Literature review on the ecology of fishes of the Lower Murray, Lower Lakes and Coorong

Report to the South Australian Department for Environment and Heritage

SARDI Publication No. F2010/000031-1
SARDI Research Report Series No. 425

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February 2010

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Government of South Australia
Department for Environment and Heritage

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This publication may be cited as:
Bice, C. (2010). Literature review of the ecology of fishes of the Lower Murray, Lower Lakes and Coorong. Report to the South Australian Department for Environment and Heritage. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 81pp. SARDI Publication No. F2010/000031-1.

Cover: clockwise from top left; 1) small-mouthed hardyhead (above) and Murray hardyhead (below) from the Lower Lakes, 2) Murray cod (photo Jason Higham), 3) black bream and 4) mulloway (photo Paul Jennings)

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Printed in Adelaide: February 2010

SARDI Aquatic Sciences Publication No. F2010/000031-1
SARDI Research Report Series No. 425

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Date:	22 February 2010
Distribution:	Department for Environment and Heritage and SARDI Aquatic Sciences Library
Circulation:	Public Domain

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Executive summary

Water levels in the Lower Lakes are currently the lowest on record and with predictions of continued below average inflows, levels are likely to continue receding. Receding water level has resulted in the exposure of extensive areas of acid sulfate soils, which upon reaction with oxygen release sulfuric acid and heavy metals that may lead to the acidification of remaining water supplies (including supplies for stock and human use). This represents a major environmental threat to the Lower Murray (below Lock 1) and the Ramsar listed Lower Lakes and Coorong and as a consequence several management options have been proposed to mitigate the threats posed by lowered water levels and acid sulfate soils.

Perhaps most extreme of these options, is the managed intrusion of salt water into Lake Alexandrina to maintain water levels above an acidification trigger level (i.e. -1.5 AHD). This option may mitigate the immediate threat posed by acidification but may potentially have a range of impacts on the freshwater adapted ecosystem of the Lower Lakes, including the diverse fish community present. Other options under consideration include doing nothing, maintaining water levels above acidification trigger levels with freshwater inflows and allowing water levels in Lake Alexandrina to fall further with associated bioremediation of areas of exposed acid sulfate soils. All potential management options are likely to present a risk of significant change to the ecological character of the Lower Murray, Lower Lakes and Coorong.

There is a need to understand the ecology of the biota of the region in order to allow the assessment of potential changes in ecological character under potential management scenarios. This report presents information on the ecology of a suite of selected fish species from the Lower River Murray (below Lock 1), Lower Lakes and Coorong. Specifically, information on key factors influencing fish distributions and abundances, spawning requirements, habitat associations, diet and physico-chemical tolerances is presented. This information is used to develop conceptual models on the lifecycles of the selected species and will aid in predicting the condition of fish communities under different management scenarios.

1. Introduction

Persistent drought conditions in the Murray-Darling Basin (MDB) combined with a history of river regulation and over extraction of water resources have resulted in below average inflows to the Lower Lakes over the last decade (DWLBC 2009). Water levels in Lakes Alexandrina and Albert have receded since mid 2006 to historically low levels and no freshwater has been released to the Coorong since March 2007. Predictions suggest inflows are likely to remain below average in the foreseeable future and lake levels are likely to continue receding.

Severely decreased water levels pose many threats to the Lower Lakes ecosystem, perhaps none as pertinent as the exposure of acid sulfate soils (ASS). The exposure of ASS may have serious impacts on the quality of remaining water supplies, particularly upon re-wetting, including acidification, mobilisation of heavy metals, anoxia and the production of noxious gases (Fitzpatrick *et al.* 2008). Thus, there exists a dire threat to the ecological and cultural character of the Lower Lakes as well as the agricultural and tourism sectors.

The Coorong and Lower Lakes were designated as a wetland of international importance under the Ramsar convention in 1985 and as such the Australian government is under obligation to maintain the 'ecological character' of this site (see DEH 2000). Additionally, the Coorong, Lower Lakes and Murray Mouth have collectively been assigned as one of six 'icon sites' in the MDB under '*The Living Murray'* program, the primary objective of which is also, 'the maintenance and enhancement of the ecological character of the site' (see MDBC 2006). As such, there is great impetus for management of the current situation to mitigate the threats posed by reduced water levels and ASS.

Several short-term management options have been proposed for the Lower Lakes with the primary objective of maintaining water above a critical level for acidification (i.e. -1.5 m AHD). With the likelihood of significant freshwater inflows in the near future very low, options for regulating water levels above acidification thresholds are limited and the managed intrusion of saltwater (from the Coorong) over the Murray Barrages features prominently amoung the management suggestions (see Bice and Ye 2009). Although this may mitigate the immediate threat posed by ASS, such management practises may have serious impacts on the freshwater adapted ecosystem of the Lower Lakes. Regardless of the management approach adopted for mitigating the threats posed by severely reduced water levels and ASS in the Lower Lakes, a detailed understanding of the ecology of the biota likely to be affected is imperative to making informed management decisions.

Fish are an important component of aquatic communities. The Lower River Murray (below lock 1), Lower Lakes and Coorong comprise a diversity of habitats with differing hydrological, physical and physico-chemical attributes and thus harbour highly diverse fish assemblages unique within the MDB. These assemblages include species of national and state conservation significance and economically important species which support the Lakes and Coorong commercial fishery.

This report aims to collate existing knowledge on the ecology of fishes of this region and develop an understanding of factors or drivers that are important in maintaining sustainable populations of fish species'. Recent data is also summarized to provide a summary of the current condition of the fish community in the region. The ecological information is used to develop conceptual models on the lifecycle of the selected fish species which in turn will provide a framework for predicting the condition of fish communities under different management options as part of a potential future Environmental Impact Statement (EIS) on the environmental benefits and costs of several management options for the Lower Lakes.

2. Study region: The Lower Murray, Lower Lakes and Coorong

The MDB is Australia's longest river system and drains an area of ~1,073,000 km^2. Over 90% of the basin is arid or semi-arid (Maheshwari *et al.* 1995) and >50% of the annual discharge is derived from <5% of the catchment (i.e. headwaters of the River Murray) (Walker 1992). Annual discharge from the system is amoung the most variable in the world (Finlayson and McMahon 1988; Puckridge *et al.* 1998), however; under regulation mean annual discharge (~4723 GL) is now just 39% of natural mean annual discharge (~12,233 GL).

The River Murray discharges into a shallow (average depth 2.9 m) expansive terminal lake system, comprised of Lakes Alexandrina and Albert before flowing into the Coorong and finally the Southern Ocean via the Murray Mouth (Figure 1). The Lower Lakes encompass a vast area (>90,000 ha; Sim and Muller 2004) and a diverse range of aquatic habitats. The Coorong is a narrow (2-3 km wide) estuarine lagoon running southeast from the river mouth, parallel to the coast, for approximately 140 km. The region was designated a Wetland of International Importance under the Ramsar convention in 1985 based upon its unique ecological character and importance to migratory wader birds. As a signatory to the Ramsar convention, the Australian government is obligated to retain the 'ecological character' of this site (see Phillips and Muller 2006). In addition it has been designated as one of six Living Murray Icon Sites in the MDB based upon its unique ecological qualities, hydrological significance, cultural and economic values (DWLBC 2008).

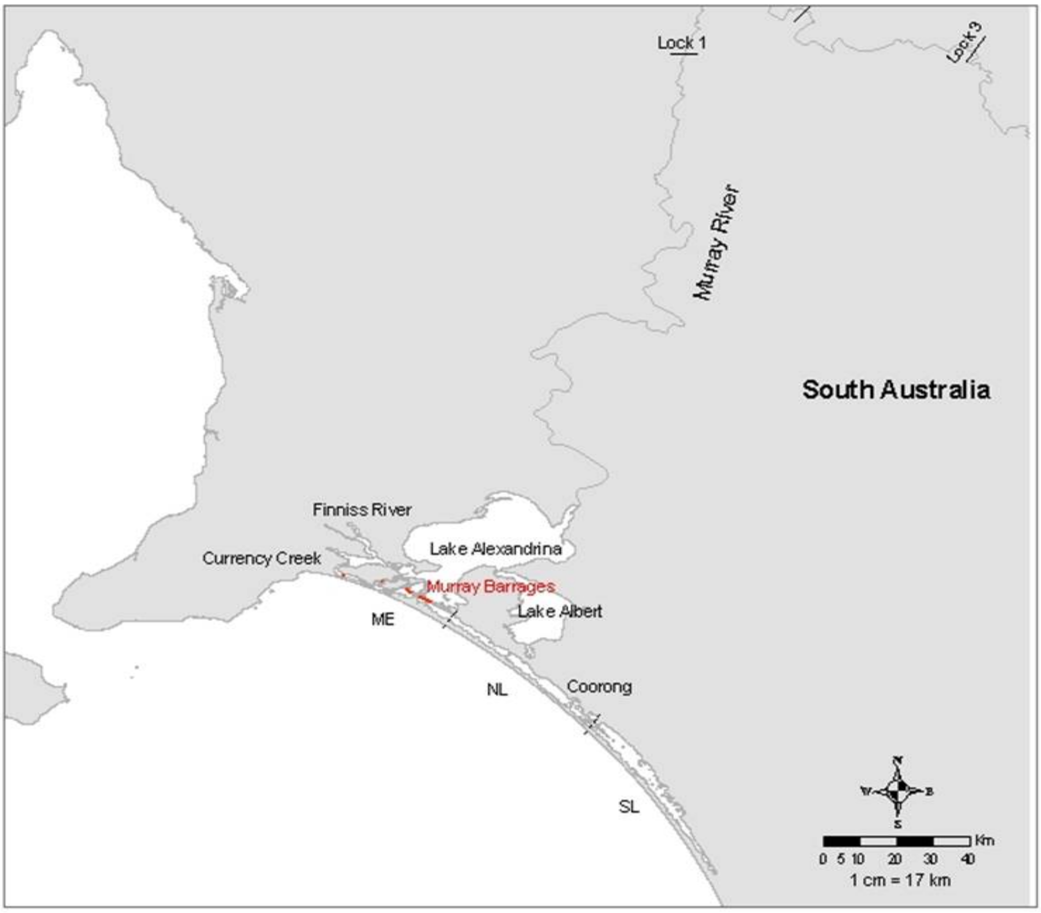

Figure 1. Map of the Lower Murray, Lower Lakes (Alexandrina and Albert) and Coorong showing the position of the five tidal barrages and divisions of the Coorong Lagoons (ME = Murray Estuary, NL = North Lagoon and SL = Southern Lagoon).

Before large-scale water extraction in the MDB, freshwater inflows to the Lower Lakes were sufficient to maintain a freshwater environment with minimal salt water intrusion from the Coorong (Sim and Muller 2004). After 1900, following significant upstream water resource development, decreased inflows resulted in an increased frequency of saltwater intrusion events (Sim and Muller 2004). Consequently, in the 1930's and 40's, five tidal barrages (i.e. Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere) with a total length of ~7.6 km, were constructed to prevent saltwater intrusion into the Lower Lakes and maintain a stable freshwater storage for water extraction (Figure 1). The construction of the Murray Barrages dramatically reduced the extent of the Murray Estuary, creating an impounded freshwater environment upstream and forming an abrupt ecological barrier between estuarine/marine and freshwater environments.

Pool level upstream of the barrages (the Lower Murray below Lock 1 (hereafter referred to as the 'Lower Murray') and Lower Lakes) is typically regulated at approximately 0.75 m AHD (Australian Height Datum). Freshwater is released to the Coorong via the barrages at water levels of 0.75-0.85 m AHD. When water levels are >0.85 m AHD, water flows over wetland areas on islands (e.g. Hindmarsh and Mundoo) in the transition zone between Lake Alexandrina and the Coorong, bypassing the barrages. Water level in Lake Alexandrina is highly dynamic with wind seiche (short-term changes in water level due to wind stress) potentially influencing daily water level immediately upstream of the barrages by >0.3 m.

Decreases in freshwater discharge to the Coorong since regulation has resulted in increased sedimentation, constriction of the Murray Mouth, reduced tidal incursion, reduced depth and increased salinities (Geddes 1987; Walker 2002). Salinity typically ranges from marine (*c.* 35 g L^{-1}) in the Murray Estuary to hyper-marine (>100 g L^{-1}) in the Southern Lagoon. Yet, during periods of freshwater inflows salinity in the estuary (between Goolwa Barrage and the Pelican point; Figure 1) and Northern Lagoon is normally brackish (i.e. 5-30 g L^{-1}).

2.1 Current water levels and conditions

With river regulation and increased extraction since barrage construction, mean annual end of system discharge has been reduced to just 39% of the natural mean and periods of no end of system flow have increased from 1 to 40% of the time (CSIRO 2008). When combined with the drought conditions experienced throughout the MDB in the last decade, inflows over Lock 1 (Blanchtown) and annual end of system discharge has been substantially lower than the post regulation mean since 2001 and has been zero on two occasions (Figure 2). Water levels in the Lower Murray and Lower Lakes have receded and freshwater has not been released to the Coorong since March 2007 (DWLBC 2009).

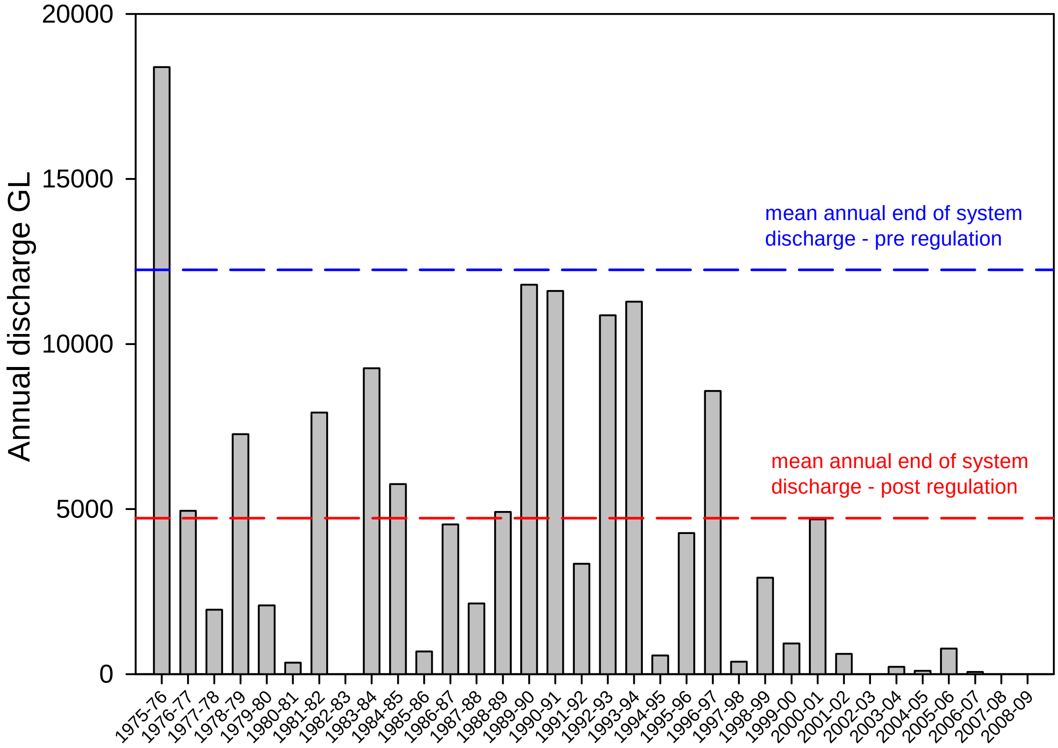

Figure 2. Annual freshwater discharge over the Murray Barrages from 1975-2009. Mean annual end of system discharge, pre-regulation and post-regulation are indicated.

Water levels in the Lower Murray and Lower Lakes are currently the lowest on record (Figure 3) and predictions suggest inflows will remain below average and water levels are likely to continue receding (Figure 4). Decreased water level has already had a significant impact on the Lower Lakes ecosystem, particularly due to the loss of important wetland habitats on Hindmarsh and Mundoo Islands (at water levels < 0.3 m AHD), extensive disconnection of the lake from edge habitats and increasing salinity. Similarly, many off-channel wetlands in the Lower Murray have also been disconnected and dried.

Perhaps the most alarming affect of lake level recession has been the exposure of ASS. ASS form naturally in waterlogged areas where large amounts of sulfate are present in surface and/or ground water together with large amounts of organic matter (Fitzpatrick *et al.* 2008). When such soils are exposed to oxygen, sulfuric acid is formed and mobilised together with various heavy metals. Thus, ASS may have serious impacts on water quality including acidification, mobilisation of heavy metals (e.g. As, Cd, Co, Ni), anoxia and the production of noxious gases (Fitzpatrick *et al.* 2008). Such dramatic changes to water quality may have catastrophic impacts on the biota of the Lower Lakes and may also lead to the contamination of water supplies for stock, irrigation and human consumption. In other parts of Australia the drainage of ASS and resultant acidification of water have also been implicated in several large fish kills (Brown *et al.* 1983; Dawson 2002).

The potential risk posed by ASS extends upstream of the Lower Lakes through the Lower Murray to Lock 1. Water off-takes for human use in the city of Adelaide are located within this reach and the risk of poor water quality in the vicinity of these off-takes due to potential upstream movement of poor quality water from the Lower Lakes has prompted the government to consider the construction of a new weir at Wellington to secure Adelaide's water supplies. The construction of this weir and its potential impacts are not discussed further in this review and is the subject of a targeted EIS (DEH 2009).

Due to the immediate risk posed by ASS in the Lower Lakes, Lake Albert was disconnected from Lake Alexandrina in early 2008 and water was pumped into Lake Albert (*c.* 200 $GL.year^{-1}$) to maintain water levels above critical trigger levels (-0.4 m AHD) to avoid acidification. It has been suggested that a water level of -1.5 m AHD in Lake Alexandrina represents a critical trigger level for acidification. Given predictions of further receding water levels in Lake Alexandrina and the potential for a lake level of -1.5 m AHD being reached in February 2010 (Figure 4), pumping to Lake Albert ceased in June 2009 to conserve water for Lake Alexandrina.

A lack of significant freshwater inflows to the Coorong since late 2006 has resulted in marine and hypermarine salinities throughout the system. Whilst salinity in the Coorong is typically spatio-temporally variable (Geddes 1987), freshwater inflows generally result in brackish zones (e.g. 5-30 $g. L^{-1}$) and salinity gradients from freshwater to marine. Such gradients have now been replaced by a gradient from marine salinities (~35 $g. L^{-1}$) in the Murray Estuary (i.e. Goolwa Barrage to Tauwitchere Barrage), to hypermarine salinities in the North and South Lagoons is now present.

