodland in South Australia, and is critical for woodland birds, bats, marsupials and reptiles.

For natural resource management activities, or actions that may have 'significant impacts' and hence require approval under national environment law, it is also important to consider the entire landscape context, the key ecological processes (particularly flow and other hydrological factors), and the environment and habitats that surround the areas that the ecological community inhabits. Surrounding vegetation, the health of upstream water and catchments, and other landscape-scale considerations influence the health and survival of the RMDS ecological community as a whole.

In particular, adequate flows are needed from upstream of the area the ecological community inhabits, for ecological and hydrological function and condition of the Coorong, Lower Lakes and Murray Mouth, including an open mouth (and see Basin Plan environmental targets, MDBA 2010b, c; OPC 2018). In addition, for groundwater there is a minimum 5000 m buffer zone depending on the intensity of the threat.

Additional areas such as adjoining native vegetation and other nearby wetlands, and areas that meet the description of the ecological community but not the Condition Thresholds, are also considered important to the survival of the ecological community into the future. For example, adjacent and nearby ecological communities are likely to play a significant complementary role in the provision of food, refuge and other habitat resources for mobile species, and thereby contribute to connectivity and maintaining biodiversity and key ecological processes. These adjoining and large nearby areas of native vegetation habitat are also critical to the survival of the ecological community when they act as buffer zones to help protect the RMDS ecological community from key threats (see Section 5 for more advice on buffer zones).

No Critical Habitat, as defined under section 207A of the EPBC Act, has been identified for inclusion in the Register of Critical Habitat at this time. That is because no significant areas of this ecological community are known to occur on Commonwealth land at this time.

Consultation Questions on habitat critical to the survival

- Is the description of areas critical to survival of the ecological community appropriate for the RMDS EC? If not, please suggest with justification, any alternatives.

3 Cultural significance

The *River Murray—Darling to Sea* EC occurs within Country (the traditional lands) of several First Nations Peoples in South Australia, NSW and Victoria—including the Ngarrindjeri, Peranangk, the First Nations of the South East (southern Coorong), First Peoples of the River Murray and Mallee, Barkindji, Latje Latje, and Kureinji Peoples. We acknowledge their spiritual and material heritage and culture and continuing link to the ecological community, the Country (land and sea) it inhabits and the waters that support it.

First Nations peoples value Country, including water, for a range of cultural, social, and economic reasons. These include heritage, identity, and connection to Country. Recognition, access, management, stewardship, ownership, and other rights are components of their ongoing relationship with the ecological community. The ecological community provides a direct link with spiritual and material culture and holds cultural significance for its Traditional Custodians.

Listing an ecological community as threatened under national environmental law does not change land ownership or tenure. Nor does it affect Native Title rights, nor traditional access and use of Country (for example, collecting bushfood and medicine). Listing the ecological community and implementing the priority conservation actions set out in this Draft Conservation Advice does not affect current lawful use (including under Native Title) and supports the protection and recovery of both ecological and cultural values.

The significance of the ecological community, particular species, spiritual and other cultural values, are diverse and varied for the First Nations Australians that live on or in the vicinity of the RMDS, and care for Country. In some cases, knowledge of this significance may be only held by Indigenous groups and individuals who are its custodians and have the rights to decide how it is shared and used.

The Ngarrindjeri Peoples have prepared a detailed Sea Country Plan that includes the Lower Lakes, Coorong, and the marine waters adjacent to the ecological community; this region aligns with their 'Creation Story' (Ngarrindjeri Tendi et al. 2007).

Section 3: Special request

- We welcome input to this Section from First Nations' representatives and groups. We are particularly keen to incorporate any Traditional Ecological Knowledge and/or documents that are relevant and appropriate for this science-based listing assessment process.

- We would like to know/acknowledge First Nations values and uses of the ecological community, totems, and other culturally significant species or places that may occur within this RMDS Ecological Community—if you are comfortable with us sharing them in this Section of the Conservation Advice (with appropriate permission and referencing).

4 Threats

The *River Murray—Darling to Sea* ecological community has been severely impacted by multiple and long-term threats, most notably river regulation, over-extraction of water, clearing of the floodplain, salinisation, and invasive species. These have compounded and intensified over the past 100 years and, over the past few decades have been exacerbated by the current and increasing threats of climate change. It is well recognised that, in addition to being a significant threat in isolation, climate change may exacerbate other threats (Newton 2009; Steffen et al. 2009). Importantly, the trends of impact associated with climate change may not be gradual or linear, and sudden step-wise changes can occur once critical thresholds are breached—some of which may be irreversible (IPCC 2023).

The effects of the Millennium Drought of 1997 to 2010, brought into sharp focus the vulnerable nature of the RMDS ecological community and the detrimental outcomes observed from a combination of past, contemporary, and ongoing threats, some of which are permanent, with some impacts likely to be irreversible.

Influence of Basin Plan and wet years

Implementation of the Basin Plan (under the *Water Act 2007*) in 2012 represented the culmination of a decades-long effort between the six Murray-Darling Basin jurisdictions to collaboratively address the degraded environmental state of the system. The Basin Plan has objectives to return environmental water to the MBD and improve the health of water-dependent ecosystems. However, the Plan is still in an implementation phase and to date only some inroads have been made (e.g. Chen et al. 2021). Importantly, the Basin Plan, being primarily concerned with water, does not have the remit to fully address the myriad of other threats currently operating on this ecological community, including those of clearing, invasive species, and climate change.

The recent three years of La Nina (2020-2023) and large-scale flooding provided a mixture of disturbance and 'temporary' recovery to certain areas of the ecological community, particularly higher areas of floodplain and wetlands. However, the backdrop of long-term environmental and ecological decline, which is well-researched and acknowledged, remains, as does the certainty of future periods of drought. With multiple long-term and increasing major threat impacts, it is becoming increasingly difficult for key plants, animals, and functions to survive, let along recover without substantial intervention.

4.1 Threats table

Table 23 outlines the key threats and associated risks and impacts facing the *River Murray—Darling to Sea* ecological community, which represent the 'main factors that cause it to be eligible for listing', as required by section 266B (2) (a) (ii) of the EPBC Act. This information supports the assessment against the regulated criteria at Section 0. Although presented as a 'list', in reality these threats and their impacts often interact and are compounded, i.e. rather than necessarily acting independently.

Overview of Threats Table (pp. 81-93)

- **Climate change related threats**
  - climate change - general threats to biodiversity
  - rising temperature
  - changes to rainfall & runoff
  - extreme events
  - fire regimes that cause declines in biodiversity
  - sea level rise (SLR) and extreme sea level (ELR)
- **Hydrology related threats**
  - flow – changes to hydrological regimes
  - extraction of surface water
  - river regulation & infrastructure
  - extraction of groundwater
  - Murray Mouth closure (& lack of flow to MM)
  - floodplain harvesting and farm dams
  - irrigation pumps
- **Water quality related threats**
  - salinisation
  - eutrophication
  - algal blooms (toxic and other)
  - blackwater events
  - pollution – chemical and litter (including micro-plastics)
  - acid sulfate soils (ASS)
  - sedimentation – infilling & turbidity
- **Land clearing related threats**
  - clearing of native vegetation
  - mining
  - grazing
- **Problem Species related threats**
  - invasive fish
  - invasive/pest birds
  - invasive mammals
  - invasive/pest invertebrates
  - invasive plants (weeds)
  - disease & pathogens
- **Other**
  - fishing pressure
  - recreational activities & impacts from urbanisation

For interpretation of Table 23, note the following legend:

Severity and consequences – the threat causes, or has the potential to cause, impacts that are:

- **extreme** (leading to loss or transformation of affected patches/occurrences)
- **major** (leading to degradation of affected patches/occurrences),
- **minor** (impacting some components of affected patches/occurrences)
- **negligible** or **unknown.**

Timing – the threat occurs in the **past** (and unlikely to return, though impacts may continue), is **ongoing** (present/continuing), is likely to occur/return in the **future,** or timing is **unknown**

Scope/extent – the threat is affecting the following amounts of the ecological community: **whole** (estimated >90%), **majority** (>50%), **minority** (<50%), **negligible, unknown.** For some threats, the particular key components that are impacted may be noted.

Trend – the severity of the threat and its consequences are likely to be **decreasing**, **increasing**, **stable/static** or **unknown**

Table 23: Threats Summary Table for *River Murray-Darling to Sea* EC

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
Climate Change related threats			
Climate Change – as an overarching threat to biodiversity (*Note, these impacts also apply to other specific climate change threats below)*	➢ extreme ➢ ongoing ➢ whole ➢ increasing	*Note: Ongoing, long-term trend of warming and drying over the region of the EC, with increased potential for significant disturbance from extreme events* ***Biodiversity decline or loss*** • freshwater biodiversity is highly vulnerable due to 'typical' ectothermic physiology and limited habitat; particularly for species occurring close to physiological tolerance limits • detrimental impacts on physiology and ecology of biodiversity and related genetic stock • phenological impacts – e.g. timing of migrations or breeding, and desynchronisation of interactions between species, e.g. predator-prey mismatch • may lead to recruitment failure of some plant and animal species, and loss of seed or egg 'banks' (e.g. via lack of water, increased fire intensity/frequency, extreme flood, increased temperature, etc.) • may result in 'range' shifts or contractions for some species (i.e. depending on their ability to disperse and recolonise) – and concomitant shifts in genetic composition; for example, poleward shift in freshwater fishes, impacting already threatened fish species, or disruption of estuarine species distributions due to disturbance of salinity gradients and acidification • reassembly of vegetation types in response to changing rainfall and temperature conditions • in combination with other threats, may result in 'tipping points' leading to irreversible change for some species or ecosystems ***Impaired ecosystem function*** • potential impacts to ecosystem function (e.g. disruption of food-web relationships and energy transfer between taxa and habitats) • simplification of food-web structure and impaired energetic transfer efficiency (for example, increasing atmospheric CO2 is projected to alter molar CNP ratios of detrital inputs)	Bunn & Arthington 2002; Chambers 2006; Bond et al. 2008; Newton 2008; Steffen et al. 2009; Morrongiello et al. 2011; Gross et al. 2014; Leigh et al. 2014; Casajus et al. 2016: Woodward et al. 2016; Finlayson et al. 2017; James et al. 2017; Cohen et al. 2018; Alexandra 2020; Lauchlan & Nagelkerken 2020; Scanes et al. 2020; Spence & Tingley 2020; Alexander 2023; IPCC 2023; Sabater et al. 2023; Tims and Saupe 2023; Dobel et al. 2024

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		Promotion of invasive species • invasion of weeds and pest animal species encouraged by changes in climate and/or associated conditions; i.e. promote conditions for invasive species to prosper • increased risk of disease and parasitism leading to biodiversity loss ***Inability to adapt*** • adaptation to climate change relies on reducing vulnerability (and therefore other threats) and building resilience; the former may not be practical, the latter may not be possible • may depend on availability and accessibility of refuge sites	
Rising temperature (in air and/or water)	➢ extreme ➢ ongoing ➢ whole ➢ increasing	• The Basin-wide average increase in temperature over 1910-2017: Mean daily = 1.0 C; Max daily = 0.8 C; Minimum daily = 1.3 C • heatwaves and heat stress (in air and/or water) impact native species, plants and animals and can lead to mortality • temperature impacts metabolic rates (also size dependent) which my constrain food-web structure and dynamics • temperature impacts many ecosystem processes and key aspects of foraging behaviour of fauna • increased evaporation of water in rivers, wetlands, and lakes • promotion of deoxygenation events and potential mass fish deaths (particularly during drought) • detrimental impacts on ecological 'triggers' for reproduction or migration, particularly if in combination with unfavourable salinity or oxygen levels • increasing temperature linked to increasing frequency and intensity of EL Nino (i.e. drought) • lower soil moisture which can impact runoff • alter photosynthesis of terrestrial and submerged plants • reduced groundwater recharge	Newton 1996, 2009; Cresswell et al. 2021; Whetton & Chiew 2021; Lawrence et al. 2022; BOM & CSIRO 2023; IPCC 2023; Wright et al. 2024; Zhang et al. 2024

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		• warming of adjacent ocean waters may impact estuarine waters and in turn physiological requirements of biota dependent upon a limited ranges of salinity and temperature combinations	
Changes to Rainfall and Runoff	➢ extreme ➢ ongoing ➢ whole ➢ increasing	• cool-season drying trend in southeastern Australia • combination of longer dry spells and increases in extreme precipitation magnitude leading to important changes in the character of the precipitation time series • changes in seasonal patterns of rainfall—resulting in miss-match of hydrological and ecological cycles, which in turn impacts biodiversity • less rainfall leading to decreased runoff and drying of aquatic habitats and poor water quality • decreased runoff leading to loss of small to overbank flows and loss of typical seasonal exchanges in productivity between the river channel and floodplain • changes to ecological 'triggers' for reproduction or migration (e.g. via flow or water-column stratification) • prolonged drought may induce a post-drought low-runoff state due to increased evapotranspiration per unity of precipitation • decreased opportunity for dispersal and recolonisation • disruptions to estuarine hydrological cycles (e.g. salt-wedge formation) which impacts zooplankton and some fish breeding	Newton 1996, 2009; Steffen et al. 2009; Cai et al. 2014; Evans et al. 2016; Glamore et al. 2016; Freund et al. 2017; NESP? (2018); Peterson et al. 2021; Lawrence et al. 2022; CSIRO & BOM 2023; IPCC 2023
Extreme Events	➢ potentially extreme ➢ periodic – unknown ➢ whole ➢ increasing	*Note: extreme events (as opposed to trends) related to flow and temperature reduce species richness, impact productivity, and may induce regime shifts in temperate river ecosystems, particularly for invertebrates* • increased frequency and intensity of drought periods resulting in degraded and reduced habitat, and declines and/or mortality in biodiversity • creation of acid sulphate soils. For instance, during the Millennium Drought the water level of the Lower Lakes fell to -1.1 m, resulting in widespread acid sulphate soils and associated poor water quality • increased frequency and intensity of severe floods resulting in degraded or reduced habitat, and declines and/or mortality in biodiversity	Bond et al. 2008; Steffen et al. 2009; MDBA 2011c; Cai et al. 2014; Leigh et al. 2014; Woodward et al. 2016; Freund et al. 2017; Phelps & Kelly 2019; Cresswell et al. 2021; Fowler et al. 2021; Peterson et al. 2021; Lawrence et al. 2022; CSIRO & BOM 2023; IPCC 2023; Sabater et al. 2023

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		• increased frequency and intensity of storms resulting in degraded or reduced habitat, and declines and/or mortality in biodiversity • intensification of short-duration rainfall events leading to localised flash flooding • increased risk of algal blooms and/or blackwater events leading to deoxygenated waters	
Fire regimes that cause declines in biodiversity	➢ potentially extreme ➢ periodic – unknown ➢ mostly floodplain ➢ increasing	• trend towards more dangerous near-surface fire weather conditions, and increased pyroconvection risk factors for southern Australia (with several megafires in the past 20 y • increased rate of lightning strikes and incidence of lightning-induced ignitions with the potential to create large and high severity wildfire events, resulting in reduced habitat, and declines and/or mortality in biodiversity abundance and composition, especially on the floodplain • shorter intervals between large-scale fires (i.e. high fire frequency) reduces potential for resilience and recovery, including resprouting of fire-tolerant vegetation • recent-historic and potential loss of seed banks, egg banks, and refuge areas • reduced water quality (including oxygen) from ash in runoff, including from fires upstream or upslope of the EC • increased risk of blackwater events when rainfall induced run-off returns • may prevent regeneration of vegetation (although it is recognised that some native species may require fire for germination/regeneration) • loss of riparian vegetation results in warmer water, less insect prey • some habitat lost to fire management, e.g. tracks, prescribed burns	Mariani et al. 2018; Dowdy et al. 2017, 2019; Di Virgilio et al. 2019; Fairman et al. 2019; Ward et al. 2020; Canadell et al. 2021; Richardson et al. 2021; Lane et al. 2023; Lawrence et al. 2022; IPCC 2023
Sea Level Rise (SLR) & **Extreme Sea Level (ELR)**	➢ potentially extreme ➢ ongoing ➢ CMMLL, coastal lakes ➢ increasing	SLR along with increased wave energy along Southern Australian coastline and increased storm surge activity (e.g. ELR) leading to: • increased marine incursions and "marinisation" of the Murray Mouth, Coorong, and Lower Lakes; in turn resulting in degraded or reduced habitat, declines and/or mortality in biodiversity, and changes to community structure and function • increased incursion and establishment of marine pest species (including pathogens) • changes to hydrological function of estuarine components resulting in reduced habitat and/or ecological function (e.g. loss of salt-wedge formation)	Newton 2009; Colberg et al. 2019; Chiew et al. 2020; Tibby et al. 2021; Lawrence et al. 2022; Ward et al. 2022; BOM & CSIRO 2023; IPCC 2023

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		• long-term increased salinity and water levels of Lower Lakes resulting in reduced habitat and impacts to ecology, phenology and recruitment of biodiversity, particularly aquatic plants and small bodied fish	
Hydrology related threats			
Flow – changes to hydrologic regimes	➢ potentially extreme ➢ ongoing ➢ whole ➢ increasing	• "*Variability of flows at temporal scales from hours to decades influence habitat availability and quality at spatial scales from micro-habitat to catchment and is fundamental in shaping ecological patterns and processes."* Keith F Walker 2006 (TSSC member 2008 – 2013) • reduced variability of flow reduces the number of 'small floods' and 'small droughts' while big droughts and big floods still occur • reduced flow variability reduces the number of the more ephemeral component swamps and increases the perennial nature of intermittent and seasonal component swamps; this in turn leads to a reduction in nutrient cycling which impacts biodiversity • under natural conditions, the median flow to the sea at the Murray Mouth was 11,880 GL per annum; flow declined to 21% (under natural conditions) by 1994 • the Lower Murray now experiences drought-like flows in over 60% of years, compared with 5% under natural conditions • declines in water availability and riverine flow (from declining rainfall and increased evaporative loss) impact a range of biodiversity and ecological functioning • change in sequencing of rainfall events may be as important as magnitude of events for hydrological impact on ecology and biodiversity • the integrity of riverine food webs, which relies on synchronised responses across trophic levels to a range of natural cues, mostly driven by flow, may be impacted • climate and catchment driven reductions in river flow combined with SLR and in-channel barriers may result in "estuarine squeeze" – loss of upper estuarine zones and potential loss of salinity stratification • low flows may facilitate algal blooms and lead to deoxygenation and/or fish death events • disruptions to life history strategies of aquatic species (i.e. these have evolved primarily in direct response to natural flow regimes)	Puckridge et al 1998; Bunn & Arthington 2002; Walker 2006; Leigh et al 2010; Morrongiello et al. 2011; Pratchett et al. 2011; Evans et al. 2016: Kingston et al. 2016; Wedderburn et al. 2017; Furst et al. 2019; DEW 2020b; Koehn et al 2020; Koster et al. 2020a, 2020b; Mallen-Cooper & Zampatti 2020; Little et al. 2022

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		• changes may particularly impact fish through habitat loss and fragmentation, and loss of ecological cues from changed flow/hydrology impacting migration, breeding, and recruitment	
Extraction of surface water	➢ extreme ➢ ongoing ➢ majority ➢ increasing	• long-term history and increasing trend due mainly to agriculture and horticulture, with lower proportions for drinking water—reduces amount of water in system for: creating habitat, flow and water quality related phenological and physiological cues, and ecological and hydrological function • loss of connectivity between channel and anabranches and floodplain • has reduced frequency and magnitude of flows to the Murray Mouth • loss of aquatic and floodplain vegetation • loss of refugia habitat	Close 1990a; Eastburn 1990; Jacobs 1990; MDBC 2003b; MDBC 2006a; CSIRO 2008; MDBA 2009; MDBA 2010b; Wilson et al. 2010; Blacke et al. 2012; Berube & Rochefort 2018; Australian Academy of Science 2019; Koehn et al 2020; Rowland et al. 2023

River regulation and infrastructure	➢ major
	➢ ongoing
	➢ whole
	➢ increasing
		Note: Locks 1 (Blanchetown) to Lock 10 (near Wentworth) built between 1922 and 1935—except for very high flow conditions, the locks stabilise water levels and flow in the main channel and impact connectivity with the adjacent floodplain wetlands and woodlands
		• stabilisation of water levels impacts:
		  ○ riparian vegetation, with increased invasion of non-native species in river channel
		  ○ biofilm formation, thus impacting foodweb dynamics
		• river channel transformed into a stepped gradient of 'weir pools', with deposition of sediments above each weir and erosion downstream, infilling of deep pools and scour holes; combined with extensive removal of snags, this has led to simplification of habitat diversity in the river channel
		• increased risk of algal blooms from weir pools with constant water levels which often stratify (particularly in summer) and have greater water clarity due to settling of sediment
		• regulation and infrastructure disrupt the natural 'drying and wetting cycle':
		  ○ floodplains and wetlands subjected to drying for a prolonged intervals due to regulation may not produce a 'pulse' of high productivity when floods occur (i.e. thereby limiting exchange of nutrients and the dispersal or recruitment of biota between the floodplain, wetlands and river channel)
			Walker 1985, 1989, 2001, 2006; Pressey 1986, 1990; Thoms & Walker 1992; Walker and Thoms 1993; Walker et al. 1994; Maheshwari et al. 1995; Burns & Walker 2000; Bunn and Arthington 2003; MDBC 2006a; MDBA 2011c, 2024; Wedderburn et al 2017

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		○ conversely, prolonged inundation of wetlands may limit their 'pulse' of plant and animal growth associated with variable flooding and drying ○ the weirs have extended the area of permanently flooded wetlands (including backwaters, sidearms, anabranches, lakes and billabongs), with their ephemeral nature lost for about 70% of these due to stable water levels in the weirs ○ change in the timing of flows (and water depth) can adversely affect aquatic plants (which tend to be summer growing) • regulation can lead to river bank erosion and destabilisation, for example: ○ extended periods of flow at near channel capacity (i.e. without overbank flow) during the irrigation season have formed an 'erosion notch' in the river bank ○ rapid drawdown from saturated banks can cause sections to slump into the river ○ increased flows can increase sediment transport, leading to increased scouring of bed and banks. • five barrages at the Murray Mouth were built between 1935 and 1940, creating a 7.6 km barrier; these are operated to maintain river level between the Lower Lakes and Loch 1, maintain the Lake levels at 0.75 m ASL, and isolate estuarine reaches of the system from the Lower Lakes • the barrages have significantly changed the ecology of the Coorong, Lower Lakes and Murray Mouth—particularly in times of drought • barrages and lochs historically create barriers to fish migration and passage; they have historically hindered diadromous fish species from completing their life cycle (i.e. no fishways for over 60-70 years) • levees and off-stream regulators used extensively along the system impacting connectivity of river and floodplain and altering bathymetry	

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
Extraction of groundwater	➢ potentially major ➢ ongoing ➢ unknown ➢ increasing	• increasing trend due to mining and agriculture resulting in rising salinity and poor water quality • loss of stygofauna • longer timeframes for recharge of groundwater which may also feed via springs into river channels and wetlands	Evans and Kellett 1989; SAMDBNRM Board 2010a; Berens et al. 2013; Nelson 2013; Goonan et al. 2015; DEW 2020d; Becher et al. 2022; Cook et al. 2022; Hose et al. 2022; Ross et al. 2022; Crosbie et al. 2023; Dobel et al. 2024; Ross & Williams 2024
Murray Mouth closure and lack of flow to MM	➢ potentially major ➢ ongoing ➢ estuaries, lakes ➢ stable (managed)	• an open river mouth is vital to connectivity between the river and the sea – for input of nutrients and salinity and as a gateway for diadromous fish, and for export of salt, sediments and pollution • reduced stream flow to Murray Mouth (annual average reduced by 61% CSIRO 2008) • increased occurrence of Mouth closure, particularly during spring (e.g. 5 of 7 years between 2002 and 2009 no flow to Murray Mouth and Coorong region of EC) • during low flows and high evaporation and demand, all barrage openings are fully closed, with no release from the lakes to the sea; this typically results in a rapid accumulation of sand inside the Murray Mouth (and the need for mechanical dredging) • build-up of salinity and other pollutants • changes to hydrological and ecological function of estuarine components (e.g. salt-wedge formation) • barrier to migration and recruitment of diadromous fish	Fluin et al. 2007; CSIRO 2008; Paton 2010; Mallen-Cooper and Zampatti (2018); Chiew et al. 2020
Floodplain harvesting & Farm dams	➢ potentially major ➢ ongoing ➢ whole ➢ increasing	A 2022 study estimated that, in NSW alone, floodplain harvesting could represent more than twice the allocated annual environmental water for the entire MDB and is unsustainable. • floodplain harvesting is the unregulated (unlawful) diversion and storage of overland flows into on-farm dams leading to significant (largely unknown) losses of water for the environment downstream, impacting hydrological and ecological processes and biodiversity; it is mainly occurring in the northern Basin, although some is known to occur in the southern Basin	Nathan & Lowe 2012; Brown et al. 2022

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
Irrigation pumps	➢ unknown ➢ ongoing ➢ whole ➢ unknown	• entrainment of native fish and other biota through irrigation systems is an environmental impact of irrigation activities, with significant levels of mortality and/or physical injury • water for irrigation is diverted by gravity into canals or by pumping into pipeline or channels—pumps may cause physical damage and mortality to a range of biodiversity • survival of fish through the pumps has been shown to be size and species specific • there are recent pump designs available that reduce impacts to biodiversity (e.g. used overseas)—but to date these are not widely used/supported in Australia	Close 1990a; Baumgartner et al. 2007, 2009; Boys et al. 2021; Hutchinson et al. 2022; Rayner & Price 2023
Water Quality related threats			
Salinity/ Salinisation	➢ potentially major ➢ ongoing ➢ water, floodplain ➢ increasing on floodplain but stable (managed) in surface water	• salinity levels in the River Murray: predicted to increase significantly over the next 50 years without further remedial action. • typical salinity in Lake Alexandrina fluctuates between 1,205 and 2,138 EC (units of electrical conductivity). In March 2010 at the height of the Millennium drought, when there had been no salt export from the Basin for years, it reached 6,200 EC. In Lake Albert it rose from a typical 415-1,300 EC to 19,000 EC • impacts emergence of zooplankton from dormant eggs and germination of seeds of aquatic and floodplain plants, resulting in reduced species richness and loss of wetland biodiversity. • some groundwater in the Murray can be more than 62,000 EC because of salts leaching into the water table (note, seawater is 54,000 EC or ~35 g/L)	EPA South Australia 2003; Nielsen et al. 2003; Stewart et al. 2010; MDBA 2011c; Mosley et al. 2012; Berens et al. 2013; Chiew et al. 2020; Hart et al. 2020; Tibby et al. 2021; SOE 2023; Verhoven et al. 2024
Eutrophication	➢ potentially major ➢ ongoing (periodic) ➢ Coorong ➢ increasing	A key driver of eutrophication (in both water column and sediments) is reduced flushing leading to increased retention and recycling of nutrients, organic matter, and salt. • Coorong – experienced long-term decline, including excess nutrients from accumulating organic matter • Leads to loss of aquatic plants and benthic invertebrates • Can lead to toxic algal blooms and deoxygenation	Aldridge et al. 2018; Huang et al. 2022; Mosley et al. 2022; Verhoven et al. 2024

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
Algal blooms (toxic & other)	➢ potentially major ➢ periodic – unknown ➢ variable ➢ increasing	• toxic algal blooms of cyanobacteria (blue-green algae) are stimulated by excess nutrients, low flows • blooms create conditions that are toxic to fish and crustaceans • decomposing blooms cause deoxygenation resulting in physiological stress or mortality to aquatic organisms (e.g. extensive fish kills) • Coorong – experienced long-term decline, South Lagoon shift from aquatic plants to filamentous algae associated with eutrophication	Foree and McCarty 1970; Reynolds 1987; Crawford et al. 2017; Aldridge et al. 2018; Australian Academy of Science 2019; Vertessy et al. 2019; Mosley et al. 2022; Stocks et al. 2022; Kingsford 2023; Verhoven et al. 2024
Blackwater events	➢ potentially major ➢ unknown ➢ variable ➢ increasing	• bacteria consuming high loads of organic matter (e.g. leaf litter) create hypoxic conditions leading to mass fish deaths by suffocation and death or emergence of large crustaceans • chemicals from eucalyptus leaves breaking down in high concentrations may also be toxic to fish (e.g. polyphenols) • large and long-standing blackwater events may have long-term effects on river health and fish communities • increased risk of severe blackwater after flooding directly following a long period of drought, and also after large-scale wildfire	Towns 1985; Meyer 1990; Qualls and Haines 1992; Gehrke et al. 1993; O'Connell et al. 2000; Howitt et al. 2007; McMaster and Bond 2008; Hladyz et al. 2011; Whitworth et al. 2011, 2012; King et al. 2012; Leigh & Zampatti 2013; Baldwin & Whitworth 2014; McCarthy et al 2014; Baldwin 2021; Gibbs et al. 2021; Koehn 2022; Tonkin et al. 2022; Kingsford 2023: Waddington et al. 2023; Verhoven et al. 2024
Pollution (chemical & litter)	➢ unknown ➢ unknown ➢ unknown ➢ unknown	• pesticides, herbicides and fertilisers from agricultural runoff • litter – including micro-plastic • other chemicals (e.g. endocrine disruptors)	Kingston et al. 2016; Ross & Williams 2024; Verhoven et al. 2024
Acid sulfate soils (ASS)	➢ potentially major ➢ unknown	• the ecological community has the 'raw materials' to form acid sulphate soils; when sulfidic soils dry out (such as under drought conditions) they oxidise and form acid. When such soils are rewetted there is the risk that significant acid and heavy metals may be released into the water. This can lead to acidification, deoxygenation and toxicity to biota.	Taylor & Poole 1931; Fitzpatrick & Shand 2008; Fitzpatrick et al. 2009; Verhoven et al. 2024

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
	➢ CLLMM wetlands ➢ increasing during drought	• through disruption of flushing, the weirs have enabled significant build-up of ASS • the Millennium Drought led to exposure of large sections of river-bank, wetlands and lakes within the EC that contained high levels of unoxidized iron sulfides.	
Sedimentation (& infilling)	➢ minor ➢ ongoing ➢ major ➢ increasing	• making Lower Lakes and Coorong shallower • increased turbidity (less light for photosynthesis)	Aldridge et al. 2018; Mosley et al. 2022
Land clearing related threats			
Clearing of native vegetation	➢ major ➢ past – mainly ➢ floodplain, some wetlands lost ➢ stable	• at least half of the MDB pre-European vegetation cover has been cleared, with much cleared from the 1950s • large-scale clearing occurred along the lower reaches of the Murray below Mannum for agriculture (i.e. Swamplands Section), with most of the wetlands here drained since the 1880s • also, large areas of native vegetation were 'thinned; rather than cleared, with river red gum now uncommon below Murray Bridge in SA • extensive areas of mallee and heath cleared on the eastern side of the Coorong post WWII • such extensive clearing has degraded the landscape leading to: loss of habitat for biodiversity, erosion of topsoil and river banks, river siltation, deterioration of soil structure, increased acidification and salination of soils • increased rate of recharge to aquifers resulting in rising groundwater and increased soil salinity • clearing of terrestrial, riparian and aquatic vegetation is a major threat to Australian wetlands and the bat communities they support • tree removal reduces availability of hollows and suitable roosting/nesting habitat for bats, birds, and possums	Alison et al. 1990; Close 1990a; Eastburn 1990; Smith & Smith 1990; Campbell 2009; Paton 2010; Steinfeld & Kingston 2011; Blakey et al. 2018
Mining	➢ unknown ➢ ongoing	• habitat and biodiversity lost to roads, tracks, and infrastructure; also fragmenting habitat and creating barriers to movement for some biodiversity	Prosser et al. 2011; Doody et al. 2019; DEW 2020; DEM 2023

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
	➢ floodplain, streams, mouth ➢ increasing	• mining of sand at Murray Mouth • water extraction and pollution impacts for groundwater and streams via runoff into to the river and Lower Lakes (e.g. tailings dam chemicals from mining activity in Mt Lofty ranges) • critical mineral mining may occur below water tables; disposal of excess water is an emerging threat that may lead to changes in riparian vegetation and Groundwater Dependent Ecosystems (GDEs).	
Grazing	➢ unknown ➢ ongoing ➢ floodplain ➢ stable	• grazing by livestock (and rabbits) results in loss of riparian vegetation (species and community structure) • increased erosion of waterway banks via trampling and loss of vegetation • increased nutrient loads (via stock faeces) • annual-plant dominance (due to grazing) • exotic plant invasion • compromise the role of riparian vegetation such as, nutrient and sediment filtering, structural support for river-banks, and habitat for native biodiversity • increases in bare ground (with no vegetation or litter) can detrimentally impact waterways • decline in water quality	Lint et al. 2019; Robertson & Rowling; Amy & Robertson 2001; Jones et al. 2022 and references therein; Nicol et al. 2022
Problem Species			
Invasive Plants (weeds)	➢ major ➢ ongoing ➢ whole ➢ increasing	• at least 150 exotic weeds occur within the EC • extreme floods can bring new weeds into the EC from upstream • a small number are abundant and widespread, and can form monospecific patches in riparian, floodplain, or channel zones, e.g. willows (*Salix* spp.), *Xanthium* spp., lippia (*Phyla canascens*), Canadian pondweed (*Elodea canadensis*) and boneseed (*Chrysanthemoides monilifera*) • monospecific stands of non-native plants (weeds) can impact native herbivores, insects, and other invertebrates by causing net reduction in food sources and habitat normally provided by native plants • can replace native 'ecosystem engineers' • compete with native plants and may impact species diversity and composition	Cunningham et al. 1992; Shulze & Walker 1997; Kennedy et al. 2003; Taylor & Ganf 2005; Nicol 2007a, c & refs therein; Gehrig 2009; Gehrig & Nicol 2010; Paton 2010; Stewart et al. 2010; Bonifacio et al. 2011; Weiss & Dugdale 2017; Nicol et al. 2018, 2020, 2023

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
Invasive/Pest Invertebrates	➢ major ➢ ongoing ➢ whole ➢ increasing	• during the Millennium Drought, the marine tubeworm (*Ficopomatus enigmaticus*) invaded Lake Alexandrina, killing and harming many native turtles through formation of huge calcareous masses on the turtle's shells	Dittmann et al. 2009; Rolston & Dittman 2009; Bower et al. 2012; Dittmann et al. 2018
Invasive Fish	➢ extreme ➢ ongoing ➢ whole ➢ increasing	• 8 introduced (alien) fish species have been recorded in the EC, to date; European carp, goldfish, oriental weatherloach, tench, eastern gambusia, redfin, brown trout and rainbow trout (see Appendix B, Table B2) • Common (European) carp (*Cyprnus carpo*) represents a major and seemingly irreversible invasion since the 1970s; it has led to increased turbidity due to their bottom feeding behaviour, loss of macrophytes, and often outcompete native species, particularly during early life-history stages, and may prey on native juveniles. • carp may displace native fish and make aquatic habitat less suitable for native fish breeding and survival • carp are the first fish into wetlands when waters rise and the last to leave • carp can tolerate a wide range of water temperatures and salinity, making them more resilient to climate change impacts • since 2016, bio-control using a virus against carp has been researched and considered—the National Carp Control Plan (2022) • eastern gambusia compete with native species for food and resources; their aggressive behaviour (chasing, fin nipping) can lead to secondary bacterial or fungal infections and potentially, mortality	Roberts et al. 1995; Koehn et al. 2000; Hammer & Walker 2004; Koehn & MacKenzie 2004; Gilligan 2005; Tonkin et al. 2006, 2012, 2014; McNiel & Hammer 2007; Macdonald & Tonkin 2008; Pyke 2008; Zampatti et al. 2008; Hammer et al. 2009; Ye & Hammer 2009; McNiel et al. 2011; Conallin et al 2012; MacDonald et al. 2012; Wedderburn & Suitor 2012; Wegener & Suitor 2013; Barrett et al. 2014; Fredburg et al. 2014 Vilizzi et al. 2014, 2015; Kingston et al. 2016; Wedderburn et al. 2017; Koehn et al. 2000, 2016; Stuart et al. 2021; FRDC 2022; Schilling et al. 2024
Invasive Birds	➢ unknown ➢ ongoing ➢ minority ➢ unknown	• invasive birds (e.g. starling, blackbird, sparrow) compete with native bird species for habitat, resources, and nesting sites • due to fragmentation and degradation of woodlands and shrublands, over-abundant native birds such as miners can aggressively exclude other native birds	McGuinnes et al. 2010; Stewart et al. 2010

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
Invasive Mammals	➢ major ➢ ongoing ➢ whole ➢ increasing	• at least 9 pest mammal species occur within the ecological community, all terrestrial • these compete with native species for habitat and food, and often lead to habitat disturbance • feral cats, foxes, black rats, feral pigs and dogs are significant predators of native animals • feral pigs, goats and deer cause major damage to habitat (wallowing, digging, herbivory, bank erosion, exacerbating invasion & spread of weeds) ; deer are increasing rapidly	Paton 2010; Stewart et al. 2010; Kingston et al. 2016; BDO EconSearch 2022
Diseases and pathogens	➢ potentially major ➢ periodic – ongoing ➢ unknown ➢ increasing	• a number of alien pathogens and parasites are now established across southern Australia, causing manifestly harmful effects to native fish species and known or suspected epizootics in native fish populations • chytrid fungus in frogs • while there are negligible impacts to date, myrtle rust and phytophthora are a potential threat to some native vegetation/habitat • highly pathogenic avian influenza to birds, including new strains, have been spreading worldwide and may come into the EC via internationally migrating birds	Boys et al. 2012; Becker et al. 2013; Sarowar et al. 2013; Kaminskas 2021 and references therein; Robinson et al. 2021
Other			
Fishing pressure	➢ minor ➢ ongoing ➢ streams, CLLMM ➢ stable (managed)	• declines from historical commercial fishing from 1800s, with significant declines observed between 1950s and 1970s • CLLMM has a small, managed commercial fishery • recreational fishing occurs throughout, with particular pressure on Murray cod and golden perch	Pillar 1980; Cadwallader and Lawrence 1990; Ye and Zampatti 2007; Ye and Hammer 2009
Recreational activities and impacts of urbanisation	➢ negligible - minor ➢ ongoing ➢ streams, CLLMM ➢ increasing	• in general, increased human populations near natural areas increases the impacts and pressure on them • recreational boating may cause erosion of banks via waves and physical disturbance • potential for litter, and plastic and/or oil pollution and/or garden waste • increased run-off from new roads and developments • potential for physical disturbance to habitat and introduction of disease or invasive species	

Threat	Severity/ Timing/ Scope/ Trend	Main Impacts on and Risks to the EC	Key References
		• potential for illegal fishing or hunting • damage to dune vegetation and nests and eggs of beach-nesting birds around Coorong and Younghusband Peninsula, from people, dogs, and vehicles	

4.1.1 Key threatening processes

National environment law (currently the EPBC Act) provides for the identification and listing of key threatening processes (KTPs). A process is defined as a key threatening process if it threatens or may threaten the survival, abundance or evolutionary development of a native species or ecological community.

Table 24 provides a list of EPBC Act-listed KTPs current at the date of writing, that may be relevant to the ecological community or specific plants and animals that comprise it.

Table 24: Key Threatening Processes (KTPs) listed under the EPBC Act relevant to RMDS EC.

Title	Date Effective
Competition and land degradation by rabbits	16-Jul-2000
Competition and land degradation by unmanaged goats	16-Jul-2000
Dieback caused by the root-rot fungus (*Phytophthora cinnamomi*)	16-Jul-2000
Predation by European red fox	16-Jul-2000
Predation by feral cats	16-Jul-2000
Land clearance	04-Apr-2001
Loss of climatic habitat caused by anthropogenic emissions of greenhouse gases	04-Apr-2001
Predation, Habitat Degradation, Competition and Disease Transmission by Feral Pigs	06-Aug-2001
Infection of amphibians with chytrid fungus resulting in chytridiomycosis	23-Jul-2002
Loss and degradation of native plant and animal habitat by invasion of escaped garden plants, including aquatic plants	08-Jan-2010
Novel biota and their impact on biodiversity	26-Feb-2013
Aggressive exclusion of birds from potential woodland and forest habitat by over-abundant noisy miners (*Manorina melanocephala*)	09-May-2014
Fire regimes that cause declines in biodiversity	21-Apr-2022

Any approved Threat Abatement Plans or advice associated with these items provides information to help landowners manage these threats and reduce their impacts to biodiversity. These can be found at http://www.environment.gov.au/cgi-bin/sprat/public/publicgetkeythreats.pl.

Consultation Questions on threats

- Please provide any feedback you may have on the threats provided in the Threats Table, including further key information sources, as appropriate.

5 Conservation of the ecological community

5.1 Primary conservation objective

To halt the loss of the *River Murray—Darling to Sea* ecological community, and hence prevent its probable extinction (and/or collapse of the associated ecosystems) in the immediate future, and to recover the abundance, diversity, integrity, and resilience (or viability) of:

(a) its component species, particularly functionally significant species and,

(b) natural processes that maintain its natural biodiversity and ecological function.

The objective will be achieved by:

- protecting the ecological community from unacceptable and significant impacts as a matter of national environmental significance under national environmental law (currently the EPBC Act).
- implementing priority conservation management and recovery actions, consistent with the recommended actions and other guidance in this Conservation Advice.

An 'optimal' RMDS ecological community meets the description (Section 1), key diagnostic characteristics, at least the minimum Condition Thresholds, and includes:

- a healthy terminal lake system
- an estuarine component connected to the sea
- natural flow and water level variability
- trophic and habitat complexity
- healthy and resilient populations of functionally important native species
- no loss of key native species, and
- comparatively few alien species.

Immediate and highest priority conservation goals include to:

- Re-instate small to moderate within-channel and overbank flows, particularly at Chowilla
- Re-establish a healthy macrophyte assemblage in the Coorong Lagoons, principally *Ruppia megacarpa*, *R. tuberosa,* the 'Ruppia Community', and *Lamprothamnium* (stonewort)
- Increase understanding of and reduce floodplain salinisation
- Reduce, exclude, or eliminate common carp, particularly at key sites such as Chowilla (possibly as part of a broader *Invasive Species Action Plan* for the Lower River Murray)
- Improve existing fish passage to accommodate the range of native species and sizes throughout the RMDS
- Support capability, capacity, and research for captive breeding and/or translocation of threatened small-bodied fish, freshwater turtles, and Murray crayfish
- Commence/continue long-term monitoring and data collection of key attributes/species, particularly threatened species and woodland birds.

Existing protection and key management plans are set out at Section 5.2 and Appendix D; principles and standards for conservation are set out at Section 5.3; and, broader priority conservation and recovery actions are set out at Section 5.4. Not all actions that may benefit the protection and recovery of the *River Murray—Darling to Sea* ecological community are encompassed. The aim is to provide overall and general guidance for threat prevention, management, and recovery, rather than being site- or species-specific.

5.2 Existing protection and management plans

5.2.1 Existing protections

RAMSAR WETLANDS

There are three Ramsar wetlands located within the *River Murray—Darling to Sea* ecological community:

- Coorong, and Lakes Alexandrina and Albert
- Banrock Station Wetland Complex, and
- Riverland.

The Riverland and the Coorong and Lakes Alexandrina and Albert are managed by the South Australian Government, whereas Banrock Station Wetland Complex is privately owned.

LIVING MURRAY ICON SITES

The River Murray is well recognised as a national asset and icon, and the ecological community also encompasses, and provides connectivity for, three of the six highly valued and nationally recognised 'Living Murray Icon Sites':

- River Murray Channel
- Chowilla Floodplain including Lindsay-Wallpolla Islands, and
- Lower Lakes, Coorong, and Murray Mouth.

The other three Living Murray Icon sites all occur upstream of the RMDS ecological community. The Living Murray Initiative was established by the Murray-Darling Basin Commission (now Authority) in 2002 in response to concerns about the environment and economic health of the River Murray system. The initiative involved a number of collective actions to return the system to a healthy working river, including a focus on achieving significant environmental benefits for the six ecological assets (Icon sites).

Environmental values of a Living Murray Icon Site are:

the River Murray supports aquatic, riparian, floodplain and estuarine habitats along its course, including Ramsar-listed wetlands and a diversity of species including vegetation, native fish, other vertebrates (e.g. birds, frogs), crustaceans (e.g. Murray crayfish, yabbies) and other invertebrates (MDBC 2006a).

The sites have been regularly monitored and reported on since 2002 by the Murray-Darling Basin Authority (and the Commission prior).

ADJACENT AND/OR INTERGRADING ECOLOGICAL COMMUNITIES, INCLUDING NATIONAL AND STATE LISTED

The *River Murray – Darling to Sea* ecological community is a highly complex system with an extensive range. It links riverine environments along its course, including floodplain forests and woodlands, wetlands, and the estuary at the river's mouth. The RMDS intergrades with and/or occurs adjacent to a wide range of native terrestrial and aquatic communities, including some ecological communities listed under national and state legislation.

Most notable of the ecological communities listed under national environment law are:

- the *Swamps of the Fleurieu Peninsula* (listed 2003), and
- *Mallee bird community of the Murray Darling Depression Bioregion* (listed 2021).

Further information on adjacent EPBC Act listed ecological communities that may overlap or lie adjacent to RMDS are listed in Appendix D.

There are no comparable ecological communities protected under State legislation. However, there are some aquatic ecological communities that overlap with the NSW and Victorian sections of the ecological community:

- *the Lower Murray River Aquatic Ecological Community* under the *New South Wales Fisheries Management Act 1994*, and
- the *Lowland Riverine Fish Community of the Southern Murray-Darling Basin* under the *Flora and Fauna Guarantee Act 1988* in Victoria.

While there are currently no provisions in the South *Australian National Parks and Wildlife Act 1972* to list ecological communities as threatened entities, the SA government maintains a provisional list. Three 'potentially threatened ecological communities that overlap with RMFS are on South Australia's list (see Appendix D).

LEVEL OF PROTECTION IN RESERVES

The RMDS ecological community is approximately 400 045 ha in area (excluding the region of the Eastern Mount Lofty Ranges region streams and Darling Anabranch) and is represented in numerous formal conservation reserves in South Australia and Victoria. However, these reserves are generally small in area and protect less than 1% of this national ecological community (see Appendix D for additional State-based information).

BIRDS UNDER INTERNATIONAL AGREEMENTS

Within the ecological community are several wetland and coastal water birds that come under various international agreements (see Appendix B, Table B5). The ecological community is considered to provide critical habitat for these species.

RELATIONSHIP TO THREATENED SPECIES

The ecological community contains, and provides habitat and resources for, a wide range of threatened species listed at Commonwealth level under national environment law (currently the Environment Protection and Biodiversity (EPBC) Act) and/or at State level under respective legislation or scheduling. Comprehensive lists of threatened species for specific taxonomic groups are provided at Appendix D; a summary is at Table 25.

Table 25: Summary of plant and animal species listed as threatened under the EPBC Act or respective State legislation (or similar scheduling arrangements) that may occur in the region of the EC. [Data sourced from: Department of Climate Change, Energy, the Environment and Water (DCCEEW) species profile and threats database (SPRAT); South Australia's Department of Environment and Water)*, Victoria's Department of Energy, Environment and Climate Action (DECCA); New South Wales Department of Climate Change, Energy, the Environment and Water (DCCEEW)]. [Note: table will be updated in November 2024]**

TAXON	EPBC Act listing	SA* listing	VIC** listing	NSW*** listing
Plants	25	68	9	3
Mammals	8 (+ 4 extinct)	18	12	8
Birds	34	88	66	60
Amphibians and Reptiles	3	9	9	4
Fish	8 (+1 on FPAL)	10* (+4 extinct)	10 (incl. 1 extinct)	10 (incl. 1 extinct)
Macroinvertebrates	0	0	2	1
TOTAL	**90**	**197**	**108**	**86**

*****South Australia National Parks and Wildlife Act 1972;
SA Fisheries Management (General) Regulations 2007 – Schedule 5
****** Victoria Flora and Fauna Guarantee Act 1988
***New South Wales Threatened Species Conservation Act 1995

5.2.2 Existing management plans

Suggested plans/management prescriptions current at the time of publishing (please refer to the relevant agency's website for any updated versions) are provided at Appendix D. This list is not comprehensive. It is intended to help identify where some other information relevant to the management of the ecological community and broader landscape may be found.

Since 2012, a particularly important national plan relevant to the *River Murray – Darling to Sea* ecological community is the Basin Plan. Under the national *Water Act 2007*, the Basin Plan aims to return more environmental water to the Murray-Darling Basin. The Plan is being implemented by the Murray-Darling Basin Authority, in collaboration with the five partner jurisdictions, QLD, NSW, ACT, VIC and SA. The latest version of the Basin Plan (2023) is available at: Federal Register of Legislation - Basin Plan 2012.

Under the Basin Plan, there are legislative responsibilities for monitoring, evaluation, and reporting against a range of objectives and outcomes. The most pertinent of these to the RMDS EC are to be found in Chapter 5 of the Basin Plan and relate to the protection and restoration of water-dependent ecosystems, their functioning and their resilience to climate change.

Consultation Questions on existing protection and management plans

- Can you provide further information or updates about the protections listed above and/or management plans or protection strategies relevant to the RMDS EC?
- If so, could you please provide details (including website links).

5.3 Principles and standards for conservation

To undertake priority actions to meet the conservation objective, the overarching principle is to maintain existing occurrences of the ecological community that are relatively intact and of high quality. Larger and more intact occurrences are likely to retain a fuller suite of native plant and animal species, and ecological functions. Certain species, particularly fauna, may not be easy to recover in practice, if lost from a site.

This principle is highlighted in the *National Standards for the Practice of Ecological Restoration in Australia* (Standards Reference Group SERA, 2021):

> ***"Ecological restoration is not a substitute for sustainably managing and protecting ecosystems in the first instance.***
>
> *The promise of restoration cannot be invoked as a justification for destroying or damaging existing ecosystems because functional natural ecosystems are not transportable or easily rebuilt once damaged and the success of ecological restoration cannot be assured."*
>
> *Standards Reference Group SERA (2021) – Appendix 2.*

The principle discourages 'offsets' where intact remnants are removed with an undertaking to set aside and/or restore other, lower quality, sites. The destruction of intact sites represents a net loss of the functional ecological community because it is unlikely that all the species and ecological functions of the intact site can be replicated elsewhere. It is therefore more cost-effective and less risky to retain an intact occurrence than to allow degradation or loss and then attempt to restore it or establish an occurrence in another area to replace it.

Where restoration is to be undertaken, it should be planned and implemented with reference to the *National Standards for the Practice of Ecological Restoration in Australia*. These Standards guide how ecological restoration actions should be undertaken and are available online from the Standards Reference Group SERA (2021). They outline the principles that convey the main ecological, biological, technical, social and ethical underpinnings of ecological restoration practice.

5.4 Priority conservation and research actions

Priority actions are recommended to abate threats and support recovery of the ecological community. They are designed to provide guidance for:

- planning, management and restoration of the ecological community by landholders, Natural Resource Management (NRM) and community groups, Traditional Owners/Custodians and other land managers (including local and/or state governments);
- avoiding impacts and setting approval conditions for relevant controlled actions under national environment law (the EPBC Act); and
- prioritising activities in applications for Australian Government funding programs.

More detailed advice on actions may be available in specific plans, such as management plans for weeds, fire, or certain parks or regions. The most relevant at the time this Conservation Advice was developed are listed in section 5.2.2.

More specific guidance may be developed in the future; restoration ecology develops continually. So it is important to reflect on the experience of others involved in restoring the ecological community, or other aquatic or floodplain communities — and adapt restoration projects as site level experience accumulates.

To achieve cost-effective investments in conservation management it is important that you consider the likely interactions between management actions at a site. They may be synergistic, or antagonistic. There are also likely to be interactions between sites and within broader catchments. Also, when you allocate management resources, it is important to consider what is the minimum investment required for success, and the follow-up required to secure long term recovery (e.g. how many years should weed management be repeated).

This Conservation Advice identifies priority conservation actions under the following key approaches.

- PROTECT the ecological community to prevent further losses.
- RESTORE the ecological community by active abatement of threats, appropriate management, restoration and other conservation initiatives.
- COMMUNICATE, ENGAGE WITH AND SUPPORT people to increase understanding of the value and function of the ecological community and encourage their efforts in its protection and recovery.
- RESEARCH AND MONITORING to improve our understanding of the ecological community and the best methods to aid its management and recovery.

These approaches overlap and are iterative— they include research, planning, action on the ground, monitoring, analysis and review.

5.4.1 PROTECT the ecological community

This key approach includes priorities intended to protect the ecological community by preventing further loss of area and condition (abundance, diversity, integrity and resilience).

PLAN FOR PROTECTION

- Preventing direct and indirect impacts to the ecological community from threats such as vegetation clearance or changed hydrology (e.g. reduced flows or connectivity) needs to be properly considered during the early stages of planning within the boundary area for the ecological community and broader catchments (before decisions are made).

- All relevant strategic planning documents at national, state, regional and local levels should include appropriate actions to prevent the loss of extent or integrity/condition of the ecological community and adjacent or nearby native habitats.

- Planning and zoning decisions should protect the hydrology/hydrogeology and other key ecological processes and areas in broader catchments that influence integrity/condition of the ecological community, including areas that support the different successional stages of characteristic species (e.g. river red gum and black box regrowth, fish, frogs, waterbirds).

- Liaise with local councils, State authorities and Local Aboriginal Land Councils and/or Elders groups, to ensure that cumulative impacts to the ecological community, and associated ecosystem functions and cultural values, are minimised as part of broader strategic planning and planning for large projects (e.g. road works, dams, levees, other developments, land and water management plans).

- Implement strong border biosecurity and plan to avoid importing or accidentally introducing invasive species and pathogens that may severely impact this ecological community.

- Plan to mitigate future climate change and therefore reduce the impacts of climate stress on this ecological community.

- Develop a Climate Extremes Emergency Plan for the ecological community — include appropriate management strategies and actions, including rescue and recovery requirements for threatened and other key native species that are highly susceptible.

MANAGE MORE HIGH PRIORITY AREAS FOR CONSERVATION PURPOSES

- In consultation with the agriculture sector and First Nations people, protect additional areas of the ecological community identified as the most important (e.g. wildlife refuges and other sites with high biodiversity, ecological and cultural significance) in formal conservation reserves.

- Consider other areas for less formal conservation tenures, preferably ones affording long-term protection. This includes investigating formal conservation arrangements, management agreements and covenants to protect occurrences on private land in-perpetuity. This is particularly important for larger areas that link to other patches of native vegetation or wetlands, riparian areas and other areas that are part of wildlife corridors or migration routes or other habitat areas critical to the long-term survival of

functionally significant species and key ecological processes (some of which are summarised in section Table 17).

- Aim for connected networks of conservation areas with functioning wetlands, floodplain and other habitats serving as refugia or linkages for the wildlife of the ecological community across the broader landscape.

- Consider additional measures to protect the ecological community through carbon offset and nature repair-biodiversity market schemes or working with landholders and First Nations peoples on other conservation programs.

MANAGE ACTIONS TO MINIMISE IMPACTS, INCLUDING CUMULATIVE IMPACTS

- Apply the mitigation hierarchy to avoid, then mitigate potential impacts on the ecological community from development or other actions within the broader catchment. The priority is to avoid vegetation clearance, hydrological changes, and other impacts to integrity and resilience, including loss of biodiversity and abundance (particularly of functional species), loss of connectivity and changes to other key natural processes (particularly hydrology). Plan projects to avoid the need to offset, by avoiding unacceptable and significant impacts to the ecological community and achieving nature positive outcomes.

- Minimise the risk of indirect impacts to the ecological community from actions outside but near to or upstream of the ecological community, such as changes to hydrology or other ecological processes and damage to landscape functions within the broader catchments.

    - Avoid building infrastructure within or near the ecological community that will interrupt or divert hydrological flows on the floodplain or cause significant run-off of nutrients. If they proceed, control runoff during nearby construction activities to prevent the spread of weeds, pathogens and nutrients into the ecological community.

- The ecological community is threatened due to the cumulative impacts from multiple land and water changes and degradation, sometimes large and sometimes small or gradual. Therefore:

    - Take into account that approval of even a relatively small loss and/or degradation of one area, characteristic or functional species, or key ecological process, can multiply the negative effects of other past and future actions and threats.
    - When considering how to minimise significant impacts and achieve nature positive outcomes — gather evidence and consider other recent, current and likely near future losses and/or degradation if actions are approved.

- Maintain the extent, condition and existing landscape scale connections between and within the ecological community and its surrounding natural environment.

- Protect other native vegetation and wetlands near the ecological community, particularly where they are important for connectivity and diversity of habitat.

- Avoid hydrological changes that could disrupt natural patterns of inundation, overland flows and water table levels, or that could increase salinity, nutrient loads, algal blooms, sedimentation/turbidity, or pollution.

- Minimise unnecessary soil disturbance that may facilitate weed establishment.
- Protect habitat features for fauna and flora, including for threatened, functional and culturally important species, noting particular vegetation structures or other species requirements. For example, mature red gums providing nests for woodland birds or a continuous canopy or sub canopy of *Duma florulenta* (lignum) as a refuge.
- Where this ecological community is regenerating, protect it to full maturity. For example, provide temporary fencing to minimise risk of damage to native tree and other vegetation regrowth if appropriate, and ensure fire response and management plans are aligned with regeneration needs.
- If approval has been provided to remove native trees or use heavy machinery that may damage the ecological community, ensure comprehensive flora and fauna surveys have identified threatened or locally important species at the site (and in the case of fauna, their potential shelter and nesting sites such as tree hollows, burrows, rocks and crevices, as well as visible nests).
    - Avoid damage to these wherever possible and, if necessary, take care to appropriately relocate flora and fauna; and avoid undertaking the works during important times, such as breeding-nesting and flowering-seeding seasons.

OTHER THREAT PREVENTION

- When conducting activities in or around this ecological community, practice good biosecurity hygiene to avoid spreading weeds or pathogens (see DoE 2015). Also implement hygiene management plans and risk assessments to protect vegetation and fauna of the ecological community from disease outbreaks. This may include, but is not limited to, ensuring that:
    - contaminated soil is not introduced into an area as part of restoration, translocation, infrastructure development or revegetation activities, and
    - in areas of disease outbreaks — disease free areas are sign posted, and hygiene stations constructed and maintained where feasible.
- Support landholders/managers to prevent introduction of invasive species and pathogens to new areas.
    - Encourage landholders/managers to engage in weed identification and intervention early, including monitoring invasion pathways and implementing prevention measures using current best management practices.
- Avoid selling known invasive species in Local Government areas where the ecological community occurs.
- Prevent planting known or potential invasive species in gardens, developments and landscaping near the ecological community; particularly known transformer weeds, or bird-dispersed species.
- Encourage appropriate use of local native plant species from the ecological community in developments in the region, through local government and industry initiatives and best

practice strategies. Review planting schedules when approving new developments and landscaping, to ensure that potential weeds are not included.

- Prevent dumping waste, particularly garden and soil waste, in or near the ecological community.
- Vehicle tracks and walking trails can spread or amplify diseases. Existing tracks should be reviewed for removal and re-alignment to protect catchments and any proposed future tracks or trails should minimise risks (particularly from impeding natural hydrology and causing runoff and weed and pathogen introduction)..
- Prevent death and injury to native fish and other aquatic fauna through installation and maintenance of modern fish-protection water pump screens. Align with relevant existing initiatives through local authorities.
- Avoid grazing in areas with threatened species or highly diverse native ground layers during peak native plant flowering and seeding times for many species (late spring and summer), and when seedlings are establishing.
    - Also minimise grazing when the soil is too wet; or when plants are stressed by other pressures.
    - Fence to exclude stock, feral and native herbivores, until seedlings are at least two metres high; individual seedlings may be protected by herbivore guards.
- Promote guidelines/restrictions, educational material (e.g. signage) and monitoring protocols for recreational activities that adversely impact on the ecological community, including: fishing; 4WD and other recreational vehicle use (e.g. at the Coorong and nature reserves); regulated hunting activity; houseboats and other recreational boating craft; camping (including lighting of fires).
- Cease/prohibit and monitor wood collection, such as for firewood or fencing, that leads to the loss and damage of riparian or floodplain trees, stags and logs, or disturbs the natural litter layer.
- Cease/prohibit and monitor destructive activities such as off-road trail bike or four-wheel-driving, such as on native dune vegetation at the Coorong.
- Cease/prohibit and monitor rubbish dumping.
- Cease/prohibit access by domestic pets to sensitive areas (e.g. waterbird and seabird nesting areas), by containing them in nearby residential areas, or keeping them on leashes.

APPLY BUFFER ZONES

- Protect and apply appropriate buffer zones (particularly adjacent areas of other native vegetation) to minimise impacts arising 'off-site'. A buffer zone is a contiguous area adjacent to areas of the ecological community that is important to protect the integrity of this ecological community but is not a part of the ecological community itself. The risk of indirect damage is usually greater where threatening actions occur nearby. Buffer zones can minimise this risk, by absorbing and reducing impacts. They can also guide land managers to notice that the ecological community is nearby and to be extra careful.

  - For instance, buffer zones help protect outermost plants and other members of this ecological community from spray drift (fertiliser, pesticide or herbicide sprayed in adjacent land), weed invasion, polluted water runoff and other damage.
  - The best buffer zones are typically areas of native vegetation. Fire breaks and other built asset protection zones do not typically provide a suitable buffer and should be additional on the outside of a vegetated buffer.

- The recommended minimum buffer zone for the ecological community is at least 200 m from the outer edge. The appropriate size depends on the nature of the threatening action and local context (e.g. groundwater or downstream impacts). Apply larger buffer zones to protect occurrences from broader landscape threats such as hydrological changes.

- Determination of wetland buffer zones can be complex and should be determined on a case-by-case basis, taking site-specific features such as the localised catchment area of the wetland into account. Exercise good judgement, to determine an appropriate buffer distance, depending on circumstances. Guideline for the Determination of Wetland Buffer Requirements (EES 2005) explains a multi-step process and buffer types/size depending on wetland attributes, objectives and threat.

Consultation Questions on the buffer zones

In your opinion, is the advice on buffer zones and recommended minimum buffer distance appropriate? If not, how should the buffer zone advice be amended to ensure appropriate application?

5.4.2 RESTORE (and MANAGE) the ecological community

This key approach includes priorities to restore areas of the ecological community by active threat abatement, appropriate management, restoration and other conservation initiatives. Act to increase the extent, condition, and landscape scale connectivity of this ecological community (including connectivity with other surrounding native habitats). The aim should be for recovery of as many key biodiversity and ecosystem attributes as practical for a particular site, so that the ecological community is on a trajectory to recovery and is self-sustaining. This should be based on following the *National Standards for the Practice of Ecological Restoration in Australia* (Standards Reference Group SERA 2021).

GENERAL

- Implement actions identified in key existing management plans such as the Murray-Darling Basin Plan, and the management plans for the six MDB Icon Sites and the three Ramsar sites.

- Restore the extent, condition and existing landscape-scale connections between and within the ecological community and the surrounding natural environment.

- Ensure that hydrological restoration and revegetation activities are coordinated and occur in the right chronological order to enable complementary and well targeted outcomes to be achieved.

- Undertake strategic invasive species management in conjunction with other management activities, to facilitate and promote natural regeneration of native vegetation and increased biodiversity.
- Consider the landscape context and other relevant values when planning and undertaking restoration works. For example, ensure threatened species, migratory species, Ramsar site characters and First Nations cultural values are not adversely impacted by restoration activities.
- Provide, maintain and monitor a network of fishways throughout the ecological community to facilitate native fish passage and breeding migrations (particularly for threatened, functionally significant and diadromous species). Carefully remove barriers where feasible or mitigate when barrier removal is not possible.
- Maintain or increase diversity of riparian and in-stream habitat (e.g. in-stream pools and low flow refuges, physical structures such as snags, logs and rocks, and leaf litter) for identified priority sites.
- Ensure that connected networks of functioning wetlands and floodplain habitats exist to serve as refugia or linkages for wildlife across the landscape.
- Identify, evaluate, and if practical and feasible, implement measures to address constraints that potentially affect environmental water delivery within the ecological community.
- Maintain and improve current management that maximises threat mitigation measures, including the delivery of environmental flows, protection of core refugia and restoration of free-flowing streams.
- Maintain or restore the condition of understorey groundcover and shrub-layer vegetation (including lignum) in river red gum and black box woodland.
- Maintain or restore the condition of semi-permanent wetland vegetation, including reeds and mixed marsh sub-communities.
- Increase river productivity and improve the abundance and resilience of native fish in the ecological community.
- Maintain and restore nesting vegetation structure at key sites for aggregating breeding waterbirds between breeding seasons, to improve their 'readiness' for future colonial breeding events.
    - Restore other waterbird habitat, including foraging grounds for juvenile waterbirds, to increase their abundance and resilience.
    - Provide environmental water, as needed (e.g. duration extension, increased depth, water quality) during breeding events.
- Restore abundance and habitat for other aquatic or semi-aquatic species, including culturally significant species (e.g. frogs, turtles, rakali, crayfish, mussels, gastropods).
- Include this ecological community as a key target in Nature Repair Market schemes and other environment restoration strategies and programs.

- Directly involve, or seek guidance, from experienced restoration experts and Traditional Ecological Knowledge from First Nations groups when planning and carrying out restoration works – from seed collection and propagation, planting, environmental flows, to invasive species management, fauna reintroductions and other activities.

RESPOND TO THE THREAT OF CLIMATE CHANGE

- Develop and implement a Climate Change Adaptation Plan for the ecological community, including determining appropriate adaptation management strategies and actions, and identifying options to enhance habitat and biodiversity resilience (e.g. riparian shading, fish hotels, shaded nesting boxes).
- Undertake activities to mitigate climate change and reduce climate stress impacts, particularly hydrological impacts.
- Enhance the resilience of the ecological community to the impacts of climate change by reducing other pressures.
- Identify important climate refuge areas for key species (including Chowilla).

RESTORE FLOW REGIMES AND OTHER HYDROLOGY

- Consistent with the Murray-Darling Basin Plan's principles to be applied in environmental watering, and to the extent possible within operating constraints, support hydrological connectivity between river channels and floodplain environments.
- Implement appropriate wetting and drying cycles and inundation intervals that do not exceed the tolerance of the ecological community's resilience or known thresholds of irreversible change for functionally significant species (e.g. river red gum, lignum).
- In consultation with First Nations groups and landholders, restore natural hydrological regimes to high priority areas of the ecological community that have been adversely impacted. This may include:
    - Removing or altering weirs, causeways, drains or other artificial structures, where feasible, or installation of levees and control structures that have positive environmental benefits.
    - Targeted environmental (and cultural) watering and other activities that will mitigate and reduce detrimental hydrological impacts and restore flows and water quality. Determine high priority areas in consultation with First Nations groups.
    - Re-instate small to medium flows to facilitate within-channel and overbank flows required for the various types of wetland vegetation and aquatic species e.g. for fish and frog spawning and native vegetation recruitment.
    - Ensure environmental watering considers whole of system influences such as: agricultural run-off, climate change, pollution, and potential impacts on culturally important areas.
- In managing flows:

- Take into consideration that variability of the natural flow regime, including implementing changes to mitigate or avoid seasonal inversions of flows. (Note: peak flows in summer tend to reduce growth of submergent water plants in the channel).
- Determine and ensure the environmental water requirements for priority environmental assets and ecosystem functions, and to maintain connectivity (as defined by this Conservation Advice, the Murray-Darling Basin Plan and other plans for obtaining positive environmental outcomes).
- Restore variability in water levels in the weir pools (also minimises stratification).
- Ensure environmental watering considers whole of system influences such as: agricultural run-off, climate change, pollution, potential impacts on culturally important areas, etc.

- While the preference is to maintain a permanently open mouth, ensure that the Murray Mouth remains open at frequencies, for durations, and with passing flows, sufficient to:
  - enable the conveyance of salt, nutrients, and sediment from the Murray-Darling Basin to the adjacent ocean, and
  - ensure that the tidal exchange maintains the Coorong's water quality within the tolerance of the Coorong ecosystem's resilience.
- Mitigate the threat of algal blooms by reducing excess nutrient inputs into the ecological community. Develop a status report of the issue, including site specific trends along the ecological community over the past 30 years.
- Promote conservation of the Chowilla Anabranch/floodplain system (including restoring variable flows), which has the most diverse range of aquatic habitats (lotic and lentic) and is a refuge and critical source of recruitment for small and large bodied fish in the ecological community.

RESTORE NATIVE VEGETATION

- Undertake restoration (including facilitating regeneration and revegetation) of lower condition patches, to restore them to a higher condition. Restoration should aspire to the 5 Star Standard of the SERA Standards. Land managers should aim for the highest and best recovery of native vegetation, to maximise biodiversity and ecological function based on appropriate metrics for each site. SERA (2021) gives guidance on implementing appropriate standards. These aspirations are particularly important for sites that are being restored or reconstructed from highly altered states.
- Identify which areas are best revegetated with either seedlings or seed (e.g. residual chemicals and nutrients in the soil of agricultural areas can suppress native species germination for up to five years).
- Aim to establish species from the full suite of life-history characteristic species; create resilient conditions to promote natural regeneration and recovery from disturbance.
- Support natural regeneration where possible (e.g. through floodplain flows).
- Replant native vegetation to riparian/littoral and floodplain areas that are not naturally regenerating using species known to previously occur locally.

- Re-establish *Ruppia* and associated species in the Coorong.
- Restore instream and riparian vegetation in the streams of the Eastern Mount Lofty Ranges components of the ecological community.
- Work with landholders/managers to restore and reconnect areas of the ecological community, and to increase adjacent or nearby native vegetation (including buffer areas).
- Maintain snags, stags, logs, large rocks and mature and old-growth trees with hollows, because they provide important habitat for fauna. If necessary, supplement (but do not replace) habitat as part of restoration projects – this may be particularly important after severe disturbance.
- Use local native species in restoration projects, and restore structure, abundance and diversity to an appropriate and sustainable level for the site.
    - In general, use locally collected seeds, where available, to revegetate native plant species. However, choosing sources of seed closer to the margins of their range may increase resilience to climate change. Take account of key plant species' growing seasons to successfully achieve seed set.
- Ensure commitment to follow up after planting, such as the care of newly planted vegetation by watering, weeding and use/removal of tree guards if needed.
- Consider the landscape context and other relevant species and communities when planning restoration works. For example, ensure that adjacent ecological communities and threatened and migratory species are not adversely impacted by restoration activities.
- Close and rehabilitate unnecessary roads and tracks and otherwise control access to restored areas; but take account of required access (e.g. by elders of Traditional Owners/Custodians to cultural sites).
- Where appropriate habitat is available, and predators and competitors can be sufficiently controlled, re-introduction of some fauna species, including those supporting important ecological functions, may be possible.
    - Consider the size of the gene pool and interactions with naturally occurring populations when introducing fauna.
    - Where key ecological services, formerly provided by fauna, are limited or missing, consider any opportunities to replicate these.
- Explore the potential for carbon mitigation investment activities to restore wooded areas through reforestation. This should be in line with appropriate reforestation methodologies such as those developed under the *Carbon Credits (Carbon Farming Initiative) Act 2011*. As part of any such initiatives, aim to also achieve biodiversity credits.
- Implement effective adaptive management regimes using information from available research and management guidelines. For example, see the National Standards for the

Practice of Ecological Restoration in Australia (Standards Reference Group SERA, 2021), relevant research or advice from local authorities.

MANAGE SALINITY

- Maintain a long-term database of salinities at each weir, in the Lower Lakes and Coorong and at the Murray Mouth.
- In recognition that the North and South Lagoon of the Coorong are different and distinct estuarine systems, ensure that the salinity loggers within the Coorong accurately reflect averages for each lagoon separately.
- Maintain a long-term database of soil, surface water, and groundwater salinities at key locations on the floodplain.
- For the Chowilla floodplain (the largest remaining riverine woodland in South Australia) aim to lower groundwater and increase flooding frequency to reduce soil salinisation and floodplain tree decline and loss.
- Support appropriate ongoing programs related to desalinisation of water and soils associated with the ecological community (e.g. salt interception schemes and irrigation management improvements) while ensuring there are no adverse impacts.

MANAGE ACID SULFATE SOILS

- Evaluate the severe Acid Sulfate Soil event and response during the Millennium Drought and identify key lessons learnt and publish management guidance for future events.
- Ensure mitigation planning, including remedial response planning for future Acid Sulfate Soil events during drought.

MANAGE WEEDS, PESTS AND PATHOGENS

Implement effective integrated control and management techniques for weeds, pests and pathogens (disease causing organisms) affecting this ecological community; and manage sites to prevent the introduction of new, or further spread of existing, invasive species.

- Enhance or develop management plans for the control of major weeds identified for the ecological community (including willow), or emerging weed threats as they develop.
- Eradicate or manage weed infestations in the ecological community using appropriate methods, especially at wetlands where new weed incursions are establishing.
- Ensure that chemicals or other mechanisms used to eradicate weeds do not adversely impact components of this ecological community, particularly aquatic components.
- Treat disease with appropriate methods when infections are identified.
- If new invasive species or pathogen incursions occur, detect and control them early, because small infestations are easier to eradicate.
- Limit or prevent grazing animals' access to sensitive areas of the ecological community (e.g. construct fences) where practicable; exotic species seeds (e.g. from cattle fodder, or from other areas) can be spread in their manure and by adhering to their coats. Provide advice and support to landholders/managers to reduce and eliminate these risks.

- Develop methods to control and eliminate common carp (e.g. install exclosures, traps), particularly at key sites such as Chowilla; and implement control and eradication programs.

- Appropriately monitor and manage feral mammals and birds. Prevent further incursions into the ecological community; and contain pets in nearby residential areas, where possible.

- Involve Traditional Custodians in detection, eradication and control programs whenever possible.

MANAGE FISHING PRESSURE

- Undertake surveys and analysis of recreational catches of native species that are part of the ecological community to track and report on trends.

- Instigate an education and awareness program to promote 'catch and release' of native species, particularly Murray cod and other threatened or declining species.

- Ensure adequate regard to environmental considerations and genetic implications of any proposed fish stocking scheme in the ecological community (see Gillanders & Ye 2011 for Murray cod).

MANAGE TRAMPLING, BROWSING AND GRAZING

- Ensure periodic recruitment and renewal of the understory and tree layer (e.g. by strategically timed reductions in grazing pressure).

- In some cases, occasional grazing may reduce exotic grass cover and manage shrub regeneration – encouraging native grass and herb growth. However, it should be managed carefully taking into account season, condition and other pressures.

- Promote native pastures rather than exotic grasses as grazing best management practice.

- Remove (access to) non-essential water sources and manage remaining watering points to avoid damage to wetlands and watercourses, and to reduce total grazing pressure on the ecological community; for example, with appropriate fencing.

MANAGE APPROPRIATE FIRE REGIMES

- Fires (including planned burns and associated activities) must be managed to:

    - maintain the integrity of the ecological community; avoid disruption of the life cycles of key species;

    - support rather than degrade habitat;

    - avoid invasion and facilitate control of exotic species;

    - avoid impacts from fire suppression and mop-up operations; and

    - avoid increasing the impacts of other threats (such as drought, prolonged heavy grazing or predation by feral predators).

- Implement appropriate fire management regimes for the ecological community and for the surrounding landscapes. Use both First Nations Traditional ecological knowledge and other ecological scientific research results and advice.
- Take into account that isolated fauna populations and threatened plants are particularly vulnerable to local extinction following intense fires, combined with other threats.
- Manage fire appropriately, including actions to protect individual hollow-bearing trees, in wooded areas of the ecological community.
- Where hazard reduction burns, or prescribed fires, are undertaken near the ecological community, ensure that the potential for the fire to escape is appropriately risk assessed and management responses are in place to protect the ecological community.
- Use a landscape-scale approach, and available local knowledge on fire histories, to identify patches of the ecological community that would benefit from reinstating appropriate fire frequency to prevent further declines because of either too low, or too high, fire frequency.
    - For areas affected by too low fire frequency, identify opportunities for applying appropriate ecological burns, including with traditional knowledge and practices.
    - For areas affected by too high fire frequency, identify options for reducing the frequency of fires and protecting important features, such as large habitat trees.
    - Fire management strategies at each location should take into account antecedent fire history, life histories of species within the community, forecasts of drought, post-fire management plans for herbivores and predators, patch size, habitat features (e.g. protect hollow-bearing trees and large logs), vegetation structure and the surrounding landscape (including property protection) to sustain biological diversity, maintain refuges for fauna (during and after fire) and increase habitat variability.
    - Ensure that an invasive species risk assessment and evidence-based management program is planned and budgeted-for ahead of proposed burning to ensure adequate protection of post-fire regeneration from invasive species. However, care must be taken whenever using herbicide to control weeds after a fire as it can be detrimental to wetland flora, invertebrates and other fauna.
    - Use available ecological information to avoid detrimental fire impacts on key and susceptible species in the ecological community. For instance, do not burn areas in or adjacent to the ecological community when key, threatened or functionally important flora and fauna (that may be adversely impacted) are flowering, nesting or otherwise reproducing.
    - Consider weather conditions. Do not burn in, or adjacent to, the ecological community when soil moisture is low, or dry conditions are predicted for the coming season. Otherwise, already stressed flora and fauna will struggle to recover and erosion may occur, or weeds may become established while vegetation cover is reduced.

- Monitor fire outcomes and the consequences of other threats. Manage these threats in an appropriate timescale (e.g. immediately put in place erosion control measures; limit access by feral predators and grazers; and control weeds as they first appear, with follow up treatments as necessary, until native vegetation has regenerated). Ensure monitoring results are considered when planning and implementing future fire regimes. For further information on monitoring priorities see section 0

5.4.3 COMMUNICATE, ENGAGE WITH AND SUPPORT

Promote public awareness of the ecological community and encourage people and groups to contribute to its protection and recovery. Gain support from (and in turn, support and encourage) key stakeholders. Increase their understanding of its value and function, as well as of its key threats, the importance of its protection and restoration, and appropriate management actions. Key groups include local restoration and NRM groups, government agencies, landholders, land managers, land use planners, researchers, schools, volunteers, First Nations communities and other community members and groups.

RAISE AWARENESS AND ENCOURAGE PARTNERSHIPS TO PROTECT AND RESTORE

- Raise public awareness about the ecological community, its threats and recovery priorities using a range of media/methods. For example, fact sheets, information brochures, field days, demonstration sites, school programs, and interpretive signs at strategic locations — in conjunction with industry or community interest groups.
- Promote latest science on threat mitigation and restoration techniques.
- Promote First Nations Traditional ecological knowledge and involvement in conservation management and recovery throughout the range of the ecological community
    - Identify and support culturally appropriate mechanisms to share this knowledge, to protect and restore the ecological community. With permission, include culturally appropriate information and values in education and awareness programs, publications and signage.
- Promote responsibilities under state and local regulations, and under the EPBC Act.
    - Install signage to discourage damaging activities such as removing dead timber, fishing regulations, dumping garden waste and other rubbish, creating informal paths and tracks, and using off-road vehicles, in parts of the ecological community.
- Highlight conservation management methods, initiatives and incentives (such as conservation agreements, stewardship projects, nature repair market and other initiatives).
- Encourage landholders/managers to talk with their peers, local community groups, local authorities, NRM organisations, First Nations and other knowledgeable groups to promote cooperation to manage threats and restore areas of the ecological community.
    - South Australia's Landscape Boards are well placed to foster relationships and stewardship with local First Nations Peoples and private landholders. The model demonstrated by the Lakes Hub in Milang during the Millennium Drought was also very successful.

- Promote knowledge about local weeds and what garden plants to avoid planting. Recommend local native species for revegetation and landscaping, or safe alternative garden plants. Discourage nurseries and DIY stores from selling weed species.
- Encourage local participation in restoration and 'landcare' efforts (e.g. through local conservation groups, creating 'friends of' groups, field days and planting projects).
- Liaise with local fire management authorities and agencies; and engage their support in appropriate fire management. Ensure land managers are supported in how to manage fire risks, to conserve the ecological community and other local ecological and cultural values.

5.4.4 RESEARCH AND MONITORING

Improve understanding of the ecological community and the best methods to help its recovery by restoration, management and protection. Relevant and well-targeted research, and other information gathering and analysis activities, are important to inform protecting and managing the ecological community.

RESEARCH PRIORITIES

- Investigate wetting and drying cycle requirements to determine optimal water regimes for key floodplain wetland sites in the ecological community.
- Investigate and monitor the resilience and responses of the ecological community to disturbance, including identifying site-specific condition thresholds and limits of acceptable change for various species or ecological functions.
- Investigate ecological requirements for transplantation and restoration of aquatic macrophytes, particularly submergent species.
- Investigate impacts (e.g. competition, predation, habitat disturbance) of invasive species on native flora and fauna, including fish, reptiles, and marsupials.
- Develop greater understanding of strategies to minimise the negative ecological impacts of 'blackwater' and other deoxygenation events.
- Build on the fish-habitat/ tributaries database developed by SARDI — in particular collect data for significant anabranches associated with the main channel.
- Support research into the biology and ecology of aquatic invertebrates that comprise the ecological community.
- Support ongoing research on the biology, ecology (and genetics) and integrated management to assist eliminating alien animals and plants, including common carp, and willows.
- Investigate and monitor the resilience and responses of the ecological community to climatic variations, including prolonged drought.
- Investigate likely distribution shifts of key native species and alien species in the ecological community due to climate change.

- Investigate the phenological impacts of climate change (e.g. timing of migrations or flowering/breeding and desynchronisation of interactions between species, such as predator-prey mismatches and disrupted pollination networks).
- Investigate potential climatic refugia throughout the ecological community. This includes improving translocation methodologies, emergency offsite storage of threatened species and developing emergency response plans for key taxa.
- Investigate the impacts of groundwater extraction; and potential responses.
- Develop an integrated system-wide database to support ongoing monitoring and analysis of the ecological community and its biota and processes.
- Research and develop effective responses for this ecological community to sea level rise (SLR) and extreme sea level (ELR) — e.g. storm surges, increased marine incursions and 'marinisation' (and their associated pest species and pathogens).
- Integrate Traditional Ecological Knowledge and other ecological scientific advice, using appropriate free prior and informed consent procedures and data use agreements.

MONITORING

- Plan monitoring before management commences and considers what data are required to address research priorities and management questions. Adequately fund and resource monitoring management activities, especially those using a novel approach, and for monitoring before, during and after management action.
    - Monitor for new weed, pest animal and pathogen incursions.
    - Monitor for signs of decline.
    - Monitor changes in the condition, composition, structure and function of the ecological community, including response to all types of management actions. Use this information to better understand the ecological community and inform future management recommendations.
- Design and implement a monitoring program, or support and enhance existing programs, to gather information on the composition, distribution and dynamics of key animal and plant populations, and inform management.
- Include monitoring of river flows, water levels and water regimes, to determine how hydrology may change in concert with changing climate, and the effectiveness of environmental watering.
- Implement long-term monitoring of condition, consistent with previous programs such as the *Sustainable Rivers Audit* and *Native Fish Recovery Strategy*.
- Implement a long-term monitoring of native and non-native fish abundance and distribution (adults and juveniles of key species) at key locations in the ecological community. Ensure consistency of data with similar strategies (e.g. the *Native Fish Strategy*).

- Ensure long-term monitoring of invasive plant and animal species throughout the ecological community and develop associated risk management plans (e.g. for marine tubeworms, weeds, pest mammals, pathogens etc).
    - Ensure long-term monitoring of common carp at all life-history stages throughout the ecological community.
- Monitor the progress of recovery of vegetation via improved mapping, estimates of extent and condition assessments of the ecological community, and effective adaptive management actions.
- Promote homogenisation of existing but disparate fish databases related to the ecological community (particularly in South Australia), with the aim of developing a single, consistent, and fit-for-purpose fish database for the ecological community.
- Monitor algal blooms and blackwater events in the ecological community and document their occurrence, conditions, impacts and longevity. Develop an associated analytical database.
- Monitor and manage impacts on biodiversity from irrigation pumping infrastructure and practices.

Consultation Questions on priority actions

- Please provide feedback on this section. Further data or information to support identification and prioritisation of contemporary conservation, recovery and research actions is welcomed for consideration by the Committee.

6 Listing assessment

This assessment outlines the *grounds on which the community is eligible to be listed* as required by section 266B (2) (a) (i) of the EPBC Act.

The Threatened Species Scientific Committee has provided this draft for assessment for consultation.

6.1 Assessment process

Reason for assessment

This draft listing assessment follows prioritisation of a nomination from the public which is on the 2023 Finalised Priority Assessment List (FPAL) under the EPBC Act.

Note: Assessment for the 2024 *Conservation Advice* is still in progress, and the Committee aims to meet the statutory deadline of 29 November 2024.

This Draft of the *Conservation Advice*, currently released for the legislative requirement for public consultation under the EPBC Act, should be considered as having an 'indicative conservation status' for the ecological community. It builds on an assessment of the same ecological community that was undertaken by the independent Threatened Species Scientific Committee (the Committee) from 2009 to 2013.

In updating this comprehensive assessment, contemporary data and analysis from the new nomination and various other sources has been incorporated but it is acknowledged that some additional data and analyses will become available in the next couple of months. This information was unavailable prior to this Public Consultation period due to Basin Plan processes being run by the Commonwealth and State governments, which have differing timelines (e.g. Schedule 12 Matter 7 & 8 reporting, and upcoming Murray-Darling Water and Environment Research Program publications).

When these additional information resources become available, they are expected to be incorporated into the Criterion assessments and the *Conservation Advice.* At this juncture, it is considered unlikely that this extra information will alter the indicative conservation status overall, but individual criteria analysis could change.

6.2 Eligibility for listing

An ecological community is eligible for listing under section 182 of the EPBC Act if it meets the prescribed criteria outlined in the EPBC Regulations. This assessment uses the criteria set out in section 7.02 the EPBC Regulations and the Guidelines for nominating and assessing the eligibility for listing of ecological communities as threatened under national environment law (TSSC 2017), as in force at the time of the assessment.

Measuring the decline in extent or condition of riverine and estuarine systems can be difficult because the nature of decline often involves hydrological changes and associated biodiversity and functional changes, rather than loss of a major proportion of the geographic distribution of the aquatic system (although areas or components of the system may be lost; e.g. fringing floodplain, individual wetlands, etc.). For the purposes of this assessment, decline or loss in part or all of the ecological community, may be considered to have occurred when (TSSC 2010, 2011, 2024):

- key representatives (i.e. keystone-type species, e.g. species, suites of species, functional roles) of the ecological community have undergone an irreversible or long-term decline in abundance and/or loss of integrity and function, and/or
- physico-chemical conditions that underpin the local function of the ecological community and its constituent habitat components are changed such that the system no longer functions, and/or
- re-establishment of ecological processes, species composition, and community structure, is unlikely within the foreseeable future (e.g. 10–100 years), even with positive human intervention.

A reference (or benchmark) state (or series of states) may be used to assess when such a decline or loss has occurred. This is a type of 'reference condition' against which future evaluations can be made, but it is not to be confused with a target for management.

It is recognised that the *River Murray—Darling to Sea* ecological community is an intensively regulated system and has been so since the locks and weirs were constructed some 100 or so years ago (Jacobs 1990). It now consists of a series of stepped weir pools superimposed on the natural bed slope (Walker 2006). While the pre-regulation condition is not a practical target for management (TSSC 2010, 2011), it is a 'natural' reference or benchmark representing the flow regime to which the native flora and fauna are adapted. However, there is limited ecological and hydrological knowledge from this period.

As a guide, a reasonable benchmark state for the aquatic component of the ecological community could be either the pre-regulation state and/or a strong flow period such as that of the early-1970s (i.e. about 50 years ago) (TSSC 2010a). This timeframe also represents the system prior to the invasion of common carp (*Cyprinus carpio*) (Koehn et al. 2000, 2016), prior to the transition of the Coorong South Lagoon to turbid (Aldridge et al. 2018; Coleman in press), and prior to the Millennium Drought of 1997–2010.

For the terrestrial component of the ecological community, a measure of decline or condition may be when aspects no longer meet specified minimum condition thresholds, as per those indicated for riparian and floodplain vegetation in this *Conservation Advice* (see section 2.2). Note: there are no condition thresholds for the more aquatic components of the ecological community.

Table 26 provides a summary of criteria assessment results for the ecological community. In the indicative assessment within this draft Conservation Advice, Criterion 1, 2 and 6 are found to be ‘not eligible’, while Criterion 3, 4 and 5 are found to be ‘eligible’. The highest conservation status was ‘Critically Endangered’, which is the conservation status that the EC will be proposed at for listing as threatened. Analyses for each of the six regulated criteria follow.

Table 26: Summary of indicative criteria assessment outcomes for the *River Murray—Darling to Sea* EC. [Conservation Status: V = vulnerable; E = endangered; CE = critically endangered]

Listing Criteria	Key Assessment Outcomes	Overall Conservation Status
C1	*Decline in geographic distribution*	Not eligible
C2	*Small geographic distribution coupled with demonstrable threat*	Not eligible
C3	***Loss or decline of functionally important species*** • Black box (E) and River red gum (E) • Tangled lignum (V) • Tassel grass and Large-fruit tassel grass (CE) • Murray cod (CE) • Freshwater catfish (E) • Congolli (V) • Small-bodied fish – suite of four species (CE, incl. 1 Extinct) • Murray crayfish (Extinct) • Freshwater snails – suite of 16 species (CE, 3 Extirpated)	**CE**
C4	***Reduction in community integrity*** • decline in integrity from biodiversity loss • decline in integrity from non-native invasive or problem species • decline in integrity from altered hydrological regime • decline in integrity from loss of connectivity	**CE**
C5	***Rate of continuing detrimental change*** • salinisation of floodplain	**E**
C6	*Quantitative analysis showing probability of extinction*	Not eligible

6.2.1 Criterion 1 – decline in geographic distribution

	Category		
	Critically Endangered	**Endangered**	**Vulnerable**
Its decline in geographic distribution is:	very severe	severe	substantial
decline relative to the longer-term/1750 timeframe	≥90%	≥70%	≥50%
decline relative to the past 50 years	≥80%	≥50%	≥30%

For the *River Murray - Darling to Sea* ecological community, the 'extent of occurrence' and the 'area of occupancy' are virtually the same. The 'extent of occurrence' for the *River Murray - Darling to Sea* ecological community is estimated to be at least 407 977 hectares, excluding the Eastern Mount Lofty Ranges streams and the section of the Darling Anabranch and Lake Victoria that are within the stated boundary, and excluding also the groundwater component of the ecological community.

Within the total extent of the ecological community, there have been losses of native vegetation and some small wetlands, with areas of floodplain that are no longer 'active'. However, the overall geographic distribution (i.e. area) of the entire ecological community, including the linear riverine corridor and associated tributary components, the various wetlands and the occupied area within the 1956 flood line, is considered not to have declined substantially.

Therefore, the ecological community is **not eligible** for listing under this criterion.