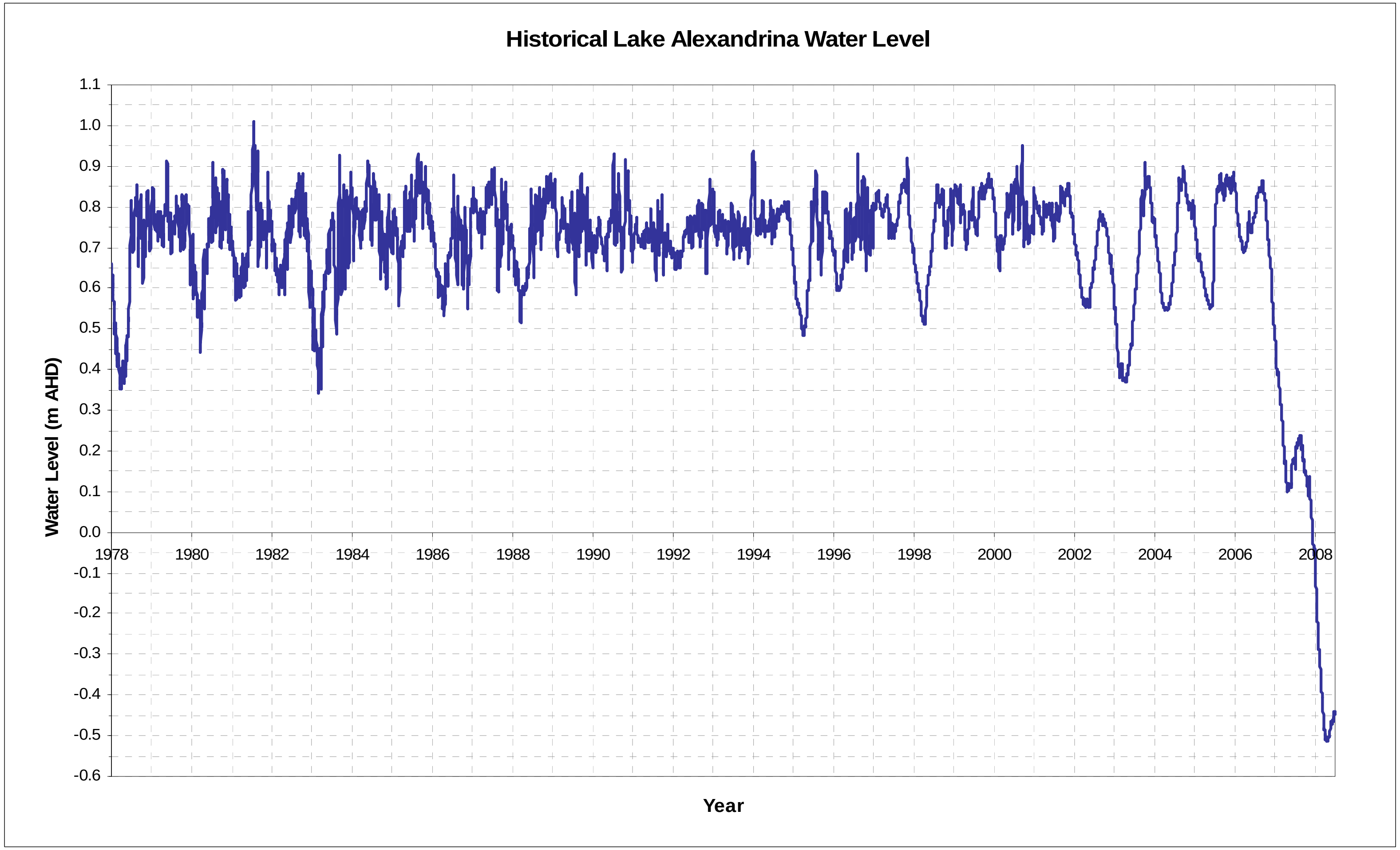

Figure 3. Water level in Lake Alexandrina between 1978 and June 2008. Graph provided by the Department of Water, Land and Biodiversity Conservation (DWLBC).

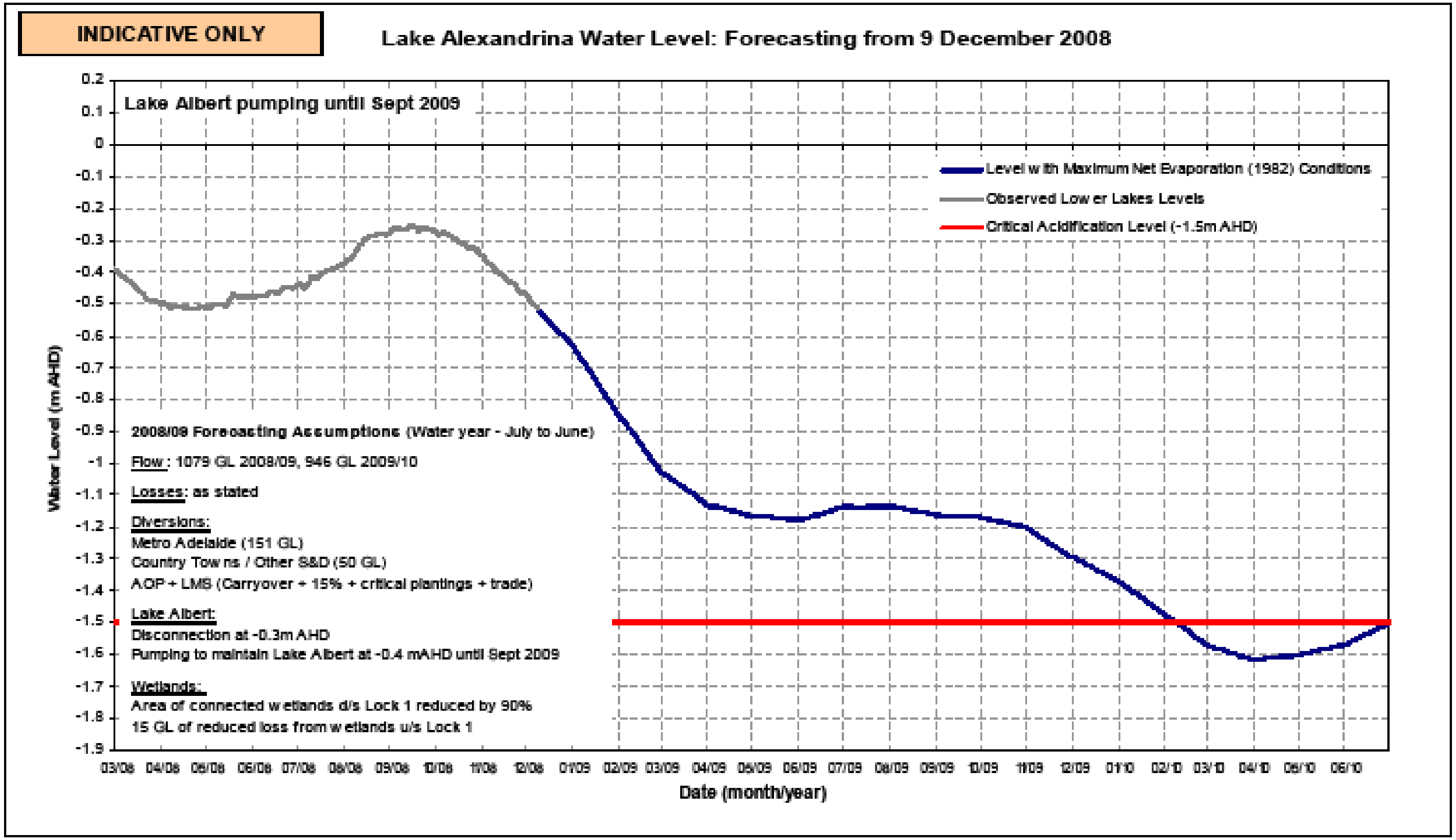

Figure 4. Predicted water levels in Lake Alexandrina above Goolwa barrage through the remainder of 2008 and into 2009. Assumptions of flow, salinity of inflowing water, water losses and diversions are indicated. Graph provided by DWLBC.

3 Fishes of the Lower Murray, Lower Lakes and Coorong

This section aims to describe the fish species of the region and to outline knowledge of the distribution, status and ecology of these species. Around 80 species of fish have been recorded from Lock 1 (Blanchtown) downstream to the Coorong Lagoons but many of these are of marine origin and are only irregular visitors (Higham *et al.* 2002). Similarly, some obligate freshwater species are more common in the upper reaches of tributary streams (e.g. the Finniss River) or further upstream in the MDB and are only encountered in this region following large floods (Eckert and Robinson 1990). Disregarding marine and freshwater species with irregular occurrence in the region, this still represents a highly diverse fish community representing various life histories.

To simplify this review process we have developed a set of criteria that must be met in order for a species to be included in the review. These include:

- The species has been collected in the region in the last 20 years and
- Possesses a national or state conservation significance or
- Is a commercially important species or
- Is considered an indicator of environmental change

Several species have been considered to be indicators of environmental change. Diadromous species (e.g. short-headed lamprey, *Mordacia mordax*) require movement between freshwater and estuarine/marine habitats to complete their lifecycle and thus are good indicators of environmental change due to their dependence on both environments and connectivity between them. Alien species (e.g. common carp, *Cyprinus carpio*) are also good indicators due to their generally wide physico-chemical tolerance ranges and propensity for degraded habitats (Koehn 2004). Some small-bodied species, both freshwater and estuarine, may also be viewed as indicators of system health. Many of these species are short-lived, have wide tolerance ranges and may exhibit rapid responses to changes in environmental conditions (e.g. small-mouthed hardyhead).

Based upon the above criteria, 34 species have been selected for review (Table 1). These are primarily obligate freshwater species but also include diadromous, estuarine and marine species. This list represents a diverse fish assemblage with an extensive size range (i.e. 40mm->1000mm), varied life history strategies and differing conservation and commercial values. As such, for the purpose of this project fish species are further 'grouped' as follows;

- Freshwater species – this represents a diverse group likely to be seriously impacted by the proposed management options and therefore these species are grouped further,

    - Large-bodied native freshwater species
        - Native species with average adult length >150mm that complete their lifecycle wholly within freshwater environments.
    - Common small-bodied native freshwater species
        - Native species with average adult length <150mm that complete their lifecycle wholly within freshwater environments and are considered common in the South Australian Murray-Darling Basin and specifically the Lower Lakes region.
    - Rare and endangered small-bodied native freshwater species
        - Native species with average adult length <150mm that complete their lifecycle wholly within freshwater environments and are considered rare in the South Australian Murray-Darling Basin and possess a state or national conservation status.
    - Alien freshwater species
        - Introduced species that complete their lifecycle within freshwater environments.
- Diadromous species
    - Both catadromous (i.e. adult freshwater residence, downstream spawning migration of adults, estuarine/marine spawning, upstream migration of juvenile fish) and anadromous species (i.e. adult marine residence, upstream spawning migration of adults, freshwater spawning, downstream migration of juveniles).
- Estuarine species
    - Estuarine resident species that generally complete their lifecycle within estuaries. This includes commercially important species.
- Marine species
    - Species often present in estuaries but may complete their lifecycle in coastal marine waters. This includes commercially important species.

Due to the highly varied environments encountered between the Lower River Murray and the Coorong, the fish fauna differs across different geographic areas or 'units' within the study region. For the purpose of this review the region will often be described in terms of units, namely; 1 – The Lower Murray (Lock 1 to Wellington), 2 - The Lower Lakes and 3 - The Coorong. The Lower Lakes may be further divided in Lake Alexandrina and Lake Albert, whilst the Coorong may be divided into the Murray Estuary, Northern Lagoon and Southern Lagoon (see Figure 1). For the purpose of this review the Lake Alexandrina sub-unit includes the Eastern Mount Lofty Ranges (EMLR) tributaries (i.e. The Finniss River and Currency Creek) up to the boundaries of the Ramsar site (i.e. Winery Road). Thus the presence of each of these species within each different sub-unit is also presented in Table 1. Presence is specified as the occurrence of a species within the defined sub-units of the region in the last twenty years.

Specific notes on the distribution of the selected species are presented in Table 2. This information is gathered from a variety of sources and seeks to provide a simple summary of historic and recent distributions. This does not represent a current condition summary but rather a summary of traditional distribution and abundance in the study region and some brief information on changes in distribution and abundance.

Table 1. Selected fish species of the Lower Murray, Lower Lakes and Coorong. Criteria for inclusion in the review are presented as follows: CS – conservation significance, C – commercial value, Ind – indicator of environmental change. The occurence of each species in each of the determined 'sub-units' of the study region in the last 20 years is indicated. The conservation status of each species is also presented. PROT = protected in South Australia under the *Fisheries Management Act 2007*, R = rare, VU = vulnerable, EN = endangered. State conservation status is taken from the *Department for Environment and Heritage 2003 Discussion Paper*.

Species	Scientific name	Criteria	Conservation status		River Murray	Lower Lakes		Coorong		
			National	State		Lake Alexandrina	Lake Albert	Murray Estuary	Northern Lagoon	Southern Lagoon
Large-bodied native freshwater species										
Silver perch	*Bidyanus bidyanus*	CS		PROT [VU]	Y	Y	Y			
Golden perch	*Macquaria ambigua*	C			Y	Y	Y	Y@		
Murray cod	*Maccullochella peelii peelii*	CS	VU	[R]	Y	Y	Y			
Bony herring	*Nematalosa erebi*	Ind			Y	Y	Y	Y@		
Eel-tailed catfish	*Tandanus tandanus*	CS		PROT [VU]	Y	Y	Y			
Common small-bodied native freshwater species										
Carp gudgeon complex	*Hypseleotris* spp.	Ind			Y	Y	Y			
Flat-headed gudgeon	*Philypnodon grandiceps*	Ind		[R]	Y	Y	Y	Y@		
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Ind		[R]	Y	Y	Y	Y@		
Australian smelt	*Retropinna semoni*	Ind			Y	Y	Y	Y@		
Murray rainbowfish	*Melanotaenia fluviatilis*	Ind		[R]	Y	Y				
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Ind		[R]	Y	Y	Y			
Rare and endangered small-bodied native freshwater species										
Murray hardyhead	*Craterocephalus fluviatilis*	Cs	VU	[EN]	Y	Y	Y			
Southern purple-spotted gudgeon	*Mogurnda aspersa*	CS		PROT [EN]	Y					
Southern pygmy perch	*Nannoperca australis*	CS		PROT [EN]		Y				
Yarra pygmy perch	*Nannoperca obscura*	CS	VU	PROT [EN]		Y				
Alien freshwater species										
Goldfish	*Carassius auratus*	Ind			Y	Y	Y	Y@		
Common carp	*Cyprinus carpio*	Ind			Y	Y	Y	Y@		
Eastern gambusia	*Gambusia holbrooki*	Ind			Y	Y	Y	Y@		
Redfin perch	*Perca fluviatilis*	Ind			Y	Y	Y	Y@		

@ Have been recorded recently in the Coorong but only under conditions of freshwater inflow to the Coorong and lowered salinities

Table 1 continued.

Species	Scientific name	Criteria	Conservation status		River Murray	Lower Lakes		Coorong		
			National	State		Lake Alexandrina	Lake Albert	Murray Estuary	Northern Lagoon	Southern Lagoon
Diadromous species (anadromous*, catadromous^)										
Pouched lamprey*	*Geotria australis*	Ind		[EN]	Y	Y		Y		
Short-headed lamprey*	*Mordacia mordax*	Ind		[EN]	Y	Y		Y		
Common galaxias^	*Galaxias maculatus*	Ind			Y	Y	Y	Y		
Short-finned eel^	*Anguilla australis*	Ind		[R]	Y	Y				
Estuary perch^	*Macquaria colonorum*	Ind		[EN]	Y	Y		Y		
Congolli^	*Pseudaphritis urvillii*	Ind		[R]	Y	Y	Y	Y	Y	
Estuarine species										
Yellow-eyed mullet	*Aldrichetta forsteri*	C				Y	Y	Y	Y	
Black bream	*Acanthopagrus butcheri*	C				Y	Y	Y		
Bridled goby	*Arenogobius bifrenatus*	Ind				Y		Y		
Tamar goby	*Afurcagobius tamarensis*	Ind				Y	Y	Y	Y	
Bluespot goby	*Pseudogobius olorum*	Ind				Y	Y	Y		
Lagoon goby	*Tasmanobius lasti*	Ind				Y	Y	Y	Y	
Greenback flounder	*Rhombosolea tapirina*	C				Y		Y	Y	
Small-mouthed hardyhead	*Atherinosoma microstoma*	Ind/keystone			Y	Y	Y	Y	Y	Y
Marine species										
Mulloway	*Argyrosomus japonicus*	C				Y	Y	Y		

NOTE: For identification and general information on these species see McDowall (1996), Lintermans (2007) and/or Gomon *et al.* (2008)

Table 2. Selected species of the Lower Murray, Lower Lakes and Coorong and specific notes on there distributions within the region. Literature source coding below table.

Species	Scientific name	Specific distribution notes	Literature source
Large-bodied native freshwater species			
Silver perch	*Bidyanus bidyanus*	Uncommon below Lock 1, rare in the Lower Lakes. Once widespread. Records from commercial fishery in Lake Alexandrina and Albert. Little recent data from lakes	1, 16
Golden perch	*Macquaria ambigua*	Widespread in Lower Murray and in the Lake Alexandrina. Also Lake Albert	1, 8, 15, 16
Murray cod	*Maccullochella peelii peelii*	Uncommon below Lock 1, likely rare in Lake Alexandrina. Once widespread. Records from commercial fishery in Lake Alexandrina and Albert. Little recent data from lakes	1, 4, 16
Bony herring	*Nematalosa erebi*	Very common and widespread in Lower Murray and Lower Lakes	1, 5, 7, 16, 17, 15, 22
Eel-tailed catfish	*Tandanus tandanus*	Uncommon below Lock 1, likely rare in the Lower Lakes. Records from commercial fishery in Lake Alexandrina and Albert. Last collected near Pomanda Point	14
Common small-bodied native freshwater species			
Carp gudgeon complex	*Hypseleotris* spp.	Very common and widespread in Lower Murray. Common and widespread in Lower Lakes	5, 13, 15
Flat-headed gudgeon	*Philypnodon grandiceps*	Very common and widespread in Lower Murray and Lower Lakes	5, 10, 13, 15
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Moderately common and widespread in Lower Murray and Lower Lakes	2, 5, 7, 10
Australian smelt	*Retropinna semoni*	Very common and widespread in Lower Murray and Lower Lakes	5, 7, 10, 17
Murray rainbowfish	*Melanotaenia fluviatilis*	Common from Lower Murray. Rare in Lower Lakes, last record in Lower Lakes proper from 1986.	2, 15, 16, 22
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Moderately common and widespread in Lower Murray and Lower Lakes	5, 7, 10, 15, 16, 17
Rare and endangered small-bodied native freshwater species			
Murray hardyhead	*Craterocephalus fluviatilis*	Declining. Traditionally present in several off-channel wetlands in Lower Murray. In Lower Lakes primarily distributed around Hindmarsh Island, Goolwa channel, Clayton and Milang Bay. Also some areas of sheltered lake edge in Lake Albert. Formerly locally abundant	5, 10, 17, 21
Southern purple-spotted gudgeon	*Mogurnda aspersa*	No records for ~30 years until one population rediscovered in Lower Murray in 2004. May still be present in low numbers below Lock 1. No records for many years in lakes	11, 21
Southern pygmy perch	*Nannoperca australis*	Former patchy distribution around Lower Lakes wetlands and swamps. Formerly abundant in drains and wetlands in Hindmarsh Island area. Declining likely restricted to remaining irrigation drains on Mundoo Island and near Milang. Populations remain in upper reaches of tributaries	6, 9, 10, 17, 21
Yarra pygmy perch	*Nannoperca obscura*	Formerly abundant in Hindmarsh Island area. Also formerly found in parts of lower Finniss River and edge of Goolwa channel. Declining, potentially extirpated from region: not collected since 2007. Represents the only population of this species in the MDB. Captive population exists	9, 10, 17, 18, 21
Alien freshwater species			
Goldfish	*Carassius auratus*	Common and widespread but patchy distribution in Lower Murray and Lower Lakes	5, 22
Common carp	*Cyprinus carpio*	Very common and widespread in Lower Murray and Lower Lakes	1, 5, 22
Eastern gambusia	*Gambusia holbrooki*	Very common and widespread in Lower Murray and Lower Lakes	5, 7, 10, 17
Redfin perch	*Perca fluviatilis*	Very common and widespread in Lower Murray and Lower Lakes	5, 7, 10, 17

Table 2 continued.

Species	Scientific name	Lower Lakes and Coorong distribution	Literature source
Diadromous species (anadromous*, catadromous^)			
Pouched lamprey*	*Geotria australis*	Rare. Record from 2006 entering the Lakes. Also historic records from Finniss and Bremer rivers	12, 19
Short-headed lamprey*	*Mordacia mordax*	Rare. Records from 2006/07 entering the Lakes. Downstream migrant recorded in 2008 (Goolwa). Recent records of ammocoetes below Lock 1	19, 22
Common galaxias^	*Galaxias maculatus*	Common and widespread in Lower Murray and Lower Lakes	5, 7, 9, 10, 17
Short-finned eel^	*Anguilla australis*	Rare. Recent records from Lower Murray. Recent (2008) record in Goolwa channel, Lower Lakes. South Australian Museum specimens from Lake Alexandrina fringes	12, 22
Estuary perch^	*Macquaria colonorum*	Very few records. Formerly common before construction of barrages	3, 5
Congolli^	*Pseudaphritis urvillii*	Moderately common and widespread. However, abundance and distribution have declined since construction of barrages. Thousands of juveniles were witnessed migrating into lakes in 2006/07, but severe declines were observed in 2007/08 and 2008/09	5, 7, 9, 10, 17, 19, 22
Estuarine species			
Yellow-eyed mullet	*Aldrichetta forsteri*	Common in Coorong, including estuary and North Lagoon. Supports a commercial fishery. Rare in Lower Lakes. Records from commercial fishery in Lake Alexandrina and Albert (most recent 2005). Other recent records in Lower Lakes from around Tauwitchere, Goolwa and Hunters creek	1, 10, 19, 20
Black bream	*Acanthopagrus butcheri*	Moderately common in Coorong, Murray Estuary. Supports commercial fishery. Some records of this species in the Lower Lakes (most recent 2009). Has been recorded moving into the barrage fishways and a recent record for upstream of Goolwa Barrage. Likely rare in Lower Lakes	1, 19, 20, 22
Bridled goby	*Arenogobius bifrenatus*	Common in Coorong, Murray Estuary. Restricted distribution in Lower Lakes, generally found close to the barrages	10, 17, 19, 20
Tamar goby	*Afurcagobius tamarensis*	Common in the Coorong, mostly Murray Estuary but also North Lagoon. Moderately common and patchily distributed in the Lower Lakes	5, 10, 17, 19, 20
Bluespot goby	*Pseudogobius olorum*	Common in Coorong (Murray Estuary) and Lower Lakes, widely distributed	5, 10, 17, 19, 20
Lagoon goby	*Tasmanobius lasti*	Common in Coorong (mostly Murray Estuary but also North Lagoon) and Lower Lakes, widely distributed	5, 10, 17, 19, 20
Greenback flounder	*Rhombosolea tapirina*	Common in Coorong, Murray Estuary and North Lagoon. Supports a commercial fishery. Rare in Lower Lakes, records from Hunters creek and upstream of Tauwitchere barrage	9, 17, 20
Small-mouthed hardyhead	*Atherinosoma microstoma*	Very common in Coorong and Lower Lakes. In Coorong found in Murray Estuary but more commonly in the North Lagoon. The only fish present in South Lagoon. Also widely distributed in Lower Lakes	5, 10, 19, 20
Marine species			
Mulloway	*Argyrosomus japonicus*	Moderately common in Coorong, Murray Estuary. Supports commercial fishery. Some commercial catches of this species in the Lower Lakes (most recent 2005). Also been recorded moving into the barrage fishways. Likely very rare in Lower Lakes	1, 19, 20

Literature sources coded as: 1-SARDI Unpublished CPUE Lakes and Coorong data, 2-(Lloyd and Walker 1986), 3-(Eckert and Robinson 1990), 4-(Ye *et al.* 2000) 5-(Wedderburn and Hammer 2003), 6-(Hammer 2004), 7-(Higham *et al.* 2005b), 8-(Ye 2005) 9-(Bice and Ye 2006), 10-(Bice and Ye 2007), 11-(Hammer 2007), 12-(McNeil and Hammer 2007), 13-(Lintermans 2007), 14-(Rowntree and Hammer 2007), 15-(Smith and Fleer 2007), 16-(Baumgartner *et al.* 2008a), 17-(Bice *et al.* 2008), 18-(Hammer 2008), 19-(Jennings *et al.* 2008a), 20-(Noell *et al.* 2009), 21-(Bice *et al.* 2009), 22-Other SARDI Unpublished data.

Key
PROT = protected in South Australia
R = rare, VU = vulnerable, EN = endangered
*Symbols in brackets represent state status as proposed under the *Department of Environment and Heritage 2003 Discussion Paper*, whilst symbols without brackets represent national listings.

3.1 Key abiotic 'drivers' of fish communities in the Lower Murray, Lower Lakes and Coorong

Many factors are involved in determining the distribution and abundance of fish species. Primarily the presence of water is required followed by more specific needs such as the presence of favoured habitat and food resources. Such requirements differ between species due to differences in life history, habitat preference, spawning requirements and tolerance limits, however; certain ecological processes or 'drivers' may be present that are broadly important to fish communities and affect the general functioning of the system. For the Lower Murray, Lower Lakes and Coorong, the following three abiotic drivers were determined to be highly important to the structure and composition of fish assemblages in the region;

- Flow regime
- Physico-chemical drivers
- Connectivity

Whilst these drivers are presented separately they should not be viewed as mutually exclusive. Flow regime could be viewed as the over-arching driver as it directly influences both physico-chemical parameters and connectivity.

Flow regime

Arid and semi-arid rivers like the Murray-Darling Basin typically have natural flow regimes characterised by high temporal variability (Maheshwari *et al.* 1995) and it is widely accepted that ecological processes in large rivers are driven by flow variability (Puckridge *et al.* 1998). This includes variability in the magnitude, frequency, timing and duration of flow events. A variable flow regime may influence fish assemblages in a number of ways including providing spawning cues and conditions suitable for recruitment (Mallen-Cooper and Stuart 2003) and structuring hydrological, physical and biological habitat heterogeneity (e.g. by influencing macrophyte growth (Blanch *et al.* 2000)). Nevertheless, the flow regime of the MDB has been highly altered since regulation with a marked decrease in flow magnitude, timing and variability (Maheshwari *et al.* 1995).

Whilst the importance of flow regime for riverine reaches is well understood (Walker and Thoms 1993; Puckridge *et al.* 1998; Blanch *et al.* 2000), the affect of altered flow regimes on estuarine systems has received less attention (Alber 2002). Freshwater inflows drive estuarine productivity by transporting nutrients and sediments (Goecker *et al.* 2009) and maintain a mixing zone between freshwater and marine environments (Whitfield 1999). The greater estuarine productivity attributed to freshwater inflows has previously been correlated with increased estuarine fish production (Robins *et al.* 2005) and the influence of freshwater inflows on estuarine salinity also plays a major role in structuring fish assemblages (Barletta *et al.* 2005). Recently Ferguson *et al.* (2008) presented evidence that mulloway recruitment in the Coorong is positively correlated to freshwater inflows.

Physico-chemical drivers

Fish assemblages may be influenced by the physiological response different species exhibit to different water quality variables and the tolerance of these species to extremes (SKM 2003). Put simply, fish must tolerate the general physical and chemical characteristics of a water body in order to persist. Physico-chemical parameters (e.g. salinity, pH) are highly influenced by inflows and thus are intrinsically linked to flow regime.

Abiotic variables are generally considered more important than biological interactions in structuring estuarine fish assemblages (Kupschus and Tremain 2001), which is likely the case in the Coorong. Salinity in the Coorong is highly spatio-temporally variable and this variation has previously been shown to influence fish assemblage structure and abundance in the Coorong (Geddes 1987; Jennings *et al.* 2008a). With an increasing period of time of no freshwater flows to the Coorong, salinities will rise and the influence on fish assemblages may be enhanced.

Whilst the abiotic characteristics (particularly salinity) of freshwater reaches are typically less variable, such factors are likely to play a major role in structuring the fish community in the Lower Lakes as conditions worsen. Salinity in the Lower Lakes is likely to rise further due to evapo-concentration or saltwater intrusion; however, other physico-chemical parameters are also likely to be important, particularly in Lake Alexandrina where the exposure of ASS may influence changes in aquatic pH. As such, the tolerance limits of the selected species to different physico-chemical parameters are a major focus of this review.

Connectivity

Fish are highly mobile organisms and all species require movement to some degree whether for the purpose of feeding, spawning, dispersal or avoidance of unfavourable conditions (Lucas and Baras 2001). Movements may be long or short distance, longitudinal or lateral and may form an obligate part of a species lifecycle (‘truly migratory’ species) or they may be facultative.

Unimpeded movement is of most importance for truly migratory species. This includes potamodromous fish, obligate freshwater species that migrate within river reaches (e.g. golden perch) and diadromous fish, species that require movement between freshwater and estuarine/marine environments in order to complete their lifecycle (e.g. short-headed lamprey). Nevertheless, obligate freshwater and estuarine species often thought to be 'non-migratory' may also undertake substantial movements although these movements may not represent obligate components of their lifecycle. Thus, connectivity between estuarine and freshwater environments, between reaches of riverine environments and between river channel and off-channel habitats is of utmost importance to fish.

The physical obstruction of fish movement by physical barriers (e.g. weirs, barrages) represents one of the greatest threats to migratory fish species throughout the world (Lucas and Baras 2001; Lassalle *et al.* 2009). The potential migratory fish community in the Lower Murray, Lower Lakes and Coorong is diverse, including several diadromous and potamodromous species but also several euryhaline estuarine species that are known to move between estuarine and freshwater environments (e.g. small-mouthed hardyhead). Several obligate freshwater species in the Lower River Murray once considered to be 'non-migratory' have also recently been shown to be highly mobile (e.g. Australian smelt) (Baumgartner *et al.* 2008b).

Whilst many native species are known to move substantial distances and the general movement patterns of several species are relatively well understood, there are still numerous gaps in current knowledge of fish movements in the region. For example the degree of movement of different species between Lake Alexandrina and the River Murray and between Lake Alexandrina and Lake Albert remains largely unknown. Nevertheless, the region is highly impacted by barriers to fish movement. Whilst recent efforts, foremost the construction of fishways (see Jennings *et al.* 2008b), partially restored connectivity between Lake Alexandrina and the Coorong, reduced water levels has led to the closure of these fishways and further construction of in stream barriers (e.g. the earthen bank now separating Lake Alexandrina and Lake Albert) continues to threaten fish populations.

3.2 Key interactions with other biotic groups

This section aims to briefly outline important interactions or dependencies of fish upon other biotic groups. A plethora of abiotic and biotic factors may influence fish distributions and abundances, however; some species are highly reliant upon particular biotic variables or characteristics of a region. Whilst many biotic interactions may be important for fishes of the region, including inter-specific interactions between fishes (e.g. predation and competition), the following two interactions were determined to be the most important;

- Interactions with aquatic vegetation (habitat) and
- Interactions with zooplankton (larval food resources)

The importance of these interactions is not equal across species but may be highly important to several species, including species of national conservation significance.

Aquatic vegetation (habitat)

Many fish species are associated with vegetation to some degree. Such habitats are particularly important for small-bodied species as they provide protection from predators, shelter and abundant food (Keast 1984; Copp 1997), whilst many species also spawn directly on vegetation. Several rare and common small-bodied native freshwater species in the MDB are associated with vegetated habitats.

Yarra pygmy perch, southern pygmy perch and Murray hardyhead are known to be associated with aquatic vegetation (Cadwallader 1979; Woodward and Malone 2002; Wedderburn *et al.* 2007) and in the Lower Lakes were traditionally most abundant in vegetated, off-channel irrigation drains and wetlands around Hindmarsh Island (Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007; Hammer 2007). These habitats were disconnected, dried and desiccated as lake levels fell below 0.3 m AHD. Yarra pygmy perch have not been collected since 2007, whilst southern pygmy perch and Murray hardyhead are now only present at a small number of sites in the region (Bice *et al.* 2009; Wedderburn and Barnes 2009). Vegetated habitats are now largely absent from the Lower Lakes (Marsland and Nicol 2009) which is likely to have catastrophic consequences for these species.

The common small-bodied native species are typically viewed as generalists, inhabiting a range of off-channel, lake and riverine habitats (Mallen-Cooper 2001). Although abundant in a variety of different habitats, most of these species exhibit some degree of micro-habitat preference within their broader habitat area. Carp gudgeon and unspecked hardyhead, and to a lesser degree, flat-headed gudgeon and dwarf flat-headed gudgeon, are typically found in areas with aquatic vegetation and may use vegetation as a spawning substrate (Lintermans 2007). Extremely low water levels and the corresponding loss of such habitat forces fish into open water where there may be increased aggregation and consequently predation, competition and disease transmission.

Larval food resources – zooplankton

Whilst the diets of the fishes investigated vary between species and with ontogeny (see section 3.3.3), perhaps the most generally important food resource for all species is zooplankton (e.g. microcrustaceans and rotifers). Many fish can be viewed as opportunistic in terms of the prey items they consume, particularly in adult life stages, however; larvae are typically limited in what prey items they may consume due to physiological constraints, including limited swimming ability and small mouth gape. As such, most species are dependent upon zooplankton (and sometimes phytoplankton) during their larval phase and may switch to larger prey and leave zooplanktivory as they grow (Lazzaro 1987).

Early larvae are typically the most vulnerable life stage of fish and experience high mortality rates (Trippel and Chambers 1997) potentially due in part to starvation upon the commencement of exogenous feeding (May 1974). Some studies have even suggested that predictions of recruitment in some fish species may be made based upon zooplankton production (e.g. Atlantic mackerel, *Scomber scombrus* and copepods) (Castonguay *et al.* 2008). Thus, whilst the zooplankton may be comprised of a diversity of biota and different fishes may consume different species of zooplankton, the presence of consumable (i.e. smaller than gape size) zooplankton at the onset of exogenous feeding is imperative to the survival and later recruitment of larval fish.

3.3 Ecology of fishes of the Lower Lakes and Coorong

This section provides a summary of information on the biology, ecology and life history strategies of the selected fish species. Specifically, knowledge of spawning (mode, egg type, sites and timing), habitat associations of different life stages (i.e. larval, juvenile, adult), diet and physico-chemical tolerances (i.e. salinity at different life stages, temperature, dissolved oxygen and pH) are summarized in tabulated form for the selected species. This information takes into account specific relationships with key abiotic and biotic factors presented in the previous two sections. The information presented provides the basis for constructing conceptual models on the lifecycles of selected fishes (see section 4). Where possible, sources of information directly from the study region were used, but in its absence, information was summarised from other regions of South Australia and in a broader context, Australia or internationally.

It is important to consider that geographically separate populations of the same species may possess differing genetic, biological and life history characteristics and as such knowledge inferred from catchments outside of the study region must be considered 'hypothesized' (McNeil and Hammer 2007). However, the information presented represents the best possible summary of available information for these species.

3.3.1 Life history strategies and spawning

The selected species are primarily characterised by four general life history strategies and are adapted from Whitfield (1999) as follows (Figure 5):

- Obligate freshwater species – those that complete their lifecycle within freshwaters and were further grouped by combinations of : size (large or small, < or > 150 mm TL), conservation status (common or rare/endangered) and origin (native/alien),

- Diadromous species – those that require movement between freshwater and estuarine/marine environments in order to complete their lifecycle. The species present represent two different forms of diadromy;
    - Anadromous species – species with marine adult residence, upstream spawning migration into freshwater habitats, freshwater spawning and larval development, downstream juvenile migration.
    - Catadromous species - species with freshwater adult residence, downstream spawning migration to estuarine or marine habitats, estuarine or marine larval development, upstream juvenile migration.

- Estuarine species – those species that are dependent upon estuarine environments and complete their lifecycles entirely within estuaries, and

- Marine species – species that may complete their lifecycles in the marine environment but commonly enter estuary or freshwater environments at some stage of their lifecycle. This usually takes the form of juvenile estuarine residence (Potter and Hyndes 1999; Whitfield 1999).

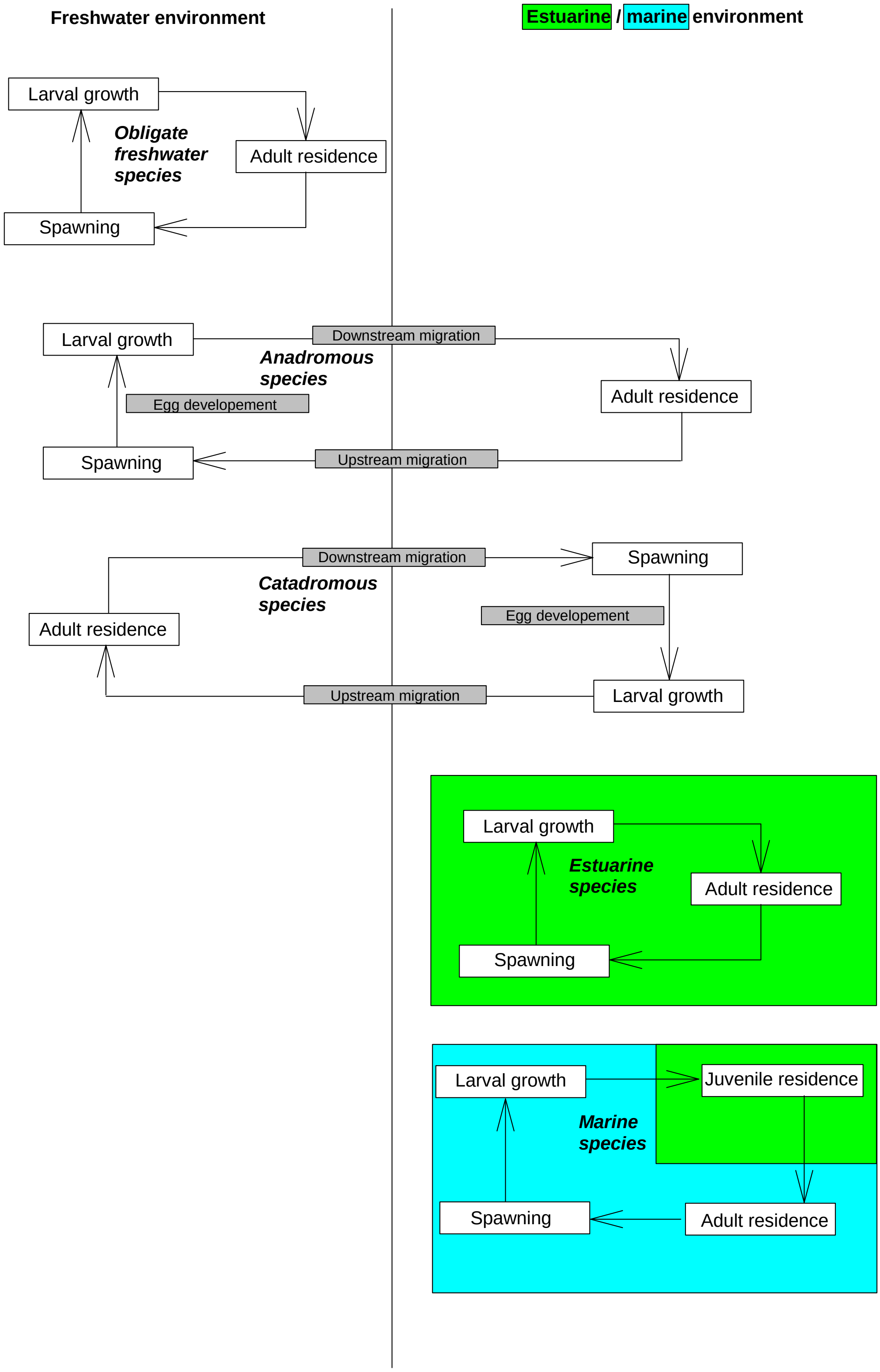

Figure 5. Schematic representation of different broad life-histories: freshwater, diadromous (anadromy and catadromy), estuarine and marine. Green represents the estuarine environment, whilst blue represents the marine environment.