6.2.2 Criterion 2 – limited geographic distribution coupled with demonstrable threat

Its geographic distribution is:		very restricted	restricted	limited
Extent of occurrence (EOO)		*< 100 km2 = <10,000 ha*	*<1,000 km2 = <100,000 ha*	*<10,000 km2 = <1,000,000 ha*
Area of occupancy (AOO)		*< 10 km2 = <1,000 ha*	*<100 km2 = <10,000 ha*	*<1,000 km2 = <100,000 ha*
Average patch size		*< 0.1 km2 = <10 ha*	*< 1 km2 = <100 ha*	-
AND the nature of its distribution makes it likely that the action of a threatening process could cause it to be lost in:				
the immediate future	*10 years or 3 generations (up to a maximum of 60 years)*	**Critically endangered**	**Endangered**	**Vulnerable**
the near future	*20 years or 5 generations (up to a maximum of 100 years)*	**Endangered**	**Endangered**	**Vulnerable**
the medium term future	*50 years or 10 generations (up to a maximum of 100 years)*	**Vulnerable**	**Vulnerable**	**Vulnerable**

This criterion identifies ecological communities that are geographically restricted or limited. Three relevant measures apply: 1) extent of occurrence (i.e. the total geographic range of the ecological community); 2) area of occupancy (i.e. the area actually occupied by the ecological community within its natural geographic range); and 3) patch occurrence and size distribution (an indicator of the degree of natural or disturbance-induced fragmentation and vulnerability of a limited size for each occurrence of an ecological community to particular threats such as a drying climate and edge effects).

An ecological community with a geographic distribution that is limited, either naturally or through modification faces a higher risk of extinction if it continues to be subject to threats that may cause it to be further degraded, fragmented and potentially lost in the future.

Although there are demonstrable and ongoing threats to the *River Murray—Darling to Sea* ecological community (see Table 23), the geographic extent, total area of occupancy and average area of occurrence of the ecological community are considered not to be sufficiently restricted or limited. Therefore, it is considered that the ecological community is **not eligible** for listing under this criterion.

Prelude to Criteria 3 and 4

The *River Murray—Darling to Sea* ecological is the assemblage of species associated with a nationally unique, landscape-scale floodplain-river ecosystem at the terminus of the Murray-Darling Basin. The interconnected components of associated habitat include: the river channel (and tributaries, including streams of the Eastern Mount Lofty Ranges), the associated floodplain (including wetlands, woodlands and forests), the Lower Lakes, the estuaries—the Murray Mouth and Coorong lagoons, and regional groundwater throughout (see Tables 2 & 3).

The diversity, integrity and resilience (c.f. 'viability' or 'health') of the ecological community depend on:

1) connectivity between the components, in terms of hydrology, geomorphology, biology and ecology (i.e. irrespective of river regulation, and such that it typically operates as one ecological entity)

2) the inherent spatial and temporal variability of the natural flow regime, and

3) trophic and habitat complexity, through conservation of native fauna and flora, particularly keystone-type (e.g. foundation, ecosystem engineer, etc.) species (or suites of species), and suppression of alien (invasive) species.

Maintaining or improving these three factors are paramount for the conservation and sustainability of the ecological community. If connectivity, habitat components, or keystone-type species, are compromised the entire ecological community (ecosystem) is put at risk of extinction or collapse.

Note: The indicative conservation status assigned to individual functionally important species for the Criterion 3 assessment applies only for the purposes of assessing their status with respect to their occurrence within, and contribution to, the *River Murray—Darling to Sea* ecological community (EC). Therefore, the outcome may be different to that of national or state-level conservation statuses for those individual species (or suites of species).

6.2.3 Criterion 3 – loss or decline of functionally important species

	Category		
	Critically Endangered	**Endangered**	**Vulnerable**
For a population of a native species that is likely to play a major role in the community, there is a:	very severe decline	severe decline	substantial decline
Estimated decline over the last 10 years or three generations (up to a maximum of 60 years), whichever is longer	*80%*	*50%*	*20%*
to the extent that restoration of the community is not likely to be possible in:	the immediate future	the near future	the medium-term future
timeframe	*10 years or 3 generations (up to a maximum of 60 years)*	*20 years or 5 generations (up to a maximum of 100 years)*	*50 years or 10 generations (up to a maximum of 100 years)*

This criterion refers to those native species (or suites of species) that play a major role and are critically important in the processes that sustain the integrity and resilience of the ecological community (EC). Their loss, removal or decline is likely to precipitate change in the ECs diversity, structure and function. Where a species' role is integral, a decline could potentially lead to very severe, severe or substantial degradation and/or loss of the EC, with restoration not likely over the immediate to medium term future.

The *Guidelines* (TSSC 2017) for this criterion provide 'indicative' timeframes linked to the severity of decline, in which the decline in the ecological community as a whole may be halted, or reversed, to ensure that it does not become (functionally) extinct. This could occur by natural processes, for example, such as replacement of one functionally important species by another, or by other processes including management intervention and/or restoration activities.

For the purposes of this assessment, the functionally most important species (or suites of species) that are likely to play a major role in the ecological community are 'keystone-type' species, including 'trophic-related' (as per Paine 1966) and 'ecosystem engineers' (as per Jones et al. 1994 or 'foundation' species Ellison 2019); and see Section 1.2.3 for further explanation. Keystone species are defined as having disproportionate importance in their community (Paine 1966, 1969; Mouquet et al. 2012); they help to maintain organisation and diversity and contribute to the functionality of ecological communities (Mills et al. 1993; Stiling 1999; Yang et al. 2020).

Ecosystem engineers are a type of keystone (or 'foundation's *sensu* Ellison 2019) species that provide structure and/or modify the physical environment and thus create, maintain, and change habitats and resources (Jones et al. 1994; Wright & Jones 2006). Changes in local populations of keystone species, including ecosystem engineers, are likely to have significant impacts on ecosystem processes, trophic relationships, habitat, and the long-term viability and resilience of the ecological community.

Assessment of this criterion is based on a suite of nine keystone-type species, or suites of species (i.e. as in the case of small-bodied fish and freshwater snails), that are deemed to be *among* the most functionally important to the ecological community, and for which substantial information is available to make an indicative determination. They are also representative of the various 'components' of the ecological community, for example: terrestrial and aquatic, freshwater and estuarine, benthic and pelagic, vertebrate and invertebrate (see Table 26).

KEYSTONE RIPARIAN-FLOODPLAIN TREE SPECIES – RIVER RED GUM AND BLACK BOX

River red gum (*Eucalyptus camaldulensis*)

Black box (*Eucalyptus largiflorens*)

Key functional role: ecosystem engineers; primary producers; structural habitat and supply of food source to pollinators and organic matter to both terrestrial and aquatic environments

Key vulnerabilities: dehydration; soil salinity; relatively short-lived seed banks; competition with weeds and alien species (e.g. willows, *Salix* spp.); regrowth dies before maturity; disease/pathogens; clearing; (see Table 17)

Key impacts on the species: high levels of stress, dieback, and death of old-growth (high habitat value) trees; spread of disease; decline in distribution; lack of recruitment; degrading seed bank

Likely causes: inappropriate flow regimes; rising saline groundwater; clearing; grazing of regrowth; climate change

Key impacts on EC: loss of complex structural habitat; loss of biodiversity; loss of production; loss of nutrient cycling; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the RMDS EC: Endangered

Woody species dominance and composition

The dominant riparian-floodplain large tree species in the ecological community are *Eucalyptus camaldulensis* (river red gum) and *E. largiflorens* (black box); *Acacia stenophylla* (river cooba) is also common as a canopy tree (or large shrub), in places. Tree coverage of the vegetated area on the floodplain in 2002–2003 was estimated as: 38% black box, 26% river red gum, and 10% river cooba, which remains broadly accurate (Smith & Kenny 2005; Holland et al. 2009; DEW 2020c, 2023c). The two keystone eucalypt species are essential ecosystem engineers, forming woodland and forest within the ecological community (e.g. Doody et al. 2021). They are long-lived, potentially hundreds of years, and take 20-30 years to reach maturity (Overton et al. 2018). These trees contribute to habitat complexity in many ways, influence local hydrology and micro-climates, and provide food for many organisms, including important pollinators (Robertson et al. 2001; MDBC 2003a; Wallace 2009).

Red gum

Lower floodplain and riparian habitats are dominated by river red gum woodland and forest, where they grow in areas subject to flooding (George et al. 2005; Doody et al. 2014). River red gums are long-lived, with estimates of 100-950 years (Ogden 1978 in Roberts & Marston 2000). Their wood is particularly durable and resistant to decay, needing an estimated 375 y to lose 95% of initial mass (Mackensen et al. 2003 in Roberts & Marston 2000). These trees contribute to important submerged habitat, with instream woody habitat (IWH) important for fish shelter, velocity refuge, and breeding—for both juveniles and adults (Crook & Robertson 1999; Humphries et al 2019; Koster et al. 2019; Koehn et al. 2020).

River red gum and their hollows provide habitat to a range of terrestrial, aquatic and amphibious fauna. In addition, the leaves of river red gums are shed continuously, slow to decompose, and support nutritious biofilms for grazing snails and other aquatic species (Schulze & Walker 1997). These trees can also moderate river temperatures by shading (Roberts & Marston 2011).

Table 27: Surveys of river red gum (RRG) & black box (BB) on the Murray floodplain.

Survey	Result	Comment	References
Entire River Murray floodplain	• 79% (by area) dieback of river red gum	• lack of large floods, soil salinity, climate change	MacNally et al. 2011.
SA River Murray floodplain below Darling 1987-1988 (355 sample plots)	• 60% trees healthy • 18% unhealthy (>40% canopy dead); 22% dead • unhealthy or dead (44% black box; 29% red gum)	• regulation, lack of flooding, over extraction of water • poor regeneration • weeds, soil salination	Smith & Smith 2014
SA River Murray various surveys 2002-2003	• 49% river red gum, 62% black box, 50% river cooba unhealthy or dead • Wentworth to Renmark, half of all trees stressed or dead • 40 - 100% of riparian overstorey stressed, dying or dead • 11% of river red gum and 12% of black box dead across 337 sites • 80% of trees stressed to some degree; 20-30% severely stressed	• lack of flooding, saline groundwater • stress indicated by changes in leaf/bark colour, or leaf loss and limb death	MDBC, 2003a; Smith & Kenny, 2005; Holland et al., 2009.
Riverland Ramsar site 2002	• 43% redgum area unhealthy or dead (1% redgum dead) • 82% black box area unhealthy or dead (6% black box dead)		DEH 2003
Murray floodplain (Pericoota to Mannum) 2002-2004	• 2002 – 51.5% RRG stressed • 2004 – 75.5% RRG stressed	• 100 sites along 1450 km	DWLBC in MDBC 2006
Chowilla floodplain 1993	• 54% of trees (RRG, BB, Cooba) in good condition in 1993 but fell to: • 35% in 2003; 24% in 2004	• without management intervention, predicted to fall to 19% by 2035	Overton et al. 2005
Chowilla floodplain	• 65% area of floodplain trees affected by soil salinisation compared to 40% in 1993.		Overton et al. 2006
Bookpurnong floodplain, 2005 - 2008	• Riparian vegetation in severe health decline (Berri to Loxton)	• soil salinisation, lack of flooding	Holland et al., 2009.
Pike River floodplain, 2009	• 57% of sites with trees in 'poor' to 'extremely poor' condition		Wallace, 2009.
Victorian River Murray 2006–09	• dieback increased from 45% to 70%		Cunningham et al. 2011.
LM Icon site Chowilla	• 80% stands were poor to severely degraded RRG + BB	• stand condition decreased 2010 to 2012	Cunningham et al. 2012
Chowilla, Pike, & Katarapko floodplains RRG: 2007/8 to 2018/19 BB: 2008/9 to 2018/19	• proportion of river red gum & black box in good or excellent condition increased	• supported by unregulated floods & targeted e-water during inter-flood dry phases	DEW 2020c
Pike Floodplain 2021-22	• 2/3 RRG & all Cooba good condition • decline in BB condition	• BB - on higher elevations and on unwatered sites	Wallace 2022; DEW 2023c

Black box

Black box woodland is typically an ecotone (i.e. a region of transition between two communities) between the lignum and river red gum dominated sub-communities of the ecological community at lower (i.e. more frequently inundated) areas of the floodplain, and mallee woodlands on the highland (i.e. never inundated). As such, they support the highest species richness of terrestrial birds for a floodplain vegetation community (Rogers & Paton 2008).

Following a flood, black box woodlands are more productive than adjacent mallee habitats and therefore, may be important habitat at a broader landscape-scale for fauna (McGinness et al. 2018; DEW 2020c). Importantly, black box 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).

Floodplain corridor and refuge

The riparian and floodplain corridor is of critical importance for dispersal of native fauna (Morris 2012; Stoltefaut et al. 2024) and as a refuge for birds and other native fauna, particularly in times of drought (MDBC 2003a). The value of eucalypt trees as a refuge within the ecological community has increased considerably over the years, due to the overall reduced ecological integrity of the floodplain and human impacts elsewhere in the broader landscape (MDBC 2003a; Overton et al. 2018; DEW 2023a).

Requirements

For health and germination, the maximum inter-flood period that can be tolerated is 2-3 years for river red gum (max. 5–7 y) and 7-10 years for black box (Rogers & Ralph 2010; Gawne et al. 2011; Kilsby & Steggles 2015). For vigorous growth, black box requires flooding every 3-7 years for 3-6 months of inundation, and although mature trees can survive for up to 19 years without flooding, the woodland will be in poor condition and have a limited capacity for recovery (Overton et al. 2018).

Condition and decline

Eucalypt woodlands, characterised by widely-spaced trees, had once covered most of the floodplains within the ecological community. Their extent has been greatly reduced by clearing since European settlement, and clearing has led to widespread dryland and riverine salinity problems (Allison et al. 1990; see also Criterion 5). Comparison of pre-European with early-1990s vegetation estimates determined that only about 40% of original tree numbers remain across the Murray-Darling Basin (Walker et al. 1993).

Notwithstanding differences in methodologies, various surveys have revealed serious declines in condition of river red gum and black box in the Murray-Darling Basin over many decades, particularly in the region of the ecological community (e.g. Smith & Kenny 2005; Val et al. 2007, Table 27). This has been attributed mainly to reduced flooding frequency, irrigation water diversions, rising saline groundwater, and weed invasion (Smith & Smith 2014; DEW 2020c; Doody et al. 2021). Symptoms of severe and prolonged water stress are typified by thinning crowns, changes in leaf colour, leaf shed and at the final stages of deterioration the cracking of bark (Lane 2003).

This situation was exacerbated by the Millennium Drought (up to 80% of trees were stressed; see Table 27 and Figure 4). However, results from a seminal 1987–88 survey demonstrate that the deteriorating condition of the vegetation was already evident in the 1980s, i.e. prior to the

Millennium Drought (Smith & Smith 2014, Table 27). Smith & Smith (2014) report of this survey,

"*The poor condition of the black box trees, coupled with their poor regeneration, suggests that the long-term future of this species along the Murray, particularly below the Darling Junction, is tenuous, even though it is a dominant component of the vegetation*."

Overton et al. (2018) also report that the condition of black box on the floodplain has declined since the 1980s, due to river regulation, drought, water extraction, irrigation drainage, grazing and land clearance. These drivers of decline have decreased the depth to the water table, increased soil salinity, and reduced the frequency (i.e. increased return period) of flooding (Overton et al. 2006, 2018).

MacNally et al. (2011) warn that the drying climate is likely to exacerbate forest and woodland dieback and lead to landscape-scale changes in the population viability of trees, as well as forest structure and understorey plant composition. Doody at al. (2021) similarly warn that along South Australian reaches of the River Murray, floodplain areas requiring flows of more than 80 000 ML/ day to flood, are well outside what is considered manageable under the current constraints and these floodplains are likely at greater risk of further decline. Of longer-term concern is that flow regimes may be inadequate to support black box breeding and marginal for red gum breeding in many areas where populations currently exist. In addition, even in good years, when recruitment of trees is possible, seedlings and saplings are at risk from grazing (e.g. from livestock, feral herbivores, native herbivores).

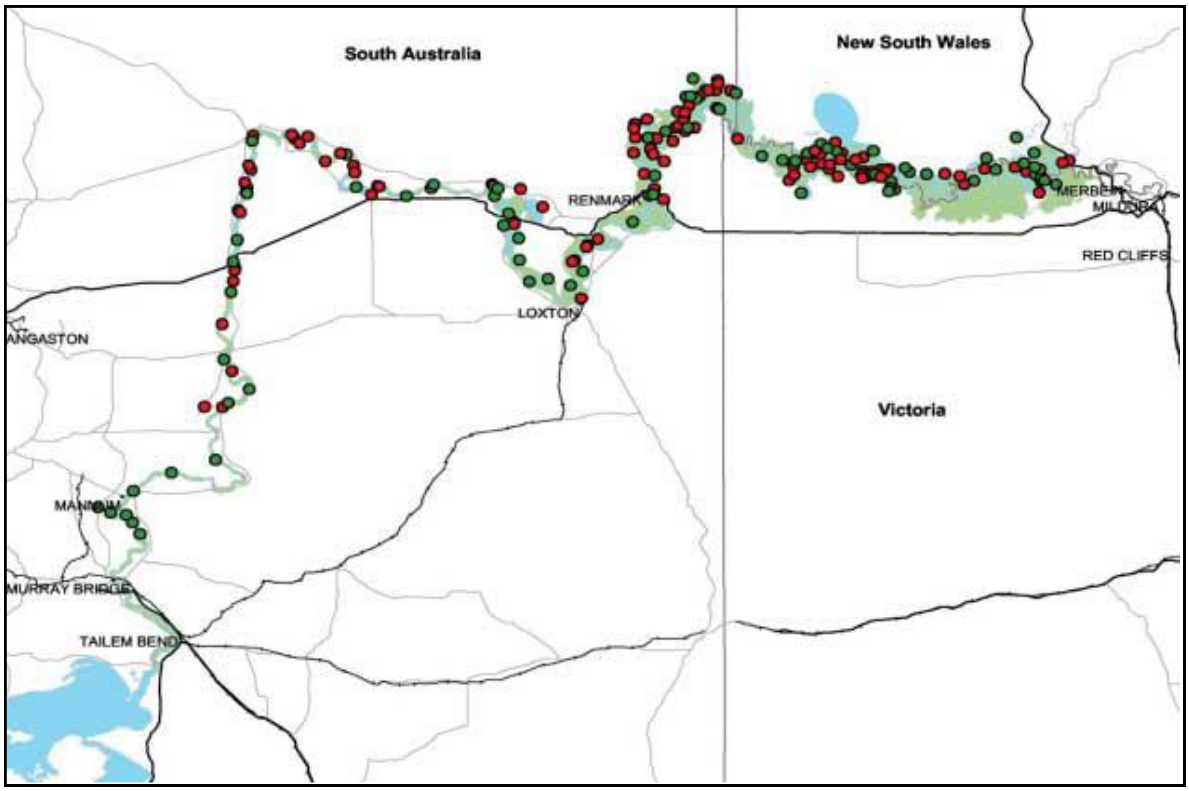

Figure 5: Extent of decline in river red gum health downstream of Mildura. Red dots indicate where more than half the trees were stressed; green dots show where less than 50% were stressed (MDBC 2003a).

The most stressed trees often occur in the meander plain, following the shallow contour lines of creeks and lagoons (MDBC 2003a; DEH 2004). These are areas that would benefit from moderate flows which occurred in 79 of every 100 years, but by the 21st century occur in only 30 of every 100 years (MDBC 2003a; *more recent data to be added*). Importantly, within the region of the ecological community, moderate flows, which normally would have flooded the elevations where many trees are located, have been reduced from an average frequency of 1 year in 3, to 1 year in 8-11 (i.e. since regulation and under climate change, Holland et al. 2009; Gawne et al. 2011; Wallace et al. 2014). On the Chowilla floodplain, the average interval between flooding has increased from 2 years (historical interval) to 9 years (regulated), and, is projected to increase to 19 years by 2030 (CSIRO 2008; *more recent data to be added if available*). Chowilla is the largest area of undeveloped floodplain habitat within the ecological community and the largest area of riverine woodland in South Australia (Overton et al. 2006; Gehrig et al. 2012; DEW 2020c).

Salinity

In addition to the effects of reduced flooding on tree health, floods have been insufficient to purge accumulated salt from the floodplain soil (MDBC 2003a; Hart et al. 2020; Verhoven et al. 2024). In these circumstances, the trees develop a higher dependence on groundwater, compounding soil-salinity problems in areas underlain by saline groundwater (Jolly 1996). Rises in saline groundwater have occurred due to river regulation since the 1920s (Overton et al. 2006, 2018). Taylor et al. (1996) estimated that in 1993 about 40% of the floodplain of the ecological community was affected by soil salinisation and this increased to 65% in 2003 (DEH 2004; Smith & Kenny 2005).

Specifically, the Chowilla floodplain is a 'sink' for naturally saline regional aquifers in the western Murray Basin (Gehrig et al. 2012). Modelling by Overton et al. (2006) suggested that 65% of trees at Chowilla were affected by soil salinisation, including trees along creeks where groundwater enters well away from the main channel (MDBC 2003a). A field comparison of water use at two sites on the Chowilla floodplain found that trees using saline groundwater (25 to 33 EC) were in better condition (higher leaf area, taller trees) than trees using groundwater close to the salinity of seawater (60 EC) (Roberts & Marston 2011).

In dry periods, river red gum rely on subsoil moisture and groundwater for growth and survival (White et al. 2000). Holland et al. (2009) demonstrated that riparian trees within the ecological community need a long-term, low salinity water source (flooding/fresh groundwater) to limit water stress, as well as bank recharge to maintain fresh groundwater. The limited extent and duration of environmental flows under present conditions of river regulation, water extraction, and climate change are not sufficient to meet their needs and to remove accumulated soil salts (MDBC 2003a; Holland et al. 2009). See Criterion 5 for the rate of detrimental change due to salinisation.

Recruitment and stand structure

Disturbances of various kinds may result in dieback and decline in tree health, as well as changed patterns of survival and recruitment, that may be manifested over years and decades (e.g. MDBC 2003a; George et al. 2005 and references therein; Lamontagne et al. 2012; Overton 2018; DEW 2020c). For populations of these eucalypt tree species to persist in the ecological community, recruitment must keep pace with mortality (George et al. 2005; Lamontagne et al. 2012). Trees are needed to replace the ageing mature trees, but few recruits had survived since the substantial floods in 1973–75 (Jensen 2011a).

Woodlands and forests in the ecological community have complex stand structures, with conspicuous gaps in size classes showing that recruitment has been episodic rather than continuous (George et al. 2005). For both river red gum and black box, flooding is the primary source of moisture for germination and seedling establishment (George et al. 2005). Towards the end of the Millennium Drought, data from floodplains around Pike River, Banrock Station, and Locks 1–4 showed that the numbers of juvenile trees were insufficient to maintain stand structure and compensate for adult mortality, with strong indications of recruitment failure, particularly for black box (George et al. 2005; Wallace 2009; Aldridge et al. 2012b; Lamontagne et al. 2012).

Lamontagne et al. (2012) cautioned it was extremely unlikely that tree condition would improve after the drought, without a return to more frequent inundation, and there was likely to be a continuing contraction in the extent of dominant riparian vegetation, reducing the 'active' floodplain to about one third of its former extent (a decline of about 66%). These authors also cautioned that, combined with the impacts of climate change, there is also likely to be transitions in species distributions in response to increasing soil salinity and reduced flood frequency and duration (e.g. river red gum replaced by black box and river cooba).

In addition, although black box is less affected by the loss of small floods than river red gum, the long-term survival of stands is threatened by reduced duration and frequency of larger floods. Very large floods (> 100 000 ML/day) are needed to alleviate stress in black box at higher elevations on the floodplain (Jensen 2011a). Drought-breaking floods occurred in 2010-11 (peak 94 000 ML/day) replenished soil moisture reserves and a new generation of seedlings germinated (Jensen & Walker 2017). In some locations these have been nurtured by environmental watering. Extreme flooding well in excess of 100 000 ML/day occurred in 2022/23—peak 186 000 ML/day at SA/VIC border (DEW 2023b, c, 2024).

Trends and outlook

Post Millennium Drought there have been targeted environmental water deliveries at various locations within the ecological community. These brought some relief to stressed eucalypts on the floodplain in specific areas, but it is increasingly clear that there needs to be longer term and more regular watering events to sustain and/or recover existing stands (Deny et al. 2019; Doody et al. 2021; DEW 2023c). However, artificial watering is not a direct substitute for regular natural floods, particularly given the limited extent and degree of salt leaching, bank recharge, and groundwater freshening in comparison to natural floods (Ye et al. 2014). Also, anecdotal evidence suggests that, for black box, the health benefits from inundation are variable; although not systematically documented, some cases of environmental watering were observed to produce little improvement (AWE 2015).

The massive flood of November 2022 to February 2023—the third largest on record in South Australia, inundated almost the entire South Australian River Murray floodplain, reaching areas that had not received water in decades (DEW 2024a). This resulted in the flushing and freshening of large areas of floodplain soils and a 'boost' for native vegetation (DEW 2024b, c). However, such floods can also contribute to erosion, siltation, and introduction of pollutants and pests. While floods such as this represent an' ecological reset' for some species and functions, they cannot reverse the long-term decline experienced by eucalypt trees within the ecological community.

The most recent monitoring of these eucalypts on the SA Murray floodplain, i.e. post 2022/23 flooding, indicates that the condition of black box has continued to decline, while that of river

red gum, while 'poor' is 'getting better' where water for the environment has been delivered (DEW 2023c, 2024b, c). It would take many years of more favourable conditions and more environmental watering for the health of both eucalypt species to be restored.

Therefore, there have been severe declines in river red gum and black box and it is not likely to be possible to restore the loss of function that they provide in the ecological community in the immediate to near future.

KEYSTONE RIPARIAN-FLOODPLAIN UNDERSTOREY SPECIES - TANGLED LIGNUM

Tangled lignum (*Duma florulenta* syn. *Muehlenbeckia*)

Key functional role: primary producer; structural habitat and flower-fruit resource for many fauna; contributes to soil-water and salt-water balance in floodplain soils

Key vulnerabilities: no soil seed bank; specific flooding requirements for reproduction and recruitment; extended drought; seedlings and saplings prone to grazing; soil and water salinisation; (see Table 17)

Key impacts on the species: historical widespread decline in abundance and distribution; patchy recruitment failure

Likely causes: drying; lack of appropriate flow& inundation regime; grazing; competition with weeds

Key impacts on EC: loss of productivity; loss of habitat (including nursery habitat); loss of biodiversity; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Vulnerable

Tangled lignum (*Duma florulenta*), a multi-stemmed shrub, is the dominant floodplain shrub in many areas of the ecological community, in both wet and dry phases. In addition to forming extensive shrublands, lignum occurs in the understorey of many floodplain woodlands (Roberts & Marston 2011). It is a long-lived and critical player in the soil and water (evaporative) balance of the floodplain ecosystem (Jensen 2011b; Jensen & Walker 2017). There are also indications that it may also help to keep saline groundwater levels down (A. Jensen, pers. comm.). Lignum is dioecious, with separate male and female plants (Chong & Walker 2005); these vary in their response to environmental conditions leading to differences in the distribution of each sex (Jensen et al. 2006).

Important habitat provider

Lignum is a keystone (ecosystem engineer) species in the ecological community and flooding is the main driver of its growth. Leaves only develop in response to flooding or heavy rainfall and are short-lived, being shed in response to drying (Capon et al. 2009). Individual plants can grow to 3 m in diameter and height and may form dense thickets (Sainty & Jacobs 1981). Branches grow upwards, then arch over and intertwine—resulting in a dense tangle (Roberts & Marston 2011).

Due to its structure and size, lignum provides habitat for invertebrates, birds (including nesting habitat), mammals and reptiles in dry times, and for waterbirds (including colonial nesting waterbirds), fish (including young stages), amphibians and invertebrates during floods. Dense stands of lignum can also protect eucalypt seedlings from grazing animals (Jensen et al. 2008; Jensen 2011b; Jensen & Walker 2017). During dry periods, the structure of lignum has been

found to facilitate the growth of floodplain understorey herbs (i.e. 'nurse plant' effect, James et al. 2015).

Resilience and reproduction

The persistence of lignum in environments prone to erratic droughts and floods appears to depend mainly on its capacity to tolerate drought, maintain vegetative growth and respond quickly to watering (Chong & Walker 2005). Lignum grows by developing new branches from its underground rootstock, by extending existing branches or be developing new shoots from viable branches (Roberts & Marston 2011). The rootstock is at least 2-3 m deep (Craig et al. 1991) and this contributes to the plant's resilience (Robers & Marston 2011). A study by Freestone et al. (2017) confirmed that lignum regenerates from dormancy, however this is variable, influenced by the length of dormancy, and may not always be successful.

Lignum has three means of vegetative spread: laterally by growth of rhizomes and stolons which root at nodes and disconnect from parent plant; layering (less common)—the capacity to grow roots from a leaning branch that makes contact with wet ground; and by dispersal of stem fragments (Roberts & Marston 2017 and references therein).

Regarding sexual reproduction, flowering may be seasonal but is generally a response to rainfall, with fruits maturing in autumn (Chong & Walker 2005). It is likely that lignum requires the right mix of season (spring for seed source), flood (to float the seeds), and moist soil at the water's edge (for the germinated seed to take root) (Jensen & Walker 2017). However, it appears that the seeds do not persist for long on the mother plant or in the soil, and importantly, there is no evidence that lignum maintains a soil seed bank (Chong & Walker, 2005). Rather, lignum has an aerial seed bank, with seeds falling from the plant and needing to germinate rapidly before they are harvested by ants and other insects. Seedlings are also prone to grazing (Jensen 2011b).

Severe declines during Millennium Drought

Historical survey maps show 'polygonum (lignum) flats' as occurring along the length of the Lower Murray (Jensen 2011b), but a 2002–03 survey indicated an estimated coverage of 14% in the region of the ecological community (Smith & Kenny 2005; Holland et al. 2009; Jensen et al. 2006). During the Millennium Drought, particularly the six years between 2004–10, there was almost no evidence of recruitment (vegetative or sexual) at sites in the Riverland region of the EC, from Morgan to Chowilla (Jensen et al. 2006; Jensen & Walker 2017). This region represents one of the most biodiverse and complex habitat mosaics within the ecological community and could be considered as a 'sentinel' for environmental change.

Post Millennium Drought and future trends

Lignum becomes stressed if flood frequency falls and the dry inter-flood period is extended, as in drought (Roberts & Marston 2011). Sustained growth of lignum into the future depends on moisture availability, particularly under climate change. Following the break of the Millennium Drought and the occurrence of multiple, minor flood peaks from late 2010 to early 2012, some regeneration of lignum occurred, with evidence of vegetative and sexual reproduction (Jensen & Walker 2017; A. Jensen pers. comm.). However, recovery remained patchy, often confined to low-lying hollows, and without the drought breaking floods, lignum would have been threatened as a regional scale (A. Jensen pers. com.).

In the years since the Millennium Drought, condition of lignum on the floodplain of the ecological community has been influenced mainly by targeted environmental water delivery (e.g. DEW 2023a, 2004b) until the unregulated flows of the extreme flood in 2022/23. For example, dry lignum basins at the Beldora and Spectacle Lakes Wetland Complex had not been

inundated since 2016, until receiving e-water in 2021 (DEW 2023a). This has led to recovery of lignum in some areas, although more recovery is needed across the extent of the *River Murray—Darling to Sea* EC to reverse historic and ongoing declines in lignum, and hence the integrity of the EC, as a whole. Overall, there have been severe declines in lignum and it is not likely to be possible to restore to normal the major functional role it plays in the ecological community in the immediate future.

Question

More recent data and analysis on trends will be available soon and will be incorporated when Murray-Darling Basin Plan reports are released, soon. In addition to that, can you please provide feedback on the preliminary river red gum, black box and lignum sections, particularly in relation to any more recent survey data, long-term trends for lignum and broader impacts, and on any results of recent environmental watering that have influenced lignum condition?

KEYSTONE WATER PLANTS OF THE COORONG – RUPPIA MEGACARPA AND RUPPIA TUBEROSA (AND 'RUPPIA COMMUNITY')

Large fruit seatassel (*Ruppia megacarpa*) and **Tuberous sea tassel** (*R. tuberosa*; surrogate for '*Ruppia/Althenia* complex' or 'Ruppia Community')

Key functional role: primary producers; provide habitat (including nursery) and food to a range of other biota, particularly invertebrates, fish, and waterbirds; remove excess nutrients and clarify water column; stabilise and reduce nutrient release from sediments; limit/prevent cyanobacterial and phytoplankton blooms

Key vulnerabilities: require specific salinity regime and water level; turbidity; desiccation; shading/smothering; specific reproduction requirements (i.e. temperature, water level, salinity); short-lived propagules (and seed banks); competition with planktonic and epiphytic algae; (see Table 17)

Key impacts on the species: extirpation of *R. megacarpa* prior to Millennium Drought; virtual disappearance of *Ruppia tuberosa* (i.e. 'Ruppia Community') during Millennium Drought; loss of seed bank; increased turbidity; increased microbial and algal blooms; changes in water biochemistry

Likely causes: decreased freshwater inflow; extended high salinity; more variable and unnaturally fast or out-of-season changes in salinity and water level; increasing sedimentation; drought; eutrophication; competition with phytoplankton and filamentous algae

Key impacts on EC: loss of habitat; loss of food supply; loss of nutrient recycling; loss of water quality and clarity; loss of biodiversity; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Critically endangered

Background

The mixed mesosaline to hypersaline macrophytes of the Coorong were and remain critical to maintaining this area as a productive estuary within the ecological community. These 'green carpets' stabilise the soft sediments, feed fish and vast numbers of waterfowl, provide habitat & shelter (e.g. for small fish & invertebrates) as well as a substrate for algal growth and fish egg deposition. More than 13 species of macroalgae and aquatic grasses have been documented within this macrophyte assemblage (past and present), which forms an interdependent gradient across the wetland (Nicol 2005; Nicol et al. 2018; Coleman in press; Appendix B, Table B1). It was described in the original listing for the Lakes and Coorong Ramsar site as the 'Hypersaline Lagoon Community' (DEW 1987).

Taxonomic uncertainty revealed

In post-regulation history, the two dominant aquatic macrophytes in the Coorong were considered as *Ruppia megacarpa* (large-fruit sea tassel) and *R. tuberosa* (tuberous sea tassel or widgeon grass) (Nicol 2005). Geddes (1987) reports that in 1983, *R. megacarpa* and *Althenia cylindrica* (syn. *Lepilaena*) beds were vigorous and extensive, occurring along the length of the North Lagoon, in addition to *Zostera muelleri* (seagrass) beds towards the ocean. Geddes (1887) also reported that *R. tuberosa* was dominant and extensive in the South Lagoon in 1984, with *Lamprothamnium* (likely *L. papulosum*, foxtail stonewort or muskgrass, DEW 1987; Paton et al. 2015) sometimes common.

R. tuberosa is essentially an annual plant that exploits the ephemeral mudflats around the shores of the southern Coorong (South Lagoon and southern North Lagoon). These ephemeral areas are typically covered with water from late autumn through spring and into summer but are often dry from late summer through autumn; annual water level changes are typically around 1 m (Paton et al. 2015). During the dry period of lowest water levels, *R. tuberosa* remains on or in the mud surface as seeds and turions.

However, it was recognised relatively recently that *R. tuberosa* and *Althenia* are indistinguishable unless flowering (Asanopoulos & Waycott 2020), and additionally, an unresolved *Ruppia* sp. in the South Lagoon has been identification by eDNA (Lewis et al. 2022). Indeed, the three main submerged macrophyte genera, *Ruppia*, *Althenia* and *Lamprothamnium*, are currently under taxonomic review, with likely 2–4 species present for each (F. Coleman pers. comm.). Lewis et al. (2022) proposed that, going forward, the assemblage of aquatic macrophytes in the South Lagoon be referred to as the 'Ruppia Community', as *R. tuberosa* is dominant. Providing certainty on the taxonomic identity of macrophytes in the Coroong will allow for a baseline distribution to augment long-term monitoring going forward (e.g. Asanopoulos & Waycott 2022).

Keystone surrogates

Notwithstanding the more recent taxonomic uncertainties, it remains clear that *Ruppia* species are key functional species in the Coorong. As such, they provide useful surrogates for this criterion assessment, and in particular, *R. tuberosa* as a surrogate for the newly termed 'Ruppia Community'. In addition to trapping and stabilising the soft sediments and helping to maintain water quality and clarity, these species historically fulfilled two key ecological roles (Geddes & Butler 1984; Nicol 2005; Phillips & Muller 2006; Rogers and Paton 2009a; Paton 2010; Whipp 2010; Asanopoulos & Waycott 2020; Lewis & Lewis 2022):

- *Primary producers* - as the main primary producers in the saline/hypersaline environment of the Coorong they serve a critical role in the food chain for invertebrates, fish, and local and

migratory water birds and waders (Nicol, 2005; Rogers & Paton, 2009a,b; Paton et al. 2018). Leaves, seeds, shoots, and the starchy tubers (turions) are eaten by waterfowl (Congdon and McComb, 1981; Nicol, 2005). *Ruppia* species were also a major source of detritus for the detrital-based food chain in the Coorong and contribute to carbon and nutrient cycling (Phillips & Muller, 2006; Waycott & Lewis 2022; Coleman in press); and

- *Habitat engineers - Ruppia* species (along with other macrophytes and algae) provide habitat, including shelter (from predation, wind, currents, etc.) and a nursery (e.g. for egg laying), for a range of small fish and invertebrates. For example, small fish such as *Atherinosoma microstoma* (small mouth hardyhead) may be dependent on *R. tuberosa* (i.e. Ruppia Community) as a substratum for their eggs in an otherwise high-energy, soft-sediment environment. In addition, these *Ruppia* species clarify and cool the water column, shade and bind the dark sediments, and reduce inorganic and planktonic turbidity (Coleman in press). Importantly, they serve to limit or prevent cyanobacterial and phytoplankton blooms (Coleman in press).

Functional extirpation and decline

Table 28 provides a summary of the comparative ecology and contemporary historical decline of the two main *Ruppia* species. *R. megacarpa* beds disappeared completely sometime between 1995 and 2003 or earlier (Geddes 2005b; Nicol 2005; Rogers and Paton 2009a; Paton 2010; Whipp 2010; Lewis et al. 2022) and *R. tuberosa* (i.e. 'Ruppia Community') declined through the 1990s and virtually disappeared from the South Lagoon of the Coorong between 1999 and 2009, primarily due to the Millennium Drought (Paton 2010).

Extreme summer salinities of >150 g/L occurred in the South Lagoon from 2007 until the drought broke in 2010 (Waycott & Lewis 2022). In studying the effects of salinity on germination, Kim et al. (2013) found that increased salinity led to a decrease in germination rates for *R. tuberosa* and *R. megacarpa*; the salinity thresholds for germination were 85–90 g/L for *R. tuberosa* seeds, 120 g/L for *R. tuberosa* turions and 30 g/L for *R. megacarpa* seeds. These authors also found that higher salinity increased mean time of seed germination 10 (Rm)–15 (Rt) days.

Surveys soon after the Millennium Drought, confirmed that, despite a tenuous return of some *R. tuberosa* ('Ruppia Community') in the southern North Lagoon, there was no viable propagule bank (seeds/turions) for either species found in the North or South Lagoons (Paton and Bailey 2012a). *R. megacarpa* was effectively 'extirpated' from the North Lagoon, and *Ruppia* (i.e. 'Ruppia Community') had ostensibly dwindled to highly isolated remnants and the seed bank was largely exhausted (Lewis et al. 2022).

Ruppia post-Millennium Drought

Ruppia tuberosa (i.e. 'Ruppia Community') has increased in the South Lagoon over the past decade or so, but recovery has been slow and patchy, despite several 'wet' years (e.g. Frahn et al. 2012; Waycott et al. 2022). There has been no recovery of *R. megacarpa* in the Coorong, although it has been observed to be growing outside of the Coorong (e.g. adjacent channel to Salt Creek fishway) (Nicol et al. 2018; Lewis et al. 2022). Of concern, is that conditions in the Coorong have continued to deteriorate since the drought (Aldridge et al. 2018; Brooks et al. 2018; Waycott & Lewis 2022). There are currently signs of severe ecological stress, as indicated by changes in biological communities, including reduced numbers or absence of fish, invertebrates and birds, through hyper-salinity, in addition to high turbidity and eutrophication (Asanopoulos & Waycott 2020 and references therein).

Table 28: Comparative ecology and distribution of *Ruppia megacarpa* and *Ruppia tuberosa* (i.e. as a surrogate for the 'Ruppia Community') in the Coorong component of the *River Murray - Darling to Sea* EC (Sources: Geddes & Brock 1977 in Nicol 2005; Congdon & McComb 1981; Geddes 1987, 2003, 2005a,b; Geddes & Butler 1984; Geddes & Hall 1990; Paton 2002 in Nicol et al. 2018; Gehrig & Nicol 2010; Jacobs & Brock 1982 in Nicol 2005; Nicol 2005, 2007a, b; Phillips & Muller 2006; Rogers & Paton 2009a; Paton 2010; Whipp 2010; Frahn et al. 2012; Paton & Bailey 2012a; Nicol et al. 2018; Asanopoulos & Waycott 2020; Lewis et al. 2022; Waycott et al. 2022).

Aspect	Ruppia megacarpa	*Ruppia tuberosa* (surrogate for 'Ruppia Community')
Plant type	• rhizomatous submergent aquatic macrophyte of brackish to hypersaline, permanently submerged habitats.	• rhizomatous submergent aquatic macrophyte in hypersaline wetlands at 0.3-0.9 m depth
Historical distribution	• historically (post 1920 regulation) dominant in **North Lagoon**	• historically (post regulation) dominant along length of **South Lagoon** (with some, tenuous expansion into the higher salinity end of North Lagoon)
Life-cycle	• long-lived perennial	• short-lived annual (dies after exposure)
Reproduction	• seed bearing (no turions) • freshwater pulses (from floods) may trigger flowering and germination • seeds may be dispersed by birds	• asexual annual • reproduces by seeds or turions when conditions are favourable (seeds may germinate over 2 y) • seeds (may be dispersed by birds) last ≤ 3 y; turions last ≤ 3 - 6 months
Regeneration	• does not flower, set seed or germinate at salinity levels close to maximum tolerance (max. • germination typically occurs below seawater salinity (i.e. 35 g/ L) • if adults killed by long-term high salinity, seeds may not be produced or germinate if salinity remains high	• needs to reproduce every few years or dispersal of seed/turion (e.g. via birds) • salinity > 80–100 g/L may restrict germination & regeneration • foraging waterbirds may play role in turning over sediment and leaving propagules at favourable depths for germination
Decline	• abundant in North Lagoon prior to mid-1980s (with profuse flowering noted in 1983 but not 1984) • between 1995 (when presence noted) & 2002, the extensive beds in the North Lagoon disappeared (survey in 2002/2003 found none in Murray Mouth or North Lagoon) • 2006–2007 disappearance confirmed, and no seed bank found in 2007	• abundant in 1984 and 1997 surveys • 1999–2009 disappeared over most of range (a few found in southern quarter of North Lagoon) • concomitant increase in salinity since ≤2007 but decline in water levels in spring (i.e. to late 2010) is likely the more critical factor in loss • 2012 survey found lack of viable propagule bank
Current Status	• effectively extirpated in North Lagoon	• seed bank <30% historical levels=low resilience

The South Lagoon and the southern end of the North Lagoon of the Coorong have become increasingly hypereutrophic and have poor sediment quality (i.e. monosulfidic ooze) (Fitzpatrick et al. 2018; Asanopoulos & Waycott 2020; Waycott & Lewis 2022; Figure 6). Fitzpatrick et al. (2018) warn there remains an extensive and considerable acid sulfate soil hazard in the entire CLLMM region. Significantly, the Coorong's South Lagoon has essentially switched to a system dominated by phytoplankton and filamentous algae, rather than by macrophytes, as was previously the case (Mosley & Hipsey 2019; Paton et al. 2021; Lewis et al. 2022; Figure 6). When water levels recede, the algae form a dense mat that excludes foraging shorebirds, and creates low-oxygen conditions in sediments, killing invertebrates and raising the risk of the build-up of sulfidic material (Brookes et al. 2018). This 'switch' has flow-on effects for the estuarine component of the ecological community.

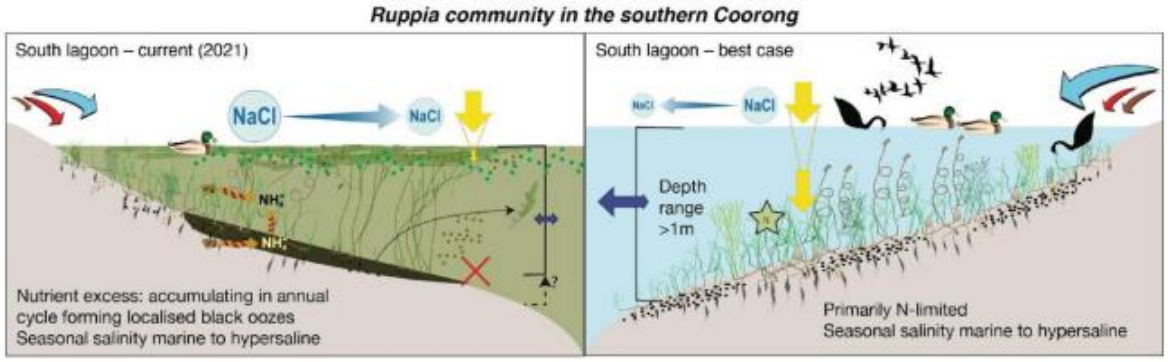

Figure 6: The biota of the southern Coorong has become dominated by fast growing primary producers, including phytoplankton and filamentous algae, that are able to rapidly utilise the hypereutrophic conditions more efficiently than the 'Ruppia Community' (Waycott & Lewis 2022).

Growth limitations

The growth of *R. tuberosa/Althenia* in the South Lagoon (southern Coorong) is limited by the combined and interacting effects of temperature, water level, salinity, nutrients loads (water and sediment) and their flow on effects to the system, in addition to external modifiers such as filamentous algae formation and grazing (Nicol 2005; Waycott et al. 2022; Figure 7). Excessive filamentous algal growth in the Coorong, starting in late spring and continuing over summer, overlaps with the reproductive cycle of *Ruppia/Althenia* and negatively impacts growth and seed production (Asanopoulos & Waycott 2020; Waycott & Lewis 2022). This has a significant effect on the annual recovery cycle, and more importantly, the formation of a resilient *R. tuberosa*/ 'Ruppia Community' in the long term.