Spawning characteristics of these species are summarized in Table 3. Specifically, these include spawning mode, egg type, spawning sites/notes and spawning period;

Spawning mode - this is adapted from categories proposed by Humphries *et al.* (1999). Spawning mode categories are based on spawning style, duration, development of larvae at first feeding (e.g. well developed and mobile) and the occurrence of parental care. The development of larvae at first feeding relates to the ability of larvae to capture and ingest prey of various sizes (e.g. Murray cod larvae are well developed and have a large gape size at time of first feeding) (Humphries *et al.* 1999). These categories were primarily developed for obligate freshwater species of the MDB but diadromous, estuarine and marine species have tentatively been categorised as members of the mode they best represent. The four categories adapted after Humphries *et al.* (1999) are as follows,

- Mode 1 – Spawn once in a relatively short season; between a thousand and tens of thousands of demersal eggs, often laid into a nest; exhibit parental care; larvae well developed upon first feeding; spawning independent of flow (e.g. Murray cod).
- Mode 2 - Spawn once when appropriate conditions occur and can delay spawning until this time; hundreds of thousands of semi-buoyant or planktonic eggs; no parental care; larvae moderately developed at time of first feeding; spawning may be linked to increased flow and floods (e.g. golden perch).
- Mode 3a – Exhibit either protracted, serial or repeat spawning over an extended period; eggs usually demersal and adhesive but may be semi-buoyant or pelagic; there may be parental care; larvae typically show poor development at time of first feeding and must feed on microcrustaceans and algae; spawning independent of flow (e.g. flat-headed gudgeon).
- Mode 3b – Similar to fishes in mode 3a but spawn only once over a shorter spawning period (e.g. Murray rainbowfish).

Egg type – these categories are adapted from terminology used by McNeil and Hammer (2007);

- N - eggs are guarded and/or laid in nest.
- A - adhesive eggs are attached to structure or vegetation with no following parental care,
- R - demersal eggs are distributed randomly.
- P - surface drifting pelagic eggs.
- L - bear live young.

Spawning sites/notes – species specific information on fine-scale spawning habitats, spawning migrations and conditions needed for spawning and any other information relevant to spawning.

Spawning period – time of year these species are known to spawn. The information presented represents a combination of different types of data from various sources that in some way infer spawning in these species. These include actual investigations of spawning periods but also observations of 'ripe' fish and the presence of larvae as an indication of spawning.

Table 3. Lifecycle and spawning information (mode, egg type, spawning sites/notes and period) for selected fishes of the Lower Murray, Lower Lakes and Coorong. Spawning modes as described by Humphries *et al.* (1999). Egg type: N – eggs guarded or laid in nest, A – adhesive eggs attached to structure/vegetation with no parental care, R – demersal eggs distributed randomly, P – surface drifting pelagic eggs, L – bear live young, Adapted from McNeil and Hammer (2007). ? – signifies uncertainty in classification. Literature source coding below table.

Species	Scientific name	Spawning mode	Egg type	Spawning sites/notes	Spawning period	Literature source
Large-bodied native freshwater species						
Silver perch	*Bidyanus bidyanus*	2	p	In riverine reaches, typically migrates upstream prior to spawning. Unknown in the Lakes. Spawning activity appears to increase during floods. Semi-bouyant eggs. Spawns at water temps >23°C	Spring and summer	5, 11, 26
Golden perch	*Macquaria ambigua*	2	p	In rivers spawning is normally flow related. Spawning at water temps >20°C. Potential spawning migrations (upstream and possibly downstream). Unknown in the Lakes. Eggs are non-adhesive and semi-bouyant	Spring and summer	5, 11, 26
Murray cod	*Maccullochella peelii peelii*	1	n	May undergo short spawning migrations. Spawning occurs at water temps >15°C. Eggs deposited on hard surfaces i.e. rocks, logs, etc. and are guarded by the male. Unknown in the Lakes. Flow may be important for recruitment	Spring and early summer	5, 11, 16, 24, 26
Bony herring	*Nematalosa erebi*	3b	p	Spawning takes place in shallow bays in Lake Alexandrina in late spring and summer. Spawning takes place at water temps >20°C	Spring and summer	6, 26
Eel-tailed catfish	*Tandanus tandanus*	1	n	Eggs are spawned into a nest of pebbles, gravel and other course material. Eggs are non-adhesive and settle in nest. Spawning at water temps 20-24°C. Male guards nest. Unknown in Lakes. Movements thought to only be local	Spring and summer	5, 11, 26
Common small-bodied native freshwater species						
Carp gudgeon complex	*Hypseleotris* spp.	3a	n	Adhesive eggs deposited on structure. Male guards eggs. Spawning at water temps >22°C	Spring and summer	5, 11, 26
Flat-headed gudgeon	*Philypnodon grandiceps*	3a	n	Adhesive eggs deposited on structure. Male guards eggs. Spawning at water temps >18°C	Spring and summer	5, 11, 26
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	3a?	n	Adhesive eggs deposited on structure. Male guards eggs. Spawning at water temps >19°C (in aquaria). Unknown in Lakes	Spring and summer	5, 11, 26
Australian smelt	*Retropinna semoni*	3a	r	Adhesive eggs are distributed over structure. Water temps >11°C	Late winter and summer	5, 11, 26
Murray rainbowfish	*Melanotaenia fluviatilis*	3b	a	Adhesive eggs are laid onto aquatic vegetation. Spawning occurs when water temps are >20°C. Unknown in Lakes	Spring and summer	5, 11, 26
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	3a?	a	Adhesive eggs are attached to aquatic vegetation. Peak spawning may occur in spring at water temps >24°C. Unknown in the Lakes	Spring and summer	5, 11, 26

Table 3 continued.

Species	Scientific name	Spawning mode	Egg type	Spawning sites/notes	Spawning period	Literature source
Rare or endangered small-bodied native freshwater species						
Murray hardyhead	*Craterocephalus fluviatilis*	3a	a	Adhesive eggs are attached to aquatic vegetation. Unknown in the Lakes	Spring and summer	5, 11, 20, 23, 26
Southern purple-spotted gudgeon	*Mogurnda aspersa*	3a	n	Adhesive eggs are deposited on structure. Spawning occurs at water temps 20-30°C. Male guards eggs	Summer	5, 11, 25, 26
Southern pygmy perch	*Nannoperca australis*	3b	a	Eggs are scattered near/on structure, e.g. submerged vegetation. Spawning occurs at water temps >16°C	Spring and early summer	5, 11, 26
Yarra pygmy perch	*Nannoperca obscura*	3b	a	Eggs are scattered over vegetation. Spawning occurs at water temps 16-24°C	Spring	26, 27
Alien freshwater species						
Goldfish	*Carassius auratus*	3a	a	Adhesive eggs deposited on structure. Spawning occurs at water temps >17°C	Summer	26
Common carp	*Cyprinus carpio*	3a	a	Adhesive eggs deposited on structure. Spawning occurs at water temps >17°C	Spring and summer	18, 26
Eastern gambusia	*Gambusia holbrooki*	?	l	Bear live young in slow-flowing areas	Spring and summer	26
Redfin perch	*Perca fluviatilis*	3a	a	Eggs deposited in ribbons amongst vegetation. Spawning occurs at temperature >12°C	Spring	26, 28
Diadromous species (anadromous*, catadromous^)						
Pouched lamprey*	*Geotria australis*	3b?	r	Migrate upstream in winter to spawn. Unknown if spawns in the Lower Lakes, more likely further upstream. Potentially EMLR tributaries	Winter and spring	5, 11, 26
Short-headed lamprey*	*Mordacia mordax*	3b?	r	Migrate upstream in winter to spawn. Spawning occurs in depressions or shallow flowing habitats. Unknown if spawns in Lower Lakes. Records from as far upstream in the River Murray as Yarrawonga. Records of ammocoetes near Lock 1	Winter and spring	5, 11, 26, 30
Common galaxias^	*Galaxias maculatus*	3b	a	Downstream migration to spawn in the lower reaches of rivers and estuaries. Eggs are deposited on riparian vegetation and develop out of the water. Often a marine larval phase. Juveniles then migrate upstream. Self-sustaining landlocked populations also exist in SE Australia	Autumn – spring	5, 11, 26, 30
Short-finned eel^	*Anguilla australis*	?	p (?)	Migrates to the Coral Sea near New Caledonia to spawn.	-	5, 11, 26
Estuary perch^	*Macquaria colonorum*	2?	p	Migrates to estuarine reaches spawning when water temps are 14-19°C. Eggs are non-adhesive and semi-buoyant. Unknown in Lakes and Coorong	Winter	5, 11, 26
Congolli^	*Pseudaphritis urvillii*	3b?	r?	Downstream migration to spawn in estuarine/marine reaches although, specific spawning information is unknown. Possible spatial segregation of sexes (females upstream, males downstream). Juveniles then migrate upstream	Autumn-spring	2, 26, 29, 30

Table 3 continued.

Species	Scientific name	Spawning mode	Egg type	Spawning sites/notes	Spawning period	Literature source
Estuarine species						
Yellow-eyed mullet	*Aldrichetta forsteri*	3b	p	Spawning occurs in the Coorong, specific sites unknown	Summer and early autumn	21
Black bream	*Acanthopagrus butcheri*	3a	p	Spawning occurs in the Coorong, more specifically, suggested near the Murray Mouth. Literature on water temps vary but all are >15°C. Eggs are pelagic but buoyancy depends on salinity at spawning site and as such may settle out of suspension. Considerable variation in literature about salinities during spawning and importance of freshwater inflows. 20,000-25,000 mg/L in Hopkins estuary, Victoria.	Spring/summer/autumn	4, 12, 13, 15, 17
Bridled goby	*Arenogobius bifrenatus*	3a	n	Adhesive eggs attached to substrate or in burrows. Guarded by male	Spring and summer	3, 11, 12
Tamar goby	*Afurcagobius tamarensis*	3a	n (?)	Spawning information limited. Possible guarding of eggs by male, common in gobies	Spring	12, 26
Bluespot goby	*Pseudogobius olorum*	3a	n	Spawns in upper reaches of estuaries and possibly freshwater. Eggs deposited in vegetation and male guards eggs. Unknown in Lakes and Coorong	Spring	9, 26
Lagoon goby	*Tasmanobius lasti*	?	n (?)	Very little known, however likely guarding of eggs by male as in other goby species	Spring(?)	26
Greenback flounder	*Rhombosolea tapirina*	3a	p	Spawns in the Coorong. Some authors suggest at water temps <13°C. Eggs buoyant and pelagic	Autumn and winter	1, 14
Small-mouthed hardyhead	*Atherinosoma microstoma*	3a	a	Spawns in Lower Lakes and Coorong. Adhesive eggs attached to submerged surfaces	Spring and early summer	8
Marine species						
Mulloway	*Argyrosomus japonicus*	?	p (?)	Likely spawns outside of Coorong, although actual locations are not known, possibly on ocean beaches (aggregations of adults in spring/summer suggest perhaps at the Murray mouth?). Coorong represents a nursery area for juvenile fish	Spring and summer (?)	18

Literature sources are coded as follows: 1-(Kurth 1957), 2-(Hortle 1978), 3-(Cadwallader and Backhouse 1983), 4-(Hall 1984), 5-(Koehn and O'Connor 1990), 6-(Puckridge and Walker 1990), 7-(Whitfield 1990), 8-(Molsher *et al.* 1994), 9-(Neira and Potter 1994), 10-(Potter and Hyndes 1994), 11-(McDowall 1996), 12-(Newton 1996), 13-(Haddy and Pankhurst 1998), 14-(Barnett and Pankhurst 1999), 15-(Sarre and Potter 1999), 16-(Ye *et al.* 2000), 17-(Norriss *et al.* 2002), 18-(Ferguson and Ward 2003), 19-(Smith and Walker 2004), 20-(Ellis 2005), 21-(Higham *et al.* 2005a), 22-(Stewart *et al.* 2005), 23-(Bice and Ye 2006), 24-(Koehn and Harrington 2006), 25-(Llewellyn 2006), 26-(Lintermans 2007), 27-(McNeil and Hammer 2007), 28-(Nunn *et al.* 2007), 29-(Jennings *et al.* 2008a), 30-SARDI Unpublished data

3.3.2 Habitat associations

A summary of habitat associations of the selected species is presented in Table 4. Many species may be associated with different habitats at different stages of their lifecycle and therefore habitat associations for larvae, juveniles and adults are presented where possible. This is of particular importance for diadromous species for whom different life stages reside in environments with differing physical and physico-chemical characteristics (e.g. short-headed lamprey) but may also be important for obligate freshwater and estuarine species.

Scale is important when investigating habitat associations of fish (see Boys and Thoms 2006) and therefore where possible both broad and fine scale associations are presented. Focused research on fine-scale habitat associations has not been conducted for many of the selected species although qualitative and observational information is available from a wide range of sources.

Table 4. Habitat associations of selected species of fish from the Lower Murray, Lower Lakes and Coorong. Broad and fine scale habitat associations are described for larval, juvenile and adult life stages where possible. Literature source coding below table.

Species	Scientific name	Habitat association			Literature source
		Larval	Juvenile	Adult	
Large-bodied native freshwater species					
Silver perch	*Bidyanus bidyanus*	Larvae are rarely collected. Unknown in Lakes	Likely the same as adults	Lowland, turbid and slow-flowing riverine reaches. Main river channel in Lower Murray. Specific habitat preference unknown for Lakes. Most literature from interstate	29
Golden perch	*Macquaria ambigua*	Larvae are rarely collected. Drift downstream with current. Collected in main channel, anabranches, and weir pools. Collected in Lower Murray in 2005	Similar to adults, associated with structure and river edges	Typically lowland, turbid and slow-flowing riverine reaches. Often associated with structure, possibly deeper holes and rocky areas in lakes	1, 6, 13, 25, 27, 29, 33,
Murray cod	*Maccullochella peelii peelii*	Usually found in fast-flowing habitats. Unknown in Lower Lakes. Collected in Lower Murray in 2005	Likely reflects adult habitat	Prefer habitat with instream cover such as rocks, snags and undercut banks. Deep holes. Unknown in Lakes, possibly deeper holes and rocky areas	17, 25, 29
Bony herring	*Nematalosa erebi*	Found in a variety of freshwater habitats	Same as adults	Found in a variety of freshwater habitats. Open water	7, 25, 30, 33
Eel-tailed catfish	*Tandanus tandanus*	Rarely collected. The main channel in the Murray. Unknown in Lakes	Likely same as adults	Slow-flowing turbid streams and lake habitats, often with fringing vegetation. Benthic species	6, 29
Common small-bodied native freshwater species					
Carp gudgeon complex	*Hypseleotris* spp.	Various - main channel, shallow ponds, weir pools, anabranches	Same as adults	Slow-flowing and still water habitats, wetlands. Normally associated with macrophytes beds and other aquatic vegetation	18, 25, 29, 33
Flat-headed gudgeon	*Philypnodon grandiceps*	Various - main channel, weir pools, anabranches	Same as adults	Variable. Benthic species normally in slow-flowing areas of streams, lakes and dams. Often found on muddy substrates with abundant cover, i.e. rocks, logs, vegetation	25, 28, 29, 33
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Unknown – possible confusion in differentiating from flat-headed gudgeon larvae	Likely same as adults	Typically in calm waters on muddy and weedy substrates with abundant cover, i.e. rocks, logs, vegetation	28, 29
Australian smelt	*Retropinna semoni*	Various - Main channel, shallow ponds, weir pools, anabranches	Same as adults	Various slow-flowing or still-water habitats including main channel, lakes, weir pools and wetlands. pelagic	18, 25, 28, 29, 33
Murray rainbowfish	*Melanotaenia fluviatilis*	Various - weir pools, ponds and fast-flowing creeks	Likely same as adults	Slow-flowing rivers, streams and wetlands. Often aquatic vegetation	18, 29
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Various - Main channel, weir pools, anabranches	Same as adults	Littoral habitats of slow-flowing rivers, lakes, wetlands, etc. Often associated with aquatic vegetation	25, 29, 33

Table 4 continued.

Species	Scientific name	Habitat association			Literature source
		Larval	Juvenile	Adult	
Rare or endangered small-bodied native freshwater species					
Murray hardyhead	*Craterocephalus fluviatilis*	Unknown	Likely same as adults	Off-channel wetlands in Lower Murray. Sheltered lake margins, wetlands and irrigation drains in the Lower Lakes. Typically associated with aquatic vegetation. Often in wetlands of elevated salinity	26, 28, 29, 31
Southern purple-spotted gudgeon	*Mogurnda aspersa*	Unknown	Likely same as adults	Benthic species normally in slow-flowing areas of streams, wetlands and billabongs. Often in areas with abundant cover, i.e. rocks, logs, vegetation	29
Southern pygmy perch	*Nannoperca australis*	Open water and submerged veg in Tasmania. Likely submerged vegetation in the Lakes	Similar to adults. Shallows amongst vegetation	Typically off-channel habitats i.e. wetlands, small creeks and irrigation drains in the Lower Lakes. Highly associated with in-stream structure most importantly vegetation but also fine woody debris and rocks	14, 19, 21, 22, 26, 28, 30
Yarra pygmy perch	*Nannoperca obscura*	Unknown. Likely submerged vegetation in the Lakes	Similar to adults. Shallows amongst vegetation	Typically off-channel habitats i.e. wetlands, small creeks and irrigation drains in the Lower Lakes. Highly associated with in-stream vegetation	19, 21, 26, 28, 30, 34
Alien freshwater species					
Goldfish	*Carassius auratus*	Unknown	Likely same as adults	Slow-flowing rivers, streams and wetlands. Normally in association with aquatic vegetation	29
Common carp	*Cyprinus carpio*	Wetlands and floodplain habitats	Wetlands and floodplain habitats	Variable. Slow-flowing turbid rivers, streams, wetlands and Lakes. In open water and in association with aquatic vegetation in the Lower Lakes	29, 30, 36
Eastern gambusia	*Gambusia holbrooki*	Likely same as adults	Same as adults	Still and slow-flowing habitats, often in littoral zone. Often associated with vegetation commonly in off-channel habitats, i.e. irrigation drains	15, 28, 29, 30
Redfin perch	*Perca fluviatilis*	Likely in association with vegetation	Likely same as adults	Slow-flowing habitats i.e. Lake, billiabongs etc. In Lakes often found in higher abundances in 'outside' i.e. lake habitat. Often with structure e.g. vegetation	15, 28, 29, 30

Table 4 continued.