Recovery and status

To kick start recovery of the 'Ruppia Community' after the Millennium Drought, from 2012-2014 seed-based translocations were undertaken at five sites (across different depths) in the South Lagoon; the donor site was Lake Cantara (i.e. within the EC) (Waycott & Lewis 2022). An area of 59 ha was treated with more than 700 tonnes of sediment, containing an estimated 400 million seeds (Waycott & Lewis 2022). Eight years later (2021), there was a significant improvement in biomass, seed bank and the number of turions produced at translocation sites, however the donor sites exhibited incomplete recovery with respect to the seed bank (Waycott & Lewis

2022). While there were positive benefits at the South Lagoon sites from these translocations, it remains uncertain if these actions had an impact more widely (Waycott & Lewis 2022).

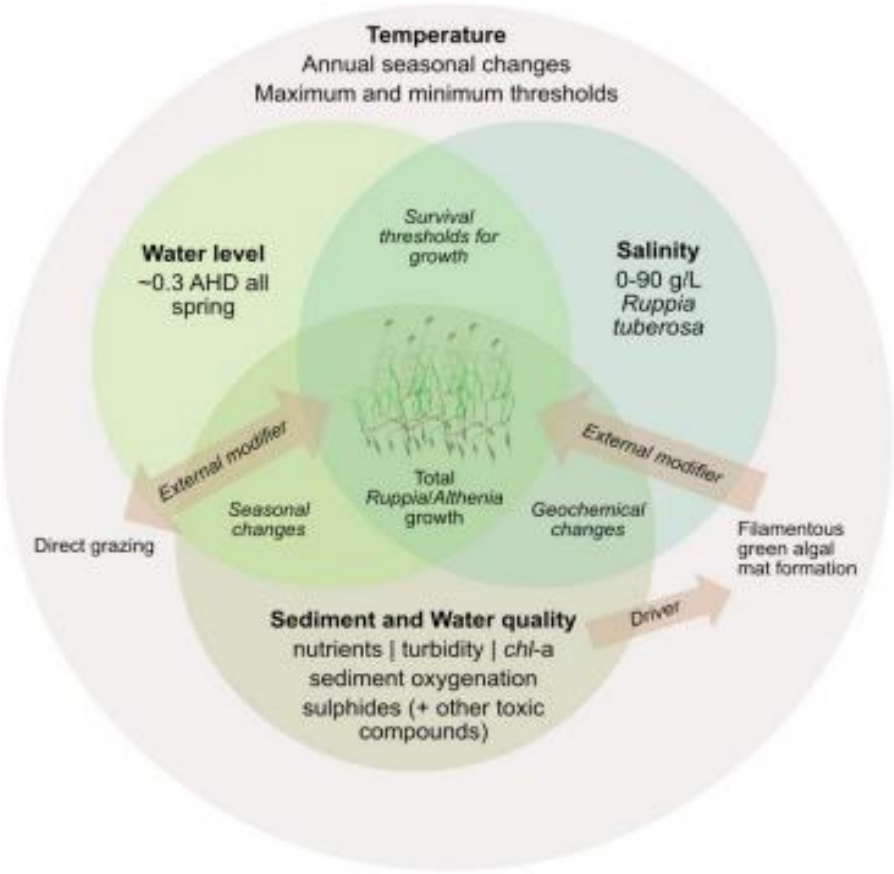

Figure 7: Growth of *Ruppia tuberosa/Althenia* complex (i.e. Ruppia Community) in the Coorong South Lagoon is limited by the combined and interacting effects of a number of variables (Asanopoulos & Waycott 2022).

The previously robust mixed submerged angiosperm community (e.g., *R. tuberosa*/*Althenia* complex, or 'Ruppia Community') in the Coorong was assessed as being in a highly vulnerable state by an expert panel review (Asanopoulos & Waycott 2020). While the 'Ruppia Community' has expanded in extent (if not density) along the South Lagoon, comparison of the seed bank with historical monitoring data, reveals the seed bank is at ~30% of pre-drought levels (Lewis et al. 2022). Lewis et al. (2022) report ongoing concern that *Ruppia* plants have poor vigour, low seed production and therefore limited resilience. Waycott & Lewis (2022) also report that the resilience of the 'Ruppia Community' in the Coorong remains low and developed a 'Recovery Strategy' (decision framework).

Asanopoulos & Waycott (2022) warn that with any attempt to recover the Coorong system (i.e. the main estuarine component of the ecological community), must involve management solutions that support the critical life cycle stages of *R. tuberosa.* This is likely to include management of salinity and water levels, and options for reducing nutrients and filamentous algae loads. Waycott & Lewis (2022) state the need to remediate salt and nutrient loads is critical to considering further direct action in restoring biota, including improving the resilience of the 'Ruppia Community' in the southern Coorong. Additionally, several important knowledge gaps remain that would support conservation management (Asanopoulos & Waycott 2022;

Waycott et al. 2022). For example, the expected optimum annual mean water surface elevation for the growing season (April–December) is currently estimated at 0.3 m AHD, however this requires updating based on the current physical structure of the system.

2022-23 Flood event and status

The major flood event from mid-October 2022 to early-February 2023 was the third highest on record for the River Murray in South Australia, with peak flow of 186,000 ML/d recorded on 23 December 2022 at the SA border; this translated to a peak flow at the barrages where all gates were open (DEW 2023a, b). As a result of higher water levels and lowered salinity, the 'Ruppia Community' increased in biomass in the central and southern Coorong (Waycott et al. 2023).

Despite *R. tuberosa* producing large numbers of turions (asexual reproduction), sexual reproduction seemingly failed, with a lack of viable seeds production for *Ruppia* spp. This meant the seed bank continued to remain depauperate, which is a concern as the seed bank is an important mechanism for population persistence through unfavourable conditions (Waycott et al. 2023). Waycott et al (2023) further caution that the inability of the 'Ruppia Community' to capitalise on what appears to have been the best growing season (possibly for decades), with extended inundation providing ample time for completion of flowering and seed set under low salinity stress, raises further concerns about the ability for future recovery after adverse conditions.

Therefore, there have been severe declines in *Ruppia* (and the 'Ruppia Community') and it is not likely to be possible to restore the loss of the major role that it plays in the ecological community in the immediate future.

Question/Request

Can you provide further information on Ruppia and macrophytes in the Coorong, particularly relating to any most-recent monitoring data and taxonomic clarifications, or alleviation of threats?

KEYSTONE APEX PREDATOR OF THE RIVER CHANNEL - MURRAY COD

***Murray cod** (Maccullochella peelii)* (Nock et al. 2010, syn. *M. peelii peelii*)

Key functional role: apex predator; foodweb dynamics

Key vulnerabilities: large and long lived; low fecundity; migrates to spawn; spawning is temperature triggered; larvae have low salinity tolerance; increased flow aids recruitment; occupies a home range; (see Table 17).

Key impacts on species: long-term recruitment failure; fragmented population structure; decline in abundance and range

Likely causes: decreased flow volume and frequency of moderate flows; loss of lotic habitats; instream barriers; increasing sedimentation; dietary competition from alien carp larvae; predation on larvae by alien carp; potential loss of egg mats to pathogen

Key impacts on EC: trophic cascades in food web; opening up recourses to non-native species; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Critically endangered

Apex predator

Murray cod, *Maccullochella peelii* is the apex (top trophic level) aquatic predator of the ecological community, and in the entire Murray-Darling Basin (Kearney & Kildea 2001; Ebner 2006). It is a keystone species, significant for its effects on food-web structure and prey populations, as predators initiate 'top-down' forces and trophic cascades (Rowland 1989, 2005; Estes et al. 2001; Ebner 2006). A trophic cascade occurs when a predator suppresses the abundance of its prey, releasing the next lower trophic level from predation. The loss of apex predators in aquatic

systems can result in the proliferation of smaller predators/omnivores that may reduce or eliminate other smaller species and lead to a dysfunctional ecosystem (Estes et al. 2001). Apex predators are more vulnerable to local extinctions than are lower trophic-level species, thus conservation strategies should be implemented to preserve the apex predator (Estes et al. 2001). Kearney & Kildea (2001) suggest the Murray cod could be the single best aquatic indicator species of ecosystem integrity for the Murray-Darling Basin. Its complex life history and the different requirements of eggs, larvae, juveniles, and adults, necessitate integration of heterogenous habitat availability and condition, and water quantity and quality.

Historical decline and fishing

Throughout the Murray-Darling Basin, and the ecological community in particular, the distribution and abundance of Murray cod has declined since European settlement. This is attributed to flow regulation, habitat loss (including instream woody debris) and degradation (including sedimentation), barriers to fish passage, cold-water releases, lowered water quality, alien species (including stocked), and commercial and recreational fishing (Allen et al. 2005; MDBC 2005; NMCRT 2010; Rowland, 2005; Zampatti et al. 2011a). Within the ecological community, fragmentation of the river by sequential weirs, alteration to hydraulics and loss of lotic habitats are considered primary threats to the persistence of Murray cod populations (Zampatti et al. 2014; Mallen-Cooper & Zampatti 2018, 2020). In 2003, Murray cod was listed as a vulnerable under the EPBC Act; a recovery plan was released in 2010 (NMCRT 2010)

Table 29: History of Murray Cod in the Lower River Murray which equates to most of the region of the RMDS EC and the entire reach of the South Australian component of the MDB.

Date	History of Murray Cod in Lower River Murray (mainly)	References
1829-1830	• abundant native fish recorded, with Murray cod, silver perch and catfish the most common large-bodied fish • Murray cod originally very abundant throughout their range, including Lower Murray and Lake Alexandrina in 1800s	Sturt 1833; Rowland 1989, 2005; Sim & Muller 2004; Blandowski 1856 in Humphries 2009
1841-1844	• abundant large Murray cod and abundant large Murray crayfish; very high-water clarity and abundant submergent macrophytes; Indigenous spear fishing reported (including at night by fire light)	Edward Eyre 1845
1856-1857	• Wilhelm Blandowski expedition provided best early records of native fish in Lower Murray-Darling, Murray cod present (Table F7)	Humphries 2009
1902	• heaviest fish recorded, 113.6 kg (from Barwon River, upstream of ecological community; estimated at 76–114 years old)	Rowland 1989, 2004
1903	• Samuel McIntosh, Chief Assistant, Director of SA Fisheries, reported (since 1891) profound depletion by 1900 of fish (Murray cod, golden perch, silver perch) in SA Murray - none caught above Overland Cnr.	NSW Fisheries Department 1903
1922 -1935	• regulation: Lock 1 to Lock 10 built (but not in sequence) • 102 kg fish taken from EC (*Adelaide Advertiser*, 13/12/1935, p. 30)	Sim and Muller 2004
1934 -1940	• regulation: Five barrages at Murray Mouth built	Sim and Muller 2004
1938	• call for protection of Murray cod using stricter fishing regulations and proper enforcement of those regulations	Dakin & Kesteven 1938
1949-1950	• first serious ecological study (but mainly Victorian/NSW reaches) • Murray cod appear not to breed in weir pools • invasions of exotic fish noted upstream of EC, including tench, gambusia, common carp (not Boolarra strain) and redfin perch • Lindsay/Mullaroo Ck anabranch only place Murray cod abundant • notes Murray crayfish abundant and silver perch common	J O Langtry 1949-1950 in Cadwallader 1977
1958-1959	• SA commercial fishery catch about 140 tonnes	Gillanders & Ye 2011
1974	• major flood event and dramatic invasion of common carp (*Cyprinus carpio*) Boolarra strain	Koehn et al. 2000
1975-1976	• strong decline in SA commercial catch to 2 tonnes	Gillanders & Ye 2011
mid to late 1970s	• decline of small-bodied and large-bodied native fish (e.g. Murray cod, freshwater catfish, silver perch)	Hammer et al. 2009; Bice et al. 2011
1980s	• commercial catches mostly below 10 tonnes	Gillanders & Ye 2011
late 1980s-early 1990s	• strong relationship between flow and recruitment evident; last known major recruitment of Murray cod (since then only low-level recruitment recorded, with most in Chowilla Creek and Lindsay River/Mullaroo Creek anabranches)	Meredith et al. 2002; Zampatti et al. 2006a; Ye & Zampatti 2007
1990-1993	• fishing moratorium for Murray cod in SA	Gillanders and Ye 2011
1994	• January - commercial fishery re-opened in SA	Gillanders and Ye 2011
2000	• first fishery assessment report in SA (+ reviewed biol. & ecology)	Ye et al. 2000.
2001-2002	• commercial catch peaks at 28.5 tonnes after re-opening	Ye & Zampatti 2007
2002-2003	• commercial catch drops to 7 tonnes	Ye & Zampatti 2007
July 2003	• commercial fishing for Murray cod ceased in SA	Ye & Zampatti 2007
2003	• small fishery independent Native Fish Monitoring Program started	Ye & Zampatti 2007
2005-2006	• NFMP shows population mainly large adult fish	Ye & Zampatti 2007
2009-2010	• Moratorium on recreational fishing for Murray cod in SA	Gillanders & Ye 2011
2010-2011	• minor overbank floods provided connectivity along River Murray and returned hydraulic complexity to the weir pools but little recruitment	Gillanders & Ye 2011; C. Bice 2012 pers. comm.
2011-	• recreational 'catch and release' allowed, except Chowilla closed area • significant mortality due to blackwater event	Ye et al. 2019 (Stock Rep)
2016-2018	• 300,000 MC fingerlings stocked in SA Murray, for first time	Ye et al. 2021 (Stock Rep)
2020	• 'depleted' under the national stock status framework	Ye et al. 2021 (Stock Rep)

Table 29 provides a summary of the history and status of Murray cod within the region of the ecological community. In the early 1800s, the fish were extremely abundant, including in Lake Alexandrina (Table 29). Fishing pressure, commercial and recreational, from the late 1800s and throughout the last century led to severe reductions in range and abundance (Table 29). There was a significant decline in annual commercial landings from 140 t in the late-1950s, to less than 10 t in the 1970s–80s (Ye et al. 2000; Ye & Zampatti 2007). Long-lived species with long generation periods, low natural mortality rates and slow growth, such as the Murray cod, are very susceptible to over-fishing (Reynolds et al. 2002; Allen et al. 2005; Rowland 2005).

Commercial fishing for Murray cod in South Australia ceased in July 2003 (Ye & Zampatti 2007; Table 29). However, Murray cod remains a popular recreational fish species and since 2011, 'catch-and- release' fishing is permitted (except for the closed area in Chowilla). Recreational fishing surveys in South Australia reported ~2.1 t (507 fish) of Murray cod was harvested from the lower River Murray in 2007-08 (Jones 2009), with none captured in 2013-14 (Giri & Hall 2015).

The loss of many of the billabongs and swamps that once bordered the lower Murray, through both reclamation and river regulation, impacted Murray cod from the 1930s onward. While research indicates Murray cod are channel spawners, these billabong and swamp habitats were valuable nursery areas for juvenile Murray cod (and other native fish) and also added significantly to the general productivity of the river system. The impacts of the disconnection and loss of these billabongs and swamps was recognised historically by local observers (e.g. Mt Barker Courier 1949). Impacts from building the sequential weirs along the river was also observed to have serious negative impacts on Murray cod (e.g. Daily News 1932).

Invasions by carp and pathogens—known and potential impacts

These drivers of decline continued to reduce Murray cod populations, with commercial catch dropping to only two tonnes by the mid-1970s (Ye et al. 2000; Table 29). This was followed by the dramatic invasion of alien carp (Boolarra strain) (*Cyprinus carpio*) into the Lower Murray, facilitated by large floods in 1974–75 (Koehn et al. 2000; Roland 2005). Alien carp added to existing drivers of decline and continued to impede Murray cod recruitment and recovery. Direct impacts include carp larvae competing with Murray cod larvae for zooplankton food (Tonkin et al. 2006; Kaminskas & Humphries 2009) and some degree of predation by larger carp on Murray cod larvae and juveniles. Indirect impacts include: diverting riverine, billabong, and wetland productivity into carp biomass; damaging and destroying aquatic habitats, particularly submergent macrophytes; and causing permanent deterioration in water quality, including dramatically increasing turbidity (Koehn 2004; Vilizzi et al. 2014, Kopf et al. 2019, Stuart et al. 2021, Fanson et al. 2024, Schilling et al. 2024).

Carp, and other alien fish species, can also introduce and/or spread alien fish pathogens and parasites to native fish, including Murray cod. The alien fish oomycete pathogen *Saprolegnia parasitica*, a co-invader spread historically with alien trout stockings, invaded the River Murray somewhere between the 1930s and 1940s, which has led to regular fish kills of bony herring (Puckridge et al. 1988; Kaminskas 2021). This pathogen is also known to infect Murray cod that have experienced rough angler handling or environmental stress, and frequently infects egg mats of Murray cod (Rowland & Ingram 1991; Kaminskas 2021). The number of Murray cod individuals and Murray cod egg mats lost to *Saprolegnia* infection in the wild, including within the ecological community, is unknown but may be significant.

Similarly, the alien 'anchor worm' ectoparasite, *Lernaea cyprinacea,* is actively vectored by carp and parasitises diverse native fish species; it infests Murray cod particularly heavily (Rowland & Ingram 1991; Harris & Gehrke 1999; Kaminskas 2021). Heavy infestations cause severe physiological distress, emaciation and spawning failure in Murray cod. The number of juvenile and adult Murray cod killed by *Lernaea* infestation in the wild is unknown but may be significant. Equally concerning, is that the early life stages of *Lernaea* parasitise the gills of fish damaging the gill lamellae (delicate oxygen-extracting capillaries) and impairing respiration, which can sometimes be fatal (Grabda 1963, Khalifa & Post 1976; Goodwin 1999). Murray cod are recorded as having the least tolerance to hypoxia out of all the large native fish species of Murray-Darling Basin (Small et al. 2014). Therefore, a heavy load of *Lernaea* in the gills may be a determining factor in Murray cod (juveniles and adults) surviving warm, oxygen-depleted conditions. Such conditions are only increasing under climate change (Steffen *et al.* 2018; BoM & CSIRO 2022).

Spawning and critical habitat

Spawning of Murray cod occurs in spring-early summer, irrespective of flow (Roland 1998), however recruitment, particularly in the main channel of the ecological community, is more successful with increased flow and flowing water habitat (e.g. > 20,000 ML/d, Bice et al. 2017). A 2005–2009 survey found that the fast-flowing aquatic mesohabitats of the Chowilla anabranch system have significantly higher relative abundances of Murray cod than other available habitats within the ecological community and may increase survival and recruitment to the adult population (Zampatti et al. 2008, 2011a, b; Leigh and Zampatti 2011, 2012). The Chowilla region is the most structurally complex within the ecological community, characterised by abundant instream woody habitat (IWH) and aquatic macrophytes in a range of slow- and fast-flowing anabranches and wetlands.

Spatial and temporal scales of elevated flows may influence recruitment of Murray cod within the ecological community. 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 & 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).

In addition to supporting spawning and recruitment, such areas also enhance foraging opportunities and provide refuge. Chowilla provides a drought refuge, conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance (Pierce 1990 in Zampatti et al. 2011a; Zampatti et al. 2011a; Leigh & Zampatti 2012). As such, it is considered 'critical habitat' within the ecological community, as it would likely confer these attributes on other fauna.

Escalating blackwater events

Following the drought-breaking floods of 2010–2011, the ecological community was impacted by a hypoxic 'blackwater' event (e.g. ABC 2011). A study tracking movements of Murray cod at that time recorded significant mortality of larger individuals, suggesting a substantial impact on Murray cod populations in the region (Leigh & Zampatti 2013). Blackwater events are emerging as a recurrent and serious threat to Murray cod populations in the River Murray and other lowland rivers. Catastrophic blackwater fish-kills of Murray cod and other native species

occurred in large sections of the River Murray in 2010–2012 (e.g. King et al. 2012), in 2016-17 (Ye et al. 2018), and again in 2020–22 (e.g. ABC 2022). These large-scale, often catastrophic, blackwater events result from heavy organic loads from floodplains that are flushed infrequently.

Historically, prior to the contemporary combined impacts of river regulation, water extraction, and reduced rainfall and run-off, floodplains were flushed regularly (often annually) resulting in smaller organic loads to waterways when high flows occurred (Maheshwari et al. 1995, Steffen et al. 2018, CSIRO and BoM 2022).

Trends

Since the late 1980s, there appears to have been low levels of recruitment or recruitment failure for Murray cod within the ecological community (Pierce 1990 in Zampatti et al. 2011a). Ye et al. (2000) also found that the fishery from 1994–2003 was mainly dependent on a few strong year classes, with a relatively low number of recruits. Ye and Zampatti (2007) found that larger individuals dominated the population and warned of a high risk of stock collapse unless further age classes could be added. A survey undertaken from 2002–10 (i.e. during the Millennium Drought when flows were < 10,000 ML/d) in the region from Lock 9 to Lock 6 found substantial declines in abundance, with little evidence of YOY (i.e. fish less than one year old) recruitment to the population, as well as age class fragmentation (Wallace 2010; Zampatti et al. 2014). This latter survey also found that the size-class distribution of common carp throughout the period indicated a strong and robust presence in this region.

Long-term monitoring of the South Australian River Murray (based on electrofishing catch-per-unit-effort (CPUE) and drum netting) during 2002–2013 found that relative abundance of Murray cod was low, fish in main channel habitats were predominantly large (> 800 mm total length (TL)), and a broad range of age classes (8–46 years) were present (Zampatti et al. 2014). Recruitment was minimal in the still waters of the main channel during this period which overlapped with the Millennium Drought, with some occurring in the flowing water habitats of the Chowilla anabranch system (Zampatti et el. 2014). Despite this, some juvenile fish (< 500 mm TL) were collected in the main channel habitats in years following increases in river flow (e.g. 2010–12) (Zampatti et al. 2014).

Long-term monitoring (electrofishing and CPUE) during 2014–20 detected some annual recruitment in the main channel in most years, with cohorts persisting in subsequent years, and overall, there was a slight increase in abundance (Ye et al. 2021, 2022). Long-term monitoring in the Chowilla Anabranch found recruitment to have continually improved over2014–2020 (Fredberg et al. 2022); this further supports its value as a critical habitat within the ecological community.

Results of monitoring in 2020-21 revealed a diverse length-frequency of Murray cod, which Ye et al. (2022) suggest reflected a healthier and more resilient population age structure. Improvement in population age structure of Murray cod in the SA River Murray is 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). However, monitoring undertaken in 2021–22 also found that Murray cod recruitment in the was relatively low, despite good flows of 20,000–45,000 ML/d (Ye et al. 2023). Of note, however, was the persistence of 2+ year olds (48% of the sampled population in 2022) born in 2019–20 during environmental water delivery which is expected to contribute to population resilience (Ye et al. 2022, 2023).

Status

The above evidence suggests that while there may be a fairly stable adult population of Murray cod in the South Australian River Murray at present, possibly including a more robust age structure, overall abundance remains low and recruitment is only periodically successful (Ye et al. 2021, 2022, 2023; DEW 2023a). Importantly, the mechanisms that influence recruitment success are still not fully understood and require further investigation (Ye et al. 2023). Significantly, there remains no evidence of any substantial increase in abundance of this species towards historical levels, which supports that the biomass of the stock (i.e. SA population) remains 'depleted' (Ye et al. 2021).

While the threat of fishing mortality has been reduced via fishery regulations, recovery of the Murray cod population within the ecological community requires intervention in terms of river flow management and environmental water delivery, combined with habitat rehabilitation/ enhancement and, if possible, removal of alien competitors. The transformation of much of the lower Murray into a series of relatively stable weir-pools (i.e. Lick 1–10) remains problematic, acutely effecting native fish including Murray cod (Walker 1985, 2001; Walker & Thoms 1993; Mallen-Cooper & Stuart 2018). Ensuring hydrological conditions that support and improve population condition, increase available spawning habitat, and enhance recruitment, remains vital (e.g. Ye et al. 2022; DEW 2023a).

In addition to increasing flows above 20,000 ML/d (Zampatti et al. 2014), supportive hydrological conditions were identified by Stuart et al. (2019) as:

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.

Without adequate flows, and the opportunity to rebuild the population in the EC, there remains tenuous insurance for Murray cod within the EC against the next prolonged drought or severe blackwater event. Therefore, there have been very severe declines in Murray cod and it is not likely to be possible to restore the loss of the major role that this functionally important species plays in the ecological community in the immediate future.

KEYSTONE DEMERSAL PREDATOR - FRESHWATER CATFISH

Freshwater catfish (*Tandanus tandanus*)

Key functional role: benthic predator (potentially displaced by carp); foodweb dynamics/trophic cascades

Key vulnerabilities: large and relatively long lived; breeding behaviour and spawning in shallow water nests; strong association with submerged vegetation/nests; limited range; competition with carp (see Table 17)

Key impact on species: decline in abundance and range; long-term recruitment failure; loss of macrophyes and woody debris

Likely causes: overfishing; potential competitive exclusion by common carp; decreased flow volume and frequency of moderate flows; barriers to movement (loss of floodplain-river connectivity); increasing sedimentation and turbidity; loss of habitat (including wetland draining)

Key impacts on EC: loss of positive benthic habitat modifier; foodweb impacts/trophic cascades; opening niche for non-native alien species that degrade the natural habitat; loss of vegetation; loss of biodiversity; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Endangered

Bottom-dwelling habitat specialist

Freshwater (eel-tailed) catfish (*Tandanus tandanus*) is a functionally important demersal (bottom dwelling) predatory, medium-bodied fish within the ecological community (i.e. as opposed to Murray cod which is more of a pelagic (water-column) species). This species has a key functional role in the aquatic foodweb and in associated transfers of energy and nutrients, and in the control of benthic prey populations (i.e. macroinvertebrates) (Clunie & Koehn 2001; Ye et al. 2015).

Freshwater catfish prefer slow flowing habitat with complex physical structure. Radiotracking found that mesohabitats containing woody debris and macrophytes were most strongly selected by freshwater catfish, while open water was avoided (Kostner et al. 2015)—suggesting that habitat complexity is vital for protection. This study also confirmed a preference for shallow water (< 1 m) near margins, and a limited range for this species (i.e. mostly sedentary behaviour) with greatest movement at night (mainly by females) (Kostner et al. 2015). Although rarer, there was also some evidence of longer movements, including between floodplain and riverine habitats (Kostner et al. 2015).

Historically, freshwater catfish in the ecological community occurred in the main channel, billabongs, wetlands, Lower Lakes, and the lower reaches of tributary streams in the Eastern Mount Lofty Ranges (Reynolds 1976 in Clunie & Koehn 2001; Hammer et al. 2009). More recent records suggest a patchy distribution of freshwater catfish, limited to a handful of locations in main channel and anabranch habitats and in wetlands (Hammer et al. 2009; Wedderburn & Suitor 2012; Ye et al. 2015). For example, in the Chowilla anabranch system, during the drought (2005-2010) they were found in fast flowing or main channel mesohabitats, however after the floods (2011-2013) they were also found in backwater and slow-flowing mesohabitats (Wilson et al. 2014). This result may also reflect loss of littoral vegetated habitat during the drought.

Breeding specialist

Freshwater catfish is a non-migratory species that builds nests and lays demersal eggs (Reynolds 1983; Merrick & Midgley 1981; Kostner et al. 2015). In one study, nest depth was found to range from 0.2-1.35 m (Burndred et al. 2017). Spawning occurs in spring–summer, with an elaborate courtship display; males guard the nest once eggs are laid until the larvae leave (Merrick & Midgley 1981). Larvae are likely to actively disperse from their nest at around 16 days of age, as they approach juvenile metamorphosis (Burndred et al. 2017).

Historical decline and fishing

A popular recreational, edible fish, freshwater catfish was once recorded as widespread throughout the Murray-Darling Basin and was a target of both commercial and recreational fishing (Rourke & Gilligan 2010; Ye et al. 2015). Data on historical abundance is limited, however it is clear that freshwater catfish has significantly declined in abundance and distribution (Clunie & Koehn 2001; Koster et al. 2015). This species is now considered as one of the rarest species of native fish in some waterways within their natural range, and it has virtually disappeared from southern catchments of the Murray-Darling Basin (Rourke & Gilligan 2010).

General reports also indicate that freshwater catfish was common throughout the South Australian section of the River Murray, and therefore was widespread in the ecological community, until around the mid-1960s. However, trends in commercial fishing catch data illustrate the decline of catfish from the early-1970s (< 20,000 kg), with catches progressively falling to low levels by the mid-1970s (6,000 kg) and very low levels throughout the 1980s and 1990s (Ye et al. 2015; Figure 8). Fishery catch data, along with limited research records, suggest a conservative estimate of decline over the last 30–40 years of at least 50% (Hammer et al. 2009). Fishing for this species was banned in South Australia in 1997. Fishing is also banned and Victoria, and restrictive regulations are in place in New South Wales (Rourke & Gilligan 2010; Ye et al. 2015).

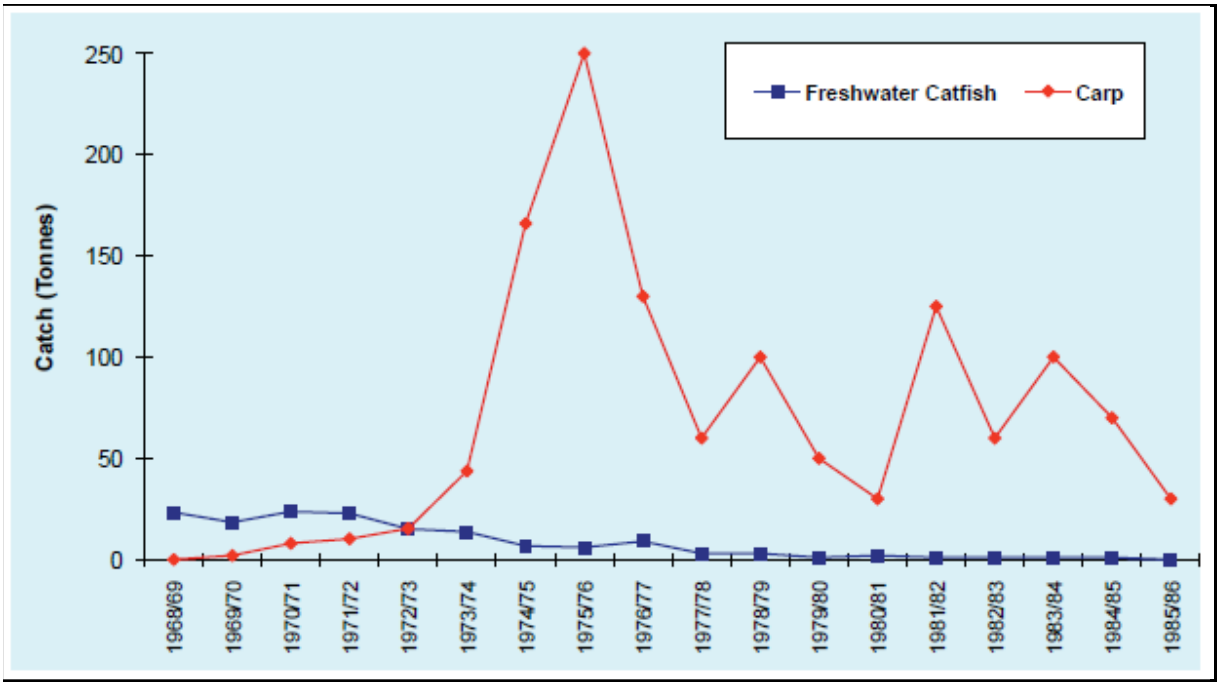

Figure 8*:* Catch data for freshwater catfish (compared to carp) from the SA River Murray Commercial Fishery between 1968 and 1986 based on SA Fisheries Statistics (Source: Hammer et al. 2009 p. 69).

Carp competitor

Anecdotally, freshwater catfish numbers declined substantially throughout the Murray-Darling Basin, and River Murray in particular, following the invasion of common carp (*Cyprinus carpio,* Boolara strain) during the 1970s (Hammer et al. 2009; Rourke & Gilligan, 2010). Carp gained a stronghold following the record-braking floods in 1974–75 (Koehn 2004). While carp may not have initiated the decline in freshwater catfish, they would have exacerbated it and limited potential recovery. As both species are benthic feeders (i.e. strong dietary overlap), common carp may have played a major role in the decline of freshwater catfish (Clunie & Koehn 2001; Kostner et al. 2015).

The behaviour of carp typically disturbs catfish habitat through siltation, bank erosion and increased turbidity, which in turn leads to decreased submerged and riparian macrophyte biomass and diversity (Koehn et al. 2000). Disturbance of freshwater catfish nesting sites by carp is also likely (Hammer et al. 2009; Koehn et al. 2000; Hammer et al. 2009). These impacts could directly affect freshwater catfish in terms of reproductive success, feeding behaviour and food availability, as well as survival (Clunie & Koehn 2010).

Conservation status

Within the Murray-Darling Basin, *Tandanus tandanus* is locally extinct over a large part of its historical range (Rourke & Gilligan 2015). Previous studies have indicated a complicated phylogenetic structure for freshwater catfish, including several cryptic species and low genetic diversity (e.g. Musyl & Keenan 1996), which has implications for use of translocations to recover populations in areas where they are extirpated (Rourke & Gilligan 2015). In South Australia, freshwater catfish have previously been stocked and populations established in water-bodies outside of the River Murray, including farm dams and several streams of the Western Mount Lofty Ranges (Ye et al. 2015).

Since 1997, freshwater catfish are a fully protected species in South Australia (under the *Fisheries Management Act 2007*, formerly *Fisheries Management Act 1982*) and must be returned to the water immediately if accidentally caught. In Victoria, the species is listed as threatened under the *Flora and Fauna Guarantee Act 1988*, and in NSW it is listed as an endangered population in the New South Wales Murray-Darling Basin (NSW Government Gazette 103). The *Action Plan for South Australian Freshwater Fishes* (Hammer et al. 2009) assigned a conservation status of 'endangered', as at the time, the freshwater catfish was considered to be facing a very high risk of extinction in the wild in South Australia.

Post Millennium Drought status

During the Millennium Drought, 1997-2010, relative abundance of catfish remained low in the main channel and the anabranch habitats of the SA River Murray (Ye et al. 2015). Similarly, common carp also declined during the drought and thus competitive pressure from this alien species on freshwater catfish may have been alleviated to some degree.

However, following the 2010–11 floods that broke the drought, there were anecdotal reports by anglers of freshwater catfish increasing in abundance, with both juveniles and adults observed (Zampatti pers. comm.). While evidence of an increase in abundance and recruitment was subsequently recorded, it proved to be an order of magnitude lower than 1997 (pre-drought) levels (Ye et al. 2015). It also proved to be temporary, with further declines in abundance evident in 2012-13 (Ye et al. 2015).

Condition monitoring of the fish assemblage within the Chowilla anabranch system (i.e. Living Murray Icon site) from 2007-2013 at 16-22 sites, recorded only 1-3 freshwater catfish from 2007-2010, with post-flood captures numbering 8, 20, and 15 for 2011,2012 and 2013, respectively (Wilson et al. 2014). Of note, is that common carp (along with other alien fish species) proliferated following the 2010–11 floods, reinstating competitive pressure on catfish (Ye et al. 2015).

Protection and research gaps

The freshwater catfish population within the ecological community remains in very low abundance (i.e. rare) relative to historical population levels, has a patchy distribution, and warrants continued protection (Ye et al. 2015). The stock status of this species in South Australia, based on the national stock status framework, remains 'undefined' (Ye et al. 2015).

The association of freshwater catfish with shallow littoral habitats has potentially important implications for the conservation and management of the species. For example, water levels are often drawn down in wetland systems in the Murray–Darling Basin for consumptive purposes, which may limit access to cover available near the margins and force fish to relocate to suboptimal habitats (Bain et al. 1988 in Kostner et al. 2015). Additionally, restricting potential grazing by stock which erode and degrade these habitats would be beneficial (e.g. Robertson & Rowling 2000; Amy & Robertson 2001).

Significant knowledge gaps remain on the biology and ecology of freshwater catfish, particularly regarding early life-history, population dynamics, and the influence of hydrology and habitat on reproduction and movement; such knowledge is needed for effective conservation and management (e.g. Ye et al. 2017; Wilson et al. 2014; Burndred et al. 2017). Additionally, long-term monitoring is essential to provide time series data on population dynamic and assess ongoing status and potential recovery within the ecological community (e.g. Ye et al. 2015).

Overall, there have been severe declines in freshwater catfish and it is not likely to be possible to restore to normal the major functional role it plays in the ecological community in the immediate future.

KEYSTONE DIADROMOUS FISH - CONGOLLI

Congolli (*Pseudaphritis urvillii*)

Key functional role: diadromous (catadromous) native fish; opportunistic carnivore and benthic ambush predator of macroinvertebrates; key food for larger fish (e.g. mulloway, black bream, golden perch); potential food for waterbirds/seabirds (e.g. pelicans, cormorants).

Key vulnerabilities: females obligate downstream migrants to spawn; defined spawning period; possible semelparity (death after spawning); need different habitats (freshwater and saltwater); fragmented population (see Table 17)

Key impacts on species: disruption of migration; long-term recruitment failure; decline in abundance and distribution range

Likely causes: loss of connectivity between habitats from in-stream barriers and decreased river flow; historical commercial fishing; poor water quality.

Key impacts on EC: loss of key functional group/ role (diadromous fish); lost productivity; loss of biodiversity; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Vulnerable

A diadromy surrogate

Congolli (*Pseudaphritis urvillii*) is a native diadromous fish that inhabits freshwater (females) and estuarine (males) waters within the ecological community (EC). Congolli is also a culturally significant fish to the Ngarrindjeri Peoples. As a catadromous fish, congolli females must undertake downstream migrations from freshwater habitats to breed in marine waters see Figure 9). For example, females migrate from Lake Alexandrina to the Coorong and then to the adjacent ocean to breed, and in late-spring/summer the juveniles migrate back into estuarine and freshwater habitats.

Congolli is a strong 'surrogate' for the functional role of 'diadromy' within the EC. Other diadromous native fish species associated with the EC include: spotted galaxias, common galaxias, estuary perch, and short-finned eel—all catadromous (migrate downstream from freshwater to saltwater to spawn), and two lamprey species—both 'anadromous', (i.e. migrate from seawater upstream into freshwater to spawn) (see Appendix B, Table B2). The unique and variable life-cycle needs of diadromous fish make them extremely vulnerable to environmental stresses such as decreased river flow and loss of connectivity (e.g. in-stream barriers). As such, they represent important indicators for the ecological health and function of the ecological community, especially the estuarine components (Bortone 2005 in Jennings et al. 2008).

Recruitment vulnerability

The life-cycle of Congolli inhabiting the CLLMM is shown by Figure 9, including the directional requirements of navigating the barrage gates and fishways. Congolli has a limited (i.e. rather than protracted) spawning period, which is a strategy that is less resilient to temporal variations in early survival conditions (Zampatti et al. 2011b). Also, in congolli populations, smaller males and individuals of indeterminate sex predominate in coastal and estuarine zones and larger females mostly inhabit freshwater habitats in rivers (Hortle, 1978 in Zampatti, et al. 2011b). This implies an obligate catadromous life history that is highly susceptible to fragmentation (Zampatti et al. 2011b). By comparison, common galaxias may show facultative catadromy, wherein migration is flexible depending on conditions (Zampatti et al. 2011b).

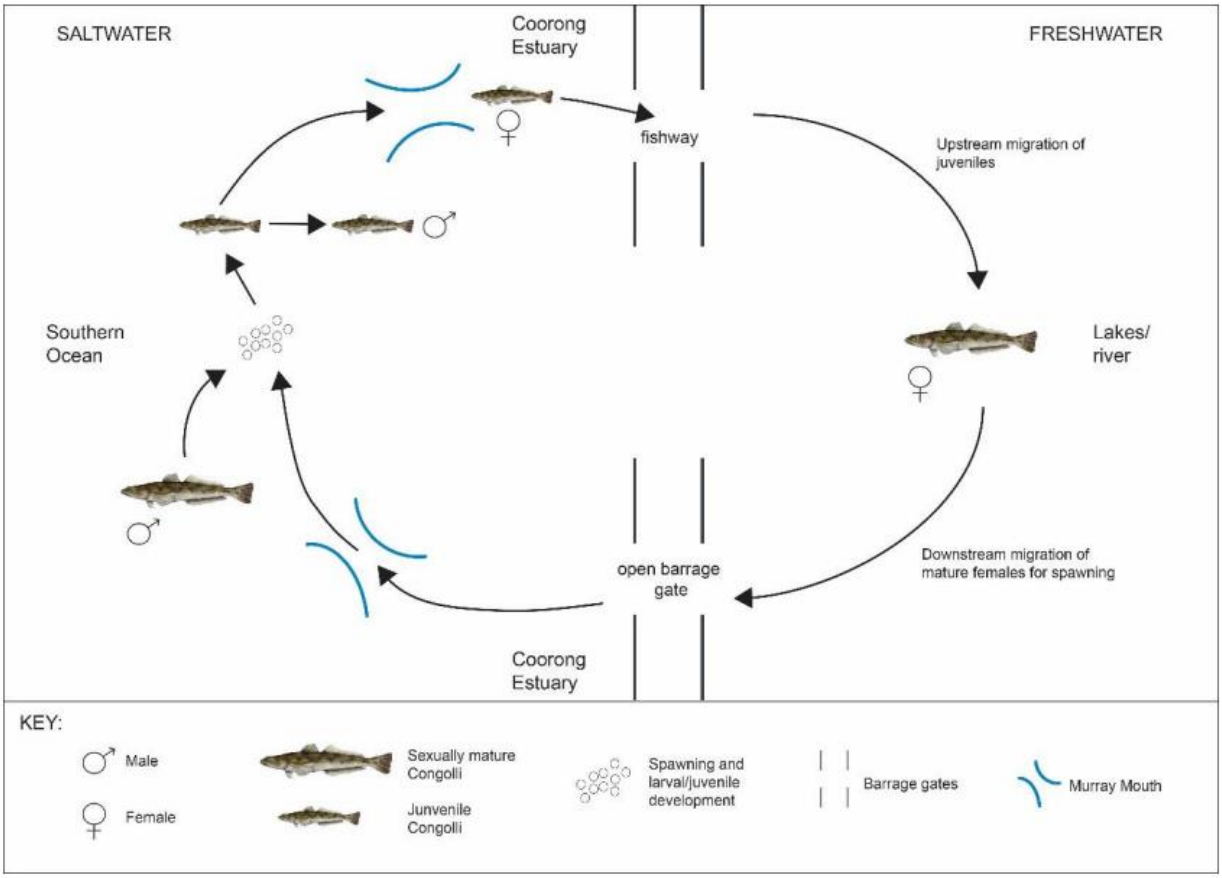

Figure 9: Life history of congolli in the Coorong, Lower Lakes and Murray Mouth region (DEW 2023d).

In addition, Bice et al. (2018b) suggest that female congolli from the lower Murray River represent the bulk of fish migrating to spawning grounds in the region, and contribute the majority of progeny along this coastline on an annual basis. This indicates their regional importance beyond the ecological community in contributing to genetic diversity and health of this species.

Pre-barrage abundance and post-barrage decline

Prior to the construction of the Murray Mouth barrages (1935-1940; Sim & Muller 2004), large downstream migrations of reproductively mature female congolli were commonly observed during winter. These migrations supported a seasonal component of the region's commercial fishery, with netting of spawning aggregations in the Lower Lakes (Evans 1991; Hammer et al. 2009); however, these no longer occur (Zampatti et al. 2010; Zampatti et al. 2011b).

The less frequent occurrence of several diadromous fish species within the ecological community likely reflects the impact of the barrages on fish migration (Bice et al. 2020). Hammer et al. (2009) noted reasons for the decline of congolli as hydrological change (e.g. 2/3 loss of average flow), instream barriers, decreased aquatic vegetation, and historical targeting by fishers of spawning aggregations.

Estuary dynamics

Construction of the barrages at the Murray Mouth greatly influenced the dynamics and conditions of the estuarine component of the ecological community, and therefore the use of the estuary by diadromous fish. There has been an increased frequency of zero freshwater inflow,

along with reduced tidal incursion and freshwater flushing, which have contributed to reduced depths, hyper-marine salinities, and lower than average dissolved oxygen levels (Geddes 1987; Walker 2002; Jennings et al. 2008). Such features are further exacerbated by drought and can lead to formation of sandbars at the Mouth and disconnection from the Southern Ocean, as happened in 2002 prior to the instigation of a dredging program (Jennings et al. 2008).

Decline compounded by Millennium Drought

Since the mid-1990s, annual freshwater flow to the Coorong had been below the post-regulation mean annual flow of about 4723 GL (Zampatti et al. 2011a, b). In 2006–07, significant numbers of juvenile congolli, common galaxias and adult short-headed lamprey were sampled at the barrage fishways (e.g. Tauwitcherie) migrating upstream into the Lower Lakes (Bice et al. 2007, 2012). Congolli were the third most abundant species (7% of total catch) and 90% of these fish were juveniles (Bice et al. 2007; Zampatti et al. 2011a, b). However, a significant decline in the abundance of migrating YOY common galaxias and congolli was observed between 2006/7 and 2007/8 (Jennings et al. 2008).

During the Millennium Drought, recruitment of all diadromous fish species was further impacted by a reduction in connectivity between freshwater and estuarine/marine habitats. No freshwater was released across the barrages to the Coorong for much of 2007 until early 2010. Closure of the barrages impeded obligate migratory movements of congolli (and other catadromous species), thus impacting spawning and recruitment. In subsequent annual fish surveys to 2009/10, following cessation of inflows into the Coorong and loss of connectivity, the abundance of congolli and common galaxias was reduced by > 95%, and no lampreys, eels or estuary perch were recorded (Jennings et al. 2008; Zampatti et al. 2011a, b; Bice et al. 2012).

At risk of extirpation?

In 2003, congolli was recommended for listing as 'Rare' in South Australia, due to significant declines in historical abundance in the Lower Lakes, Lower River Murray, and East Mount Lofty Ranges streams (Wilson & Bignall 2009). Similarly, congolli was deemed to be 'vulnerable' under the *Action Plan for South Australian Freshwater Fishes* (i.e. considered to be facing a high risk of extinction in the wild)—with both lamprey species also classed, as 'endangered' (Hammer et al. 2009). At the peak of the Millennium Drought, closure of the barrages and the catastrophic drop in congolli numbers meant the species was at risk of extirpation (local extinction) within the ecological community.

In addition, despite the increased presence of fishways across the barrages, contemporary hydrology which includes managed environmental flows and barrage operation still exert a substantial influence on connectivity and population dynamics of diadromous fish. This has been demonstrated by long-term (2006-2017) monitoring of fish migration at fishways on Tauwitchere and Goolwa Barrages (Bice et al. 2017a, b; Bice 2023).

Fish passage

Many fish species (>30) move or attempt to move between the Coorong and Lower Lakes, comprising a variety of life stages (Bice et al. 2018a). The previous lack of connectivity between the Lower Lakes, Coorong, and adjacent ocean, caused by the five Murray Barrages drastically impacted diadromous fish populations and precipitated much of their decline.

Fishways (or fish ladders) are commonly used to facilitate fish movement past instream barriers and restore connectivity within fragmented river systems (Clay 1995 in Bice et al. 2017a). Paired or multiple vertical-slot fishways are recommended for diverse (i.e. by species and size)

native fish assemblages on low-level estuarine barriers such as those of the Murray Mouth barrages (Barrett & Mallen-Cooper 2006; Bice et al. 2017a).

Between 2004 and 2008 (i.e. during the Millennium Drought), three purpose-built fishways were installed on two of the barrages (Table 30). However, in the later stages of the drought, the barrages, and by default the fishways, were closed for several years (2007-2010) to prevent saltwater entering the Lower Lakes (Jennings et al. 2008; Bice 2023). A further six fishways were installed between 2015 and 2018 (i.e. post-Millennium Drought) on the remaining three barrages (Table 30), in order to cater for a wide variety of fish species and life stages over varying hydrological conditions (Appendix B, Table B4) (Jennings et al. 2008; Bice et al. 2017a, b, 2018a; Bice 2023).

Post- Millennium Drought trends

Extensive rainfall in the MDB in winter/spring 2010 broke the Millennium Drought and led to the resumption of freshwater flow to the Coorong and a decrease in salinities downstream of the barrages (Zampatti et al. 2012). These conditions led to a rise in abundance of congolli and common galaxias, demonstrating early restoration of these populations.

The introduction of more fishways at the barrages (Table 30), combined with targeted delivery of environmental water and a period of wetter years with higher connectivity, has resulted in a rise in abundance of congolli and other diadromous fish, such as pouched lamprey (*Geotria australis*) and common galaxias (Bice & Zampatti 2015; Bice et al. 2017b). More recently, the delivery of environmental water has helped to ensure a continuous flow of water through the barrage fishways. However, experts caution that population recovery is likely to be 'long and slow' for these diadromous fish species (e.g. Ye et al. 2012).

Diadromous fish species require open barrage gates in winter for the downstream migration of reproductively mature fish to spawn, and open fishways for the upstream migration of juveniles to the Lower Lakes and tributaries of the eastern Mount Lofty Ranges (Bice et al. 2018a), where they mature (Bice et al. 2021; see Figure 9).

In spring-summer 2020/21, the abundances of congolli and common galaxias were high relative to 2006-2011, and moderate relative to the period 2011-2020 (i.e. the latter being the wetter period), although >80% were newly recruited YOY (Bice et al. 2021). The delivery of water to maintain open barrage gates in winter and operable fishways in summer improved diadromous fish recruitment, however, the abundance of juveniles was likely limited by the low population of reproductively mature adults until 2014–15 (Bice et al. 2021). Additionally, in winter-spring 2020, the highest abundance (102) of pouched lamprey was observed since monitoring began in 2006 (Bice et al. 2021). Overall, diadromous fish recruitment in the CLLMM was determined to be 'getting better' over the duration of the assessment period (2006/07 to 2021/22), with the condition of diadromous fish populations classed as 'fair' and 'getting better' in 2021/22 (DEW 2023d).

Intervention needed for future protection

Understanding the influence of river hydrology, connectivity, and other cues on the migration and recruitment of diadromous fish is fundamental for species management and conservation (Bice et al. 2018b; Bice 2023). Despite a long-held view that increased flow was critical to stimulate downstream migrations of catadromous fish (e.g. Harris 1986), Reinfelds et al. (2013) documented likely temperature-related and flow-independent downstream migration of over a third of tagged fish in their study of diadromous fish. In the case of Australian bass, congolli, and potentially other catadromous fish species, downstream spawning migrations may primarily be

Table 30: Fishway installation and design within the RMDS Ecological Community. There are fishways on the tidal barrages across the five channels leading from Lake Alexandrina to the Murray Mouth, in addition to fishways on the ten Locks within the EC (Source: Jennings et al. 2008; DENR 2013; MDBA 2024).

Year	Name/Where	Design	Comment
Barrages *(built 1935–1940) & Fishways (installed 2004–2005 & 2015–2018)*			
2003	Goolwa barrage	• partial-depth vertical slot	large-bodied fish >150 mm TL
2015	Goolwa barrage	• full-depth, large vertical slot	upgrade? Boat lock??
2017	Goolwa barrage	• small vertical slot + fish lock	upgrade?
2004	Tauwitchere barrage	• large vertical slot	for large-bodied fish >150 mm TL
2004	Tauwitchere barrage	• rock ramp	for small-bodied fish < 150 mm TL
2008	Tauwitchere barrage	• vertical slot	additional
2018	Tauwitchere barrage	• trapezoidal	additional
2015	Boundary Creek	• small vertical slot	
2016	Ewe Island barrage	• dual vertical slot	
2016	Mundoo barrage	• dual vertical slot	
2009	Hunters Creek	• small vertical slot	
Locks *(built 1922–1935) & Fishways (installed mainly 2003–2013)*			
1930?	6 – Murtho SA	• based on North. Hem. Salmonid design	ineffective for many native fish species
2010	6 – Murtho SA	• vertical slot • small fish lock	upgrade of original
2003	8 – Wangumma SA	• vertical slot	2005 assessed performance re slope
2004	7 – Rufus River SA	• vertical slot	
2005	9 – Kulnine SA	• vertical slot	
2006	10 – Wentworth NSW	• vertical slot	
2009	1 – Blanchtown SA	• vertical slot	
2011	3 – Overland Corner SA	• vertical slot	
2012	5 – Renmark SA	• vertical slot	
2013	2 – Waikerie SA	• vertical slot	
2013	4 – Bookpurnong SA	• vertical slot	
2013	11* – Mildura VIC	• Denil with baffles	next lock upstream of EC
2023	11* – Mildura VIC	• Denil with baffles	improvements to baffles

driven by decreasing or minimum photoperiod and temperature, rather than increases in flow (i.e. an adaptation to variable inter-annual hydrology) (Reinfelds et al. 2013; Bice et al. 2018b).

Of note, is that under the increased temperature regime of climate change, such temperature-related cues may be impacted in the future. Studies using acoustic telemetry on female congolli also indicated the importance of a full moon phase and photoperiod as cues for downstream migrations, and results were suggestive of semelparity (i.e. mortality after spawning) (Bice et al. 2018b). It seems that rather than triggering spawning migrations, flow is most critical for providing the hydrological connectivity that enables fish to reach the ocean.

A key driving factor behind the recent improved recruitment of congolli and common galaxias was attributed to greater flow-related connectivity between freshwater, estuarine and marine environments (Bice et al. 2021; Bice 2023). Based on fishway monitoring from 2006-2022 and allied projects, Bice et al. (2023) recommend freshwater discharge and fishway operation should be facilitated at the barrages annually from at least June–January, to allow for both downstream and upstream migrations of diadromous fish and the completion of their life-cycles (i.e. open barrage gates in winter and operable fishways with attractant flow in spring and summer). Specifically, June-January encompasses three key periods (Bice et al. 2021, 2023):

- June–August to allow for downstream spawning migrations of congolli and common galaxias and upstream migrations of pouched lamprey
- August–November to allow for upstream migrations of short-headed lamprey, and
- October–January to allow for the upstream migrations of juvenile congolli and common galaxias.

Given the above, it is apparent that human-intervention is required for the future viability and protection of diadromous fish such as the congolli within the ecological community, which remain highly vulnerable into the future. This is particularly the case given the likelihood of future extreme drought conditions, where the barrages and fishways may not be optimal or operable for long periods, combined with increasing temperatures under climate change which may impact cues for spawning migrations.

Overall, there have been substantial declines in congolli and it is not likely to be possible to restore to normal the major functional role it plays in the ecological community in the immediate future.

Question

Can you provide feedback on the congolli section, particularly in relation to any more recent survey data and long-term trends on the species and broader impacts, and on any results of recent recovery efforts?

KEYSTONE FLOODPLAIN WETLAND ECOLOGICAL SPECIALISTS – SUITE OF SMALL-BODIED FISH

Suite of Small-bodied Fish

- **Olive perchlet** (*Ambassis agassizii*) – Extirpated
- **Flat-headed galaxias** (*Galaxias rostratus*) - Extirpated
- **Yarra pygmy perch** (*Nannoperca obscura*) – Extinct (unique genetic lineage in MDB)
- **Southern pygmy perch** (*Nannoperca australis*) **–** unique genetic lineage in MDB
- **Murray hardyhead** (*Craterocephalus fluviatilis*)
- **Southern purple-spotted gudgeon** (*Mogurnda adspersa*)

Key functional role: convert resources at base of food chain (e.g. plant detritus, epiphytes, zooplankton); nutrient recycling; prey for higher-order native predators, e.g. fish, birds

Key vulnerabilities: limited dispersal ability; short life-span; small distribution ranges; dependent on specific habitats (e.g. feathery macrophytes) and hydrology (slow flow, water level variability); increased salinity for some species (& see Table 17)

Key impacts on species: decline in abundance and range/ local extinction (extirpation)/ extinction

Likely causes (threats): long-term & extensive river regulation; decreased flow volume; inappropriate water levels; reduced water quality; floodplain wetland habitat loss; impacts from invasive fish; sedimentation; over-exploitation; severe drought; climate change

Key impacts on EC: foodweb (trophic) impacts/ loss of food source and productivity transfer; reduced nutrient cycling and transfer; loss of biodiversity; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Overall indicative conservation status within the EC for C3: Critically Endangered

Overview

Ecological specialists are species with specific habitat requirements or a dependence on particular aspects of the natural flow regime; globally, they make up approximately two-thirds of the freshwater fish species threatened with extinction (Galat & Zweimuller 2001 in Wedderburn et al. 2014). The suite of small-bodied native fish considered here, sometimes referred to as 'the Magnificent Six' (Lovett 2019), is comprised of six 'ecological specialists', adapted to ephemeral wetlands with natural flow regimes within the ecological community (i.e. as in box above, Wedderburn et al. 2012, 2014; Whiterod 2019).

These six species of small-bodied fish were once widespread throughout the ecological community, however historical declines from river regulation and a range of other threats (see box above) were exacerbated by the prolonged Millennium Drought (1997–2010). The prolonged drought heavily impacted freshwater habitats—including dramatic lowering of wetland water levels and loss of macrophytes, particularly the Lower Lakes and adjacent wetlands (e.g. Hammer et al. 2009, 2013; Wedderburn et al. 2017, 2022; Whiterod 2019). There is growing evidence that prolonged drought exacerbates the impacts on freshwater fishes from river regulation and over-extraction of water (e.g. habitat disconnection, salinisation, drying etc.) to cause regional extinctions of ecological specialists (Wedderburn et al. 2012, 2014, 2020, 2023; Whiterod et al. 2021).

Emergency conservation measures were undertaken for some species during the Millennium drought, such as rescues for temporary maintenance in refugia and captive breeding programs, with varying degrees of success (Hammer 2008, 2009; Wedderburn et al. 2017; Whiterod et al. 2019, 2021). While some recovery efforts and related research continue (Lovett 2019; Whiterod et al. 2021), three of the six species remain extirpated from the ecological community.

Experts consider that the persistence and/or meaningful recovery of these six small-bodied fish species will only be possible with active hydrological/species management and reintroductions, as well as mitigation of invasive species and other prevailing threats (Whiterod et al. 2021). Further, Beheregaray et al. (2021) caution that rescue for recovery is not a 'silver bullet' and should not be seen as an easy key management solution, but rather as a supplement to long-term habitat protection and restoration.

In addition, threatened species often show reduced genetic variation compared to non-threatened species, and this is considered indicative of lowered evolutionary potential, compromised reproductive fitness, and elevated extinction risk (Sasaki et al. 2016). Based on improved genetic understanding of freshwater fish in the MDB, Brauer & Beheregaray (2020) argue that proactive measures to reconnect fragmented/isolated riverine populations (and subpopulations) are urgently needed. Enabling inter-mixing will limit the loss of genetic diversity through disturbance and inbreeding and improve species' resilience to future environmental challenges (Brauer & Beheregaray 2020; Marshall et al. 2021).

Olive perchlet

Olive perchlet was once widespread throughout the MDB, including within the ecological community (Hammer et al. 2009; Lintermans 2023). While captive maintenance and breeding has more recently occurred for northern MDB populations, this species remains extirpated (extinct) within the ecological community. The species was last recorded in South Australia in 1983 and in Victoria in 1922 (Whiterod et al. 2021). Attempts to establish a backup population in SA in the 1990s, failed (Hammer 2008; Whiterod et al. 2021).

Flat-headed galaxias

The flat-headed galaxias is listed as Critically Endangered under the EPBC Act and is extinct in the wild in South Australia, i.e. extirpated (Whiterod et al. 2021). In historical records, the species occurred as far as Murray Bridge, and substantial declines likely occurred prior to the Millennium Drought (Hammer et al. 2009). Ecological knowledge remains limited and there is a need for investment in surveys and establishment of backup populations (Whiterod et al. 2021).

Yarra pygmy perch (YPP – and see Table 31)

While Yarra pygmy perch occurs in several major catchments in south-eastern Australia, the genetically unique population in the MDB was known to only inhabit wetlands of Lake

Alexandrina at the terminus of the system. These YPP (i.e. that once occurred within the ecological community) were an endemic lineage classified as an evolutionarily significant unit (ESU) isolated since the Pleistocene (Brauer et al. 2013).

YPP was last recorded in 2008 towards the end of the Millennium Drought (Wedderburn 2018; Wedderburn et al. 2012, 2014, 2019, 2022). At this time, 200 individuals were rescued for captive breeding (Hammer et al. 2013) and there have been several 'reintroduction' (reintro.) attempts between 2011 and 2015 (Bice et al. 2014; Wedderburn et al. 2020, 2023). However, these attempts seemingly failed, for reasons that remain unresolved—although low genetic

Table 31: Suite of small-bodied fish of the Lower Lakes and fringing wetlands in the RMDS EC (source: references cited in the Criterion 3 assessment of the suite of small-bodied fish).

Aspect	Murray Hardyhead	Sothern Purple-spotted Gudgeon	Yarra Pygmy Perch	Southern Pygmy Perch
Conservation Status (EPBC)	Endangered ('Protected' in SA)	2024 FPAL	Vulnerable ('Protected' in SA)	Vulnerable ('Protected' in SA)
Size	• < 90 mm	• < 150 mm	• < 85 mm	• < 85 mm
Longevity	• < 1.5 y	• 1 – 5 y	• 1 – 5 y	• up to 5 y
Habitat preference	• still to low flowing waters • water level variability • fresh-brackish waters • salt-tolerant, remnant populations in >1000 EC) • wetlands, edges or sites fringing Lower Lakes • highly mobile, schooling • need zooplankton food • aquatic veg. – shelter, lays eggs on • recruitment off-channel	• shallow < 1m wetlands & slow-moving creeks • low salinity (<1000 EC) • abundant submerged macrophytes, e.g. *Myriophyllum*, *Vallisneria* • mainly found around vegetated margins	• sedentary nature • shallow littoral zone Lake Alex/ wetlands • low salinity <1000 EC • dense submerged macrophytes for food & shelter, e.g. *Myriophyllum*, *Vallisneria, Ceratophyllum, Scheonoplectus*	• slow flow, pools • dense aquatic veg. – shelter, food, egg laying • fringing wetlands of Lake Alex. & islands • RM – rock banks, aquatic & riparian vegetation, e.g. *Ceratophyllum*, *Typha* • water level variation
Condition trend	**Past 50 y:** severe decline in range & abundance **2003:** abundant at sites fringing Lower Lakes **2007:** extirpated NSW **2014:** partial recovery SA **2020: on** verge of extirpation in VIC **2021:** last detected in Lake Albert in 2009; reintros. in recent years failed	**1990s:** Extirpated in SA & NSW section of Murray (last record from wild in 1973) **2002:** rediscovered in Jury Swamp (rescued) **2003:** abundant SW Lower Lakes **2021:** persists in EC with regular reintroductions; no self-sustaining popn.	**2003:** abundant Hindmarsh Island at Lower Lakes **2008:** last observed in wild **2012**: reintroduction attempt failed **2015**: reintroduction attempt failed **2019:** extirpated/ extinct in EC	**2008:** extirpated in EC **2019-20:** low numbers from reintroductions **2021:** 4x numbers of previous survey ('reestablished) **2024:** increasing numbers on Mundoo Island, lowering numbers on Hindmarsh Island
Surveys (from Nov. 2009)	**2009-2012:** none past Nov. 2010 **2014:** 74 sites – at 13 sites **2015:** high abundance 2 saline sites with habitat recovery + e-water, in SA Riverland **2016:** at 7 of 20 sites **2017:** 8 known sites from SA & VIC **2019-21:** at 5 of 23/4 sites	**2009-2012:** None **2014:** 74 sites – None **2016:** 20 sites - None **2019:** 23 sites - None **2021:** 24 sites - None	**2009-2012:** None **2013-14:** short-term survival & wild recruitment observed **2014:** 74 sites, one fish **2016:** 20 sites - None **2018:** occupancy study of 32 sites – None **2021:** 24 sites - None **2023**: recaptures few weeks after reintro.	**2009-2012**: 2 recaptures Nov. 2011 (from intros 3 weeks prior) **2014:** at one of 74 sites **2016:** at 5 of 20 sites TLM **2019:** at 9 of 23 sites TLM **2021:** at 9 of 24 sites TLM **2024**: at 6 of 24 sites (total 448 fish) in The Living Murray (TLM) condition monitoring
Potential cause of decline	• river regulation • Millennium Drought • poor water quality • isolation of wetlands • competition/ predation from invasive fish • lack of dispersal mechanisms • eggs less tolerant of high salinity	• river regulation (flows and diversions) • habitat loss • predation/ competition by alien fish • drought • potentially bushfire	• river regulation • Millennium Drought • low Lake levels • desiccation of fringing vegetation • changes to aquatic vegetation • invasive fish impacts • poor water quality • low zooplankton	• river regulation • Millennium Drought • low Lake levels • loss of fringing veg. • changes to aquatic vegetation composition • invasive fish predation/ competition • poor water quality • low zooplankton (food)

Aspect	Murray Hardyhead	Sothern Purple-spotted Gudgeon	Yarra Pygmy Perch	Southern Pygmy Perch
Translocations	**2014-15:** fish translocated from Riverland sites to VIC **2018:** successful captive breeding VIC **2018:** 830 translocated from SA to NSW (with e-water); 3 wetland sites, appeared successful in 2019	**2002:** rediscovered popn. Rescued; captive breeding; refuge popn. **2011-12:** 1120 fish reintroduced to historical site, but it dried up **2014-19:** 5043 fish reintroduced to rediscovery site	**2008:** rescued; captive breeding **2011-2014:** 5850 fish to 5 former sites **2014:** surrogate refuge collapsed (backup lost) **2015:** 900 fish, 3 sites **2018:** surrogate refuge created from captive **2023**: reintroduced 2000 Hindmarsh Island	**1997:** from northern MDB to southern MDB **2007:** – 65 rescued **2008:** rescued; captive breeding **2011-12:** 1000s reintroduced LM **2023**: reintroduced 500 Pelican Lagoon, Lake Alexandrina

diversity of the YPP lineage may have been a contributing factor (Attard et al. 2016; Buckley et al. 2022), as may have predator naivety (Wedderburn et al. 2022).

Repeated surveys targeting the species in 2018 failed to detect YPP, and modelling for imperfect detection, combined to provide strong evidence that *Nannoperca obscura* is extirpated from the MDB (Wedderburn et al. 2021, 2023), and therefore the ecological community. In 2019 the MDB YPP lineage was considered extinct (Beheregaray et al. 2021). Given its genetic status, a lineage distinct from that of other catchments, this finding confirmed the first known extinction of a freshwater fish from the entire MDB (Wedderburn et al. 2022, 2023). Natural recolonisation is now unfeasible for this genetically unique small-bodied native fish (Wedderburn et al. 2022).

Southern pygmy perch (SPP – and see Table31)

Southern Pygmy Perch once thrived throughout the MDB, and was commonly found in wetlands and creeks, including the Lower Lakes and Eastern Mt Lofty tributaries (Hammer et al. 2009). The SPP lineage has experienced large-scale subpopulation extinctions from most of the middle MDB, and survives now only in very small population fragments, mainly in tributaries of the upper River Murray and in pockets of the lowermost reaches of the Basin (Beheregaray et al. 2021; Buckley et al. 2023). The SPP found in the lower MDB is geographically isolated, locally adapted, and genetically divergent from other regional populations (Brauer et al. 2016). Threats resulting in loss of genetic variability is a key risk-factor for remaining subpopulations, of which 14 genetically distinct 'demes' (isolated subpopulations) are now recognised (Cole et al. 2016)—four of these occur within the ecological community.

The knowledge and outcomes related to the YPP story remain highly relevant to its congener, the southern pygmy perch, which is ecologically similar (Wedderburn et al. 2022). Therefore, SPP is considered at high risk to ongoing threats and future prolonged drought. While the previous efforts at captive breeding and reintroductions failed for YPP, efforts were considered successful for SPP (Beheregaray et al. 2021). This was attributed to developing capability to retain genetic diversity within the captive breeding program, along with the ending of the Millennium Drought Buckley et al. 2022, 2023). Thousands of southern pygmy perch were reintroduced to the area in 2011–12 which led to the population's re-establishment in Lake Alexandrina (Whiterod et al. 2019, 2021).

The status of SPP in Lake Alexandrina has been assessed since 2007 under the Living Murray initiative (TLM) of the Murray-Darling Basin Authority. The overall status of the species has improved slightly within the ecological community (i.e. wetlands of Lake Alexandrina and Eastern Mount Lofty streams), due to reintroductions, surrogate refuges, and natural recovery

(Whiterod et al. 2021). This has been supported through targeted environmental watering and water level management (Wedderburn et al. 2012, 2020). Spring flow pulses, to generate ecological productivity, and maintenance of adequate water levels over the critical period when young fish are still growing (following hatching in September–October) leads to greater recruitment success. If water levels fall too low during spring and early autumn in the Lower Lakes, wetland habitats become shallow and water recedes from fringing water plants, leaving young fish vulnerable to additional pressures (e.g. reduced habitat availability; increased exposure to invasive species).

While SPP continues to decline across the southern MDB, with exception in some isolated areas associated with Lake Alexandrina (Wedderburn & Bailey 2024), future conservation efforts need to consider the genetically distinct units within the species (Brauer et al. 2016; Whiterod et al. 2021) in addition to hydrological requirements to enhance recruitment success.

Murray hardyhead (MHH – and see Table31)

The Murray hardyhead is a salt-tolerant species, endemic to the MDB, occurring in wetlands of lowland floodplains. It prefers slightly to moderately saline (0.4–20 g/l), well-vegetated habitats (e.g. *Myriophyllum*, *Ruppia*), although eggs and early larval stages do better in lower salinities than those tolerated by adults and juveniles (Wedderburn et al. 2014; Stoessel et al. 2020). The life history strategy of MHH is well suited to early colonisation of newly inundated habitats such as floodplain wetlands (Hammer & Wedderburn 2008).

Significant and long-term declines in this species have occurred due to river regulation and loss of well-vegetated, shallow saline wetland habitat (Hammer et al. 2013; Wedderburn et al. 2017, 2022), and more recently exacerbated by critical water shortages during the Millennium Drought (Whiterod et al. 2021). A few key sites for MHH within the ecological community were maintained through the Millennium Drought via environmental watering; fish rescues were also undertaken for wild-to-wild reintroductions and to establish backup populations at captive facilities (Hammer et al. 2013; Wedderburn et al. 2013; Whiterod et al. 2019, 2021). During 2010-11, a surrogate refuge within the ecological community (Munday Dam) was successfully established using fish sourced from various sites across the Lower Murray, with another established in 2017 (Whiterod et al. 2021).

Since the Millennium Drought, there has been some fragmented recovery of wild populations, due partly to human intervention (Bice et al. 2014; Wedderburn et al. 2014; Whiterod et al. 2021). This has been achieved through improved management knowledge (including genetic) and successful use of captive facilities, refugia, translocations, and reintroductions. Tailored environmental watering regimes for isolated populations within the ecological community have also been adopted at key sites (Whiterod et al. 2021).

Through such interventions, subpopulations of MHH appear to be persisting at several locations within the ecological community (Whiterod et al. 2021 and references therein; Murraylands and Riverland Landscape Board unpublished data). However, these have been found to be genetically distinct from upstream subpopulations and, to avoid reinforcing genetic isolation, it is recommended to manage more broadly, such as at the meta-population level (Theile et al. 2020). Koehn et al. (2020) found that less than 59% of knowledge that is needed for future management and conservation of the various life history stages of this species is available.

Southern purple-spotted gudgeon (SPSG – and see Table 31)

The southern MDB subpopulation of the southern purple-spotted gudgeon is considered genetically distinct from those of the northern MDB, and thus a distinct 'conservation unit'

(Sasaki et al. 2016). The species was once widespread and common in wetland and fringing river habitats in the southern MDB (Hammer et al. 2009; Whiterod et al. 2021). However, it was declared extinct in South Australia in the early 1990s, following the last verified record in the wild in 1973 (Hammer et al. 2009). The last record from the NSW section of the southern MDB was in 1996.

After 30 years, in 2002, the SPSG was rediscovered within the ecological community—in Jury Swamp near Murray Bridge, SA (Hammer et al. 2015). The discovery coincided with increasing severity of impacts from the Millennium Drought, and fish were fortuitously rescued into three captive breeding facilities, with the view of establishing surrogate populations to safeguard the species (Hammer 2007). An approach was taken to 'train' fish prior to release to enhance survival, as part of broader restoration program (Hammer et al. 2012).

Successful captive breeding led to several reintroductions between 2011 and 2019, with varying levels of success (Bice et al. 2014; Whiterod 2019). The bulk of these translocations occurred at Jury Swamp, and while low numbers were regularly detected the establishment of self-sustaining populations has not occurred (Whiterod et al. 2019, 2021).

The Lower Murray subpopulation continues to exist within the ecological community, with the assistance of regular reintroductions and maintenance of backup populations in captive facilities (Whiterod 2019; Whiterod et al. 2021). However, according to Whiterod et al. (2021), the future of the species remains precarious in the southern MDB, as it is only known from a few locations which have resulted from reintroductions, and in the Lower Murray it has yet to reestablish a self-sustaining population. In addition, considerable knowledge gaps exist regarding both biology and ecology of SPSG (Koehn et al. 2017).

Conclusion re suite of small-bodied fish

Of the six species of ecological specialists, i.e. the suite of small-bodied fish, half (3) are either extirpated or extinct within the ecological community. All six have State recognition as a threatened or protected species, and five are listed as threatened species under the EPBC Act (exception olive perchlet; see Appendix B, Table B2).

The dire situation of these small fish during the Millennium Drought led to captive breeding programs for four species, YPP, SPP, SPSG, and MH. Translocations ensued, with limited to no success. However, it is increasingly recognised that captive breeding programs need to retain genetic diversity and allow for predator naivety. With human intervention, including some targeted environmental watering, two of the species, MH and SPSG, have had some fragmentary recovery—although, SPSG shows no sign of self-sustaining populations. The extant small-bodied fish are considered by experts to be at high risk to ongoing threats and future prolonged drought.

Given the level of decline suffered by these small-bodied fish species, and that restoration is not likely in the immediate future, a conservation status of Critically Endangered within the EC is applied. Overall, there have been very severe declines in small-bodied fish species and it is not likely to be possible to restore to normal the major functional role they play in the ecological community in the immediate future.

KEYSTONE RECYCLER/DETRITIVORE – MURRAY CRAYFISH

Murray Crayfish (*Euastacus armatus)*

Key functional role: largest macroinvertebrate; scavenger/predator/detritivore/recycler; habitat modifier; food for terrestrial wildlife

Key vulnerabilities: slow growing, long lived (~28 y); late sexual maturity (M 4 y; F 8-9 y); low fecundity (< 2000 eggs/ annual breeding event); winter-spring brooder; sedentary; intolerant of low dissolved oxygen, high temperature, and high salinity (& see Table 17)

Key impacts on species: decline in abundance and range/ local extinction (extirpation)

Likely causes (threats): decreased flow volume and flow velocity; construction of weirs; fishing pressure; reduced water quality; sedimentation; thermal pollution; climate change; bushfire impacts

Key impacts on EC: foodweb (trophic) impacts/ loss of food source; reduced nutrient cycling and transfer; loss of habitat structuring; loss of biodiversity; climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Extirpated/ Critically Endangered

An iconic crustacean

The Murray (or River Murray or Murray Spiny) crayfish (*Euastacus armatus*) is restricted to the River Murray and its southern tributaries (Geddes, 1990; McCormick, 2012; Fisheries Scientific Committee NSW 2013), and is one of two freshwater crayfish that occur within the ecological community—the other being the common yabby (*Cherax destructor*). Reported to grow to 3 kg (and up to 50 cm total length), the Murray crayfish is the second largest freshwater crayfish in the world (the largest, *Astacopsis gouldii*, occurs in Tasmania); by comparison, the yabbie is much smaller and rarely exceeds 250 g (Geddes, 1990; Horwitz 1990 in Gilligan et al. 2007).

Important ecological role

Murray crayfish is a keystone species that serves an important ecological role in the benthic environment by shredding and processing large quantities of organic material, such as leaf litter and attached invertebrates, and by burrowing in and mobilising sediments (Nystrom 2002 in McCarthy 2005). These crayfish provide food for many species and are an important trophic link in the transformation of energy from microbiota through to predators such as fish, birds, water rats, and terrestrial mammals (Nystrom 2002 in McCarthy 2005). As such, Murray crayfish influence multiple trophic levels in addition to acting as ecosystem engineers, adding structure to the habitat with their burrowing behaviour (Gilligan et al. 2007; Whiterod & Zukowski 2019).

Critical habitat

While there may be some differences between upland and lowland environments, and between individual streams, typically the Murray crayfish has a preference for areas of cool, well oxygenated waters of intermediate flow velocity, with strong habitat complexity. Rocks, woody debris (e.g. snags), and riparian vegetation can provide shelter and refuge, and stable (clay) banks are needed for burrowing (Gilligan et al. 2007; Zukowski 2012; Nobel & Fulton 2017).

Vulnerabilities and environmental tolerances

Several features of the biology and ecology of the Murray crayfish serve to make it a species vulnerable to disturbance: low dispersal ability, longevity, low fecundity; high mortality (~ 50%) prior to maturity (e.g. Geddes 1990; Gilligan et al. 2007 and references therein; Zukowski et al.

in press). In addition, it has been hypothesized that annual mating occurs over a brief period and is cued by a rapid decline in water temperature to about 12 – 15 °C (O'Conner 1986 in Gilligan et al. 2007).

It is well documented that this large freshwater crayfish is highly vulnerable to poor water quality. Geddes et al. (1993) recorded Murray crayfish to have the following longer-term tolerances:

- temperature as high as 27 °C (LD_{50}s 30 °C)
- dissolved oxygen concentration as low as 3 g/L (LD_{50}s 2.2 mg/L)
- salinities less than 16 ppt (33% mortality at 16 ppt).

Of concern, is that under climate change, rising temperatures, future heatwave conditions, and other extreme events, may see these thresholds exceeded within the region of the ecological community (e.g. MDBA 2019; Lawrence et al. 2022).

A widespread 'crawl-out' of Murray crayfish occurred in 1992-93, in the middle River Murray downstream of the Barmah-Millewa Forest, in response to low oxygen water (< 2 mg/L) associated with a 'blackwater' event (McKinnon, 1995; Walker et al. 2009). Such 'crawl-outs' were also observed across the southern Murray-Darling Basin in 2010/11 when the prolonged flooding that ended the Millennium Drought produced a large-scale blackwater event (McCarthy et al. 2014; Whiterod et al. 2018). Despite the ability of Murray Crayfish to emerge from these hypoxic conditions, McCarthy et al. (2014) found significant population declines (~80%) two years later at affected sites. A similar mass crawl-out occurred in 2022 in the southern Riverina region of the Murray, of which a large number were rescued (NSW DPI 2022). Lengthy recovery trajectories (e.g. 50 years) to reach pre-disturbance population sizes have been proposed, with recovery timeframes delayed under any harvesting pressure (Whiterod et al. 2018).

Geddes et al. (1993) also demonstrated this crayfish was sensitive to low flow or no flow conditions. These authors found Murray crayfish did not survive in the Lock 3 weir pool in reduced flow velocities of 0.02 m/s, although they did survive at flows of 0.31 m/s (Geddes et al. 1993). Flow velocity, and its link to higher DO concentrations, is now recognised as an important habitat feature for this species and it is largely absent from slow-flowing impoundments and weir pools (McCarthy 2005; Gilligan et al. 2007; Zukowski 2012; Noble & Fulton 2017).

Crayfish are known to be particularly sensitive to chemical pollutants and pollution is often cited as a contributing factor in their decline. Widespread use of pesticides during the 1950s likely contributed to abrupt population declines (Geddes 1990; Geddes et al. 1993). However, an understanding of the sensitivity and thresholds of Murray crayfish to agricultural chemicals and pesticides, remains lacking (Gilligan et al. 2007; Zukowski et al. in press). This species has the capacity for short-term emersion to avoid adverse conditions, however mortality can result from periods out of the water due to desiccation, predation and illegal collection (McKinnon 1995).

A sentinel species

Given its high level of vulnerability and sensitivity to environmental conditions, Murray crayfish also serve as important 'environmental indicators' of water quality and the condition of aquatic habitats. Furse and Coughran (2011c) flag that *Euastacus* species, in general, will likely be the first to be broadly impacted by the combined effects of various threats (i.e. increasing temperature and dryness, reduced flow, land use practices, invasive species, etc.) and should be considered a 'sentinel' genus that could serve as an early warning indicator for other native

fauna. The fact that Murray crayfish has been extirpated within the ecological community for decades represents such a warning.

History

Once common and widespread, the Murray crayfish has suffered considerable declines throughout its range in distribution and abundance, particularly in the region of the ecological where it is assumed to be locally extinct or extirpated (e.g. Whiterod & Zukowski 2017). Historical records indicate the species occurred as far downstream as Murray Bridge (Geddes 1990) and even Pomanda Point in Lake Alexandrina in the 1960s (Warneke 2000 in Whiterod & Zukowski 2019). Early explorer John Eyre, observed in the Lower River Murray that First Nations peoples could readily harvest the species by spear and hand in clear, shallow water, which attests to how plentiful it once was (Eyre 1845 in Whiterod & Zukowski 2019). Furthermore, the species was in sufficient abundance to support a commercial fishery as well as recreational harvesting the Lower River Murray during the 20th century (Geddes et al. 1993; Gilligan et al. 2007; see Table 32).

Declining trends and extirpation in the EC

Murray crayfish has not been officially detected in the South Australian section of the River Murray for more than 40 years (Zukowski et al. in press). The history of decline and disappearance of this species from the ecological community is outlined in Table 32, which also includes the conservation status in each jurisdiction in which it occurs/occurred.

The declining trend of Murray crayfish over the past 50 years throughout the Murray-Darling Basin has been attributed to threats such as overfishing (largely historical), poor water quality, habitat disturbance, and environmental changes related to flow regulation and dislocation by weirs (Gilligan et al. 2007; Walker et al. 2009; Whiterod & Zukowski 2019). Fishing (commercial and recreational) has been banned in South Australia since 1989, however there has been no recovery of Murray crayfish reported. Recreational fishing of Murray crayfish still occurs under regulations in Victoria and New South Wales (Whiterod & Zukowski 2017; Forbes et al. 2019)—and therefore, potentially within the NSW and Victorian reaches of the ecological community (i.e. should Murray crayfish occur there).

There has been no recovery in South Australia reported, despite intensive targeted surveys being undertaken to detect Murray crayfish (Whiterod & Zukowski 2019). Following much research, Whiterod et al. (2018) called for greater emphasis on conservation of the species, and a precautionary approach to recreational fishery management in order to promote recovery and sustainability.

Walker (1982, 2001) attributed the disappearance of Murray crayfish from the South Australian River Murray to the construction of weirs and subsequent river regulation, which transformed the region into a series of weir-pools, where hydrology (e.g. seasonal flows), hydraulics, sedimentation rates and biofilm composition are all altered from the natural riverine state. In contrast, flow regulation and the construction of weirs have promoted yabbie populations in the river channel within the ecological community, given the yabbies' preferences for warmer, stiller waters (Walker et al. 2009). McCarthy (2005) further demonstrated the avoidance of weir-pool environments by Murray crayfish in the Mallee region, which supports the proposal that river regulation is an important threatening process within the ecological community, by creating barriers to movements and low-flow environments that are unsuitable for Murray crayfish (e.g. Gilligan et al. 2007).

Table 32: History of decline for River Murray crayfish (*Euastacus armatus*) in the ecological community and upstream MDB (after Geddes 1990; McCarthy 2005; Gilligan et al. 2007; Walker et al. 2009; McCormick 2012; Zukowski 2012; Fisheries Scientific Committee NSW 2013; Zukowski et al. in press).

Period	History
	The Murray crayfish is the only described *Euastacus* species west of the Great Dividing Range—of some 50 species in the genus; it is also the largest species in the genus
1800s	• very abundant throughout the Murray-Darling Basin
mid-1800s – 1940s	• significant commercial fisheries (supported by introduction of railway) in New South Wales and South Australia (down to Murray Bridge)
mid-1940s	• range and abundance decreased; market value decreased
mid-1950s – mid-1960s	• professional fishers in SA noted a decline • occasional catches with only a few relict sites where it was common
mid-1960s	• cessation of potting (and related catch information)
1965	• no longer commercially targeted in SA
mid-1960s–1980s	• only occasional specimens caught (recreationally) in SA
1989	• all fishing banned in SA and Murray crayfish declared 'Protected' in SA (*Fisheries Act 1982*) (Note, despite this, no Action or Recovery Plan was developed)
1990	• reported as locally extinct in River Murray downstream of Mildura (Note, that includes the entire length of the Murray within the ecological community) • end of commercial fishery in NSW
1991	• recreational fishery closed in ACT and taking of Murray crayfish prohibited
1997	• listed as Vulnerable in ACT (*Nature Conservation Act 1980*), with Action Plan prepared in 1999
2001	• listed as Threatened in Victoria (*Flora and Fauna Guarantee Act 1988*)
2002	• protected in New South Wales as part of the Endangered ecological community of the Lower Murray River Catchment (*Fisheries Management Act 199*4) • interim order to allow recreational fishing while a Species Impact Statement prepared (As a result of SIS, regulations changed from December)
2003	• Action Statement published in Victoria (*Flora and Fauna Guarantee Act 1988*)
2013	• listed as a Vulnerable Species in NSW (*Fisheries Management Act 1994)*
2018	• Action Plan updated for ACT (*Nature Conservation Act 2014*)
2023	• 200 reintroductions (translocations from upstream blackwater affected populations) conducted at suitable location of SA River Murray (29 animals with a tracking device)

It is also likely that increased sedimentation, which is characteristic of the weir-pools, may impact upon crayfish habitat. Sedimentation was exacerbated during the 1956 floods, when a huge silt burden was deposited and completely filled parts of the channel (Walker 1982). The

silt burden has remained in the river in the absence or reduced frequency of flushing flows (Gilligan et al. 2007).

SA reintroduction attempt

Although numbers of Murray crayfish have declined in both the Victoria and NSW sections of the River Murray over the past 50 years, the species still survives upstream of the ecological community. However, dispersal limitations coupled with its biological traits, suggest that there is limited potential for natural recolonisation following population decline (Whiterod et al. 2016).

Therefore, to re-establish a population of this species in the South Australian section of the River Murray (i.e. within the ecological community) requires human intervention.

The reintroduction of Murray crayfish back into the SA section of the River Murray was first proposed in the 1980s (Geddes et al. 1993), but a comprehensive strategy was not developed until 2019 (Whiterod & Zukowski 2019). Subsequently, an opportunity arose to undertake translocations following the 2022-23 large-scale floods and blackwater event across the southern Murray-Darling Basin (Zukowski et al. in press). Of the many crayfish rescued from hypoxic waters upstream of the EC and later returned, about 200 were retained and housed in aquarium facilities. Subsequently, a range of sizes and sexes were released in suitable habitat in an undisclosed location within the South Australian River Murray system, from April to August 2023 (Zukowski et al. in press). This included 29 animals fitted with transmitters to track activity and survival before their next moult. At early April 2024, the tracked individuals were surviving but were due to moult (and lose their tracker) around mid to late April (Zukowski et al. in press).

Overall, there have been very severe declines in Murray crayfish and it is not likely to be possible to restore to normal the major functional role it plays in the ecological community in the immediate future.

Question/Request

Any further recent references or information related to Murray crayfish within the EC that are currently not included within this Draft Conservation Advice, would be welcomed (e.g. further information on the result of the 2023 translocations).

KEYSTONE GRAZER DETRITIVORES - THE SUITE OF NATIVE FRESHWATER SNAIL SPECIES

Native freshwater snails (8 Families; min. 16 species)

Key functional role: grazer detritivores - converting primary and microbial production into secondary production

Key vulnerabilities: dependent on high nutritional diet from microbial based biofilms; (see Table 17); some species with limited dispersal ability; need slow flow or still waters

Key impacts on species: long-term recruitment failure; decline in abundance and range; regional extinctions of some species; loss of food source

Likely causes: changed habitat and food availability due to regulation; predation by common carp; competition with alien snails

Key impacts on EC: foodweb impacts; loss of biodiversity; opening niche for non-native alien species that degrade the natural habitat; climate change impacts exacerbated (e.g. heat, drying, flood impacts); climate change impacts exacerbated (e.g. heat, drying, flood impacts)

Indicative conservation status within the EC: Critically endangered

The ecological community formerly supported at least 18 native freshwater gastropod snail species from eight families (Sheldon & Walker 1993; Ponder & Walker 2003; Table 33). There is doubt over the precise number due to the paucity of early collections and recurrent taxonomic issues (Sheldon & Walker 1993; Ponder & Walker 2003). Freshwater snails (Mollusca, Gastropoda) include caenogastropods (formerly 'prosobranchs') with gills and an operculum to close the shell aperture, and pulmonates with a vascularised 'lung' to aid respiration but without an operculum (Walker et al. 2009, 2018). In general, the operculate species prefer flowing, well-oxygenated water, and the pulmonates inhabit wetlands where oxygen levels and other conditions vary (Walker et al. 2009, 2018).

All freshwater snails are grazers, equipped with a radula to scrape bacteria, algae and detritus from submerged surfaces. Evidence from analysis of gut and faecal pellets, and stable carbon isotopes, shows that these taxa are 'detritivores', feeding mainly on amorphous organic detritus and algae, bacteria and fungi as 'biofilms' (Sheldon & Walker 1997). As detritivores, they play a critical role in the aquatic foodweb. Microbial colonisation of detritus and dead leaves that fall into streams is a significant pathway for energy transfer (Boulton & Brock 1999). In particular, microbial production in the biofilms on leaves, rocks and logs is important, and along with the fungi and algae (e.g. diatoms) that co-occur in the films, is a nutritious food source for invertebrates. The grazing of snails is a vital link in the release and exchange of this energy from biofilms in the aquatic foodweb (Boulton & Brock 1999).

Evidence from various sources, including Aboriginal shell middens, indicates that the freshwater snails were very abundant in the region of the ecological community during the first half of the 20th century (Sheldon & Walker 1993 and references therein). However surveys from the 1980s onwards, of riverine and floodplain environments within the ecological community show that most species have declined sharply in range and abundance or disappeared entirely (Sheldon & Walker 1993 and references therein; see Table 33). Natural populations of nearly all taxa, particularly the caenogastropods *Thiara balonnensis* and *Notopala hanleyi* have declined markedly over the last 50 years throughout the Murray-Darling Basin (Sheldon & Walker 1993; Holmes et al. 2013; FSC 2015; DISRD 2018). These two species are considered to be regionally

extinct in the wild (Table 33) and within the ecological community (Holmes et al. 2013). As of the mid-1990s, the only native gastropod taxa that remain common and widespread in the ecological community are the freshwater limpets (Ancylidae) (Botting 1995 in Ponder & Walker 2003).

The decline of an entire functional (taxonomic) group is evidence of profound changes in the river environment. Importantly, some of the snail species still occur in the Murray upstream of the junction with the Darling (Bennison et al. 1989), suggesting that the decline in the ecological community is at least partly due to local factors (Sheldon & Walker 1993). The decline in freshwater snails in the ecological community has paralleled intensified flow regulation and is most likely due to changes in the composition of biofilms, predation by common carp, and changes in connectivity between the river and its floodplain wetlands (Walker et al. 1992, 1994, 2009, 2018):

- Before regulation, prior to the 1920s, littoral biofilms were dominated by microbial biomass, as fluctuating water levels and high turbidity would have limited algal growth and maintained the biofilms in a state of early succession (Sheldon & Walker 1997). However, by stabilising seasonal water levels, regulation would have promoted the growth of filamentous algae. Biofilms that are predominantly algal rather than bacterial are a much less-nutritious food source for detritivorous snails (i.e. high C:N ratio, Sheldon & Walker, 1997; Walker et al. 2009). The dark confines of the irrigation piplines, where some species have found refuge, have bacterial-dominated biofilms and the snails are much less prone to predation by carp (Sheldon & Walker 1997; Holmes et al. 2013).