Species	Scientific name	Habitat association			Literature source
		Larval	Juvenile	Adult	
Diadromous species (anadromous*, catadromous^)					
Pouched lamprey*	*Geotria australis*		Ammocoete: soft substrates i.e. mud and silt. Potentially in slow-flowing waters? Prefers shady areas	Most of adult life spent in marine environment. Little known in freshwater apart from upstream spawning migration	6, 15, 29, 30
Short-headed lamprey*	*Mordacia mordax*		Ammocoete: soft substrates i.e. mud, sand and silt. Slow-flowing waters near stream edge	Most of adult life spent in marine environment. Little known in freshwater apart from upstream spawning migration	6, 15, 29, 30
Common galaxias^	*Galaxias maculatus*	Has pelagic marine larvae or lentic larvae depending on life history of given population (i.e. catadromous or land-locked). Typically catadromous in Lakes but possible recruitment in the Lakes in 07/08	Juveniles migrate upstream from estuary. In freshwater likely similar to adults	Generalist, found in a variety of habitats in the Lower Lakes. Typically slow flowing or still waters, streams, irrigation drains and lake margins	28, 29, 35
Short-finned eel^	*Anguilla australis*	Ocean	Lower reaches of rivers/estuaries. Found in sediments	Rivers lakes and swamps in slow flow or still waters. Last recorded in open water/lake habitat in the Lower Lakes	6, 29, 36
Estuary perch^	*Macquaria colonorum*	Ocean and estuaries?	Likely similar to adults	Typically in tidal influenced estuarine waters but will penetrate into freshwaters. Associated with structure. Unknown in study region	6, 29
Congolli^	*Pseudaphritis urvillii*	Estuarine/marine, specific habitats unknown	Typically found in estuaries before migrating into freshwater	Terminal wetlands and lowland streams. Off-channel and main channel habitats in the Lower Lakes. Often with structure but also on sandy and mud substrates	2, 28, 29, 30

Table 4 continued.

Species	Scientific name	Habitat association			Literature source
		Larval	Juvenile	Adult	
Estuarine species					
Yellow-eyed mullet	*Aldrichetta forsteri*	Estuarine and marine	Same as adult although likely more common around structure, i.e. shallow reef, and shallow beaches	Pelagic, estuary. Show a preference for deeper channels than juveniles	23, 35
Black bream	*Acanthopagrus butcheri*	Planktonic in estuary prior to settlement in littoral zones	Likely similar to adults. Although probably more common in shallow habitats with complex structure, i.e. reef	Estuaries, lower reaches of rivers and tidal lakes. Deep pools/holes/channels containing hard substrates and complex structure	4, 9, 16, 36
Bridled goby	*Arenogobius bifrenatus*	Estuary, specific habitat unknown	Likely similar to adults	Mud and sandy substrates in estuaries and freshwater where it shelters in burrows. Also structurally complex habitat	15, 36
Tamar goby	*Afurcagobius tamarensis*	Estuary and possibly freshwater, specific habitat unknown	Likely similar to adults	Still or slow-flowing waters on silt or mud substrate with structure i.e. rocks, and vegetation, in both estuary and adjacent freshwaters	3, 15, 26, 32, 35, 36
Bluespot goby	*Pseudogobius olorum*	Estuary and possibly freshwater, specific habitat unknown	Likely similar to adults	Shallow areas, Muddy and rocky substrates, often with aquatic vegetation in freshwater and estuary. Has been associated with sheltered off-channel habitats in the Lakes and Coorong	3, 15, 21, 28, 30, 36
Lagoon goby	*Tasmanobius lasti*	Estuary and freshwater, specific habitat unknown	Likely similar to adults	Still or slow-flowing waters on silt or mud substrate with structure i.e. rocks, and vegetation, in both estuary and adjacent freshwaters	21, 28, 30
Greenback flounder	*Rhombosolea tapirina*	Larvae are pelagic in ocean and estuary	Inhabit more shallow areas than adults, e.g. beaches, intertidal zones	Estuary, preferring unvegetated sandy and muddy substrates	4, 8, 10, 12, 36
Small-mouthed hardyhead	*Atherinosoma microstoma*	Estuarine and freshwater, specific habitat unknown	Likley similar to adults	Typically estuarine but also found in abundance in the Lower Lakes.. Generalist, typically abundant in all habitats in the Lower Lakes	11, 15, 21, 26, 28, 32
Marine species					
Mulloway	*Argyrosomus japonicus*	Likely larval development in ocean	Estuaries, hyposaline water. Typically in deep holes and gutters	Adults are typically found in nearshore surf zones in the region and occasionally enter estuaries	4, 20

Literature sources are coded as follows: 1-(Lake 1967), 2-(Hortle 1978), 3-(Cadwallader and Backhouse 1983), 4-(Hall 1984), 5-(Clements 1988), 6-(Koehn and O'Connor 1990), 7-(Puckridge and Walker 1990), 8-(May and Jenkins 1992), 9-(Kailola *et al.* 1993), 10-(Connolly 1994), 11-(Molsher *et al.* 1994), 12-(Edgar and Shaw 1995a), 13-(Gehrke *et al.* 1995), 14-(Humphries 1995), 15-(McDowall 1996), 16-(Willis *et al.* 1999), 17-(Humphries *et al.* 2002), 18-(Meredith *et al.* 2002), 19-(Woodward and Malone 2002), 20-(Ferguson and Ward 2003), 21-(Wedderburn and Hammer 2003), 22-(Hammer 2005), 23-(Higham *et al.* 2005a), 24-(Stewart *et al.* 2005), 25-(Zampatti *et al.* 2005), 26-(Bice and Ye 2006), 27-(Boys and Thoms 2006), 28-(Bice and Ye 2007), 29-(Lintermans 2007), 30-(McNeil and Hammer 2007), 31-(Wedderburn *et al.* 2007), 32-(Bice *et al.* 2008), 33-(Cheshire and Ye 2008), 34-(Hammer 2008), 35-(Jennings *et al.* 2008a), 36-SARDI Unpublished data.

3.3.3 Diet

The diets of the species investigated are highly diverse. Variation in the food resources exploited exists between species and also between different life stages of a given species. Diet generally differs between species as a function of life-history (e.g. freshwater species vs. estuarine species), habitat use, size (i.e. larger species/life stages may take larger prey items) and degree of specialisation. Whilst some species have highly specialised diets (e.g. adults of lamprey species) many species can be considered opportunistic, consuming a variety of plant matter and other biota. Several species of fish being investigated under the current review have been shown to have highly variable diets both temporally and spatially and are largely influenced by resource availability (Baumgartner 2007; Medeiros and Arthington 2008; Sternberg *et al.* 2008).

Ontogenetic shifts in diet are common and well understood in fish (Mol 1995; Garner 1996; King 2005). Changes in diet with ontogeny may occur due to changes in morphology with growth (e.g. mouth gape size; Krebs and Turingan 2003) or due to ontogenetic changes in habitat usage with growth and corresponding changes in the availability of food resources (Werner and Hall 1988). Therefore, dietary information for different life stages (where possible) of the selected species is presented below in Table 5.

Whilst diet commonly differs between species there is often some degree of overlap, with interspecific dietary overlap typically greatest during early larval phases (Garner 1996). The larval diets of most of the selected species' are dominated by zooplankton (e.g. rotifers, microcrustaceans) and consequently is arguably the most important food resource throughout a species lifecycle. Early larval stages of fish typically experience very high natural mortality rates (Trippel and Chambers 1997) potentially as a result of starvation upon the commencement of exogenous feeding (May 1974). Thus, the presence of consumable (size less than mouth gape) zooplankton is imperative for the survival of nearly all species under investigation.

Table 5. Dietary information for selected fish species of the Lower Murray, Lower Lakes and Coorong. Diets of larval, juvenile and adult life stages are described where possible. Literature source coding below table.

Species	Scientific name	Diet			Literature source
		Larval	Juvenile	Adult	
Large-bodied native freshwater species					
Silver perch	*Bidyanus bidyanus*	Likely microcrustaceans		Omnivorous – aquatic plants, snails, aquatic insects, crustaceans	29
Golden perch	*Macquaria ambigua*	Likely microcrustaceans	Aquatic insects, microcrustaceans	Opportunistic carnivore – fish, aquatic insects, terrestrial insects, crustaceans	26, 28
Murray cod	*Maccullochella peelii peelii*	Microcrustaceans (cyclopoids and cladocerans) and aquatic insects	Likely shift towards larger prey items – fish, crustaceans	Carnivore – apex predator of fish, crustaceans and frogs	24, 26, 28, 29
Bony herring	*Nematalosa erebi*	Likely microcrustaceans	Largely microcrustaceans (Moinidae and calanoida)	Algal detrivore – detritus, algae, microcrustaceans	29, 30, 31
Eel-tailed catfish	*Tandanus tandanus*	Likely microcrustaceans	Aquatic insects	Opportunistic carnivore – fish, aquatic insects, terrestrial insects, crustaceans	29
Common small-bodied native freshwater species					
Carp gudgeon complex	*Hypseleotris* spp.	Microcrustaceans (copepods and cladocerans) and rotifers (particularly important for early stages)	detritus, aquatic insects, microcrustaceans, rotifers, algae	Generalist omnivore – detritus, aquatic insects (cironomids, etc), microcrustaceans, fish larvae, algae	7, 21, 25
Flat-headed gudgeon	*Philypnodon grandiceps*	Likely microcrustaceans and rotifers		Opportunistic carnivore – aquatic insects, crustaceans, fish	29
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Likely microcrustaceans and rotifers		Carnivore – aquatic insects	29
Australian smelt	*Retropinna semoni*	Microcrustaceans (copepods and cladocerans), aquatic insects and rotifers (important to early stages)		Opportunistic carnivore – zooplankton, aquatic insects, terrestrial insects	16, 24, 29
Murray rainbowfish	*Melanotaenia fluviatilis*	Microcrustaceans (copepods and cladocerans), algae		Opportunistic carnivore – aquatic and terrestrial insects	24, 29
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Likely microcrustaceans, rotifers		Carnivore – aquatic insects and zooplankton	29
Rare or endangered small-bodied native freshwater species					
Murray hardyhead	*Craterocephalus fluviatilis*	Likely microcrustaceans, rotifers		Omnivorous, microcrustaceans, aquatic insects, algae	29
Southern purple-spotted gudgeon	*Mogurnda aspersa*	Likely microcrustaceans, rotifers		Benthic carnivore – aquatic insects, fish	29
Southern pygmy perch	*Nannoperca australis*	Likely microcrustaceans, rotifers		Carnivorous – microcrustaceans and aquatic insects	14, 29
Yarra pygmy perch	*Nannoperca obscura*	Likely microcrustaceans, rotifers		Carnivorous – microcrustaceans and aquatic insects	29

Table 5 continued.

Species	Scientific name	Diet			Literature source
		Larval	Juvenile	Adult	
Alien freshwater species					
Goldfish	*Carassius auratus*	Likely microcrustaceans, rotifers		Omnivore – plant material, detritus	29
Common carp	*Cyprinus carpio*	Likely microcrustaceans copepods and cladocerans), rotifers, aquatic insects		Omnivore – plant material, aquatic insects, microcrustaceans, crustaceans, molluscs	22, 29
Eastern gambusia	*Gambusia holbrooki*	Likely microcrustaceans, rotifers		Carnivorous – aquatic and terrestrial insects	15, 29
Redfin perch	*Perca fluviatilis*	Likely microcrustaceans, rotifers		Carnivore – crustaceans, fish	8, 19
Diadromous species (anadromous*, catadromous^)					
Pouched lamprey*	*Geotria australis*	Ammocoetes are filter feeders on detritus, algae and other microorganisms		Parasitic on fish	29
Short-headed lamprey*	*Mordacia mordax*	Ammocoetes are filter feeders on detritus, algae and other microorganisms		Parasitic on fish	29
Common galaxias^	*Galaxias maculatus*	Likely marine zooplankton		Opportunistic carnivore – aquatic and terrestrial insects, microcrustaceans, amphipods	2
Short-finned eel^	*Anguilla australis*		Crustaceans, insects	Carnivore – fish, crustaceans, molluscs, insects	4, 29
Estuary perch^	*Macquaria colonorum*	Likely microcrustaceans	Carnivore – crustaceans, aquatic insects, amphipods	Opportunistic carnivore – crustaceans (i.e. amphipods, shrimp), fish, aquatic insects (tricopteran larvae)	23
Congolli^	*Pseudaphritis urvillii*	Likely estuarine/marine zooplankton		Benthic carnivore – fish, crustaceans, aquatic insects	3, 29

Table 5 continued.

Species	Scientific name	Diet			Literature source
		Larval	Juvenile	Adult	
Estuarine species					
Yellow-eyed mullet	*Aldrichetta forsteri*	microcrustaceans		Omnivorous – detritus, seagrass, algae, polychaetes, molluscs, crustaceans	1, 12
Black bream	*Acanthopagrus butcheri*	Microcrustaceans, fish larvae	Crustaceans, molluscs, polychaetes	Opportunistic omnivore – crustaceans, molluscs, fish, plant material, algae	17, 18, 20
Bridled goby	*Arenogobius bifrenatus*	Likely microcrustaceans		Carnivore - invertebrates, fish	13
Tamar goby	*Afurcagobius tamarensis*	Likely microcrustaceans		Likely opportunistic carnivore	
Bluespot goby	*Pseudogobius olorum*	Likely microcrustaceans		Omnivore – crustaceans, microcrustaceans, algae	10
Lagoon goby	*Tasmanobius lasti*	Likely microcrustaceans		Likely opportunistic carnivore	
Greenback flounder	*Rhombosolea tapirina*	Microcrustaceans, other invertebrate larvae (bivalve veligers) and eggs.	Amphipods, benthic nauplii		6, 9
Small-mouthed hardyhead	*Atherinosoma microstoma*	Likely microcrustaceans		Carnivore - microcrustaceans	5
Marine species					
Mulloway	*Argyrosomus japonicus*	Likely microcrustaceans	Carnivore – similar to adults but smaller prey items.	Carnivore – primarily fishes but also crabs, prawns and worms	11, 26

Literature resources are quoted as follows: 1-(Thomson 1957), 2-(Pollard 1973), 3-(Hortle and White 1980), 4-(Sloane 1984), 5-(Geddes 1987), 6-(Jenkins 1987), 7-(Gehrke 1992), 8-(Pen and Potter 1992), 9-(Shaw and Jenkins 1992), 10-(Gill and Potter 1993), 11-(Kailola et al. 1993), 12-(Edgar and Shaw 1995b), 13-(Larson and Hoese 1996), 14-(Humphries 1995), 15-(Arthington and Marshall 1999), 16-(Lieschke and Closs 1999), 17-(Willis et al. 1999), 18-(Sarre et al. 2000), 19-(Morgan et al. 2002), 20-(Norriss et al. 2002), 21-(Stoffels and Humphries 2003), 22-(Khan 2003), 23-(Howell et al. 2004), 24-(King 2005), 25-(Balcombe and Humphries 2006), 26-(Ebner 2006), 27-(Taylor et al. 2006), 28-(Baumgartner 2007), 29-(Lintermans 2007), 30-(Medeiros and Arthington 2008), 31-(Sternberg et al. 2008)

3.3.4 Physico-chemical tolerance limits

Water quality can greatly influence the structure and composition of fish assemblages. Influences on populations are primarily driven by the physiological response different species exhibit to different water quality variables and the tolerance of these species to extremes (SKM 2003). Simply, fish must tolerate the general physical and chemical conditions of a given water body in order to persist.

Information on the tolerance of given species to particular variables (i.e. salinity, temperature, dissolved oxygen, pH) provides insight on factors potentially affecting fish assemblage structure and may assist in predicting fish response and assessing the impacts of drought or management interventions (e.g. salt water intrusion). Laboratory based trials to elucidate species tolerances to certain variables are valuable but generally provide information on the tolerance of given species up to lethal limits. However, prior to lethal levels being reached different water quality variables may have a range of sub-lethal impacts on fish species, such as increased risk of infection, reduction in available habitat (e.g. due to vegetation loss) and decreased growth rates or reproductive success, but this has received little research effort in Australia.

The influence of water quality on a certain species may also vary throughout its lifecycle. Different life stages of fish (i.e. egg, larval, juvenile, adult) often possess varying physiological tolerances and abilities to avoid unfavourable conditions through movement, and as such, some life stages are more vulnerable to poor conditions.

The water quality tolerances of selected fishes from the Lower Murray, Lower Lakes and Coorong (where available) are summarised in Table 6. Great focus is placed upon species' tolerances to salinity at different life stages (i.e. egg, larvae, juvenile and adult), whilst also considering tolerances to temperature, dissolved oxygen and aquatic pH.

Salinity

Spatial differences in salinity have been shown to greatly influence fish assemblages (Echelle *et al.* 1972; Gill and Potter 1993; Wedderburn *et al.* 2008). Changes in aquatic salinity may affect fish directly by impacting osmoregulation and reproductive success (e.g. by impacting sperm motility) or indirectly by influencing prey abundances or impacting habitat (e.g. macrophytes; Nielsen *et al.* 2003). For the purpose of this study we have focused on the direct physiological impacts of rising salinity on fish. Species-specific salinity tolerances were gleaned from reports of laboratory trials and LC50 values are presented (the salinity that results in 50% mortality of test subjects over a given time) in Table 6. LC50 values can be generated from two types of trials; 1 – slow acclimation (i.e. salinities are gradually increased at a standard rate until mortality occurs) and 2 – direct transfer (i.e. trial fish are directly transferred from holding salinities to test salinities and mortality is assessed at pre-determined time intervals) and the type of trial that LC50 values were generated from is also indicated. LC50 values are not conservative estimates of tolerance as a 50% mortality rate represents a significant impact on a fish population (Clunie *et al.* 2002) and the salinity at which individuals become stressed is likely to be lower. Additionally laboratory trials are undertaken in controlled environments where all other physico-chemical variables are typically kept constant and thus usually do not take into account the impact of multiple stresses on fish. Therefore this data must be viewed with caution as salinities that may negatively impact fish in the wild may be lower than those presented here. However, the information presented represents the best tolerance data available. Field observations of these species in the MDB at high salinities are also included.