- The European carp (*Cyprinus carpio*) has attained very high numbers within the ecological community, especially after the floods in 1974-75 (Koehn et al. 2000, 2004). Carp is an indiscriminate feeder on benthic (bottom dwelling) animals, including snails (Walker et al. 2009).

- River regulation and diversions for irrigation have depleted and changed seasonal patterns of flow. This has led to changed connectivity between the river and floodplain which has isolated the channel, the main corridor for dispersal of flora and fauna, from many of the wetlands that are nurseries and refuges for snails and other species (Walker et al. 2009; FSC 2015; DISRD 2018).

It is also likely that the increasing presence of invasive (alien) snail species is exacerbating the above impacts through competition and growth suppression, for example, competition between the European pond snail *Physa acuta* and native species (Zukowski & Walker 2009).

Overall, there have been very severe declines in snail species and it is not likely to be possible to restore to normal the major functional role they play in the ecological community in the immediate future.

Table 33: History and status of freshwater snails recorded from the RMDS EC. All formerly abundant but many are now rare or regionally extinct. Most families need taxonomic revision, with many confusing synonymies in older literature. (EMLR = streams of the Eastern Mount Lofty Ranges).

Family	Species	Notes	Status	Key reference/s
Bithyniidae	*Gabbia ventiginosa*	• Found in irrigation pipeline at Renmark, 1984	• Uncommon	Sheldon & Walker 1993; Ponder & Walker 2003
Hydrobiidae (operculate snails)	*Fluvidona angasi* *Austropyrgus* sp. *Posticobia* sp. **Potamopyrgus antipodarum*	• *Austropyrgus angasi,* irrigation pipelines at Waikerie & Cadell, 1990-92 • *Austropyrgus*: Marne and Somme rivers, creeks of EMLR • *Posticobia*: rare in wetlands from Murray Bridge to Woods Point • New Zealand mudsnail *P. antipodarum* (syn. *P. jenkinsi*, *P. niger*)	• Rare; relict populations in pipelines • Mudsnail - common alien	Sheldon & Walker 1993; Walker et al. 2009
Lymnaeidae	*Austropeplea lessoni* *A. tomentosa* **Lymnaea stagnalis*	• Species of Austropeplea, esp. A. tomentosa, are vectors for common liver fluke (Fasciola hepatica) • Most regional records from Mannum to Tailem Bend • *L. stagnalis* (mudsnail) is an alien northern hemisphere species	• Rare • *L. stagnalis* - common alien	Walker et al. 2009
Planorbidae (pulmonate or non-operculate snails)	*Glyptophysa aliciae* *G. connica* G. gibbosa *Gyraulus meridionalis* *Helicorbis* sp. *Isidorella newcombi* *Helicorbis australiensis* *Ferrissia petterdi*	• Occasional records of *G. connica*, *Gyraulus meridionalis* since 1980s • *G. aliciae*: Calperum, Chowilla, Tailem Bend • *G. aliciae*: irrigation pipelines at Renmark,1984 • *Isidorella*: Pilby Creek, Marne River, Reedy Creek • Gyraulus and *Helicorbis*: few floodplain sites below Mypolonga • Growth of *Glyptophysa* may be suppressed by *Physa acuta* • Tiny species (syn. *F. tasmanica*), on snags, rocks, water plants • Irrigation pipeline at Renmark, 1984	• Rare	Sheldon & Walker 1993; Walker et al. 2009; Zukowski & Walker 2009
Physidae	**Physa acuta*	• European pond snail, resembles native *G. gibbosa*	• Common alien	Walker et al. 2009
Pomatiopsidae	*Coxiella* sp.	• Known only from Salt Creek in EMLR	• Regionally extinct	Walker et al. 2009
Thiaridae	*Thiara balonnensis*	• Last recorded at Morgan, 1982 • Irrigation pipelines, Renmark, 1984; Waikerie and Cadell, 1990-92	• Regionally extinct in wild • May persist in pipelines	Sheldon & Walker 1993; Walker et al. 2009
Viviparidae	*Notopala hanleyi*	• River snail: declined from 1950, no records after mid-1970s • Re-discovered in pipeline near Barmera, 1992 • Introduced to Banrock Wetland on three occasions • Only in artificial habitat – Banrock Station, Kingston Squatters Tank 2013 surveys	• Regionally extinct in wild • Status of captive populations uncertain	Sheldon & Walker 1993; Walker 1997; Ponder & Walker 2003; Holmes et al. 2013

***** non-native (alien) species # pers. communication Dr Winston Ponder, Australian Museum, Sydney

CONCLUSION - CONSERVATION STATUS FOR CRITERION 3

Indicative conservation status assessments for the 9 keystone-type (functionally important) species (or suites of species) are shown above (and see Table 26). It is acknowledged that there have been some improvements, however these have been due mainly to human interventions, such as delivery of environmental water, captive breeding and translocations, and instillation of fishways. It is also yet to be proven that temporary improvements will be able to reverse ong-term declines. Ryan et al. (2021) concluded that while environmental watering has had some positive outcomes for some [threatened] species in some locations on some occasions, the benefits, and their monitoring and reporting, are patchy and inconsistent; further, monitoring of temporal trends in distribution, occurrence and abundance of species is typically inadequate to evaluate success.

Overall, there has been, and remains, widespread declines or losses (extirpations/extinctions) of these important 'keystone-type' species, which represent a wide diversity of taxa and ecological functions within the ecological community. This has occurred throughout the various habitat and georaphical components of the *River Murray - Darling to Sea* ecological community, and has often combined with significant, sometimes catastrophic (e.g. during drought), and in many cases, ongoing, recruitment failure or exacerbation of threats.

Therefore, a conservation status of **Critically endangered** is indicated, as the decline is very severe and restoration of these species and their functions within the ecological community as a whole is unlikely in the immediate future.

Questions

- *More recent data and analysis on trends will be available soon when Murray-Darling Basin Plan reports are released. In addition to that:*
- *Do you have any feedback on the preliminary assessment under Criterion 3 or further data or information that would support or update the assessment outcomes?*

6.2.4 Criterion 4 – reduction in community integrity

	Category		
	Critically Endangered	**Endangered**	**Vulnerable**
The reduction in its integrity across most of its geographic distribution is:	very severe	severe	substantial
as indicated by degradation of the community or its habitat, or disruption of important community processes, that is:	very severe	severe	substantial
such that restoration is unlikely (even with positive human intervention) within	*the immediate future (10 years or 3 generations up to a maximum of 60 years)*	*the near future (20 years or 5 generations up to a maximum of 100 years)*	*the medium-term future (50 years or 10 generations up to a maximum of 100 years)*

Criterion 4 recognises that an ecological community can be threatened with 'functional' extinction through on-going modifications that do not necessarily lead to total destruction of all components of the community. Where data availability allows, an assessment against this criterion should aim to capture detrimental changes in: the identity and number of component

species, the relative and absolute abundances of those species, and the state of the abiotic environment that supports them. It includes declines and loss (including irretrievable) of native species and invasion by non-native species, as well as changes in critical components of the physical environment sufficient to lead to ongoing changes in the assemblage of biota and/or their ecological function.

Changes in integrity may be measured by comparison with a 'benchmark state' ('reference condition'), particularly if this is known and relevant. They can also be measured by loss, or by a relatively consistent declining trend over an ecologically 'relevant' period.

Criterion 4 recognises that ecological processes are important to maintain an ecological community (e.g. flooding) and that disruption to those processes can lead to a decline in integrity of the ecological community. Importantly, this criterion allows for potential recognition of a problem at an early stage (should that be the case), while also allowing for consideration of inherent variability due to natural dynamics.

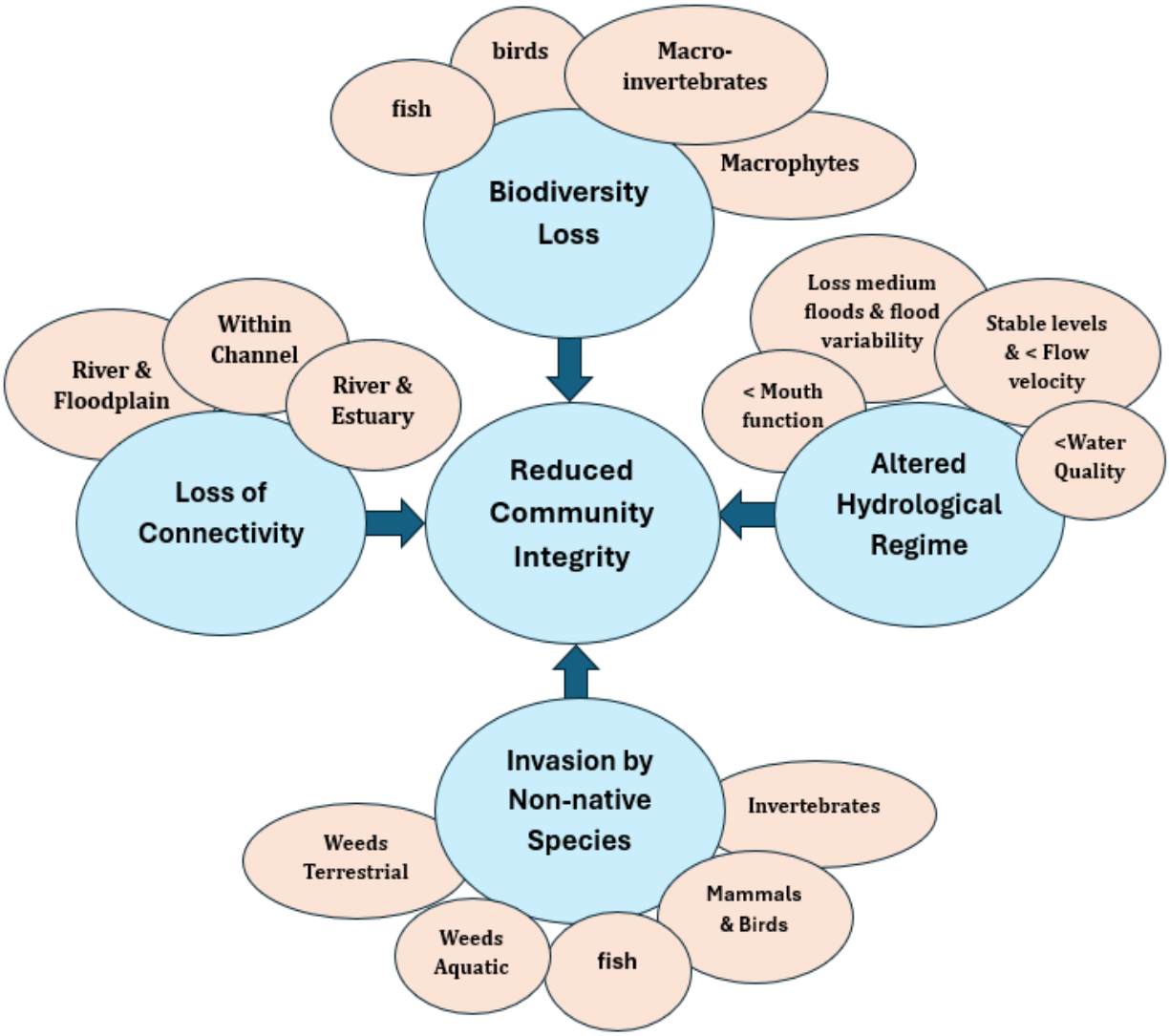

Figure 10: Multiple lines-of-evidence (drivers and/or indicators) considered for assessment against *Criterion 4: Reduction in Community Integrity* for the *River Murray—Darling to Sea* Ecological Community (GM Newton).

For the *River Murray—Darling to Sea* EC, assessment of Criterion 4 takes a multiple lines-of-evidence approach, against four main categories—each with three to five sub-categories (see Figure 10). In particular, the following drivers and indicators of reduction in community integrity are pertinent to this assessment, due to the threats outlined in Table 23.

Overview of Criterion 4 Assessment

1a) Decline in integrity from biodiversity loss

- macrophytes
- macroinvertebrates
- fish
- birds

1b) Decline in integrity from invasion by non-native species

- aquatic weeds
- terrestrial weeds
- common carp & other non-native fish
- feral mammals & birds
- non-native invertebrates

2a) Decline in integrity from altered hydrological regime

- altered flooding regime - loss of medium floods and flooding/flow variability
- increased water level stability and reduction in flow velocity
- decline in functional mouth condition
- decline in water quality (salinity, turbidity, ASS, algal blooms, eutrophication, blackwater, etc.)

2b) Decline in integrity from loss of connectivity

- between river (and tributaries and lakes) and floodplain
- within channel
    - between freshwater sections
    - between freshwater and estuary sections
    - between estuary and adjacent ocean

Note Regarding Criterion 4 parts 1b) and 2a) and 2b)

- *These components of Criterion 4 require further updates.*
- *More recent data and analysis on trends for these aspects of Criterion 4 are expected to become available soon, when Murray-Darling Basin Plan reports are released.*
- *In particular, this relates to the five-yearly Schedule 12 Matter 8 reports from South Australia, and the Matter 7 reports from the MDBA, including underpinning technical reports.*
- *Also expected soon, the latest reports on hydrology and climate change, due under the Murray-Darling Environment and Water Research Program (MD WERP).*

1A) DECLINE IN INTEGRITY FROM BIODIVERSITY LOSS

Loss of Macrophyte biodiversity

History of decline

Herbarium vouchers and annotations suggest that riverine aquatic and semi-aquatic vegetation was historically more diverse and extended into deeper water than contemporary riverine aquatics do (Sainty and Jacobs 1990; Blanch and Walker 1998; Australian Virtual Herbarium, accessed 18/4/2024; and see Appendix B, Table B1). Species such as *Cyperus gymnocaulos*

(spiny flat-sedge), *Eleocharis pusilla* (small spike-rush), *Lythrum hyssopifolia* (lesser loosestrife), *Schoenoplectus tabernaemontani* (river club-rush), *Myrophyllum catput-medusae* (coarse milfoil), *Potamogeton perfoliatus* (clasped pondweed) were all observed and/or vouchered along the river channel prior to construction of the locks. An even greater diversity was observed among the fringing wetlands (see Appendix B, Table B1).

The greatest decline of macrophytes within the river channel and fringing wetlands was experienced by species that did not adapt well to increased sedimentation, were highly palatable to introduced herbivores, required variable water levels or which needed light penetration to the benthic sediments for germination (Sainty and Jacobs 1990; Walker 2006). Water flow and depth variability has a significant impact on aquatic plant composition, with Walker et al. (1994) finding a broad correlation between the composition of the plant assemblages and the distance below a weir (hence the amplitude of water level fluctuation).

Gehrig & Nicol (2010, and references therein) demonstrated for a range of functional groups of plant species, that water regime is the primary driver of plant community composition upstream of the barrages, while salinity was also an important driver downstream of the barrages. Rogers & Ralph (2011) and Kilby & Steggles (2015) provide further useful information on preferred water regimes to support condition and recruitment of key floodplain and riparian flora.

Macrophytes in the Lower Lakes

Prior to river regulation, the Lower Lakes were surrounded by dense beds of reeds and contained extensive macrophyte cover, at least a mile out from shore (Sim & Muller 2004; Nicol et al. 2018; Coleman in press). Construction of the barrages resulted in fresh and relatively stable water levels, however shoreline erosion resulted in almost vertical shorelines in places, which did (does) not favour colonisation of littoral vegetation (Nicol et al. 2018). The areas with greatest abundance and diversity of submerged and amphibious species are fringing wetlands and sheltered areas along the western shoreline of Lake Alexandrina; the northern shoreline of Hindmarsh Island, Goolwa Channel and the lower Finnis River; and lower Currency Creek (Nicol et al. 2018).

Due to the Millennium Drought, there was a complete loss of submergent species (Gehrig et al. 2011a, b), however a viable seed bank remained present in some places (Nicol & Ward 2010). In addition, fringing wetlands in the Lower Lakes and floodplain wetlands upstream of Wellington that were historically permanent, dried up completely. This resulted in the loss of large areas of submergent plant species (e.g. *Vallisneria australis*, *Potamogeton crispus*) and amphibious plant species (e.g. *Myriophyllum* spp.) from these habitats. Importantly, species lost from the permanent wetlands did not colonise the remnant inundated habitats (the main channel and Lower Lakes) (Gehrig and Nicol 2010). Other submergent macrophyte species historically recorded in the Lakes but not observed since 2007 include: *Lepilaena cylindrocarpa* (water mat), *L. australis* (Austral water mat), *Myrophyllum simulans* (amphibious water milfoil), and *Ranunculus trichophyllus* (thread-leaf crowfoot) (Nicol et al. 2018 and references therein).

At the end of the drought, increased inflows breached the Clayton regulator and Narrung bund (i.e. structures put in place during the Millennium Drought to assist raising water levels in the Goolwa Channel and Lakes) and enabled reconnection throughout the Lower Lakes (Nicol et al. 2018). Resulting water levels have since been maintained between 0.4 and +1 AHD and salinities reduced, which has helped to increase abundance of submergents in Lake Alexandrina and adjacent wetland habitats (Nicol et al. 2017; DEW 2023e). However, on balance long-term

declines of macrophytes have very severely impacted community integrity and disrupted ecological processes over extended periods, with recovery not possible in some areas, and unlikely in other areas.

Macrophytes in the Coorong

The Coorong component of the ecological community is an internationally recognised, ecologically significant coastal lagoon. Its dense macrophyte sub-community was (and remains) the primary food source for the vast numbers of waterfowl once common on the Coorong (Delroy 1974), as well as for fish and other grazing species. Dense macrophyte stands increase the resilience of coastal lagoons to climate change, while clarifying and cooling the water column, shading dark sediments, and reducing both inorganic and planktonic turbidity. Historically, the macrophyte sub-community of the Coorong was known to stabilise, oxidise, and reduce nutrient release from sediments (Waycott et al. 2023; Coleman in press). However, this estuarine component of the ecological community has experienced major changes in plant composition since regulation—associated mainly with increased salinity, changes in water chemistry, unseasonable variation in water depth, turbidity, nutrients, sedimentation, and grazing pressure from birds (Dick et al. 2011; Hunt et al. 2019).

Prior to 1978, a diverse macrophyte cohort covered more than 60% of the submerged Coorong sediments (including areas as deep as 4 metres) and these filled a range of key ecological functions as outlined above (Coleman in press; Appendix B, Table B1). Deeper-water macrophyte communities are currently almost entirely restricted to propagation material within the sediment of the South Lagoon, likely due to salinity stratification (Waycott et al. 2023; Coleman in press). Decades ago, this component of the community had more standing biomass and denser stands than their shallow water counterparts. These deepwater macrophyte stands were once up to 2.4 m tall and would have utilised vast amounts of nutrients from the water column (Coleman in press).

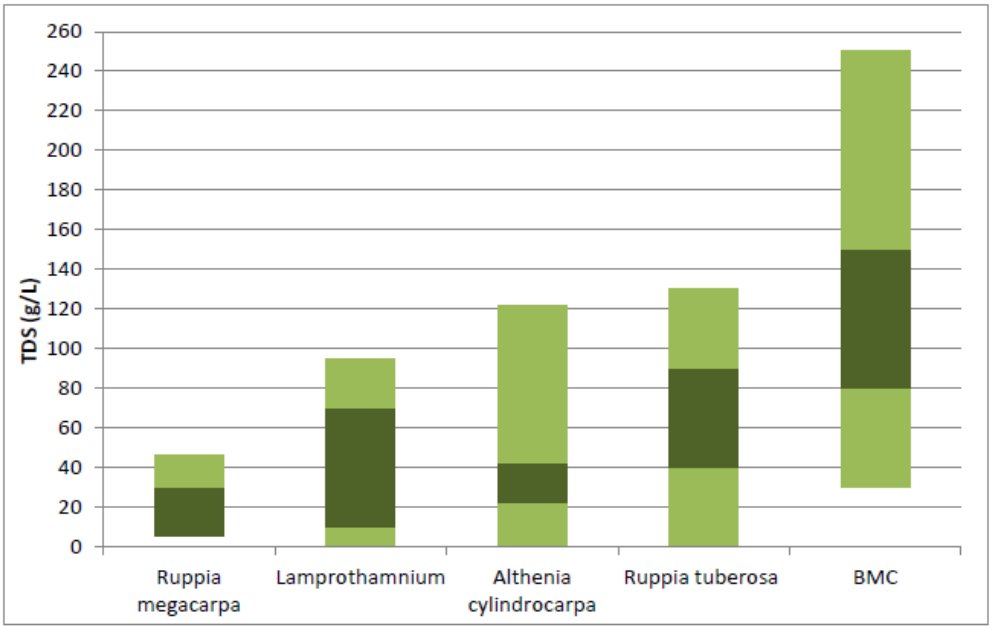

Figure 11: Macrophytes in the Coorong - salinity ranges required for species growth and reproduction, with optimal range in dark green and tolerated range in light green; BMC is Benthic Microbial Communities, which often provide sediment cover in hypersaline environments (Coleman in press).

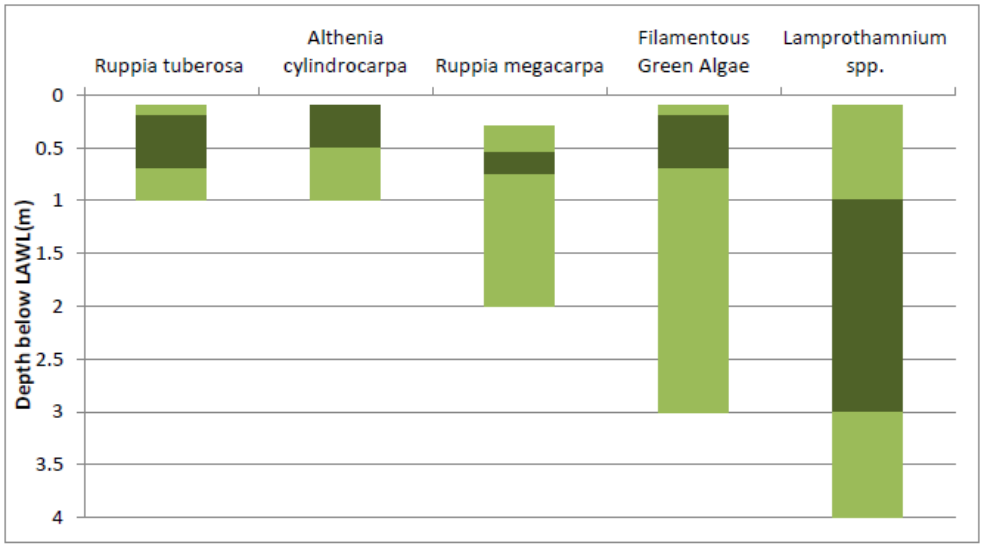

Figure 12: Depth below lowest average water level (LAWL) for growth and reproduction, with optimal range in dark green and tolerated range in light green (Coleman in press).

Specific salinity and depth tolerances of key macrophyte species are shown in Figures 11 and 12. While each macrophyte species has its own tolerances, the macrophyte community is generally only found in salinities from about 10–70 g/L, with higher salinities only tolerated for short periods, and then by the most tolerant of species (note, seawater is around 35 g/L Total Dissolved Solids). When salinities exceed the preferred salinity range, the species will usually persist as reproductive material within the sediment (Coleman in press). There is also, typically, a preferred depth range.

As discussed in Criterion 3 for *Ruppia*, the South Lagoon of the Coorong has switched to a plankton/filamentous alga dominated system. Light-dependent macrophytes have been light-limited by high turbidity (i.e. due to plankton blooms and increased sedimentation), in addition to shading by filamentous algae (Nicol et al. 2018; Waycott et al. 2022; Coleman in press). Concomitantly, increased sediment anaerobia, hydrogen sulfide generation, and poor structure impedes rooted macrophytes from persisting in deeper, clearer waters (Mosley et al. 2020). While historically the waters of the Coorong were much clearer, macrophytes are currently mainly growing in the littoral and tidal zone, Salt Creek, fringing ephemeral lagoons, or where freshwater springs pool (i.e. rather than in the deeper parts of the Coorong) (Coleman in press). However, here, the macrophytes are more vulnerable to higher temperatures, water level changes, and risk desiccation.

Deline in Diversity – Angiosperms in the Coorong

Notwithstanding recent taxonomic reviews are likely to reveal more species (e.g. Lewis et al. 2022 *Ruppia* sp. nov.; Coleman in press), at least 14 known species of submergent macrophytes have been documented from the Coorong lagoons (Coleman in press; Appendix B, Table B1). A dramatic loss of macrophyte species diversity has occurred, for example, from at least four angiosperm taxa and four calcifying macroalgae taxa prior to the 1970s, down to two angiosperm taxa in the present-day South Lagoon (Coleman in press). In particular, there has been significant loss and decline for the two previously dominant macrophytes in the Coorong system (and see Criterion 3):

- *Ruppia megacarpa* is now 'functionally extirpated' in the North Lagoon, although Lewis et al. (2022) reported finding seeds in a 2019-2022 sediment survey (10% of *Ruppia* seeds, however it was unclear as to which lagoon these were from). Of note, is that its decline commenced prior to the Millennium Drought and that this species does occur in some wetlands adjacent to the Coorong (DEW 2021).

- *Ruppia tuberosa* (surrogate for the 'Ruppia Community', which includes another angiosperm—*Althenia*) was significantly impacted by the Millennium Drought and all but disappeared from the South Lagoon (Nicol et al. 2018; Waycott et al. 2022). Recovery after the drought has been slow and patchy, and the seed bank remains low and 'not resilient' (Nicol et al. 2018; Asanopoulos & Waycott 2020; Lewis et al. 2022). In addition, seasonal blooms of filamentous algae are interfering with the reproductive outputs *of R. tuberosa* (and *Althenia*) (Waycott et al. 2022).

Asanopoulos and Waycott (2020) observed that suitable salinities for *Ruppia megacarpa* and *Ruppia polycarpa* now occur within the Coorong at times, yet neither species has reappeared within the main waterbody. Additionally, there has been major loss of *Zostera muelleri* (estuarine sea grass) meadows from the North Lagoon (DEW 2021), with it only recently found as remnants around the Murray Mouth (Lewis et al. 2022).

Decline in Diversity – Calcifying macroalgae in the Coorong

The South Lagoon of the Coorong is considered to have transitioned from a clear-water to a turbid state in around 1976-78, which coincided with an observed shift in dominance from the charophyte *Lamprothamnium papulosum*, (foxtail stonewort) to filamentous green algae (likely Cladophor sp.), in deeper waters (Coleman in press). Stoneworts are green, calcifying macroalgae that represent an important food resource for many waterbird species (Womersley 1975; Fox & Stipniece 2024).

Dick et al. (2011) found *Lamprothamnium* oospores through the equivalent of 3,600 years of a single sediment core within the South Lagoon. Further, sediment core studies found that calcified oospores of *Lamprothamnium* continued to decline throughout the 1960s and 1970s (Reeves et al. 2015). The spore-bank of viable desiccation-tolerant *Lamprothamnium* oospores can survive decades or more, to re-establish populations once a wetland is inundated (Casanova 2013). During their 2019-2022 survey of the Coorong, Lewis et al. (2022) found only a few, and very unhealthy, specimens of *Lamprothamnium* amongst filamentous algae samples.

Although not monitored or as widely reported on as was *Ruppia* over the past several decades (e.g. Coleman in press), Lewis et al. (2022) noted that the loss of *L. papulosum* could be indicative of the decline in water quality in the South Lagoon. For example, calcifying macroalgae precipitate calcium phosphate deposits, binding phosphorus in dense sedimentary beds of calcium carbonate rich 'marl' over millennia, thus removing phosphorus from the water column (Dick et al. 2011). Fox & Stipniece (2024) concur that charophytes are ideal indicator species of ecological change.

The loss of calcifying algae within the ecological community, such as *L. papulosum*, and *Acetabularia peniculus* (balloon tops, not observed in the South Lagoon since 1979; Appendix B, Table B1) would have contributed to the current turbid, nutrient rich conditions. The loss of these important calcifying macrophyte taxa is related to changing water chemistry, including higher acidity and salinity (i.e. increases in sodium and chloride and decreases in magnesium,

sulphate and calcium). In addition, within the South Lagoon, the decrease in dissolved inorganic carbon and increase in organic carbon over the past seventy years has resulted in a low aragonite saturation state, which limits the ability of calcifying algae to bind excess phosphorous and photosynthesise (Coleman in press).

Importantly, Lewis et al. (2022) stressed that, going forward, the mixed community of aquatic macrophytes found in the 'Ruppia Community' should be managed to maintain the mixed assemblage rather than one dominant species (i.e. *R. tuberosa*).

Loss of Macroinvertebrate biodiversity

Overview

Macroinvertebrates typically occur in three main habitats—benthic (bottom-living), pelagic (open-water), and littoral (lake/stream-edge). Of these, the littoral habitat typically has the richest species diversity, with species composition influenced by the type and amount of aquatic vegetation. Therefore, loss and decline in emergent and submergent plants will translate to loss and decline in a considerable portion of the macroinvertebrate biodiversity (see Macrophyte biodiversity section above).

Macroinvertebrates are susceptible to catastrophic damage whenever flows cease to connect the River, Lakes, and sea for extended periods of time (Walker et al. 2018). Flows from the highly turbid Darling River can also affect invertebrate communities in the Murray channel and adjacent wetlands of the ecological community, and when the Darling River's contribution is increased by regulated flows from Lake Victoria (via Rufus River), the abundances of many species decline (Blanch et al. 1999). This may reflect a loss/degradation of aquatic plants and habitats for macroinvertebrates due to increased turbidity and lowered underwater light, lack of variability in water level, and, the possibility of pesticide contamination (Bennison & Suter 1990; Walker et al. 2009).

Freshwater macroinvertebrates

In May 2006, the Sustainable Rivers Audit sampled the Lower Murray Valley which overlaps with much of the ecological community (i.e. River Murray from lock 10 below the confluence with the Darling River, down to the Murray's entry to Lake Alexandrina and including the tributaries of the Eastern Mount Lofty zone) for macroinvertebrates. They were found to be in 'Poor Condition' in the Upper and Mt Lofty zones, and in 'Very Poor Condition' in the Lower and Middle zones (Davies et al. 2008, 2010, Table 34).

While most (82%) of the expected families were recorded in the Valley in 2006, family richness was less than the 'Reference Condition used for 98% of the 33 sites sampled (Davies et al. 2008). Diversity was moderate to low, with the most diverse sites occurring in the Mt Lofty zone. The Murray sites generally had impoverished macroinvertebrate communities but retained most disturbance sensitive families (Davies et al. 2008). For SRA 2, sampled towards the end of the Millennium Drought, 2008-10, although benthic macroinvertebrates had a higher overall rating of 'Moderate' (Table 34), there were substantial declines in the frequency and occurrence of expected macroinvertebrate families. Family richness was low, particularly as compared to Reference Condition (Davies et al. 2012).

In 2003-2004, before the worst impacts of the Millennium Drought, macro-crustaceans collected from Lake Alexandrina were: the amphipods *Austrochiltonia* and eusirids, the isopod *Heterias*, and the decapods *Paratya*, *Caridina*, *Macrobrachium*, *Amarinus* and *Cherax* (McEvoy & Oxley 2013). However, by 2009-10, just prior to the end of the drought, amphipods were the only

Table 34: Summary of Sustainable Rivers Audit 1 & 2: 2004 – 2010, Outcomes for 'Lower Murray Valley' (i.e. overlaps with RMDS EC) (Davies et al. 2008, 2010).

Indicator	Condition Status	Outcome SRA 1: 2004-2007	Condition Status	Outcome SRA 2: 2008-2010
Hydrology	**Poor**	Condition of the Lower Murray was Poor throughout, with Hydrology Index scores of 50–60. High-flow magnitudes reduced by 69–88%, 66% and 68–69% in the Upper, Middle and Lower Zones, respectively. Reductions in magnitude of low flows by 45-58% in all 3 mainstem Zones. All sites showed a 31–40% decline in variability. All sites showed a Moderate Difference from Reference Condition in seasonality. All sites showed a Very Large Difference from Reference Condition. No data available for the streams of the Mt Lofty Zone.	**Very Poor**	The river system's Hydrology was in Very Poor condition, with the mainstem River Murray reaches in Extremely Poor condition and characterised by substantial alteration in flow variability, flow seasonality and high flow events relative to Reference Condition; and considerable alteration in flow gross volume and low flow events in the main channel.
Riverine Vegetation	N/A	N/A	**Poor**	[Lower zone: Extremely Poor; Middle zone: Good; Upper zone: Good; Mt Lofty zone: Extremely Poor]. Reduced abundance, stability, nativeness, & structural integrity in the Near Riparian and Lowland Floodplain domains, and minor to no increase in fragmentation in the Lowland Floodplain.
Benthic Macro-invertebrates	**Poor – Very Poor**	The Lower and Middle Zones were in Very Poor Condition, and the Upper and Mt Lofty Zones in Poor Condition. Most sites had impoverished faunas but retained many of their disturbance-sensitive families.	**Moderate**	[Mt Lofty zone: Good; Lower zone: Poor; Middle zone: Moderate; Upper zone: Moderate]. Substantial declines in the frequency and occurrence of expected macroinvertebrate families. Family richness generally was low and was also low compared to Reference Condition.
Fish	**Poor**	Only 40% of predicted native species were caught, although 'Nativeness' was increased by the abundance of native fish. The Mt Lofty Zone was drought–affected, and the community there was different from those in the weir– pool habitats of the Murray. Thirteen predicted species that require access to the estuary were missing, due to the barrier effect of the barrages. The community had lost much of its native species richness and its biomass was dominated by alien fish.	**Poor**	[Lower zone: Poor; Middle zone: Poor; Upper zone: Poor; Mt Lofty zone: Extremely Poor]. Some expected species were absent. Species count and abundance were dominated by native species, but biomass was dominated by aliens; recruitment levels among the remaining native species were high. The Valley had lost much of its native species richness and alien species contributed over 69% of fish biomass. Native fish recruitment was Very Poor in the Mt. Lofty zone and Poor to Moderate in the Upper, Middle and Lower zones of the River Murray, respectively.
Ecosystem Health	**Poor – Very Poor**	The Lower Murray Valley river ecosystem was in Poor Health [Lower and Middle Zones: Very Poor; Upper and Mt Lofty Zones: Poor]. If Mt Lofty Zone excluded, the rating is Very Poor. Fish abundance dominated by native species in all Zones, but biomass dominated by alien species, and most expected species absent. Most expected macroinvertebrate families absent from the Murray and Mt Lofty Zone, and many disturbance-sensitive families absent. The regime had substantial long-term reductions in the magnitudes of mean and median annual flows and high flows, with substantial changes in variability and moderate changes in seasonality.	**Poor**	[Upper: Moderate; Middle: Poor, Lower and Mt Lofty: Very Poor] Hydrology was the worst out of the 23 SRA Valleys. But it ranked 7th in terms of Ecosystem Health. The physical form of the river system was in Moderate condition, with bank dynamics in Good Condition and channel form and bed dynamics in Moderate condition. There were moderate to high levels of sediment delivery to the floodplain.

crustaceans collected, probably due to high salinity; once floodwaters entered the region in late-2010, isopods and decapods slowly recolonised to regain former diversity by about 2014 (Walker et al. 2018). While re-establishment of many aquatic species began soon after the end of the extended Millennium Drought in the Lower Lakes, recovery was incomplete after four to five years, and many groups and species remained absent or had restricted distributions compared with what was known prior to the drought (Walker et al. 2018).

Contemporarily, the deeper parts of Lake Alexandrina (max. depth 4 m) and Lake Albert (max. depth 2 m) are sparsely populated by macroinvertebrates—i.e. in alignment with contemporary macrophyte distribution. The freshwater submerged aquatic plant communities that were once extensive in the Lakes are now restricted to near-shore habitats due to higher turbidity and light limitation (Sim & Muller 2004; Coleman in press). Additionally, little is known about the macroinvertebrates that live in the shallow freshwater wetlands (some ephemeral) that surround the Lakes (Walker et al. 2018), however these areas would be highly susceptible to evaporation and drought. An exception may be for spring-fed wetlands, which may then constitute a refuge.

Snails: There has been widespread loss and decline in the high biodiversity and abundance of freshwater snails that once occurred in the ecological community. Of some 18 species, none are common, with many now rare or with limited patchy distribution. At least two species are confirmed as regionally extinct. Conversely at least three species of non-native snails are now common. See also Criterion 3, Table 33.

Mussels: Freshwater mussels are important ecosystem engineers in rivers and lakes and serve a key role in transferring suspended material from the water column to the benthos, thus influencing water clarity, production, biogeochemical cycles, and sedimentation rates (Vaughn 2018).

The two main species of freshwater mussels within the ecological community have been impacted by the series of weir-pools created by the ten locks in the River Murray below the junction with the Darling River (Table 4). This has allowed *Velesunio ambiguous* (floodplain mussel; prefers slow flowing to still waters) to extend its range, whereas the range of *Alathyria jacksoni* (river mussel, prefers flowing waters) has diminished (Walker 2006; Walker et al. 2009, 2018). *A. jacksoni* is currently listed as data deficient on the IUCN Red List, however recent surveys in the northern MDB indicate that *A. jacksoni* is in severe decline after the 2019-20 drought (Sheldon et al. 2020) and an update of its conservation status is underway (Klunzinger 2023).

Freshwater mussels vary in their physiological tolerance of emersion and response to habitat drying, with those that use their muscular foot to burrow into sediment often more tolerant of desiccation than species that simply horizontally track receding water (Wright et al. 2024). *A. jacksoni* is less tolerant to drying, and therefore drought, compared to *V. ambiguous*, however both species experience mortality at prolonged temperatures greater than 35 °C (Wright et al. 2022). As a result of the Millennium Drought, mass mortality of mussels occurred throughout the ecological community, with the large beds around Lake Alexandrina the most obvious (Walker et al. 2018). This was likely due to increased salinity, as the salt tolerance of *V. ambiguous* is quite low (Walker pers. obs.) in addition to low lake levels and acid sulphate soils (Mosley et al. 2014). There have been recent signs of recolonisation in the Lake (which has been likely via their larvae which parasitise fish) (Walker et al. 2018).

Crayfish: The largest macroinvertebrate, one of only two crayfish species to occur within the ecological community, the once-common *Euastacus armatus* (Murray crayfish), has been locally extinct for some 35 years. As with the freshwater mussels, the weir-pools have favoured *Cherax destructor* (yabby), a native lentic habitat specialist which has extended its range from the floodplain habitats, at the expense of the Murray crayfish, a lotic specialist (Walker et al. 2009, 2018).

In addition to occurring in the main river and streams within the ecological community, the yabby historically supported a small but locally important commercial fishery in the Lower Lakes with a catch of > 100 t/y (Walker et al. 2018). However, the fishery declined during the late 1970s due to a number of implied causes, such as over-fishing, competition with introduced fish species, and the reduction in flooding through the regulation of water levels in the River Murray (Walker et al. 2018). While yabbies remain broadly distributed across the region, numbers are considerably lower than they once were, with an average commercial catch of only about 6 t/y for the past 30 years (Walker et al. 2018). Walker et al. (2018) urge the Lower Lakes should be maintained above sea level, to ensure that the habitat needs of freshwater species, such as the yabby, are met into the future.

Supported by several years of research, there are current attempts (May 2023, 2024) to reintroduce the Murray Crayfish back into the South Australian River Murray (Zukowski in press; see Criterion 3).

Estuarine macroinvertebrates

Estuarine macroinvertebrates of the Coorong and Murray Mouth components of the ecological community are a vital food source for fish and birds, particularly migratory shorebirds (many of which are under international agreements). Salinity is the strongest environmental determinant influencing distribution of macroinvertebrates; a salinity threshold of 64 g/L (ppt) separates communities in the Murray Mouth and parts of the North Lagoon from a hypersaline community found in the southern reaches of the Coorong (Dittmann et al. 2015). Highest numbers and biomass of macroinvertebrates, including 'deep-large' taxa, occur in the Murray Estuary and North Lagoon (Dittmann et al. 2022). Species diversity is low in the South Lagoon, where the macroinvertebrate community is dominated by chironomid larvae (Dittmann et al. 2022, 2023).

Water regulation and construction of the barrages constrain river flows reaching the Murray Mouth and Coorong; periods occur with low or no flow over the barrages, which exacerbates drought conditions, when occurring (Dittmann et al. 2018). During a drought, extreme hypersalinity affects a wider area and lower water levels lead to long-term exposure of mudflats—both impact macroinvertebrate habitability and abundance. If drought conditions persist for several years (i.e. as per the Millennium Drought) macroinvertebrate distribution ranges and abundances decline, and some species may not persist (Dittmann et al. 2018).

Recovery of macroinvertebrates can take years, depending on species-specific responses and post-drought flows. Many macroinvertebrate species have low dispersal abilities. Typically, amphipods respond quickly to freshwater inflows, but for most other taxa there is a time-lag; this is influenced by life-history, tolerance to salinity and dissolved oxygen, and habitat suitability (Geddes 1987; Dittmann et al. 2015). Surveys after the drought-breaking flood of late-2010-11, indicated that sediments in deeper sections can function as a refuge during a drought, or flood event, and provide a source for macroinvertebrate recolonisation of near-shore sediments (Dittmann et al. 2016). However, for some taxa, dispersal from estuaries further afield may account for their delayed return to the system (Dittmann et al. 2018).

Under drought conditions, overall numbers of macroinvertebrates are low with a few larger-bodied organisms occurring, whereas under flood conditions small-bodied opportunistic species tend to be abundant (Dittman et al. 2018). Dittmann et al. (2015) demonstrated that continuity of flow over the barrages (i.e. of intermediate to above average flow volumes) is needed to sustain macroinvertebrate communities and thus food supply for fish and birds in the Coorong. Under estuarine-marine conditions with more continuous river flows, a more functionally diverse and abundant benthic macroinvertebrate sub-community occurs (Dittmann et al. 2018). With more suitable flows, water levels and salinities occurring in the Coorong, macroinvertebrates are showing signs of recovery after the long drought. Recently, Dittmann et al. (2022) have also found, that macroinvertebrate diversity (individual and biomass densities) is highest at salinities < 40 g/L (ppt). These authors suggest that lowering salinity to below 40 or 50 ppt could have a beneficial outcome for the Coorong food web.

Macroinvertebrates are regularly monitored as part of the Lower Lakes, Coorong and Murray Mouth Living Murray Icon Site for 18 years; a summary of outcomes against targets from 2016–2022 is at Table 35. The macroinvertebrate sub-community in the North Coorong Lagoon has stabilised since 2013 (i.e. post-Millennium Drought) and shifted into a different state of similar abundance (Dittmann et al. 2021, 2022). However, the effects of high nutrient loads and algal matts are leading to deteriorated conditions in the mudflats for macroinvertebrates (Dittman et al. 2022). Filamentous algae mats are often a consequence of eutrophication and can themselves further impact on biogeochemical processes and benthic fauna in sediments (Le Moal et al. 2019 in Dittmann et al. 2021). The high organic matter in mudflats of the South Coorong reflect eutrophic and degraded conditions (Mosley et al. 2020). Deteriorating conditions for macroinvertebrates could increase if filamentous algal mats and eutrophication persist (e.g. Dittmann et al. 2022).

The extended period of high flows from the spring-summer 2022/23 flood resulted in reduced salinities and a shift of macroinvertebrates further south into the northern South Lagoon (Dittmann et al. 2003). Overall, abundances were similar to previous monitoring years (Table 35). However, an autumn post-flood survey (April 2023) revealed a flood related impact on macroinvertebrates in the Murray Mouth region, with flood related water quality and/or sediment deposition as possible causes (Dittmann et al. 2023).

Table 35: Summary table of how monitoring targets have been met in spring/summer for The Living Murray Icon site (LLCMM) that are related to macroinvertebrates; 11 sites monitored, 5 in Coorong's North Lagoon, 2 in Murray Mouth region and 4 in Coorong's South Lagoon; the weather patterns are indicated for each year as per MDBA Report Cards*; the flow categories are defined by total flow per flow year (July to June), with Low = 115 to 600 to 2500 – 7000 GL, and Very High = >12000 GL; Target 4 of the mudflat habitat condition was discontinued in 2022 (after Dittmann et al. 2023).

Monitoring target	2016	2017	2018	2019	2020	2021	2022
Weather pattern	**Floods**	**Dry**	**Dry**	**Dry**	**Moderate**	**Wet**	**Floods**
Flow	**Moderate**	**Low-moderate**	**Low**	**Low-moderate**	**Low-moderate**	**Moderate**	**Very high**
Macroinvertebrates							
1. Species richness increases throughout the Murray Mouth and Coorong.	Partially met	Partially met	Partially met	Partially met	Partially met	Partially met	Partially met
2. Occurrence extends along the Coorong into the South Lagoon	Partially met	Not met	Not met	Not met	Not met	Not met	Partially met
3. Area of occupation exceeds 60% of the sites sampled.	Met	Partially met	Partially met	Partially met	Partially met	Partially met	Partially met
4. Abundance is maintained at, or increases above, reference levels.	Met	Partially met	Partially met	Met	Met	Met	Met
5. Biomass is maintained at, or increases above, reference levels.	Met	Met	Partially met	Partially met	Partially met	Partially met	Met
6. Communities are similar to those occurring under intermediate continuous flows.	Met	Met	Met	Met	Met	Met	Met
Mudflat habitat condition							
1. Habitable sediments are occurring along the Coorong into the South Lagoon.	Partially met	Partially met	Partially met	Partially met	Partially met	Partially met	Partially met
2. Sediments are maintained as fine to medium sands and are mostly moderately well sorted.	Met	Partially met	Partially met	Met	Partially met	Partially met	Partially met
3. Sediment organic matter is maintained.	Met	Partially met	Not met	Met	Partially met	Not met	Met
4. Sediments provide microphytobenthic food for the benthic food web.	Not met	Met	Met	Met	Partially met	Partially met	n/a

* Lower Lakes, Coorong and Murray Mouth Report Card 2022–23 | Murray–Darling Basin Authority (mdba.gov.au)

Loss of Fish biodiversity

Fish trends in the MDB

In 2003, experts estimated that native fish populations in the Murray-Darling Basin (MDB) were about 10% of their pre-European settlement levels (MDBC 2004). In 2020, expert opinion confirmed that native fish populations in the Basin have further declined since that 2003 assessment (MDBA 2020), based on the following:

- an estimated 47% of native freshwater fish species/populations are threatened under national/State lists
- there have been a high number of large-scale fish death events over the past decade; notably in the Lower River Murray in 2010/11 (King et al. 2012; Leigh & Zampatti 2013) and 2016 (Ye et al. 2018), and the lower Darling River in the summer of 2018-19 (AAS 2019; Vertessy et al. 2019), early-2023 (ABC 2023; Williams & Schulz 2023), and early 2024 (ABC 2024)
- due to impacts from a range of threats (see Table 23), many native fish species in the MDB are now restricted in their range and have been reduced to small, fragmented populations (often genetically distinct) that are vulnerable to extreme events (Sasaki et al. 2016; Brauer & Beheregaray 2020; Whiterod et al. 2021; Wedderburn 2022; Beheregaray et al. 2021; and see Criterion 3).

Concomitantly, introduced fish species have continued to prosper (Koehn & MacKenzie 2004; Barrett et al. 2014; Schilling et al. 2024). These trends led to the renewal of a *Native Fish Recovery Strategy* for the MDB, released in mid-2020 (MDBA 2020).

Biodiversity loss in the RMDS EC

Even lower levels of fish populations, i.e. than considered above for the MDB, are likely in the region of the ecological community (Ye and Hammer 2009; Figure 13). Notwithstanding marine strays in the estuarine components of the EC, there have been approximately 47 species of freshwater, estuarine and diadromous fish species recorded within the ecological community, including 21 species of conservation significance (i.e. locally extinct or threatened) and eight alien species (Lloyd & Walker 1986; Hammer & Walker 2004; Hammer et al. 2009, 2012; Ye & Hammer 2009; Bice et al. 2011, 2018; Wedderburn & Suitor 2012; Wedderburn et al. 2017; Thacker et al. 2022a, b; Wedderburn & Bailey 2024). This represents a significant component of the MDB fish fauna.

Key fish species in the ecological community include (and see Appendix B, Table B2):

- ***small-bodied native fish*** (7 species) – flathead galaxias (extirpated), Murray hardyhead, Olive perchlet (extirpated), southern purple-spotted gudgeon, southern pygmy perch, spotted galaxias, yarra pygmy perch (extirpated/extinct)
- ***large-bodied fish*** (8 species) – estuary perch, freshwater catfish, Macquarie perch (extirpated), Murray cod, river blackfish, golden perch, silver perch, trout cod (extirpated)
- ***diadromous fish*** (7 species, including some species from above groups*) – congolli, estuary perch (extirpated), longfinned eel, pouched lamprey, shortfinned eel, short head lamprey; spotted galaxias*.

These fish represent a range of functionally important groups across the geographic distribution and a variety of habitats within the ecological community (including the streams of the Eastern Mount Lofty Ranges). The Lower Lakes harbour the most diverse fish community in the MDB, and thus the EC, because they are inhabited by estuarine, diadromous and freshwater species (Wedderburn and Hammer 2003).

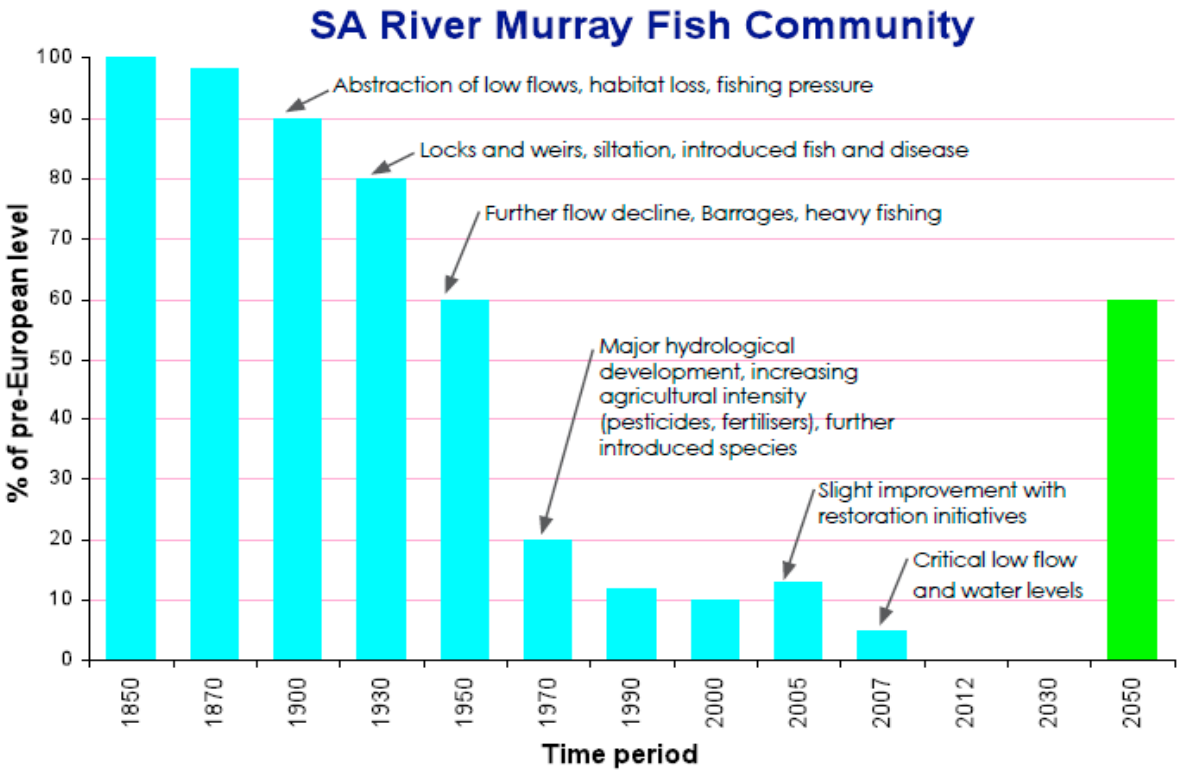

Figure 13: Decline of the SA River Murray fish community since European settlement. The model is developed after the 2003 *Native Fish Strategy* which considered decline in species diversity and abundance of native fish to have reached 10% of pre-European levels for the MDB. The green bar represents the target for restoration under the same strategy (MDBC 2004).

Close to half of the fish biodiversity within the ecological community has some form of recognised 'conservation status, i.e. 21 of 47 species (see Appendix B, Table B2; Hammer et al. 2009; Bice et al. 2011). It has also been depleted by at least five local (or functional) extinctions (i.e. extirpations), with many other species now recognised from records over the past 10–20 years, as very rare and/or restricted in distribution (Appendix B, Table B2)

The loss of fish biodiversity from declines in abundance and extirpations, along with their associated ecological functions, indicate substantial impacts on productivity and trophic structure of the fish assemblage within the ecological community. There are also genetic implications. Genetic variation serves a pivotal role in species viability and resilience, and the maintenance of population genetic variation is essential for conservation (e.g. Lloyd & Walker 1986; Sasaki et al. 2016; Thiele et al. 2019). Threatened species often show reduced genetic variation compared to non-threatened species, and this is considered indicative of lowered evolutionary potential, compromised reproductive fitness, and elevated extinction risk (Sasaki et al. 2016). In addition, genetic studies have revealed that discrete breeding populations (stocks) may have sub-specific status (e.g. Keenan et al. 1996; Thacker et al. 2022).

Significant loss from functional groups

A significant part of the small-bodied fish assemblage is missing compared to that present and before the advent of European carp (Boolarra strain) (see Criterion 3). These small species relied on submergent aquatic plants for refuge and breeding sites, and common carp, by virtue of their destructive feeding habits, undoubtedly have contributed to the decline of plants and associated small fish (Koehn & MacKenzie 2004; Kopf et al. 2019; Fanson et al. 2024; Schilling et al. 2024).

The loss of diadromous fish is even more pronounced, particularly as a result of lost connectivity during the Millennium Drought (Jennings et al. 2008; Bice 2023; see also Criterion 3). Diadromous species move between freshwater and estuarine/marine habitats to complete their life cycles and are dependent on connections between these environments (Bice 2010). The estuarine component of the ecological community is separated from the lower river by five tidal barrages that form an abrupt physical and biological barrier (Zampatti et al. 2011a, b).

Three fishways were installed on the barrages between 2004 and 2008, however these remained largely ineffectual due to low flows (Jennings et al. 2008; Bice 2023). A further six fishways were installed between 2015 and 2018 (Bice 2023; see Table 30). Surveys have demonstrated that the barrage fishways (e.g. Tauwitchere, Goolwa) facilitate fish movement during high end-of-system flows, however continuing high flows are needed for the restoration of populations of congolli, common galaxias, and other diadromous species (Zampatti et al. 2012; Bice 2023; Bice et al. 2017 a, b, 2018, 2023).

It is apparent that human-intervention is required for the future viability and protection of diadromous fish within the ecological community, which remain highly vulnerable into the future. This is particularly the case given the likelihood of future extreme drought conditions, where the barrages and fishways may not be operating optimally, or at all, for long periods, combined with increasing temperatures under climate change which may impact cues for spawning migrations (e.g. Reinfelds et al. 2013; Bice et al. 2018b).

Loss of Bird biodiversity

Overview

The course of the River Murray through semi-arid and more temperate environments, including fresh and estuarine waters, and thus provides for a diverse range of bird species. The ecological community contains foraging habitat, critical breeding habitat, and refuge for many woodland birds and waterbirds (Paton et al. 2009 and references therein). The Chowilla Floodplain is the largest region of floodplain habitat in the lower River Murray, occupying 1,650 km^2 upstream from Renmark (O'Malley & Sheldon 1990). Within the ecological community, the Chowilla region has a particularly high species diversity of birds, with some 165 woodland and waterbird species recorded (Newall et al. 2009; DEH 2010). A March 2002 survey of the Murray Mouth reserves recorded 85 bird species (at 22 sites), of which 9% were waders and 27% were waterbirds (Brandle 2002). During a 1988-89 a survey of Hindmarsh Island, 114 species were recorded, with waders and waterbirds dominating (Paton et al. 1989).

Declining trends

Many woodland and waterbird species throughout the ecological community continue to decline due to habitat loss, fragmentation and degradation (Paton et al. 2009, 2018). Although broad-scale vegetation clearance has virtually ceased in South Australia, birds and their remnant habitats continue to be lost or degraded, by altered water regimes and inadequate environmental flows; rising salinity on the floodplain; altered fire regimes; drought and climate

change; invasive species; and overgrazing of understorey plants (Paton et al. 2009; McGuinness et al. 2010; Stewart et al. 2010). River regulation has also impacted on waterbird breeding and survival, with the amount of breeding that previously occurred during medium and small floods, diminished (Briggs 1990; REF). While targeted environmental watering may result in increases for some species waterbirds at some locations on the floodplain (e.g. DEW 2022, 2023), this is against a backdrop of long periods without flooding and reduced flooding frequency.

Terrestrial/Woodland birds

There has been no regular monitoring of woodland birds along the River Murray floodplain corridor, with the first systematic survey (from SA border to Murray Bridge, and within the 1956 flood line) conducted in 2002-04, involving 135 sites (Stewart et al. 2010). The survey recorded 174 bird species (from 53 Families), with eight of these introduced species (Stewart et al. 2010). The survey found the range of structural vegetation types provided the variety of habitats to support diverse bird assemblages (Figure 14). Woodland and forest supported the highest number of species and provided a corridor for a number of species into mallee communities either side of the River Murray (Stewart et al. 2010). Importantly, species such as E*ntomyzon cyanotis* (blue-faced honeyeater), *Philemon citreogularis* (little friarbird), *Plectorhyncha lanceolata* (striped honeyeater) and *Polytelis alexandrae* (princess parrot) only persist in this region of South Australia because of their association with the River Murray (Stewart et al. 2010).

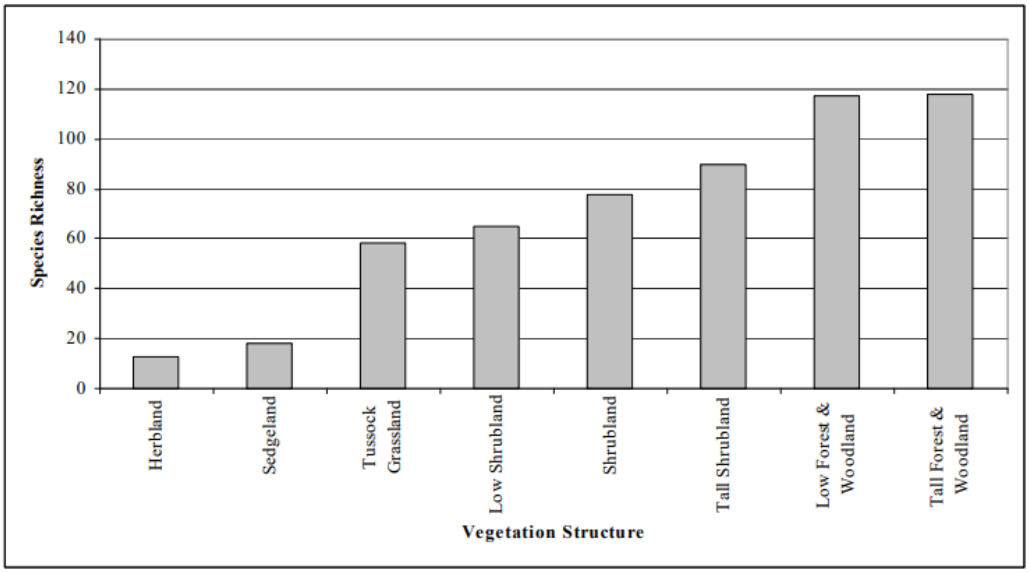

Figure 14: Bird species richness recorded by vegetation structure type from the Chowilla 1988 survey (O'Malley & Sheldon 1990) and the 2002-04 Murray Valley Floodplain surveys (Stewart et al. 2010).

These authors also noted that when combining all sources of bird records from the Biological Survey Databases of South Australia (BDBSA at 2007), 229 bird taxa had been recorded from the study area. Therefore 55 bird taxa (from 28 Families) were not recorded during the survey in 2002-04, including seven species of honeyeaters (Meliphagidae), six species of sandpipers (Scolopacidae), five species of thornbills (Acanthizidae) and four species of rail and crakes (Rallidae).

McGuinness et al. (2010) examined the importance to woodland birds of floodplains, floods, and associated vegetation communities, highlighting potential links between declining water availability, habitat degradation, and bird populations. These authors found that floodplain woodlands and forests may be important refuges for woodland bird populations, in part due to the supply of water, sediment and nutrients from floods, which drives productivity (i.e. compared to woodlands with no flooding). Importantly, floodplain woodlands often act as a source population for surrounding non-floodplain woodlands (McGuinness et al. 2010).

As part of their survey, Stewart et al. (2010) determined that the bird species most at risk from rising salinity on the floodplain, are those that rely on habitat features likely to be reduced by this threat. They identified 24 species with South Australian conservation ratings as being at risk—with seven species highlighted as being at greatest risk, including five terrestrial species and three waterbird species (see Table 36). These authors caution that the seven species, in particular, are likely to disappear if salinity continues to rise and further degrade riverine and floodplain habitats. A fifth species (white-bellied sea-eagle) was identified as being more significantly threatened by factors unrelated to increasing salinity (Stewart et al. 2010).

Table 36: Conservation rated bird species records and exposure to salt risk (i.e. low, medium, high) on the River Murray Valley Floodplain, calculated using the FWIP Salt Risk Model as part of the Murray Valley survey of 2002-04 (after Stewart et al. 2010).

Common Name	Species Name	AUS	SA	Total No Sites	Not in Salt Model	Low	Med	High
Australasian Bittern	*Botaurus poicilopilus*		V	1				1
Australasian Shoveler	*Anas rhynchotis*		R	27	11	7	3	6
Baillon's Crake	*Porzana pusilla*		R	4	1	1	1	1
Blue-billed Duck	*Oxyura australis*		R	3	2	1		
Blue-faced Honeyeater	*Entomyzon cyanotis*		R	27	9	8	6	4
Brown Quail	*Corturnix ypsilophora*		V	8		6	2	
Bush Stone-curlew	*Burhinus grallarius*		V	7	1	4	2	
Cape Barren Goose	*Cereopsis novaehollandiae*		R	2	1	1		
Crested Shrike-tit	*Falcunculus frontatus*		V	2		2		
Freckled Duck	*Stictonetta naevosa*		V	8	2	2	1	3
Glossy Ibis	*Plegadis falcinellus*		R	2	1	1		
Golden-headed Cisticola	*Cisticola exilis*		R	5	2	3		
Great Crested Grebe	*Podiceps cristatus*		R	12	6	2		4
Intermediate Egret	*Ardea intermedia*		R	8	2	1	3	2
Latham's Snipe	*Gallinago hardwickii*		V	2	2			
Little Bittern	*Ixobrychus minutus*		R	1	1			
Little Friarbird	*Philemon citreogularis*		R	70	7	22	24	17
Major Mitchell's Cockatoo	*Cacatua leadbeateri*		V	3		1		2
Musk Duck	*Biziura lobata*		R	10	6	2		2
Peregrine Falcon	*Falco peregrinus*		R	35	7	17	4	7
Redthroat	*Pyrrholaemus brunneus*		R	7		4	1	2
Regent Parrot	*Polytelis anthopeplus*		V	88	15	55	8	10
Striped Honeyeater	*Plectorhyncha lanceolata*		R	34	6	12	8	8
White-bellied Sea-Eagle	*Haliaeetus leucogaster*		V	3		1		2

Waterbirds – Coorong, Murray Estuary, and Lower Lakes

Waterbird habitat occurs throughout the ecological community (e.g. Suter et al. 1993, 1995), but the Coorong, Murray Estuary and Lower Lakes, in particular, are nationally and internationally recognised wetlands for native and migratory waterbirds (Paton et al. 2018, 2023). About one-third of South Australia's wader population and one of the largest concentrations of migratory waders anywhere in Australia has been found along the Coorong in the past (Lothian & Williams, 1988 in Nicol, 2005).

These wetlands are particularly important summer and drought refugia for waterbirds, with greatest abundances and diversities of species present during summer and autumn (Paton 2010; Paton et al. 2009, 2018, 2022, 2023). During summer, the Coorong (including the South and North Lagoons and Murray Estuary) typically support twice as many individuals compared to the freshwater Lower Lakes (Paton et al. 2023). Although, the numbers of bird species and their abundance varies between years according to a range of factors, such as: availability of food resources, hydrological regime, climate, resources available in central and northern Australia, breeding and migratory success in other parts of the world (Brandle 2002; Paton et al. 2018).

Carpenter (1995 in Brandle 2002) collated available historical summer bird count data for the Coorong and Lower Lakes and estimated: 60 000 waders of 30 species; 40,000 migratory of 20 species; 110,000 waterfowl of 14 species; and 70 000 other waterbirds of 38 species (i.e. total of around 240,000 birds and 82 species). This provides a 'rough' reference guide for comparison of future monitoring/surveys. A declining trend in bird counts was observed from the 1980s for the Coorong and Murray Mouth area, from counts of ~140,000 to ~235,000 during the early 1980s declining to ~48,000 to ~103,000 in the early 2000s (Gosbell et al. 2002).

Bird surveys in the Coorong demonstrate the extent of the decline for many species (Paton et al. 2009b; Rogers & Paton, 2009b; Paton & Bailey, 2011a, b, 2012b, c). Declines in the abundance of some key species between 1985 and 2000 intensified with the Millennium Drought and once-common birds were recorded only rarely by 2007 (Paton et al. 2009; Rogers & Paton 2009b). For example, regular summer surveys of waterbirds have been undertaken in the Lower Lakes, Coorong and Murray Mouth (LLCMM) MDB Living Murray Icon site since 2000 for the Coorong (up to 81 species recorded, Paton et al. 2018), and since 2009 for the Lower Lakes (up to 72 species recorded, Paton et al. 2019).

For the 2023 summer survey, total abundance of was down by 70 000 birds, with 31 of the 49 species present below long-term median abundance (LTMA); in the Lower Lakes, abundance was up by 17 000 birds, however of 48 species present, 16 were below the LTMA (Paton et al. 2023). The objective to maintain or improve water bird populations in the LLCMM was not met in January-February 2023 (Paton et al. 2023). The overall substantial decline observed in waterbirds follows on from substantial declines in overall abundance recorded over the previous three years (Paton et al. 2023).

Long-term threshold ecological targets set for the abundance and distribution of 25 species in the Lower Lakes and 40 species in the Coorong were not met, and the resultant negative Whole of Icon Site Score (WOISS) for the two wetlands was the lowest on record since the end of the Millennium Drought; -79 for Coorong (Figure 15); -54 for Lower Lakes (Figure 16) (Paton et al. 2023). The biggest declines were for fish-eating group in the Lower Lakes, and for wading shorebirds in the Coorong. Declines are likely related to changes in food resources and access to those resources (i.e. due to changes in water depth) (Rogers & Paton, 2009b; Paton et al. 2018,

2023). For changes in food resources (i.e. macroinvertebrates, macrophytes, small fish) see sections above in Criterion 4 and Criterion 3.

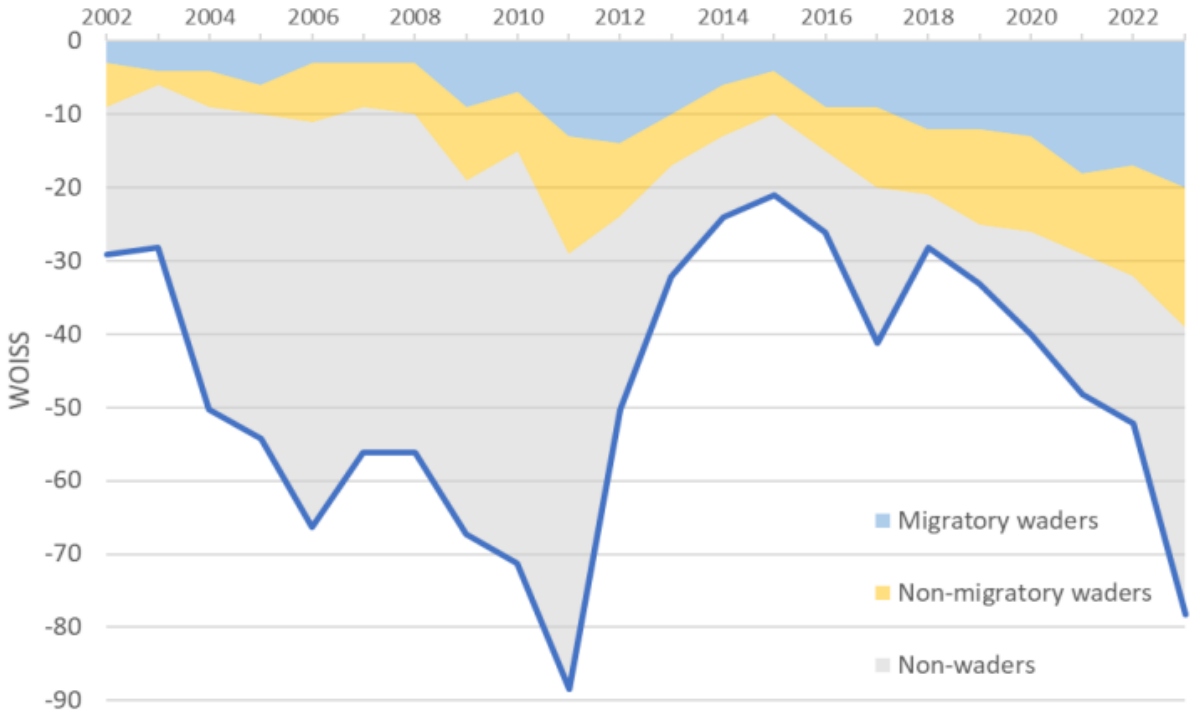

Figure 15: Changes in the Whole of Icon Site Score (WOISS) for waterbirds using the Coorong in January from 2002 to 2023 (dark blue line). The shaded areas indicate the contributions of different components of the waterbird community (namely the migratory waders, non-migratory waders, and non-waders (all other species) to the WOISS through time (Paton et al. 2023).

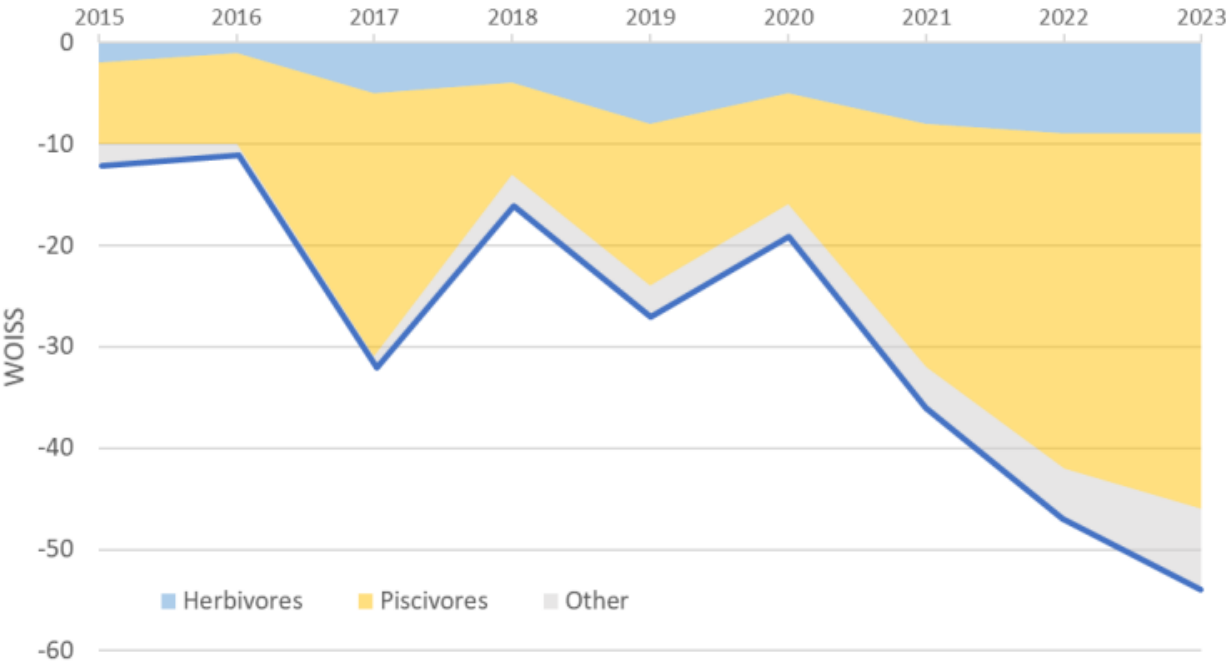

Figure 16: Changes in the Whole of Icon Site Score (WOISS) for waterbirds using the Lower Lakes in January from 2015 to 2023 (dark blue line). Shaded areas indicate the contributions of different waterbird community components (namely predominantly herbivorous species (blue), predominantly piscivorous species (orange); and other species (grey) (Paton et al. 2023).

Questions

- *Do you have any feedback on the preliminary assessment for part 1a) under Criterion 4 or further data, information or reports that would support or update the assessment outcomes?*

1B) DECLINE IN INTEGRITY FROM INVASION BY NON-NATIVE SPECIES

Weeds

Terrestrial – riparian & floodplain weeds

Over 160 weeds occur within the ecological community, and some are abundant and widespread (Brandle 2002; Nicol 2007c; Gehrig & Nicol, 2010; Gehrig et al. 2012; Nicol et al. 2018). Weeds can form dense, monospecific patches in riparian, or floodplain, or channel zones. They can particularly impact herbivores and invertebrates, causing a net reduction in available food sources and habitat normally provided by native plants (Weiss & Dugdale 2017; and see Table 17 on threats). The spread of weeds can be particularly assisted by large floods, such as occurred in 2022/23.

Some examples of priority weeds include:

- Willows (*Salix* spp.) form dense monospecific stands along the river -banks in areas where water levels are stable (Kennedy et al. 2003). These trees now dominate about one-third of the river's 830 km course within the ecological community, where they rival river red gum as the dominant riparian tree (Schulze & Walker 1997; Kennedy et al. 2003). Their dense foliage crowds native plants and casts deep shade over the aquatic habitat. Their leaves and bark contain chemicals that deter native herbivores and are less nutritious for insects (Schultze & Walker 1997). Riverine willow infestations drain a substantial amount of water from waterways—from 3.9 to 5.5 ML per year for each hectare of willow canopy in cool temperate and semi-arid climates, respectively (T. Doody pers. comm.).
- Weeds like Noogoora burr and California burr (*Xanthium* spp.) form large persistent soil seed banks on the floodplain awaiting the next over-bank flow and out-compete native seedlings (Cunningham et al. 1992).
- Lippia (*Phyla canescens*) can form extensive dense mats on the floodplain that exclude almost all other species and is tolerant of both desiccation and inundation (Taylor & Ganf 2005).
- Canadian pondweed (*Elodea canadensis*) is a submergent aquatic that colonised large areas of the main channel in the Lock 2,3,6 and 7 weir pools between 2007 and 2010 (i.e. during the limited flows of the Millennium Drought) but declined after the late-2010 flood.
- Long-term surveys of the high refuge value Chowilla floodplain system within the ecological community, have recorded 86 exotic weeds (Nicol 2007c). The distribution and abundance of weeds in the seed bank at Chowilla is unknown.
- African boxthorn, boneseed, golden dodder, sagittaria, opuntia species, yellow water lily – priority weed species.

Aquatic weeds

Aquatic weeds compromise aquatic habitats including impeding water flow, reducing oxygen levels, restricting light and photosynthesis, and changing water temperatures. They can be grouped according to their growth habitat, including floating, submerged and emergent. Most aquatic weeds found in the EC are the result of illegal/accidental release to the wild (Ref). For example, the submerged leafy elodea (*Egeria densa*) which invades lakes, ponds, and slow-moving streams, the floating salvinia (*Salvinia molestta*) and water caltrop (*Trapa natans*) which can cover creeks, and the emergent Senggal tea plant (*Gymnocoronis spilanthoides*) which invades wetlands and slow-moving waterways.

Common carp and other alien (non-native) fish

Alien fish (i.e. exotic to Australia) are usually disadvantaged by the extremes of natural variability in dryland rivers but tend to dominate fish communities in regulated rivers (i.e. such as with the EC) (Wedderburn et al. 2017 & references therein). Eight introduced fish species have been recorded in the ecological community that have, with the likely exception of trout and tench, self-sustaining populations (see Appendix B, Table B2 and Table 37). A couple more species have been recorded within the EC in the past, but at a low number and with no self-sustaining population observed (i.e. Atlantic salmon, *Salmo solar*, and brook trout, *Salvelinus fontinalis*) (Hammer et al. 2009).

Most the alien fish species continue to have significant to severe impacts on the flora and fauna of the EC, particularly the native fish fauna and their aquatic habitats. In addition to competition, predation, and physical habitat degradation impacts, there are a range of alien parasites and pathogens associated with alien fish species that can potentially harm native species (see Table 17 & 37). This includes *Lernaea cyprinacea* ("anchor worm"), the oomycete *Saprolegnia parasitica*, Epizootic Haematopoietic Necrosis Virus (EHN Virus) and the spreading threat of Epizootic Ulcerative Syndrome (EUS or "red-spot disease") (Boys et al. 2012; Becker et al. 2013; Zhu et al. 2020; Kaminskas 2021). Some of these have been known to lead to fish mortality within the EC (e.g. Puckridge et al. 1988; Rowland & Ingram 1991; Kaminskas 2021).

Each of the eight invasive fish species has an impact on the ecological community (see Table X), with that of common carp (*Caprinus carpio*) the most pervasive; goldfish, redfin perch and eastern gambusia are also prolific, occurring across most habitats (Wedderburn et al. 2017). Carp are a hardy, opportunistic fish and are the most abundant large-bodied freshwater fish species across the MDB (Kohen and MacKenzie 2004; Davies et al. 2012). The biomass dominance of carp, over 90%% at times, is a severe and ongoing impact to the native fish assemblage, other aquatic organisms and aquatic habitats. In the Lower River Murray, alien fishes make up a modest proportion of the abundance of fish, but more than half of the total fish biomass may be attributed to common carp (Davies et al. 2010; Wedderburn et al. 2017).

Carp degrade aquatic habitats through their bottom feeding behaviour, which leads to raised turbidity and loss of macrophytes (Kopf et al. 2019; Fanson et al. 2024; Schilling et al. 2024). Adult carp have been observed becoming more predatory since their invasion of the MDB and are suspected of placing increasing predatory pressures on juvenile native fish (Tonkin et al. 2006). Carp are strongly linked to decline and loss of small-bodied native fish, primarily through macrophyte decline (e.g. Lewellyn 1971, 2006, 2008; Gilligan 2005).

Given the above, the impacts outlined in Tables17 and 37, it is likely that carp and other alien fish species have contributed significantly to habitat degradation and the decline of native fish assemblage in the ecological community (Wedderburn et al. 2017), particularly freshwater catfish and the suite of small-bodied fish species (see Criterion 3).

Table 37: Eight alien fish species occurring in the EC, their introduction and impacts.

Name	Introduction	Ecop-type	Impacts	References
Common carp (*Caprinus carpio*)	• in late 1960s-eqrly 1970s from illegal imports and releases • spread through MDB via 1974 flood	• large-bodied, bottom feeder, extremely abundant	• increased turbidity, loss of macrophytes • competition with native fish • predation on juvenile native fish • implicated in decline/loss of small-bodied fish species in EC • implicated in native fish reintroduction failures	Lewellyn 1971, 2006, 2008; Koehn & Mackenzie 2004; Hammer et al. 2009; Vilizzi et al. 2014, 2015; Koft et al. 2019; Stuart et al. 2021; Fanson et al. 2024; Schilling et al. 2024
Eastern Gambusia (*Gambusia holbrooki*)	• in the 1920s under mistaken belief it offered control of mosquito larvae • abundant in most parts of MDB	• small-bodied, aggressive	• attacks small native fish by fin-nipping leading to disease/mortality • implicated in native fish reintroduction failures in billabongs and wetlands	Becker et al. 2005; Macdonald & Tonkin 2008; Hammer et al. 2009; MacDonald et al. 2012: Tonkin et al. 2012, 2014; Wedderburn et al. 2013
Redfin perch (*Perca fluviatilis*)	• lowland habitats of MDB, riverine & off-river between 1920s & 1960s • alien carp largely displaced redfin perch in the 1970s	• large-bodied	• highly predatory, particularly on small-bodied fish and juveniles • abundant in reservoirs & lakes; now less common in river and billabong habitats • an exception is the Eastern Mount Lofty Ranges streams	Cadwallader 1977; Hammer 2004; Hammer et al. 2009; Wedderburn et al. 2014; Wedderburn & Barnes 2016; Rowland 2020; Lintermans 2023
Asian wealtherloach (*Misgurnus anguillicaudatus*)	• via ornamental fish trade & illegal release into wild around mid-1980s • invading southern MDB and first observed in EC after 2010-11 floods	• hardy	• knowledge limited but significant competitive impacts indicated • EC native fish fauna naïve to this invader until relatively recently.	Lintermans 2004; Hammer et al. 2009; Wegener & Suitor 2013; Fredberg et al. 2014; GAWS 2024
Trout species Rainbow (*Oncorhynchus mykiss*) Brown (*Salmo trutta*)	• introduced for recreational fishing in late 1800s • rainbow trout dominated the Lower Lakes in the 1920s and 1930s, but retreated due to rising thermal regime • minor presence in EC today, with the exception of Eastern Mount Lofty Ranges (EMLR) streams due to legal & illegal stocking, & natural breeding	• aggressive predators	• likely to declines of native fish in EMLR streams of EC, especially southern pygmy perch, mountain galaxias, and river blackfish populations • presence of trout in EMLR streams means they cannot effectively function as refugia and/or a source of native fish for recolonisation/translocation to Lower Lakes	Advertiser 1936; Hammer 2004; Hammer et al. 2009; Kaminskas 2023
Goldfish (*Carassius auratus*)	• via ornamental fish trade & illegal release into wild • ubiquitous throughout MDB (& EC)	• small	• largely benign compared to other alien fish • likely to play a role in vectoring alien fish parasites and pathogens	Hammer et al. 2009; Kaminskas 2021; GAWS 2024
Tench (*Tinca tinca*)	• introduced in 1870-80s for rec fishing • largely displaced by carp from 1970s • now quite rare in SA and EC	• medium-bodied, red eyes	• prefer still & slow flowing habitat • benthic carnivores • impacts unclear/ unknown	Advertiser 1936; Cadwallader 1977; Hammer et al. 2009; Lintermans 2023

Feral mammals and birds

There are eleven main pest mammal species that have been recorded in the ecological community: fox (*Vulpes vulpes*); cat (*Felis catus*); dog (*Canis familiaris*); rabbit (*Oryctolagus cuniculus*); brown hare (*Lepus capensis*); house mouse (*Mus musculus*); black rat (*Rattus rattus*); pig (*Sus scrofa*); goat (*Capra hircus*); and red deer (*Cervus elaphus*) and fallow deer (the latter mainly in the Eastern Mt Lofty region of the RMDS EC).

Particularly on the floodplain of the ecological community, pest mammals compete with native species for habitat and food, and predators like the cat, dog and fox prey on birds and other native animals. For example, birds such as the endangered rufus bristlebird (*Dasyornis broadbenti*) spend much of their time foraging for insects on the ground and build bulky nests close to the ground. They are therefore likely to be vulnerable to predation by foxes and cats (Paton 2010).

Of particular concern is fox predation of freshwater turtles and their eggs (Howard et al. 206; Van Dyke et al. 2019).

There are also many pest bird species that occur within the ecological community, such as starlings (*Sternus vulgaris*), blackbirds (*Turdus merula*) and sparrows (*Passer domesticus*). These would similarly compete with native species for habitat, resources and nesting sites.

Invading marine tubeworm

Ficopomatus enigmaticus (Australian tubeworm) tolerates a wide range of salinities, from marine to hypersaline, but prefer brackish conditions. It is a normal inhabitant of the Coorong, where it forms large reefs which contribute habitat heterogeneity (Dittmann et al. 2018). However, during the Millennium Drought, these worms colonised Lake Alexandrina as result of declining water levels and rising salinities following the ingress of sea water (Dittmann et al. 2009; Rolston & Dittmann 2009). The worms formed calcareous masses on the shells of freshwater turtles, which proved fatal to many (i.e. from drowning and disease), particularly the short-necked turtle (Dittmann et al. 2009; Rolston & Dittmann 2009; Bower et al. 2012).

Native versus non-native biodiversity

Table 38 provides examples of large-scale surveys with information on total species counts, including invasive species. This demonstrates that for plants, fish, and mammals the proportion of invasive species often represents about a third of the total number of species. There is limited information on reptiles, apart from the red-eared slider, and it seems that there may be only one invasive frog species—the black-spined toad. To date and proportionally, birds have few invasive species, with the maximum recorded to date for the EC at around six (McGuinnes et al. 2010).

Table 38: Selected surveys showing total species counts and proportions of invasive species per taxon group.

Taxon Group			Survey/Monitoring		Reference
Total Species	**No. Invasive**	**% Invasive**	**Location**	**Period**	
PLANTS					
767	256	33	Murray floodplain (below Hume Dam to Lake Alex.)	1987–1988	MDBC 1990
596	187	31	Murray Valley SA	2002–04	Stewart et al. 2010
216	73	33	Murray Mouth Reserves	2002	Brandle 2002
2153	554	26	Riverland and Murraylands	1990–2005	Robinson et al. 2009
353	132	37	Lock 1 downstream to Sea	1975–2010#	Gehrig & Nicol 2005
35	5	14	Pike Anabranch & Floodplain	2015	Nicol et al. 2015
65	N/A	-	Chowilla	2006–2022	Nicol et al. 2023
FISH					
26	7	30	Eastern Mt Lofty Streams	2001–03	Conalin & Hammer 2003
19	4	21	Murray Mouth Reserves	2002	Brandle 2002
35	11	31	River Murray SA border to confluence Lake Alex.	1974–2007	Ye & Hammer 2009
10	4	40	Chowilla	2021	Fredburg et al. 2022
REPTILES					
37	N/A	-	Murray Valley SA	2002–04	Stewart et al. 2010
26	N/A	-	Murray Mouth Reserves	2002	Brandle 2002
27	N/A	-	Riverland Ramsar Site	2003	Newell et al. 2009
BIRDS					
174	8	5	Murray Valley SA	2002–04	Stewart et al. 2010
234	9	4	Murray Mouth Reserves	2002	Brandle 2002
179	N/A	-	Riverland Ramsar Site	2003	Newell et al. 2009
MAMMALS					
36	12*	33	Murray Valley SA	2002–04	Stewart et al. 2010
12	2	16	Murray Mouth Reserves	2002	Brandle 2002
18	7	38	Riverland Ramsar Site	2003	Newell et al. 2009

2A) DECLINE IN INTEGRITY FROM ALTERED HYDROLOGICAL REGIME

Altered flooding regime – loss of medium floods and flooding variability

The range of flow conditions experienced by the ecological community is at Table 39. Flow regimes have been progressively altered by diversions, regulation and associated infrastructure, both within the region of the ecological community (i.e. below the Murray-Darling confluence) and upstream (Walker et al., 1978; Walker, 2006; Walker et al, 1995). In particular, the main channel of the ecological community contains a series of 10 weirs (built 1922–1935), with five barrages (completed 1940) at the Murray Mouth, as well as numerous levees and offstream regulators. The lower Murray is, in effect, a cascading series of pools that are maintained near bankfull capacity except during large floods (Walker, 2006). Regulated flows are much reduced compared with unregulated conditions (Walker and Thoms, 1993; Maheshwari et al., 1995; CSIRO, 2008). The median annual flow to the sea is about 27% of what it would have been under natural conditions (MDBC, 2006a). Also, modelling has determined that annual stream flow at the Murray Mouth is reduced by 61% (CSIRO, 2008). Importantly there is an increasing trend in water extraction from the River Murray and of groundwater (e.g. Eastern Mount Lofty Ranges).

Table 39: Components of Flow Regime under Basin Plan and under regulated conditions in the Lower Murray. Note, the Lower Murray does not experience cease-to-flow conditions, and as a result of the stabilisation of water levels, the delivery of managed entitlement flows represent the base flows (Wallace et al. 2014).

No.	Flow Components recognised under Basin Plan	Flow Components applicable to Lower Murray	Velocity for LMR ML/day
1	cease-to-flow	regulated entitlement flows	<7000
2	low-flow season base flows	in-channel low flows	7000-15,000
3	high-flow season base flows	in-channel moderate flows	15,000-30,000
4	low-flow season freshes	bankfull flows	30,000 - 40,000
5	high-flow-season freshes	small overbank flows	40,000 - 60,000
6	bankfull flows	moderate overbank flows	60,000-80,000
7	overbank flow	large overbank flows	>80,000

Regulation of the River Murray has reduced peak flows, and the historical frequency (35-62%) and duration (40-80%) of extensive floods that connect the River Murray to its floodplain (Maheshwari et al., 1995). In essence, the effects of regulation, diversions and infrastructure have been to:

- eliminate small floods where within-channel flow is achieved (up to 1 in 7 y frequencies; 25–40,000 ML/d), and to
- reduce the frequency and duration of moderate sized floods where strong overbank flow may be achieved (up to 1 in 20 y; 40–60,000 ML/d).

For example, at Chowilla (which represents the largest area of natural floodplain in the ecological community and an area of high complexity and refuge value), natural flood frequencies of 1 in 2 y have been reduced to 1 in 4–9 y and this is projected to increase to 1 in 19 y by 2030 (Sharley and Huggan, 1995 in Jensen et al, 2007; CSIRO, 2008). Flows of around 50 000 ML/d are required for significant overbank flow downstream of the Darling junction. Vulnerable floodplain areas within the ecological community (e.g. the meander plain following shallow contour lines of creeks and wetlands) would benefit from flows of at least 50 000 ML/d which used to occur 79 of every 100 years, but now occurs in 30 of every 100 years (MDBC, 2002 in MDBC, 2003a).

Floods play a vital role in maintaining floodplain vegetation (Robertson et al., 1999; George et al., 2005) and as a result of the altered flooding regime, the floodplain generally is drier (Walker and Thoms, 1993). Flooding is the primary source of water for eucalypts, recharging shallow aquifers and maintaining soil moisture supplemented by local rainfall. River red gum and black box on the floodplain depend on flooding as their main water source. Such overbank flows come from medium and large floods. However, very little of the river red gum floodplain now experiences extensive (1000s of ha), long-term (> 3 months) flooding to promote recruitment. Between 1996 and 2009 there were no effective overbank flows which severely affected these floodplain trees (see also Criterion 3).

Floods, or overbank flows >35,000 ML/day, are critical, because they connect channel, riparian and other floodplain environments. Importantly, minor in-channel flows are also important because they facilitate transport of salt, sediment, nutrients and longitudinal movements by fish and other animals. In some species, these minor flows also promote low-level or 'bridging' recruitment that maintains the resilience of populations, particularly for flood-cued spawners. For example, within-channel flows of 15-25 000 ML/d from late spring through summer would promote spawning and recruitment and improve the resilience of golden perch populations in the ecological community (Zampatti and Leigh, 2013). In many respects, the elimination of smaller flows has been the most significant impact of flow events. Major floods and droughts by comparison are beyond the control of dams and weirs.