Sub-lethal affects of salinity (e.g. limits to sperm motility) are presented where available but information of this nature is scant. Larvae of most species are typically the least tolerant and therefore most vulnerable life stage to increased salinity (Hart *et al.* 1991). Larvae are also much less mobile than larger con-specifics and therefore also possess a limited ability to avoid unfavourable conditions via movement. As such salinities greater than larval tolerance may result in recruitment failure of a population but adults, with a greater tolerance range, may persist and thus this can be viewed as a 'sub-lethal' impact on a population. This primarily relates to large and medium-bodied species with relatively long life spans. Some small-bodied species have largely annual life-cycles (e.g. Murray hardyhead, Australian smelt) and recruitment failure therefore represents a catastrophic impact to a population rather than sub-lethal. Therefore data on larval tolerance is perhaps the most useful salinity tolerance information provided in this review.

Temperature

Temperature may also greatly influence fish assemblages (Matthews 1998). Fish, particularly small-bodied species, have internal body temperatures relative to external water temperatures and as such, drastic changes in water temperature are accompanied by severe changes in internal physiology (Crawshaw 1979). At water temperatures above tolerances proteins denature causing death. Low temperatures may impact fishes by reducing spawning cues (Preece and Jones 2002), development rates (Clarkson and Childs 2000) and the ability to capture prey and escape predation due to limited swimming ability (Walker *et al.* 2005). The tolerance information presented is a combination of laboratory trials and field observations.

Dissolved oxygen

Dissolved oxygen is critical to fish survival but most species may tolerate short periods of depleted aquatic oxygen (hypoxia or anoxia) (Matthews 1998). Whilst most fish will avoid hypoxic or anoxic waters many species may tolerate these conditions either through physiological adaptation (e.g. greater blood oxygen affinity)(Cech *et al.* 1979) or behavioural mechanisms (e.g. air-surface-respiration). Several species native to the MDB are able to survive periods of hypoxia via air surface respiration (McNeil and Closs 2007).

Many water quality variables are not mutually exclusive but rather exhibit synergistic relationships (SKM 2003). This is true for dissolved oxygen and water temperature whereby the solubility of oxygen decreases with increasing temperature and metabolic oxygen demands also increase (Matthews 1998). Thus, these two parameters should be reviewed in unison when predicting potential impacts on fish populations. The information presented in Table 6 is primarily based upon laboratory trials.

pH

The general affects of acidity (low pH) and alkalinity (high pH) on fish are well understood (Fromm 1980), yet species specific information for Australian species is scant and is not presented in Table 6. Although tolerance to acidification may vary between species, adults of most fish species are intolerant of pH below 5 or above 10 and mortality at low pH may occur via several different mechanisms. Fish are poor regulators of internal pH; at low pH (<5) a fish's ability to regulate internal pH deteriorates, resulting in the inability of blood at the gills to be saturated with oxygen regardless of aquatic oxygen concentrations (Matthews 1998). Additionally, lowered pH may alter enzyme activity and electrolyte composition of body fluids, resulting in severe stress (Packer and Dunson 1970). Low pH can also change acid-base regulation at the gills, mucous secretion and physical gill structure (McDonald 1983). Whilst these affects of altered pH may result in adult mortality there are many sub-lethal impacts that may result from more subtle variations in pH.

Subtle variation in pH (between pH 5-6.5) may lead to sub-lethal physiological impacts such as decreased oogenesis (Ruby *et al.* 1977), decreased fertilisation rates (Craig and Baksi 1977) and reduced egg and larval development (Von Westernhagen 1988). Additionally, fish may exhibit altered behaviours such as decreased activity and feeding (Jones *et al.* 1985) and areas of differing pH may potentially represent chemical barriers to fish movement (Kroon 2005). Fromm (1980) suggests a general 'no effect' level of pH depression on reproduction in fish of around 6.5 and this level is adopted in the current review. Whilst this may be conservative for some species it is preferred to take a cautionary approach. Additionally, for the purpose of this report pH below 5 or above 10 will be considered beyond the adult tolerance of all selected fish species.

Table 6. Physico-chemical tolerances of selected fishes from the Lower Murray, Lower Lakes and Coorong region. Salinity tolerances of eggs, larvae and adults are presented where possible. LC50 values, the salinity that results in 50% mortality of test subjects over a given time, are used where available. Slow acclimation (slow) and direct transfer (direct) trials are indicated. Observations in the MDB do not imply high tolerance but notes records of these species at given salinities. Temperature tolerance and tolerance of hypoxia are also presented where possible. Literature source coding below table.

Species	Scientific name	Salinity tolerance ($mg.L^{-1}$)			Temperature tolerance	Low DO/Hypoxia	Literature source
		egg/larval/juvenile	Adult	Observations MDB			
Large-bodied native freshwater species							
Silver perch	*Bidyanus bidyanus*	9000 LC50 (eggs) 7600 LC50 (larvae, direct) 21,000 LC50 (juvenile, slow)	13, 700 LC50 (direct) 16,000 LC50 (slow)		2-37°C	>2 $mg.L^{-1}$	1, 21, 36, 39, 41
Golden perch	*Macquaria ambigua*	12,000 LC50 (larvae, direct) 22,400 (juvenile, slow)	14,400 LC50 (direct) 33, 000 LC50 (slow)	8030	4-37°C	2.7 $mg.L^{-1}$ (larvae)	16, 25, 39, 41
Murray cod	*Maccullochella peelii peelii*	9410 LC50	13,200 LC50 (direct) 15,700 LC50 (slow)		10-37°C		7, 16, 27, 32
Bony herring	*Nematalosa erebi*		35,000	~35,000 Estuary; Coorong	9-38°C		7, 13, 42
Eel-tailed catfish	*Tandanus tandanus*	11,400 LC50 (larvae, direct) 19,000 (juvenile, slow)	13,600 LC50 (direct) 17,800 LC50 (slow)	4660	4-38°C		1, 7, 16, 39, 41

Table 6 continued.

Species	Scientific name	Salinity tolerance ($mg.L^{-1}$)			Temperature tolerance	DO/Hypoxia	Literature source
		egg/larval/juvenile	Adult	Observations MDB			
Common small-bodied native freshwater species							
Carp gudgeon complex	*Hypseleotris* spp.	7,600 (eggs) 6,300 LC50 (larvae, direct) 30,200 (juvenile, slow)	38,000 LC50 (direct) 50,000 LC50 (slow)	>9000		Tolerant below 1 $mg.L^{-1}$ (short periods) ASR, eggs vulnerable	9, 14, 37, 41, 43
Flat-headed gudgeon	*Philypnodon grandiceps*	21,000 (eggs) 12,300 (larvae, direct) 40,300 (juvenile, slow)	23,700 LC50 (direct) 40,000 LC50 (slow)	>25,000 estuary		Tolerant below 1 $mg.L^{-1}$ (short periods) ASR	16, 37, 41, 43
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	21,000 (eggs) 6900 LC50 (larvae, direct) 35,000 LC50 (juvenile, slow)		33,000			39, 41
Australian smelt	*Retropinna semoni*	28,000 (juvenile)	59,000 LC50 (direct)	>25,000 estuary	28°C	Moderate tolerance <2 $mg.L^{-1}$, ASR-poor	11, 14, 37, 39, 43
Murray rainbowfish	*Melanotaenia fluviatilis*	12,000 LC50 (fry) 33,500 LC50 (juvenile, slow)	21,100 LC50 (direct) 30,000 LC50 (slow)	2050	28°C		9, 11, 14, 39, 41
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*		43,700 LC50 (slow)	8800	9-36°C		3, 7, 14, 39
Rare or endangered small-bodied native freshwater species							
Murray hardyhead	*Craterocephalus fluviatilis*	≥30,000	45,900, 110,000	>35,000, Highly tolerant	10-28°C		28, 30, 36
Southern purple-spotted gudgeon	*Mogurnda aspersa*	12,200 LC50 (larvae, direct) 21,000 LC50 (juvenile, slow)	17,100 LC50 (direct)		19-34°C		28, 36, 41
Southern pygmy perch	*Nannoperca australis*			<10,000	3-38°C	Tolerant below 1 $mg.L^{-1}$ (short periods) ASR	1, 3, 37
Yarra pygmy perch	*Nannoperca obscura*	6300 LC50 (larvae, direct)		3010	10-30°C		36, 39

Table 6 continued.

Species	Scientific name	Salinity tolerance (mg.L-1)			Temperature tolerance	DO/Hypoxia	Literature source
		egg/larval/juvenile	Adult	Observations MDB			
Alien freshwater species							
Goldfish	*Carassius auratus*		13,056 LC50 (direct) 19,176 (slow)	7500		Tolerant below 1 mg.L-1 (short periods) ASR	10, 32, 39
Common carp	*Cyprinus carpio*	8330 (limit to sperm motility) 11,715 LC50 (juvenile, direct) 13,070 LC50 (juvenile, slow)	12,800 LC50 (direct)	7500		Tolerant below 1 mg.L-1 (short periods) ASR	6, 26, 32, 38, 39
Eastern gambusia	*Gambusia holbrooki*		17,100 LC50 (direct) 59,000 (for 30d)	19,500	44°C	Highly tolerant <1 mg.L-1 efficient ASR	13, 37, 39
Redfin perch	*Perca fluviatilis*		8000 LC50 (direct)	7,500		Moderate tolerance <2 mg.L-1, ASR-poor	13, 37, 39, 43
Diadromous species (anadromous*, catadromous^)							
Pouched lamprey*	*Geotria australis*	Ammocoetes in freshwater	marine	>25,000 Coorong			11, 40
Short-headed lamprey*	*Mordacia mordax*	Ammocoetes in freshwater	marine	>25,000 Coorong			11, 40
Common galaxias^	*Galaxias maculatus*	49,000	45,000 LC50 (direct) 62,000 LC50 (slow)	*c.* 25,000 (adults) >25,000 (juveniles)			3, 40, 43
Short-finned eel^	*Anguilla australis*		Likely highly tolerant	13,400 (vic)	Wide range	Likely tolerates low oxygen	3, 6
Estuary perch^	*Macquaria colonorum*			>2000			36
Congolli^	*Pseudaphritis urvillii*	98,000 LC50 (juvenile, slow 14°C) 92,000 LC50 (juvenile, slow 23°C)	Probable free movement between salt and fresh	>35,000 catches in Coorong	20°C		4, 36, 39, 41, 42

Table 6 continued.

Species	Scientific name	Salinity tolerance (mg.L^{-1})			Temperature tolerance	DO/Hypoxia	Literature source
		egg/larval/juvenile	Adult	Observations MDB			
Estuarine species							
Yellow-eyed mullet	*Aldrichetta forsteri*	88,000 LC50 (juvenile, slow 14°C) 86,000 LC50 (juvenile, slow 23°C)		>35,000 Coorong	14-24°C?		5, 41
Black bream	*Acanthopagrus butcheri*	10,000-35,000 (egg) 82,000 LC50 (juvenile, slow 14°C) 88,000 LC50 (juvenile, slow 23°C)		300 - >40,000 Preferred range likely 10,000 – 35,000	26°C		29, 31, 33, 41
Bridled goby	*Arenogobius bifrenatus*			34,000 (larvae) 1800 - >35,000 Coorong (juv/adult)	26°C	Tolerant <1 mg.L^{-1}, efficient ASR	12, 24, 43
Tamar goby	*Afurcagobius tamarensis*	72,000 LC50 (juvenile, slow 14°C) 70,000 LC50 (juvenile, slow 23°C)		1800 - >35,000 Coorong	23°C	Tolerant <1 mg.L^{-1}, efficient ASR	12, 24, 41, 43
Bluespot goby	*Pseudogobius olorum*	>35,000		1800 - >35,000 Coorong	28°C	Tolerant <1 mg.L^{-1}, efficient ASR	12, 17, 43
Lagoon goby	*Tasmanobius lasti*			1000 - >35,000 Coorong	26°C		17, 43
Greenback flounder	*Rhombosolea tapirina*	35,000-45,000 (fertilisation) 15,000-45,000 (eggs) 15,000-35,000 (juvenile)	Likely wide range	15,000- >35,000	Likely wide range		19, 22, 23
Small-mouthed hardyhead	*Atherinosoma microstoma*		Upper 108,000 LC50 (direct) Lower 3300 LC50 (direct) 2000-120,000 (slow)	Extremely wide range 100-130,000			2, 8, 20

Table 6 continued.

Species	Scientific name	Salinity tolerance (mg.L^{-1})			Temperature tolerance	DO/Hypoxia	Literature source
		egg/larval/juvenile	Adult	Observations MDB			
Marine species							
Mulloway	*Argyrosomus japonicus*	5000-35,000 (larvae) 63,000 LC50 (juvenile, slow, 14°C) 58,000 LC50 (juvenile, slow 23°C)		15,000-25,000 (preferred for juveniles) >35,000 Coorong	30°C		18, 27, 34, 35, 42

Literature sources are coded as follows: 1-(Lake 1967), 2-(Lui 1969), 3-(Chessman and Williams 1974), 4-(Hortle 1978), 5-(Chubb *et al.* 1981), 6-(Cadwallader and Backhouse 1983), 7-(Merrick and Schmida 1984), 8-(Potter *et al.* 1986), 9-(Williams 1987), 10-(Jasim 1988), 11-(Koehn and O'Connor 1990), 12-(Gee and Gee 1991), 13-(Hart *et al.* 1991), 14-(Williams and Williams 1991), 15-(Bacher and Garnham 1992), 16-(Jackson and Pierce 1992), 17-(Gill and Potter 1993), 18-(Gray and McDonall 1993), 19-(Kailola *et al.* 1993), 20-(Molsher *et al.* 1994), 21-(Guo *et al.* 1995), 22-(Hart and Purser 1995), 23-(Hart *et al.* 1996), 24-(Newton 1996), 25-(Rowland 1996), 26-(Karimov and Keyser 1998), 27-(Fielder and Bardsley 1999), 28-(O'Brien and Ryan 1999), 28-(Haddy and Pankhurst 2000), 30-(Hardie 2000), 31-(Sarre *et al.* 2000), 32-(Clunie *et al.* 2002), 33-(Partridge and Jenkins 2002), 34-(Aquaculture SA 2003), 35-(Ferguson and Ward 2003), 36-(SKM 2003), 37-(McNeil 2004), 38-(Whiterod and Walker 2006), 39-(McNeil and Hammer 2007), 40-(Jennings *et al.* 2008a), 41-(McNeil and Westergaard In Prep), 42-(SARDI Unpublished CPUE Lakes and Coorong data), 43-(SARDI Unpublished data).

4 Conceptual models for fishes of the Lower Lakes

Conceptual models have been developed to illustrate the lifecycles of selected fishes of the Lower Lakes and Coorong (Figures 6-17). The models essentially depict the different life stages of fish, key processes/events (e.g. spawning, survival) and different environmental factors (e.g. water quality, habitat availability) that facilitate or hinder progression between stages. Specific habitat and salinity tolerance for different life stages have been included where known. Given potential changes in salinities and impacts on habitat due to proposed management options, these models may facilitate in the assessment of potential impacts (negative or positive) on fishes at different life stages.

For the development of conceptual models fish were further categorised by similarities in life-history and spawning modes described by Humphries *et al.* (1999). For example the 'large-bodied native freshwater fish' grouping was split into 3 groupings, A – Golden perch and silver perch (flow-dependent spawners), B – Murray cod (flow independent spawner but flow dependent recruiter?) and C – catfish (flow independent spawner and nester). Similarly, eastern gambusia formed a group separate to other exotic species as it is a live bearer and estuarine species were further grouped based on body size.

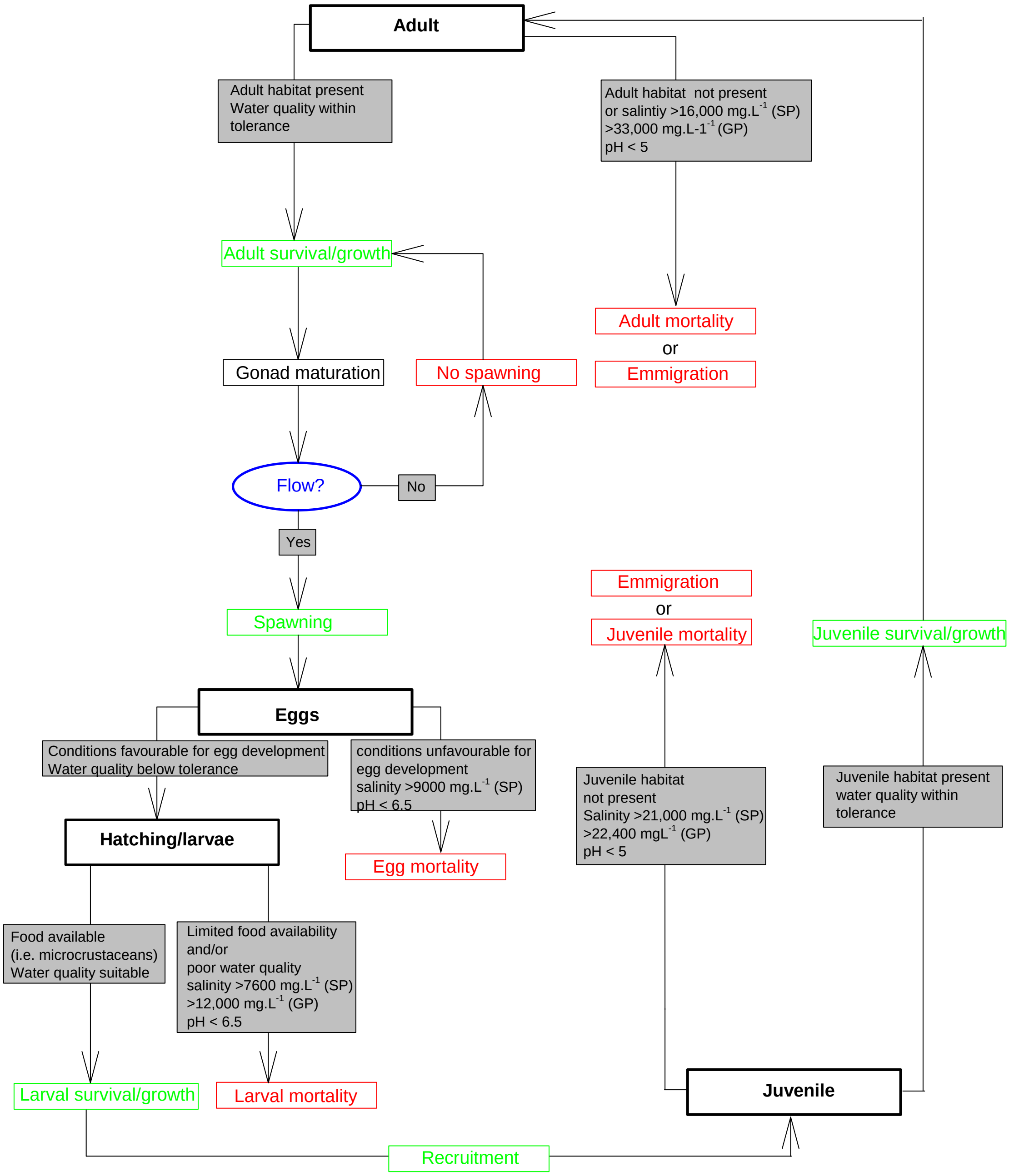

Figure 6. Lifecycle of silver perch and golden perch. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