Increased water stability and reduced flow velocity

Weirs elevate the water level above them, creating a 'weir pool' that extends for tens of kilometres upstream. The weirs are operated to hold a stable river level above them, even when the rate of flow changes. Immediately below each weir, there are daily rises and falls in river level (typically ±200 mm daily) during periods when the river is flowing (Walker et al., 1994). Many native species of plants and animals rely on flow or water-level cues for reproduction, dispersal or migration. The weirs have changed the river from a lotic (flowing) environment into a more lentic (still water) environment, favouring a different suite of species. In addition, the river channel along the ecological community is progressively developing a stepped gradient, with deposition of sediments above each weir and erosion downstream (Thoms and Walker, 1992).

The propensity for river flows to vary widely is reflected in the life cycles of many native species that are opportunistic, tolerant and capable of rapid dispersal. The effects of regulation, however, have reduced flow variability within and between years, and generally favoured alien species, with regular, seasonal life cycles, over native species.

Other pertinent examples of the impacts of such changes on the integrity of the ecological community involve aquatic macroinvertebrates: the species of freshwater mussel normally associated with the floodplain, has now moved into the more stable channel environment of the weir-pools, at the expense of the river mussel; the yabbie has similarly moved into the weir-pool habitat at the expense of the now locally extinct Murray crayfish. In addition, changes in the water level of the channel affect the growth of biofilms that provide food for fish, snails and other grazing invertebrates. Also, emergent plants along the riverbanks are now mostly wetland species that have been able to invade the river margins as levels are kept stable (Blanch et al., 1999).

Decline in functional mouth condition

The Murray Mouth, near Goolwa in South Australia, is part of dynamic system influenced by the flow of River Murray water from Lake Alexandrina via barrage releases, in addition to tidal movement from the adjacent ocean, and at times, wind (Walker 2002a.b; Webster, 2005). An open, functioning mouth provides connection between the Southern Ocean, the Coorong, and the Lower Lakes of the River Murray and this is critical to a healthy ecological community (TSSC 2009, 2010). The consequences of low flow or mouth closure are broad ranging. For example, sand movement around the mouth is affected and may cause increased salinities (and potentially temperatures) in the Murray Estuary and Coorong (Walker 2002a, b; DEW 2023a, b). To simulate pre-regulation conditions and maintain a healthy ecological state, the mouth of the Murray should be kept open permanently, in order to flush out salt and excess nutrients and pollutants from the system (N. Harvey, B. Bourman and J. Tibby pers. comm.). Additionally, connectivity with the adjacent ocean is vital for diadromous fish species (Bice et al. 2018).

Evidence from paleo-history of diatoms and foraminiferans in sediments confirms that mouth closure was rare over the past 3000 years, with only four brief periods of closure identified (Cann et al. 2000; Fluin et al. 2007). Further, historical records also confirm that until 1981, the mouth has not closed permanently since European settlement (James 2004). In the 1930s, prior to regulation, some 80% of the water entering the River Murray annually went out to sea. However, by the 1990s this was reduced to 27%, with only 4% recorded from 2000–04 during the Millennium Drought (MDB, 2006a; Paton 2010). CSIRO (2008) modelling suggested that, on average, 39% (4723 GL) of the natural mean annual discharge (12 233 GL) reaches the sea. In addition, the river ceases to flow through the Murray Mouth 40% of the time, compared to only 1% under natural, unregulated conditions (CSIRO 2008).

The Murray Mouth closed for the first time on record in April 1981, after there was no flow through the barrages for 196 days, resulting in sand deposition and the need for to re-connect the river to the sea (Bourman & Harvey 1983; Goode & Harvey 2009). During the Millennium Drought, dredges were employed from 2002 to 2010 to keep the Murray Mouth open. Dredging ceased during the drought breaking flood of late 2010-11. However, low flows returned in 2014 and mouth condition deteriorated; dredging began again in January 2015 and has continued since, with a break during the extreme flooding of 2022/23 (DEW 2023b).

Although, as Figure 17 demonstrates, Murray Mouth openness has been improving over the past decade, however this has only occurred due to human intervention, i.e. relatively continuous dredging operations since 2015 (DEW 2023a, b). Maintaining an open Murray Mouth is a key objective of the Murray-Darling Basin Plan, adopted in 2012. At present, the condition of the Murray Mouth is considered 'poor' while dredging is required to maintain openness (DEW 2023a, b).

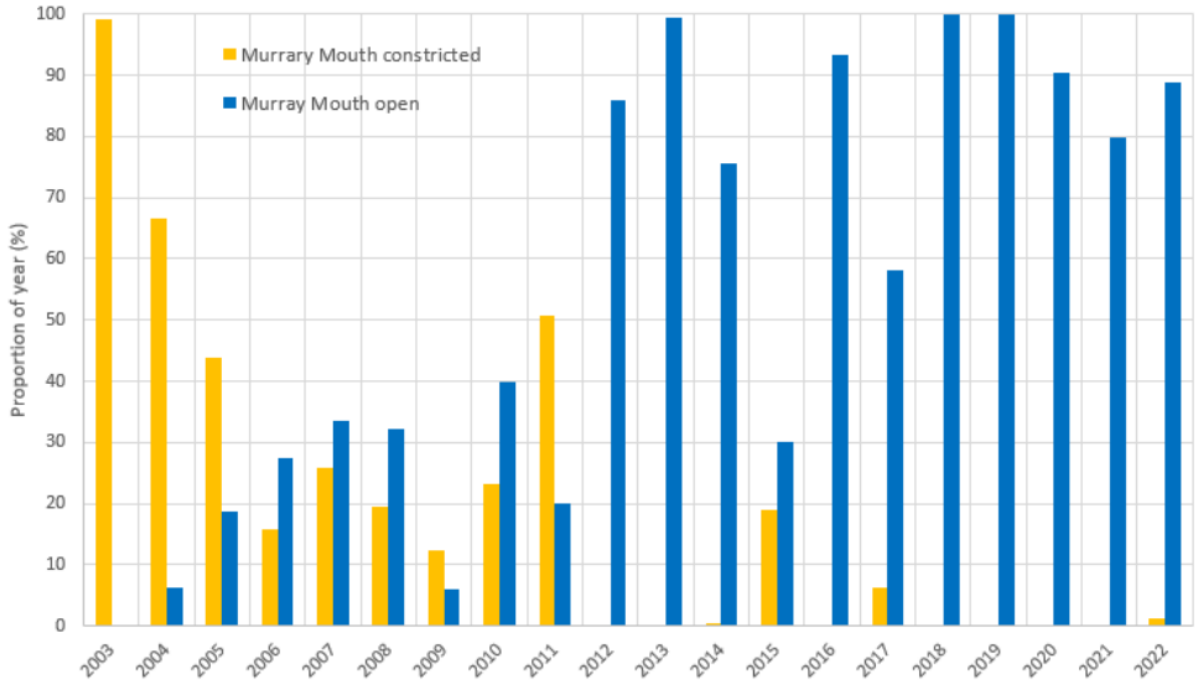

Figure 17: Proportion of time each year that the Murray Mouth was open (DTR > 0.3) or critically constricted (DTR ≤ 0.2); note DTR = Diurnal Tide Ratio is an indicator of Murray Mouth openness and 0.3 is the Murray Mouth open threshold (source DEW 2023b).

Decline in water quality

Water quality within the ecological community has declined significantly due to several factors, with some persistent, such as salinity (from rising saline groundwater and reduced flows) and temperature (rising levels from climate change), and others episodic (e.g. algal blooms and blackwater events from excess nutrients and organic matter, or acid sulphate soils from drying and exposure).

While mitigation measures (e.g. SA salt interception scheme which slows the rate of increase) are now in place to help address the issue of salinity, some 1000 tonnes of salt passes down the river channel daily and overall salt is accumulating, particularly on the floodplains (TSSC, 2010). Native flora and fauna of the ecological community have evolved in an environment where the salinity fluctuated (Close, 1990b), however most will only tolerate increased salinity up to a certain threshold. Prior to the Millennium Drought, there was little evidence that river salinities were outside the tolerance of phytoplankton, invertebrates, fish or birds that live in the river or the native vegetation that grows along its banks (e.g. Close, 1990b). However, the Millennium Drought exacerbated the dryland salinity problem in the floodplain and wetland components of the ecological community. In particular river red gum and black box trees were increasingly salt-affected with high levels of stress and dieback reported, and some areas were invaded by halophilic plants (Walker, 2006; Holland et al., 2009; see Criterion 3 and 5). Salinity levels rose in the Lower Lakes, and the Murray Estuary and Coorong became increasingly hypersaline which had major impacts on ecosystem function and biota (see Criterion 3). Importantly, the South Lagoon of the Coorong changed from a macrophyte-fish-chironomid system, to a hypersaline system dominated by brine shrimp and algae (Paton, 2010).

The installation of weirs and barrages has provided for stable pool levels since the 1930s. This has had the effect of producing wetland environments that have retained the sulfur as pyrite in their soils, i.e. instead of having the normal oxidation, reduction and flushing cycle, that cycle has been interrupted (Fitzpatrick et al., 2009). This change has promoted the significant build-up of sulfide minerals that can result in acid sulfate soils when exposed (Fitzpatrick and Shand, 2008). This can lead to serious environmental consequences such as soil and water acidification, deoxygenation of water and formation of H_2S. The Millennium Drought led to exposure of large sections of river bank, wetlands and lakes within the ecological community that contained high levels of unoxidised (reduced) iron sulfides (Fitzpatrick and Shand, 2008; Fitzpatrick et al., 2009). The Lower Lakes receded considerably during the prolonged drought, uncovering extensive areas (up to 20 000 to 30 000 ha) of sulfidic material in the formerly subaqueous soils. Although remedial measures were taken (e.g. liming, re-vegetation), this event represented a significant and prolonged disturbance of the integrity of the ecological community.

Blackwater events occur from high dissolved organic carbon loads and create low dissolved oxygen levels (O'Connell et al, 2000; Howitt et al., 2007). During the Millennium Drought there was a buildup of organic matter (e.g. leaves) under the low flow conditions, throughout the ecological community. Following the drought-breaking late-2010–11 floods a large blackwater event affected some 1800 km of the Murray channel as far down as Murray Bridge, South Australia (Whitworth et al., 2011, 2012). There were widespread fish and crustacean kills (Whitworth et al., 2012) and a tracking study of Murray cod in the ecological community at the same time recorded a high mortality rate (Leigh & Zampatti 2013). Importantly, hypoxic conditions were recorded as long as seven months after initial flooding in some parts of the River Murray, suggesting that large blackwater events could have long-term effects on the health of the river system and fish communities (King et al., 2012; Whitworth, et al., 2012). It is likely that with the advent of drier conditions projected under a changing climate (e.g. CSIRO, 2008) that blackwater events may occur more often.

2B) DECLINE IN INTEGRITY FROM LOSS OF CONNECTIVITY

Between river and floodplain

Connectivity, the hydrological connection between the floodplain and river, is of critical importance and supports a myriad of ecological functions and interactions (Goode & Harvey 2009). The floodplain flora and fauna depend on the river for dispersal and replenishment, and in turn, the riverine biota depend on the floodplain for food, nurseries and refuges (Walker, 2001). For example, an extensive survey by Van Dyke et al. (2019) found that *E. macquarii* occurred mainly in backwater, lagoon, lake, and tributary habitats connected or close to main channels.

A useful general model for the lowland floodplain reaches of large rivers, such as for the ecological community, is the *Flood Pulse Concept* (FPC) which recognises the importance of lateral linkages between the river and floodplain and consequent exchange of water, organic material, nutrients and organisms (Junk et al. 1989; Robertson et al. 1999; Tockner et al, 2000; Junk and Wantzen, 2004). The FPC is based on overbank inundation driven by floods, considered to be the key ecological determinant of ecosystem function and trophic linkages (Junk et al., 1989; Puckeridge et al. 1998).

The river channel, unlike most floodplain habitats, is generally characterised by strong currents, unstable sediments and a shallow photic zone. The littoral zone, at the channel edge, supports a narrow band of emergent and submerged plants that forms a refuge for many animals and is often a place of high biodiversity (Walker et al., 1992; Blanch et al., 1999; Walker et al., 2009).

Although weir construction has modified the assemblage of littoral plants (see above). The distribution of aquatic/emergent plants is influenced by the frequency of flooding and exposure (Walker et al., 1994; Blanch and Walker 1998; Blanch et al., 1999, 2000). Floodplain wetlands occur along a water-availability gradient that governs the zones where particular plant and animal species may occur (Brock, 1994). Wetlands are adapted to intermittent periods of wetting and drying (Passfield et al., 2008) and the wetting-drying sequence is also important for habitats within the river channel component of the ecological community. Primarily, changes in the water level in the channel affect the growth of biofilms that provide food for fish, snails and other grazing invertebrates (Walker, 2001). However, regulation has tended to stabilise flow and water level within the ecological community and decreased the frequency of overbank flows and thus connectivity between the channel and floodplain (Walker, 1991).

Thus, within the ecological community, the channel is a conduit for transport of water, sediment and other material, and a corridor for dispersal, and the floodplain is the site of key biological processes. Connectivity along the channel, between the channel and floodplain, as well as throughout the drainage network is important. For example, Leigh and Zampatti (2013) found from radio tracking studies of Murray cod that connectivity between the main channel and off-channel habitats was critical to their movement and reproductive success. The floodplain as a whole is, by definition, dependent on flows in the river and the fauna and flora of the channel also depends on access to floodplain habitats and resources. Regulation (and infrastructure) and reduced flows have led to fragmentation and widespread disconnection within the ecological community (Norris et al., 2001).

Within channel including between freshwater and estuarine/marine habitats

Under regulated conditions, approximately 39% (4723 GL) of natural mean discharge (12 233 GL) reaches the sea (CSIRO, 2008), however due to over abstraction and the Millennium Drought River Murray inflows were extremely low (e.g. < 600 GL/y 2007-09). With high rates of evaporation in the Lower lakes (typically > 750 GL/y; CSIRO, 2008), inflows were insufficient to maintain typical regulated water levels (~0.75 m AHD) and the lakes fell below sea level, reaching a historical low in May 2009 (-1.0 AHD) (Zampatti et al., 2011b). Receding water level was accompanied by the complete physical and biological disconnection of the Lower Lakes and the estuarine Coorong in March 2007.

Longitudinal movement is a major part of the ecology of most native fish species, however many physical and hydrological barriers impede fish movement within the ecological community (Stuart et al., 2008; Zampatti et al., 2011a, b, c). There has been much effort over the past decade to improve fish movement through installation of fishways, although much more research needs to be done in terms of assessing their effectiveness for small and large-bodied fish, and prioritising locations of further installations (Stuart et al., 2008).

Freshwater inflows and connectivity between freshwater and marine/estuarine environments play a crucial role in structuring the composition of biotic assemblages within the ecological community, and in particular native fish assemblages. For example these connections facilitate recruitment of diadromous (i.e. catadromous and anadromous) fish such as congolli (and common galaxias, eels and lampreys) in the Coorong estuary (Zampatti et al., 2011b). In their four year survey, Zampatti et al. (2011b) found that:

- cessation of freshwater inflow and disconnection of the Coorong estuary from the freshwater Lower Lakes resulted in increases in estuarine salinities and a concomitant decrease in species richness

- when brackish conditions prevailed, fish assemblages were characterised by a diversity of freshwater, diadromous and estuarine and marine species
- when salinities increased, freshwater, diadromous and estuarine species were lost and marine species become more common; and
- as freshwater inflows into the Coorong diminished, the abundance of diadromous species decreased dramatically (with lampreys disappearing completely when inflows ceased).

Variable within-channel flows are also important for native fish recruitment. Many species are cued to spawn by rising flows and others rely on post-spawning migration downstream flow of larvae and juveniles. A prime example of such a flow-ecology relationship is that of golden perch (*Macquaria ambigua ambigua*). Golden perch recruitment appears negligible in years when flow is low and stable but low-level recruitment occurs in within-channel flows of > 15 000 ML/d if prolonged (i.e. medium or moderate sized flows; Leigh and Zampatti, 2012). These authors indicate that these medium flows (i.e. 15 000 - 25, 000 ML/d) can be practically restored within the current constraints of regulation operation.

The Chowilla system is an important area of permanent lotic (flowing anabranch) habitats, which are uncommon in the remainder of the ecological community (Zampatti et al., 2011b). It is recognised as an important area for fish breeding and refuge, including for Murray cod (Zampatti et al., 2011b). Connectivity between this area and the remainder of the ecological community is therefore vital. However regulating structures impede the movements of fish and other biota between mesohabitats within this area. Promotion hydrological connectivity is vital to maintaining and potentially restoring native fish populations and other aquatic biota within the ecological community (Zampatti et al., 2011b,c).

CONCLUSION CRITERION 4

The combined impacts of the various threats operating have reduced the integrity of the ecological community through:

- reductions in biodiversity, including genetic diversity (e.g. Frankham, 1996), across a range of taxa and habitats
- promotion of conditions that favour alien species, including 'pests', and
- altered hydrological regimes and loss of connectivity leading to disruption of key ecological processes, such as: natural cycles of reproduction, recruitment and regeneration, maintaining movement and dispersal corridors (in the water-column and on land), and providing complex habitats.

These reductions in integrity have impaired the resilience of the ecological community due to ongoing natural and anthropogenic pressures, which will further exacerbate the continued and combined impacts of the various threats, including climate change.

A number of management actions have been taken, and are ongoing, to remove pressures and restore resilience. For example, the Basin Plan in particular is aimed at restoring environmental flows. However the Basin Plan will not be fully implemented for some time, and is unlikely to restore the integrity of the ecological community in the immediate future.

After preliminary assessment, the Committee considers that the change in integrity experienced by the ecological community may have met the relevant elements of Criterion 4 (i.e. **very severe** and restoration across the extent of the ecological community is unlikely in the immediate future) to make it eligible for listing as **Critically Endangered**.

Consultation Questions on listing assessment

More recent data and analysis on trends will be available and will be incorporated when Murray-Darling Basin Plan and Water and Environment Research Program (WERP) reports are released soon. In addition to that:

- Do you have any feedback on the preliminary assessment under Criterion 4 or further data or information on changes in integrity and processes that would support or update the assessment, including references?

6.2.5 Criterion 5 – rate of continuing detrimental change

	Category		
	Critically Endangered	**Endangered**	**Vulnerable**
Its rate of continuing detrimental change is: as indicated by:	very severe	severe	substantial
(a) rate of continuing decline in its geographic distribution, or a population of a native species that is believed to play a major role in the community, that is: OR	very severe	severe	serious
(b) intensification, across most of its geographic distribution, in degradation, or disruption of important community processes, that is:	very severe	severe	serious
an observed, estimated, inferred or suspected detrimental change over the immediate past, or projected for the immediate future (10 years or 3 generations, up to a maximum of 60 years), of at least:	*80%*	*50%*	*30%*

Eligibility under this criterion is about demonstrating an observed, estimated, inferred, or suspected ongoing detrimental change; where detrimental change may refer to either of the components of this criterion, i.e. to:

- changes in the geographic distribution of, or changes to populations of, critically important species, or,
- degradation or disruption of important processes.

Data and information to demonstrate this criterion must be documented. They can be in the form of direct measurements of any of the components, levels of exploitation, or the known effects of introduced biotic or abiotic elements on any of the components of the ecological community.

The main threat contributing to an increased rate of detrimental change under Criterion 5 for the RMDS ecological community, and for which there is sufficient data at the time of the preliminary assessment, is salinisation of the floodplain.

SALINISATION OF THE FLOODPLAIN

History

The Murray-Darling Basin (MDB) is geologically and climatically prone to concentrating salt in an ancient landscape that was once covered by ocean. Much of the salt in the Australian landscape is dissolved sodium chloride in groundwaters and soil waters, in large sedimentary aquifers (Herczeg et al. 2001). The generally flat terrain, low rainfall and high evaporation,

combine to concentrate an estimated more than 150 000 million tons of salt in the groundwater[14] (Simpson et al. 1994 in Hart et al. 2020; Herczeg et al. 2001; MDBC 2008c).

The southern MDB, which corresponds with much of the RMDS, is particularly vulnerable to salinity problems (Hart et al. 2020). Prior to river regulation, salt accumulation was mitigated by flushing from frequent floods which inundated the floodplains. Pre-European Settlement salt loads in the South Australian River Murray were estimated at 800-900 tonnes/day (Felder 2015). Over the long-term there was a salt balance in the soil and, subsequently, stable vegetation communities developed (Jolly 2004).

The Soil Salinity Problem

Soil salinity problems on the floodplain (often referred to as "dryland salinity") occur when the upward groundwater fluxes (discharge) which carry salts up into the surface soils, predominate over the downward fluxes (recharge) of relatively low-salinity water (Jolly et al. 1993b; Peck & Hatton 2003). By the mid-1980s, salinity was recognised as one of the most significant environmental and economic challenges facing the southern MDB (MDBA 2014; MDBMC 2015).

Since the early 20th Century, the surface and groundwater hydrology of the floodplains has been dramatically altered by the impacts of river regulation, vegetation clearance, and the development of large irrigation areas on the higher areas adjacent to the floodplains (Figure 18). Salt is accumulating in floodplain soils at an increased rate due to:

- increased saline groundwater discharge caused by raised water table levels
- point-source saline discharge from adjacent irrigation areas, and
- a lack of flushing by floods (Jolly 2004).

For example, to maintain crop productivity, salt must be removed from the root zone. Leaching is the most common approach. It is achieved by applying more water than is needed by the crop. This results in water and salt draining past the root zone and eventually into the groundwater table (DEWNR 2017). There can be significant time delays (several decades or more) between the start of irrigation and increased salt loads appearing in the river and floodplain, so salt loads will continue to increase over time, even if no new irrigation schemes are implemented (Connor 2008; Government of SA 2011; Figure 18).

Recharge: In arid and semi-arid environments, recharge events occur intermittently, as a result of extreme rainfall or floods (Gee & Hillel 1988). Before river regulation, there was probably a net recharge regime (Jolly et al. 1993a). This is no longer the case. For example, on the Chowilla floodplain, regulation of the River Murray, by weirs (such as Lock 6) and major storages, has reduced the frequency of flooding (by at least a factor of three) (Overton et al. 2006). This has led to rising of the water tables beneath the adjacent floodplain (Ohlmeyer 1991). Rises in saline groundwater, due mainly to river regulation, have been observed since the 1920s (Overton et al. 2006).

[14] And Herczeg et al. (2001) gave an estimate, that 1.5 million tons of new salt is deposited in the MDB each year by rainfall (4110 t/d). The groundwater chemistry has evolved by a combination of atmospheric fallout of marine and continentally derived solutes and removal of water by evapo-transpiration over tens of thousands of years of relative aridity. Carbonate dissolution/ precipitation, cation exchange and reconstitution of secondary clay minerals in the aquifers results in a groundwater chemistry that retains a 'sea-water-like' character. Knowing the sources of salt, and its transport mechanisms through the hydrosphere, is necessary for long-term management and protection of water resources that salt can affect.

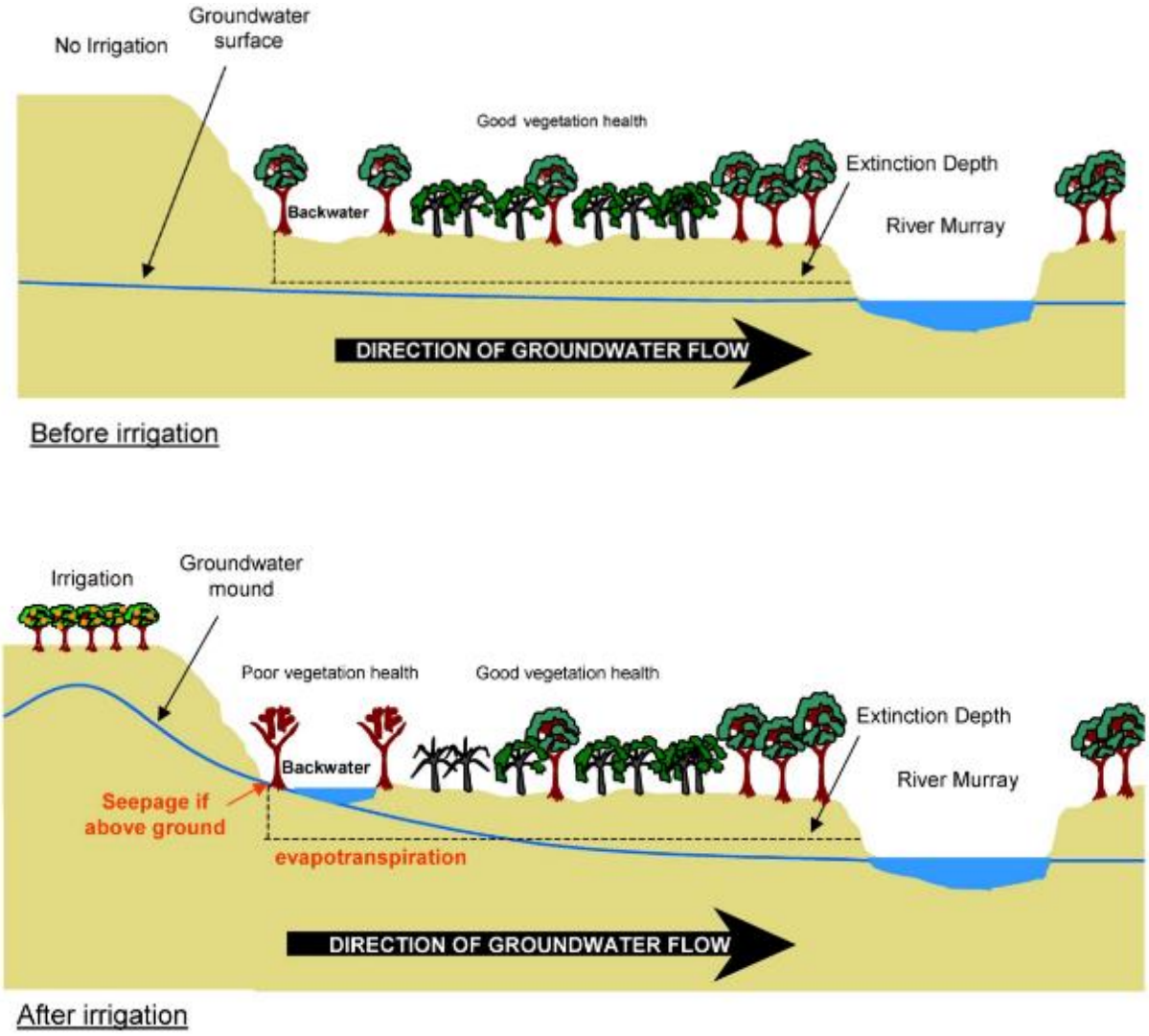

Figure 18: A diagrammatic representation of a change in hydraulic gradients — how groundwater influences salinity—pre and post irrigation (after Felder 2015).

Land clearing: Loss of native vegetation compounds the problem of soil salinisation. Land clearance and cropping replaces deep-rooted native vegetation with shallow-rooted agricultural crops. Crops use less water than native vegetation, leaving more rainwater to recharge the groundwater (Government of SA 2011). This additional recharge, allied to river regulation and irrigation schemes, causes saline water tables to rise, saline groundwater inflows to increase, and salt mobilisation to occur. Most of the salt mobilised does not get exported through the rivers to the sea; instead it stays in the landscape, or gets diverted into irrigation areas and floodplain wetlands (MDBMC 1999). As a result, the River Murray floodplain in South Australia is now badly affected by salinity and is degrading further (MDBC 2003a; Government of SA 2011).

Table 40 provides estimates of salt mobilised to the land surface in the Murray Darling Basin in SA, as well as the amount of mobilised salt that would be retained in the landscape (as opposed to flushed into the rivers) (MDBMC 1999). It shows a projected increase in the amount of mobilised salt, retained in the landscape, of 38% between 1998 and 2020 (over 22 years), and an increase of 105% between 1998 and 2050 (over 52 years). This represents a severe to very

severe intensification in degradation, across most of the geographic distribution of the floodplain of the ecological community.

Note that the figures in Table 40 neither take account of remedial action since 1999 (e.g. irrigation efficiencies, salt interception schemes, and land management changes). Nor do they take account of the Millennium Drought, which was followed by large floods in 2010-11 and 2022-23, which would have both leached and exacerbated salinity. However, updated estimates of salt mobilised to the land surface have not been available in more recent years, so there is some uncertainty regarding the intensity and rate of increase.

Table 40: Estimated quantity of salt mobilised to the land surface, 1998–2100, Lower Murray in South Australia (Source: MDBMC 1999).

Aspect	**Salt mobilised to land surface (tonnes per year)**						
	1998	**2020**	**2020 increase as % of 1998**	**2050**	**2050 increase as % of 1998**	**2100**	**2100 figure as % of 1998**
Barrages to Lock 2	105 000	190 000	81%	260 000	148%	335 000	219%
Lock 2 to SA/NSW Border	329 000	450 000	37%	610 000	85%	685 000	108%
Total salt mobilised	434 000	640 000	47%	870 000	100%	1 020 000	135%
Ratio of amount retained in landscape: the total salt mobilised[1]	3:5.1	3.7:6.7*		5:8.3		6.5:10.3*	
Above ratio expressed as a percentage	59	55		60		63	
Increase in the amount of salt retained in the *landscape, as a percentage of the 1998 figure*			**38%**		**105%**		152%

Notes: [1]The ratio is expressed as a ratio of the total amount of 'mobilised salt' to the land surface for the entire MDB in Australia: to the amount retained in the landscape for the entire basin. The percentage increase from the 1998 figure is then calculated by multiplying the total salt mobilised (in the row above) by the ratio (e.g. 0.59 for 1998 and 0.55 for 2020). *Estimate, by inspection of Figure 7 in MDBMC (1999).

Impacts of salinisation

Soil salinisation has long been considered an issue of great concern for the long-term health of riparian and floodplain vegetation along the River Murray (Margules & Partners et al. 1990). Although native flora and fauna have evolved with and are, to some extent, adapted to saline conditions, there are limits. As salt accumulates beyond particular physiological thresholds for a species, germination and recruitment is impeded. Eventually, adults of many plants (e.g.

functionally important eucalypts and herbaceous wetland species) are likely to be lost, particularly if high soil salinity is coupled with long drought periods and/or waterlogging (e.g. by extreme floods). Dieback of tree species on floodplains has long been attributed to increased soil salinisation due to raised groundwater levels, which have resulted from irrigation and river regulation (Jolly et al. 1993b; Doody et al. 2015, 2021, 2023). This situation is exacerbated by a reduction in flooding frequency and duration of inundation, both of which are impacted by over extraction of water and climate change (Jolly et al. 1993b) and see image of Clark's floodplain – Bookpurnong, below.

Clark's Floodplain – Bookpurnong, SA © R. Felder 2015

Floodplain salinisation is a threatening process (refer to Section 4). It causes detrimental change to the ecological community by disrupting the fresh water supply to native vegetation on the floodplain, that is used for transpiration and biological functioning. Raised weir pool levels and the development of irrigation areas adjacent to the floodplain have further increased rates of evapotranspiration (and hence increased movement of salt up into the plant root zone (Jolly 1996). Long-term, high salinity ultimately reduces the structural complexity of habitats (such as woodlands) to that of low shrubland, with a resulting reduction in species able to use the habitat (Stewart et al. 2010). For example, indications are, that at high salinities, native mammal species richness is suppressed (Stewart et al. 2010).

With respect to the Chowilla floodplain, the largest area of undeveloped floodplain in the ecological community and with high refuge value, Taylor et al. (1996), using GIS-based modelling, estimated that in 1993, 43% of the floodplain was affected by soil salinisation, and this had increased to 65% by 2003 (DEH 2004; Smith & Kenny 2005). Specifically, the Chowilla floodplain is a 'sink' for naturally saline regional aquifers in the western Murray Basin (Gehrig et al. 2012).

Keystone floodplain trees and impacts of salinisation

Slavich (1997) showed that *Eucalyptus largiflorens* (black box, river box) trees on the Chowilla floodplain could live as long as 450 years; *Eucalyptus camaldulensis* (river red gum) can live even longer, possibly to 950 years (Ogden 1978; MDBC 2003a). These two keystone eucalypt species

are essential ecosystem engineers and characterise the dominant vegetation communities of the ecological community (Stewart et al. 2010; Gibbs et al. 2020; Doody et al. 2021; see Criterion 3). As outlined in Section 1.2.3, they provide high-value habitat for a range of flora and fauna and provide ecosystem services throughout the ecological community; for example, bird species richness is greatest in the more structurally complex woodlands and forests (Stewart et al. 2010; Overton et al. 2018).

These eucalypts also influence local hydrology and micro-climates, and provide food for many organisms, including important pollinators (Robertson et al. 2001; MDBC 2003a; Wallace 2009). River Red Gums contribute energy directly to the river in the form of dissolved organic carbon, provide structural features such as snags, and moderate river temperature by shading (Roberts & Marston 2011). They alter soil properties nearby. On floodplains, floodwater percolates into the soil more rapidly (2-17 times faster) near black box than in adjacent bare ground (Bramley et al. 2003).

Although salt-tolerant to varying extents, black box and river red gum are vulnerable to additional salinisation of floodplain soils and to the influx of saltwater into the plant root zone (Stewart et al. 2010). This is heightened as droughts become more severe under climate change (e.g. Millennium Drought), with trees more dependent on groundwater—which compounds soil salinity problems in areas underlain by saline groundwater (e.g. Jolly 1996).

There is strong and consistent evidence that old-growth floodplain trees in the ecological community are stressed, showing dieback, dying, or suffering recruitment failure—all largely due to soil salination (i.e. as per Table 27, particularly MDBC (2003), McNally et al. (2011), Cunninham et al. (2011), and Overton et al. (2006). During the Millennium Drought, Walker et al. (2005) estimated that 40% of the floodplain (40 000 ha) was severely degraded by soil salinisation[15]; and, in the case of trees alone, 68% of the floodplain vegetation communities (28 653 ha) were suffering health decline, with 17% reported as dead.

Although there has been a slight improvement in red gum condition given targeted environmental watering and recent wet years (e.g. DEW 2023; and see Table 27), the limited extent and duration of environmental flows under conditions of river regulation, water extraction, and climate change going forward, are considered insufficient to meet the needs of floodplain trees, remove accumulated soil salts, and reverse the long-term trend of decline (MDBC 2003a; Holland et al. 2005, 2009; Doody et al. 2021; DEW 2023). High (unregulated) flows are important for the system, and they are critical to reach areas of the floodplain that cannot be supported through managed inundation (DEW 2020b). Artificial watering is not a direct substitute for regular natural floods given the limited extent and degree of salt leaching, bank recharge, and groundwater freshening in comparison to natural floods (Ye et al. 2014).

Vegetation and Fauna at high risk from saline soils

In a seminal 2002-04 survey of the South Australian Murray floodplain (Murray Valley), which overlaps with a significant component of the ecological community, Stewart et al (2010) concluded that the impact of increasing salinisation is likely to change areas of woodland vegetation to low shrubland dominated by samphire, which would most likely also impact arboreal or semi-arboreal species, such as gliders and possums and the many bat species that

[15] 40% of the SA DEH vegetation mapping (for the Lower River Murray floodplain from Wellington to the SA/NSW/Vic border) was classed as unhealthy trees, dead trees, or halophytes, which are indicative of floodplain salinisation.

shelter in tree hollows along the River Murray (particularly species that are highly-dependent on the river). These authors determined that 5 of 35 floodplain vegetation sub-communities recorded, and 24 fauna species (of 295 vertebrate species), were at highest risk from rising salinity levels (see Tables 41a and 41 b). Species dependent on cracking clay soils, such as Giles Planigale and Fat-tailed Dunnart, are also likely to decline in the region if surface salt levels are high enough to alter this character of those soils (Stewart et al. 2010). The authors suggested that such biodiversity assets could be the focus of future monitoring to help evaluate salinity management actions.

Table 41a: Vegetation sub-communities at highest risk from rising salinity levels (from survey outcomes of 2002-04 Murray Valley, after Stewart et al. 2010).

Id. \ Vegetation Community Name
9 Common Reed (*Phragmites australis*) Tussock Grassland +/- Lignum (*Duma florulenta*[1]) and River Red Gum (*Eucalyptus camaldulensis* var. *camaldulensis*)
10 Narrow-leaf Bulrush (*Typha domingensis*) Sedgeland +/- Common Reed (*Phragmites australis*) +/- River Club-rush (*Schoenoplectus validus*) and emergent River Red Gum (*Eucalyptus camaldulensis* var. *camaldulensis*
15 Lignum (*Muehlenbeckia florulenta*) Tall Shrubland
27 River Box[2] (*Eucalyptus largiflorens*) Open Woodland over River Saltbush (*Atriplex rhagodioides*) +/- Ruby Saltbush (*Enchylaena tomentosa*) / Round-leaf Pigface (*Disphyma crassifolium* ssp. *clavellatum*)
28 Prickly Bottlebrush (*Callistemon brachyandrus*) Tall Shrubland over Ruby Saltbush (*Enchylaena tomentosa* var. *tomentosa*) Warrego Summer- grass (*Setaria jubiflora*) +/- River Box (*Eucalyptus largiflorens*) / River Red Gum (*E. camaldulensis* var. *camaldulensis*) Open Woodland
Notes: [1]*Duma florulenta* (synonym *Muehlenbeckia florulenta*) - tangled lignum / lignum. [2]*Eucalyptus largiflorens* - river box / black box.

Salt Interception

Groundwater gradients now exist in many reaches, and they drive saline water directly into the river (Figure 18). Salt interception aims to reduce this hydraulic gradient, by drawing down the elevated saline groundwater table at the edge of the floodplain, with pumps. The saline water accumulated from interception is piped to evaporation basins several kilometres away from the river (Connor 2008)[16]. Without salinity management, salt loads in the river in South Australia were predicted to reach almost 2500 tonnes of salt/day (t/d) by 2050 (Felder 2015).

Between 1990 and 2014, six salt interception schemes (SIS) were installed along the South Australian Murray, from Lock 2 - Waikerie to Pike. Together, they intercepted an average of 500 t/d of salt (Felder 2015; DEWNR 2013; DEW 2019); from 2015-2021 the average was 630 t/d of salt (MDBA 2018, 2020, 2022). Other initiatives such as pipelines, bores and salt

[16] However, when intercepted saline groundwater is deposited in evaporation basins it eventually creates sufficient hydraulic gradient to force more saline groundwater back into the river (Connor 2008). An analysis concluded that the operation of salt interception basins is likely to lead to returns of salt to the river at rates of between three and 30% of the total salt pumped to the interception basins (Collingham & Forward 2005 in Connor 2008), beginning 30 to 100 years after the basins start operating.

Table 41b: Fauna species at highest risk from rising salinity levels (from survey outcomes of 2002-04 Murray Valley, after Stewart et al. 2010)

Scientific Name	Common Name	SA1[1]	EPBC[2]
Birds			
Anthochaera[3] *phrygia*	regent honeyeater	E	CE
Botaurus poiciloptilus	Australasian bittern	E	E
Entomyzon cyanotis	blue-faced honeyeater	R	-
Haliaeetus leucogaster	white-bellied sea eagle	E	M
Philemon citreogularis	little friarbird	-	-
Plectorhyncha lanceolata	striped honeyeater	R	-
Podiceps cristatus	greater crested grebe	R	-
Stictonetta naevosa	freckled duck	V	-
Mammals			
Acrobates pygmaeus	feathertail glider	E	-
Mormopterus sp.2	eastern freetail-bat	-	-
Myotis macropus	southern myotis	E	-
Planigale gilesi	Giles planigale	-	-
Trichosurus vulpecula	common brushtail possum	R	-
Reptiles			
Chelodina expansa	broad-shelled tortoise	V	-
Chelodina longicollis	common long-necked tortoise	-	-
Emydura macquarii	Macquarie tortoise	-	-
Eulamprus quoyii	eastern water skink	-	-
Morelia spilota	carpet python	V	-
Notechis scutatus	eastern tiger snake	-	-
Varanus varius	tree goanna	R	-
Frogs			
Crinia parinsignifera	eastern sign bearing froglet	-	-
Limnodynastes fletcheri	long-thumbed frog	-	-
Litoria peronii	Peron's tree frog	-	-
Litoria raniformis	golden bell frog	V	V

Notes:[1]National Parks and Wildlife Act 1972 (SA) Jan 2020 list Status: V = Vulnerable; R = Rare.
[2]Environment Protection and Biodiversity Conservation Act 1999 Status: V = Vulnerable;
E = Endangered; M= Marine. [3]Formerly known as *Xanthomyza Phrygia*.

management basins also contribute. For example, the Salinity Management Measures project aims to reduce the amount of salt that enters the Pike Floodplain. A series of groundwater pumping wells, connected by a pipeline, move saline groundwater away from the floodplain. This prevents up to 120 t/d of salt entering the Pike Floodplain from groundwater in the highland and around the floodplain (DEW 2024b). Groundwater production bores also lower the floodplain water table and draw low salinity river water into the floodplain aquifer to improve tree water availability (Holland et al. 2013). The total salt load diverted from the River Murray and adjacent landscapes is in Table 42. In addition to the salt load diverted away from the river system and nearby landscapes by the SIS, for the three years July 2018 to June 2021 an estimated annual average of 470,000 tonnes of salt was exported over barrages in SA (MDBA 2022).

Table 42: Total salt load diverted from the River Murray and adjacent landscapes from 2009-10 to 2020–21 Source: MDBA (2018, 2022). Note, this includes SIS and other measures.

Reporting year	Salt load diverted (t/yr.)	Salt load diverted Avg (t/d)
2009–10	490 000	1342
2010–11	324 164	888
2011–12	362 508	990
2012–13	322 686	884
2013–14	397 739	1090
2014–15	432 454	1185
2015–16	524 728	1434
2016–17	395 388	1083
2017–18	484 586	1328
2018–19	474 201	1299
2019–20	471 471	1288
2020–21	452 430	1240

Although management measures (such as salt interception schemes and irrigation management improvements) have reduced the regional sources of salt to the floodplain (MDBC 2001) — river regulation has also reduced the frequency and duration of the floods that can leach salt from the plant root zone and supply fresh water for transpiration (Jolly 1996; Overton et al. 2006). Modelling indicates that, over the long term, salt interception could be highly beneficial in reducing the salinity risk to floodplains and wetlands; however, large amounts of salt stored in the floodplain would need to be removed before the benefits to vegetation and wetlands would be realised (Holland et al. 2005, 2009). And, as noted previously, an estimated 1.5 million tons of new salt is deposited in the MDB each year by rainfall (4110 t/d) (Herczeg et al. 2001).

E-water v Flood

Artificial watering does not inundate as great an area as a natural flood (e.g. the Chowilla floodplain where 2,175 ha was artificially watered between 2005/06 and 2011/12 compared with >11,000 ha inundated by the 2010/11 flood). However, it can be an important way to maintain floodplain function at a reduced level —and to enable the floodplain to partially fulfil some of the ecosystem services it provided prior to river regulation; and to enable the floodplain to function at a higher level during the next flood (Holland et al. 2013).

The massive flood of November 2022 to February 2023 (the third largest on record in South Australia) inundated almost the entire South Australian River Murray floodplain; and it reached areas that had not received water in decades (DEW 2024a). This flushed and freshened large areas of floodplain soils and gave a boost to native vegetation (DEW 2024a). However, such floods can also contribute to erosion, siltation, and introduce pollutants and pests. And although they represent an 'ecological reset' to some extent, they cannot on their own reverse the long-term decline of the ecological community, and they can exacerbate salinity impacts and thus ongoing declines in RMDS integrity (as outlined here in Criteria 3 and 4 analysis).

Floodplain harvesting (the diversion and storage of overland flows into on-farm dams) is a widespread practise in the MDB which is likely to exacerbate salinity issues (Clark et al. 2007). It is not known if this is a major issue in the RMDS based on existing data.

CONCLUSION CRITERION 5

Notwithstanding uncertainty about patterns of floodplain salinisation and the varying responses of floodplain trees in different areas, evidence indicates an intensifying and continuing trend of floodplain salinisation, contributing to tree dieback across large areas of the ecological community. This trend represents a severe to very severe intensification in degradation across most of the geographic distribution of the floodplain of the ecological community. It indicates a severe rate of continuing detrimental change (immediate past and immediate future) in the health and recruitment of keystone floodplain tree species, which play a major role in the RMDS (3 generations is at least 60 years for these trees). Following preliminary assessment the ecological community may be eligible for listing as at least **Endangered** under this criterion.

Consultation Questions on Criterion 5

- Do you have any feedback on the preliminary assessment under Criterion 5, or further data and/or information that would support or update the assessment? For example, how accurately does it reflect the current situation.
- Most particularly, please provide updated data/information for Table 40: Estimated quantity of salt mobilised to the land surface, 1998–2100.
- Please provide information on (any new) schemes that have a particular impact on soil salinity. Please provide details/evidence of specific impacts, where possible.
- Please provide information on how/if "floodplain harvesting" has a particular impact on soil salinity. Please provide details/evidence of specific impacts, where possible.

Please provide any supporting evidence or references you have.

6.2.6 Criterion 6 – quantitative analysis showing probability of extinction

	Category		
	Critically Endangered	**Endangered**	**Vulnerable**
A quantitative analysis shows that its probability of extinction, or extreme degradation over all of its geographic distribution, is:	at least 50% in the immediate future	at least 20% in the near future	at least 10% in the medium-term future
timeframes	*10 years or 3 generations (up to a maximum of 60 years)*	*20 years or 5 generations (up to a maximum of 100 years)*	*50 years or 10 generations (up to a maximum of 100 years)*

There are no quantitative data available to assess the ecological community under this criterion.

Therefore, it is **not eligible** for listing under this criterion.

Appendix A – Additional information on 'area in nature'

Appendix B – Additional information on 'assemblage of species' (i.e. Flora and Fauna)

References

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Department of Climate Change, Energy, the Environment and Water
GPO Box 858, Canberra ACT 2601
Telephone 1800 900 090
Web dcceew.gov.au

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