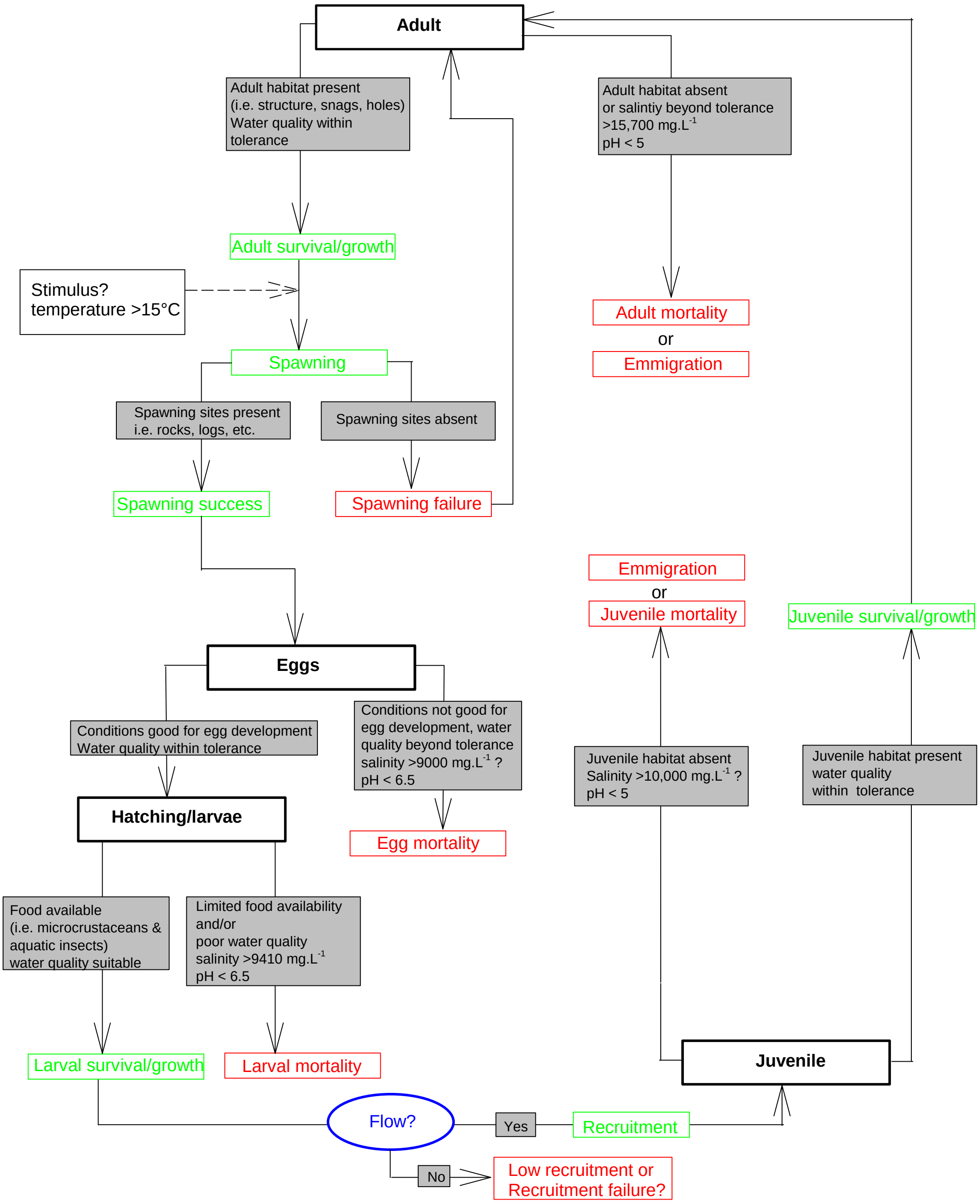

Figure 7. Lifecycle of Murray cod. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

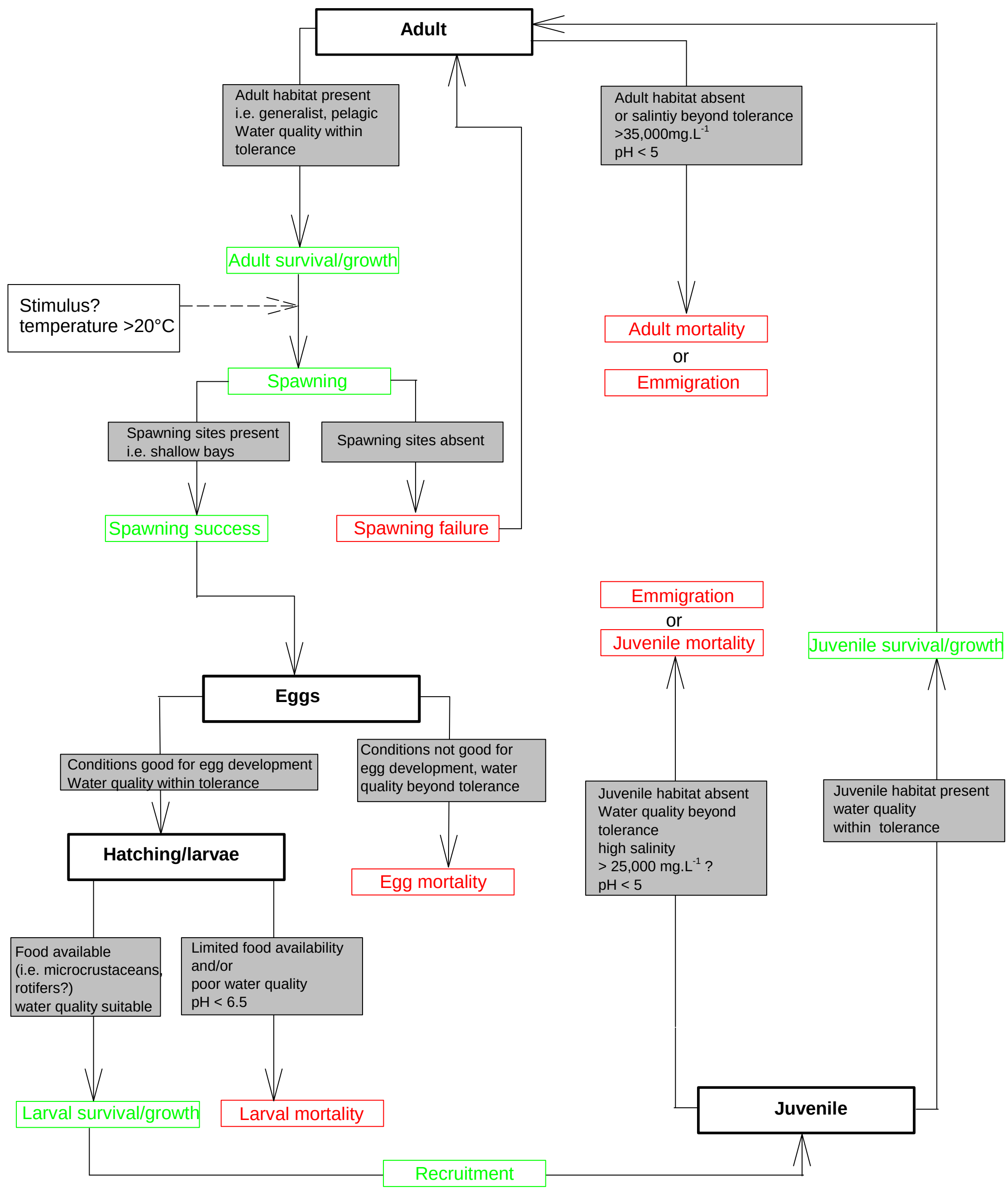

Figure 8. Lifecycle of bony herring. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

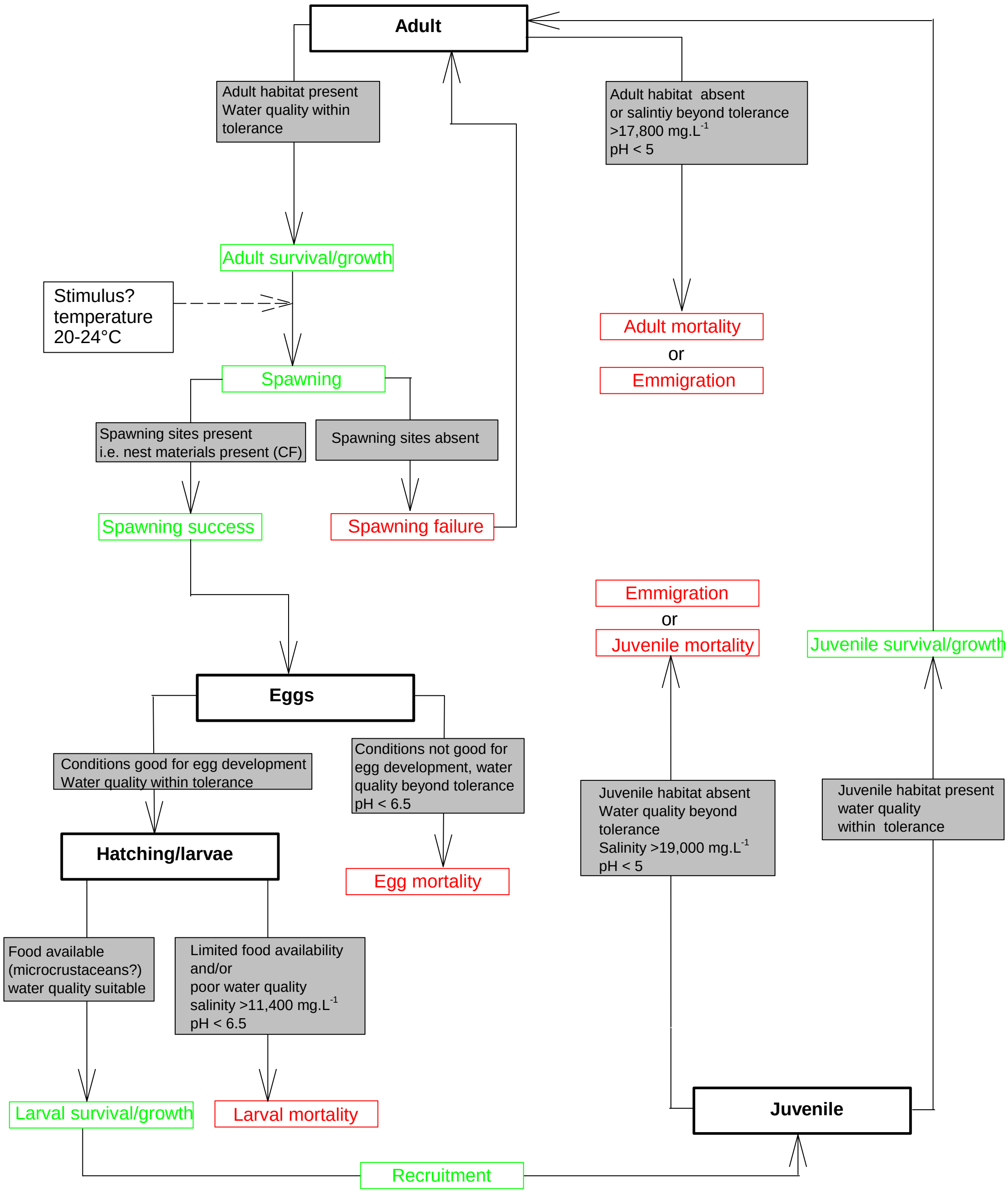

Figure 9. Lifecycle of eel-tailed catfish. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

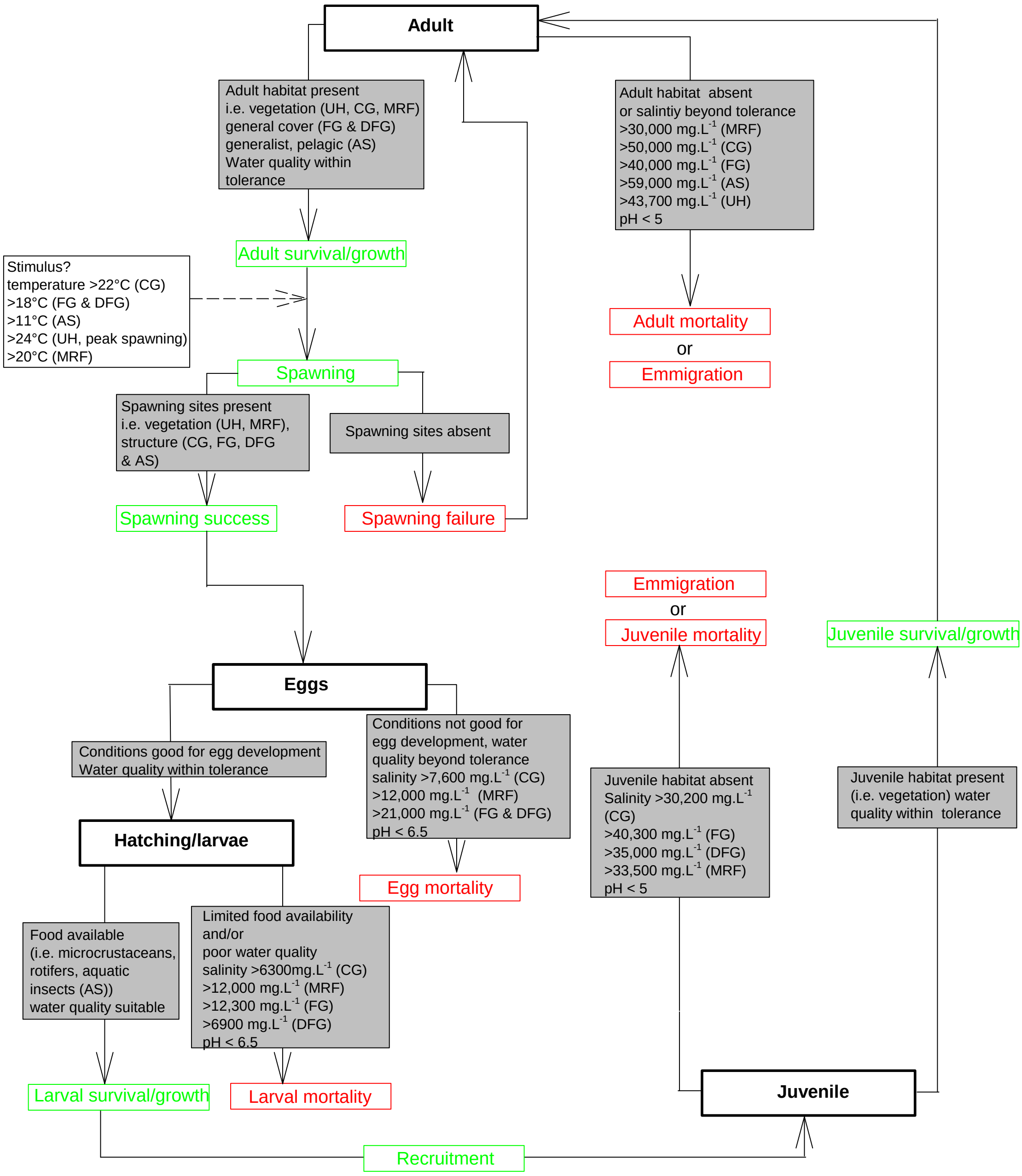

Figure 10. Lifecycle of common small-bodied native freshwater species, carp gudgeon complex (CG), flat-headed gudgeon (FG), dwarf flat-headed gudgeon (DFG), Australian smelt (AS), unspecked hardyhead (UH) and Murray rainbowfish (MRF). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

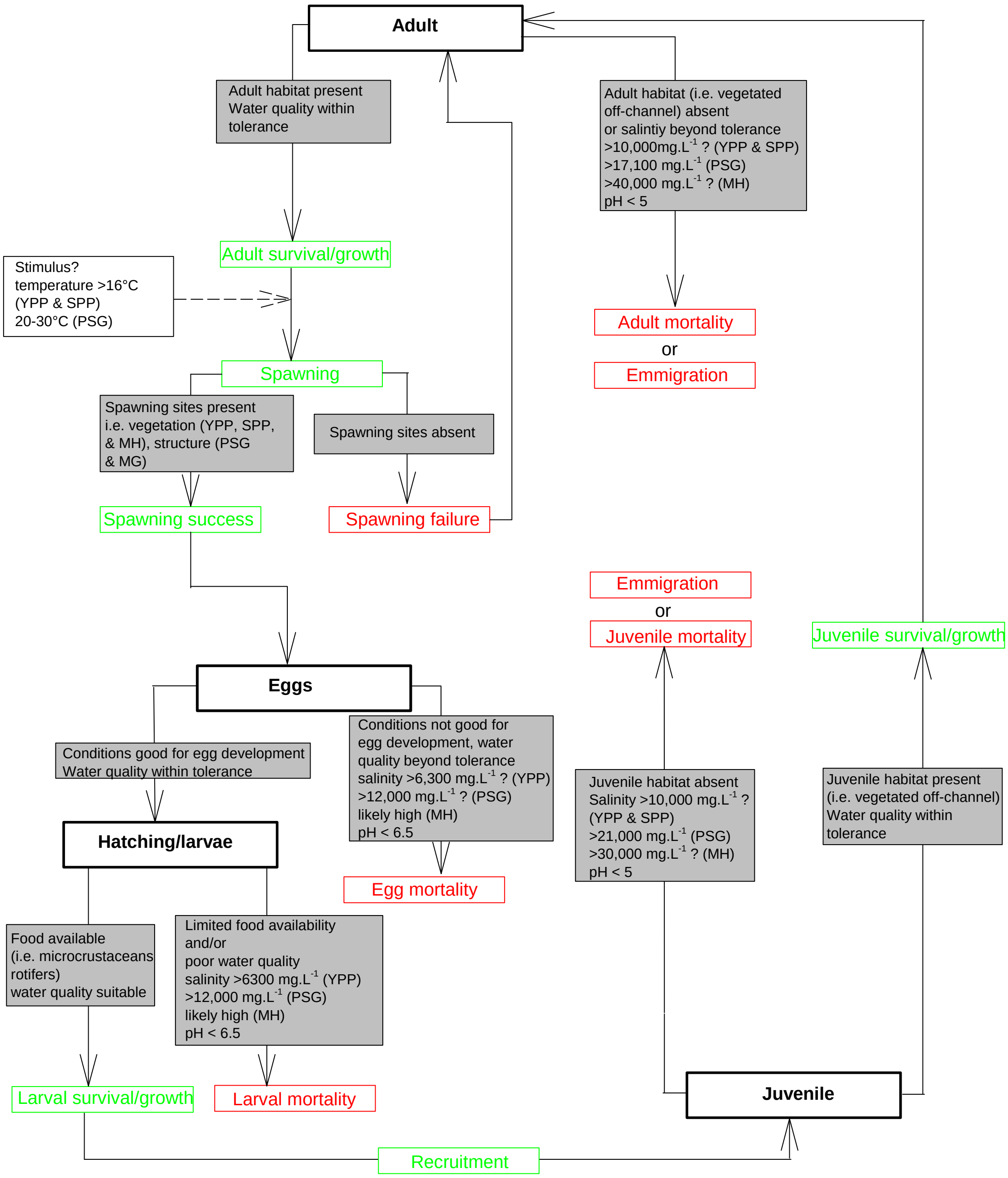

Figure 11. Lifecycle of threatened or endangered small-bodied native freshwater species, Yarra pygmy perch (YPP), southern pygmy perch (SPP), southern purple-spotted gudgeon (PSG), and Murray hardyhead (MH). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

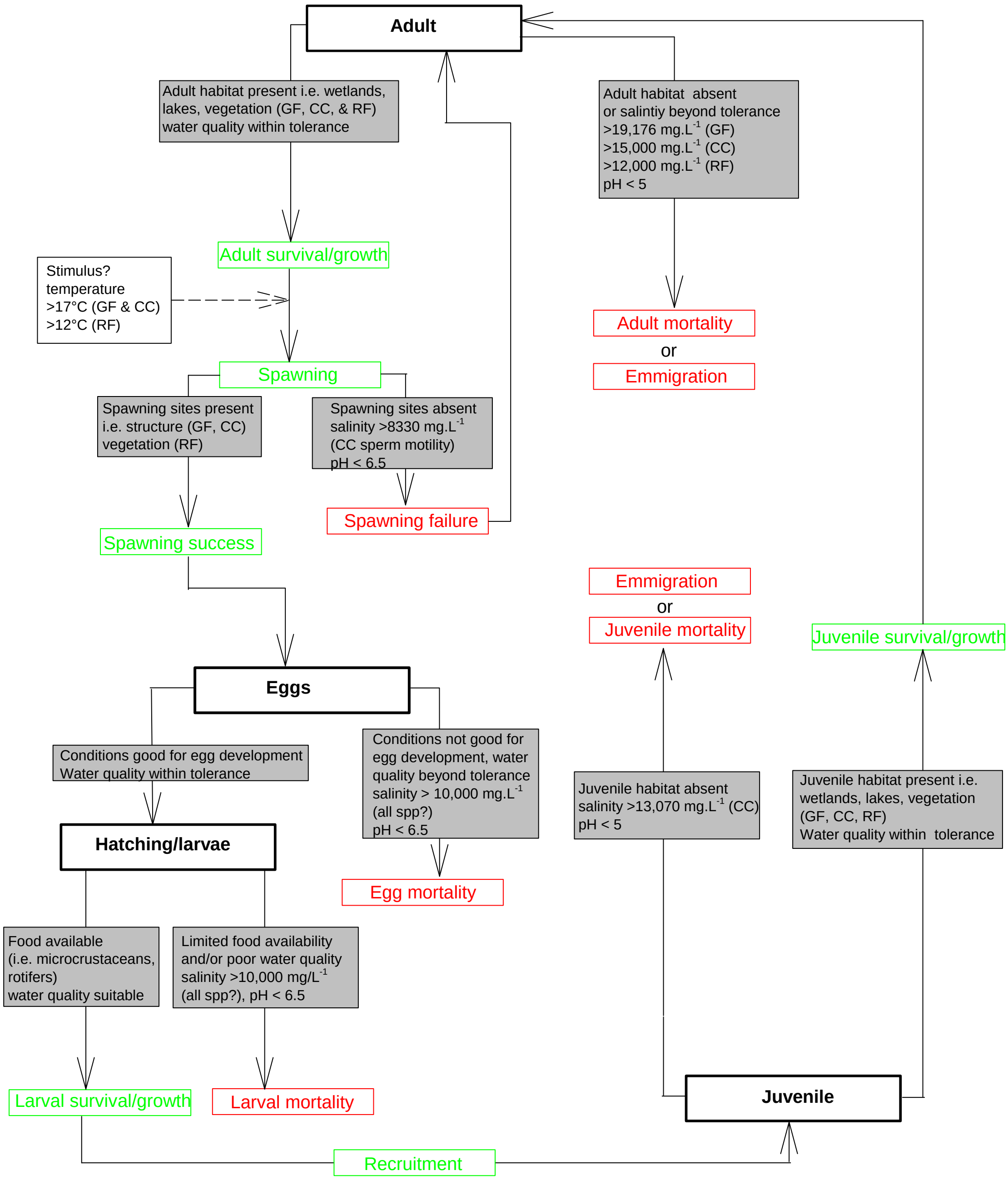

Figure 12. Lifecycle of alien freshwater species, goldfish (GF), common carp (CC) and redfin perch (RF). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

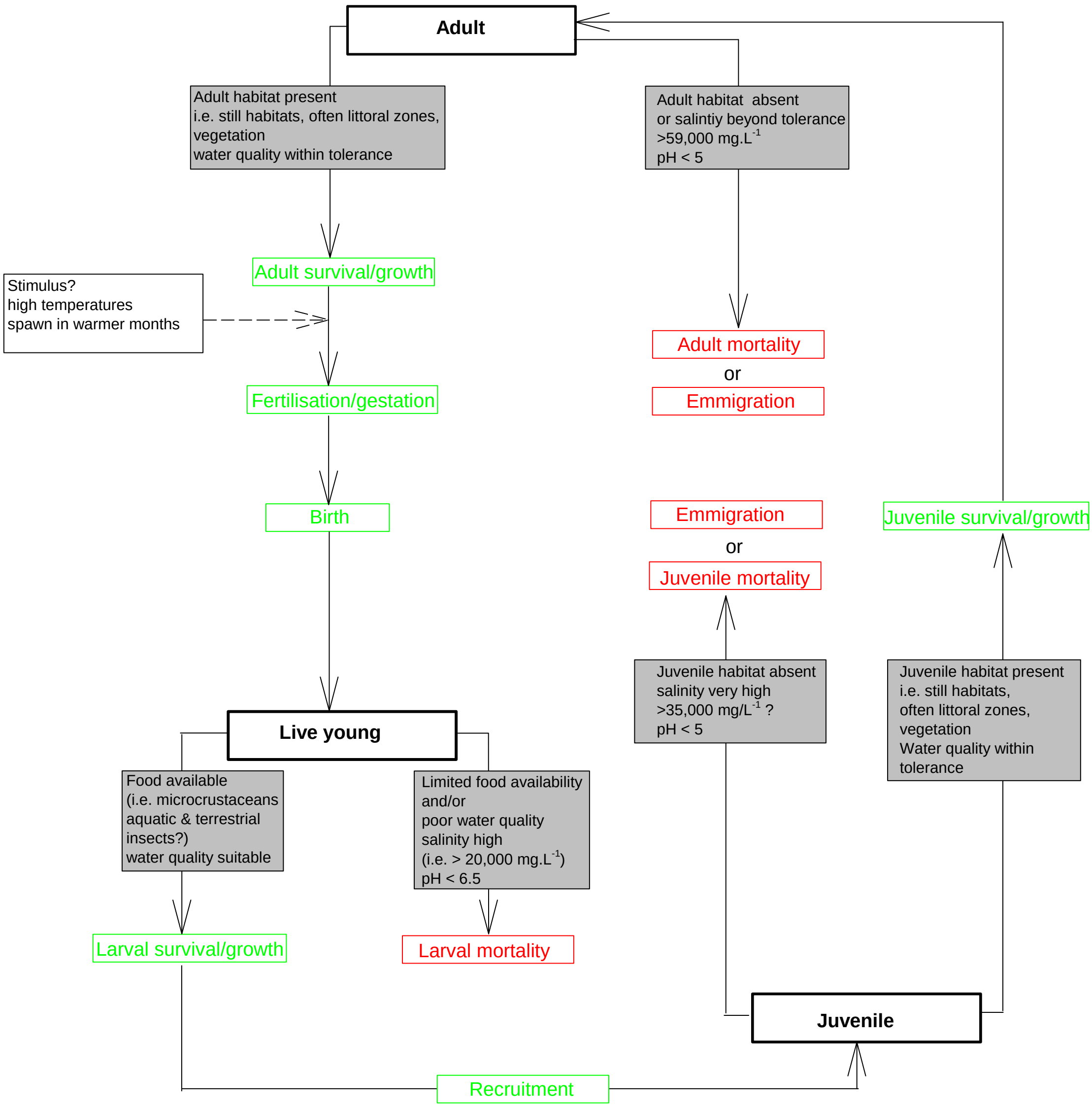

Figure 13. Lifecycle of the alien freshwater species, eastern gambusia. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

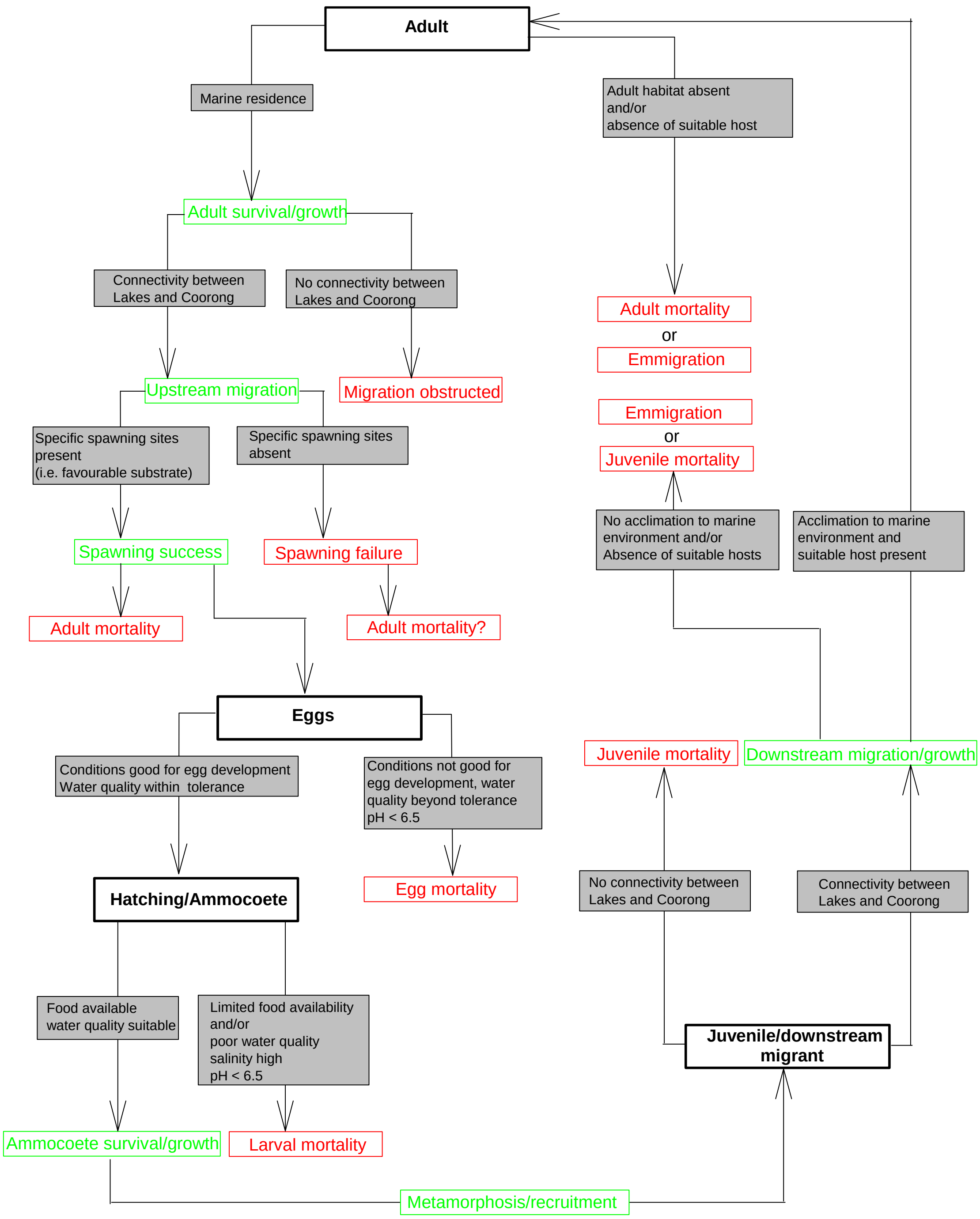

Figure 14. Lifecycle of pouched lamprey and short-headed lamprey, Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

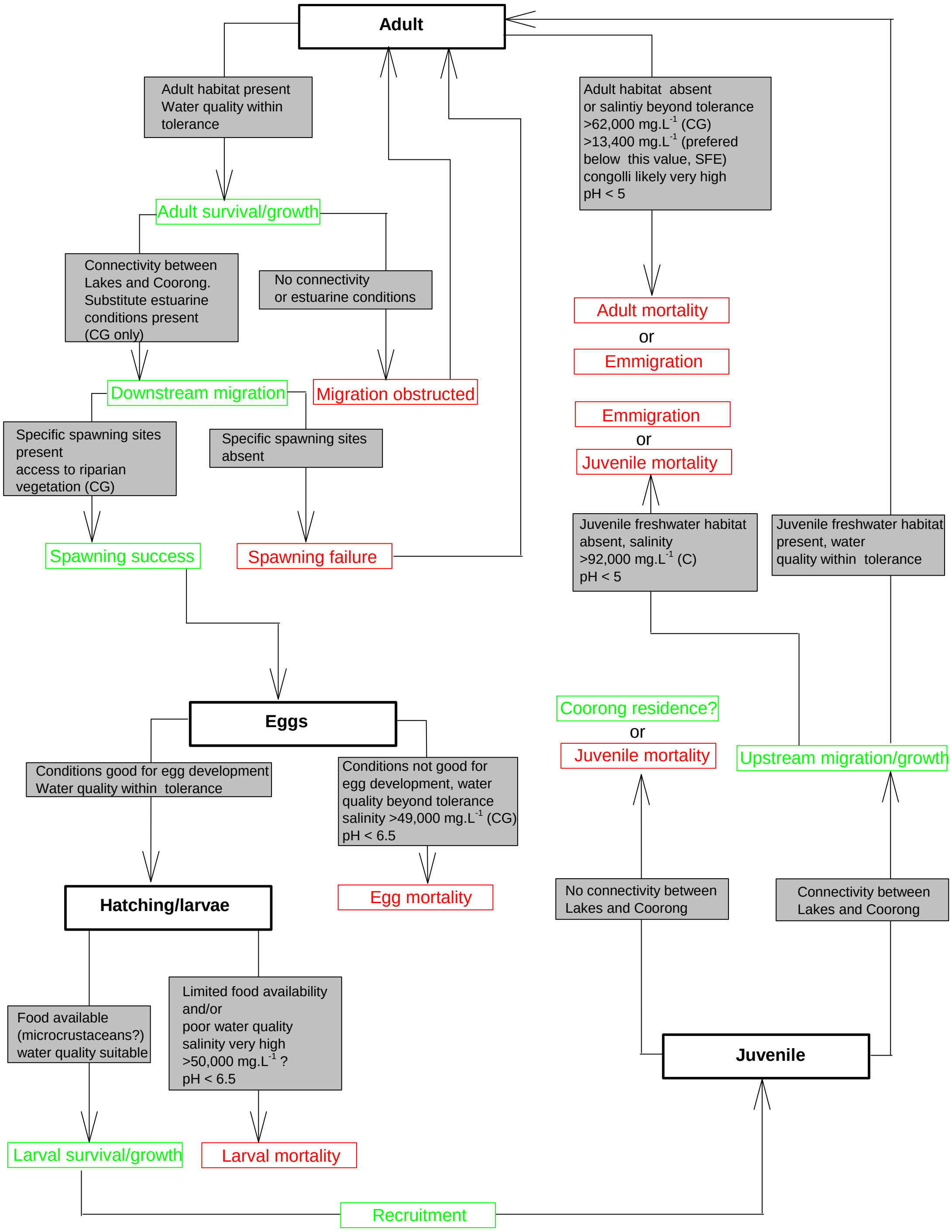

Figure 15. Lifecycle of Catadromous species, common galaxias (CG), short-finned eel (SFE), congolli (C) and estuary perch (EP). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

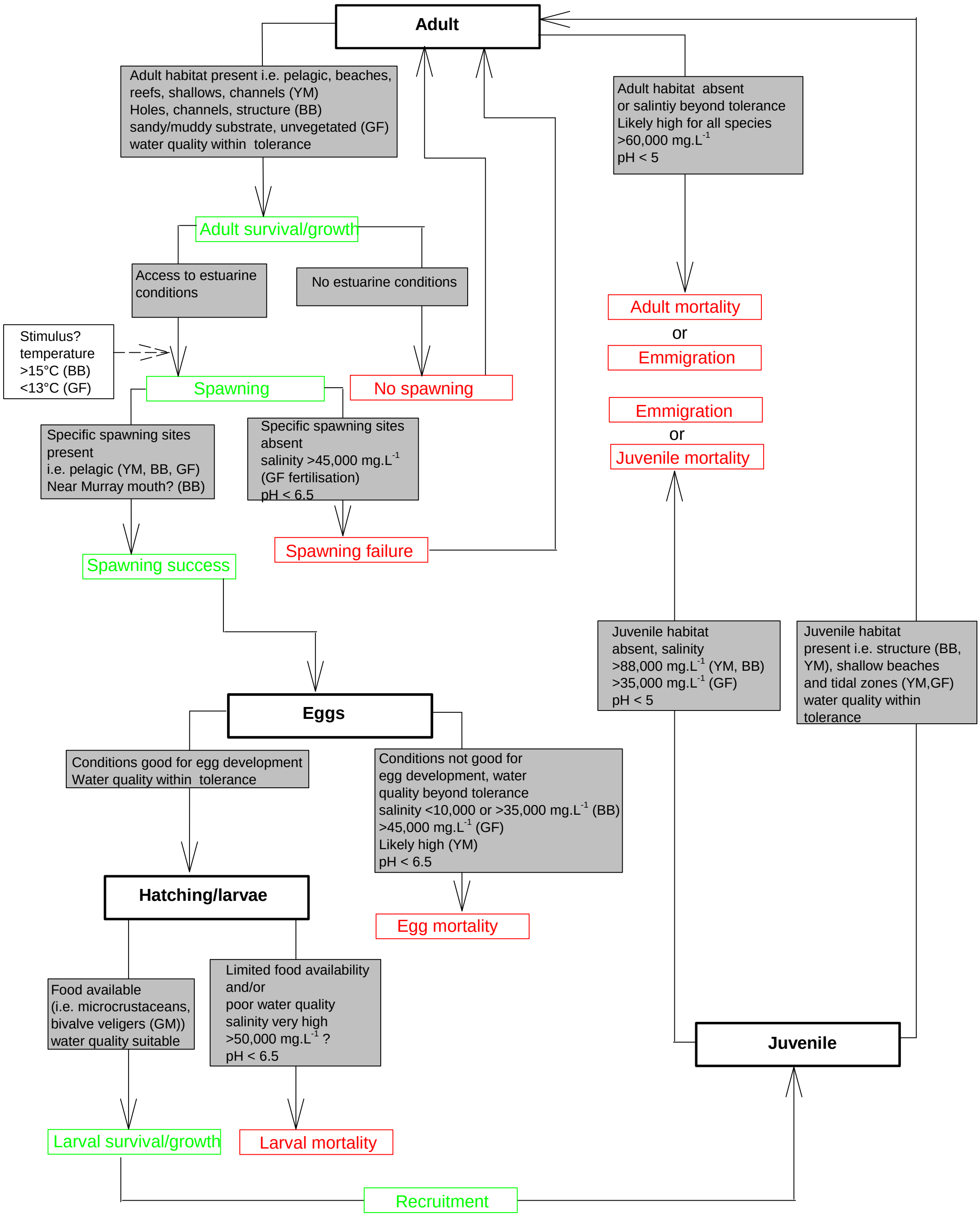

Figure 16. Lifecycle of large-bodied estuarine species, yellow-eyed mullet (YM), black bream (BB) and greenback flounder (GF). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

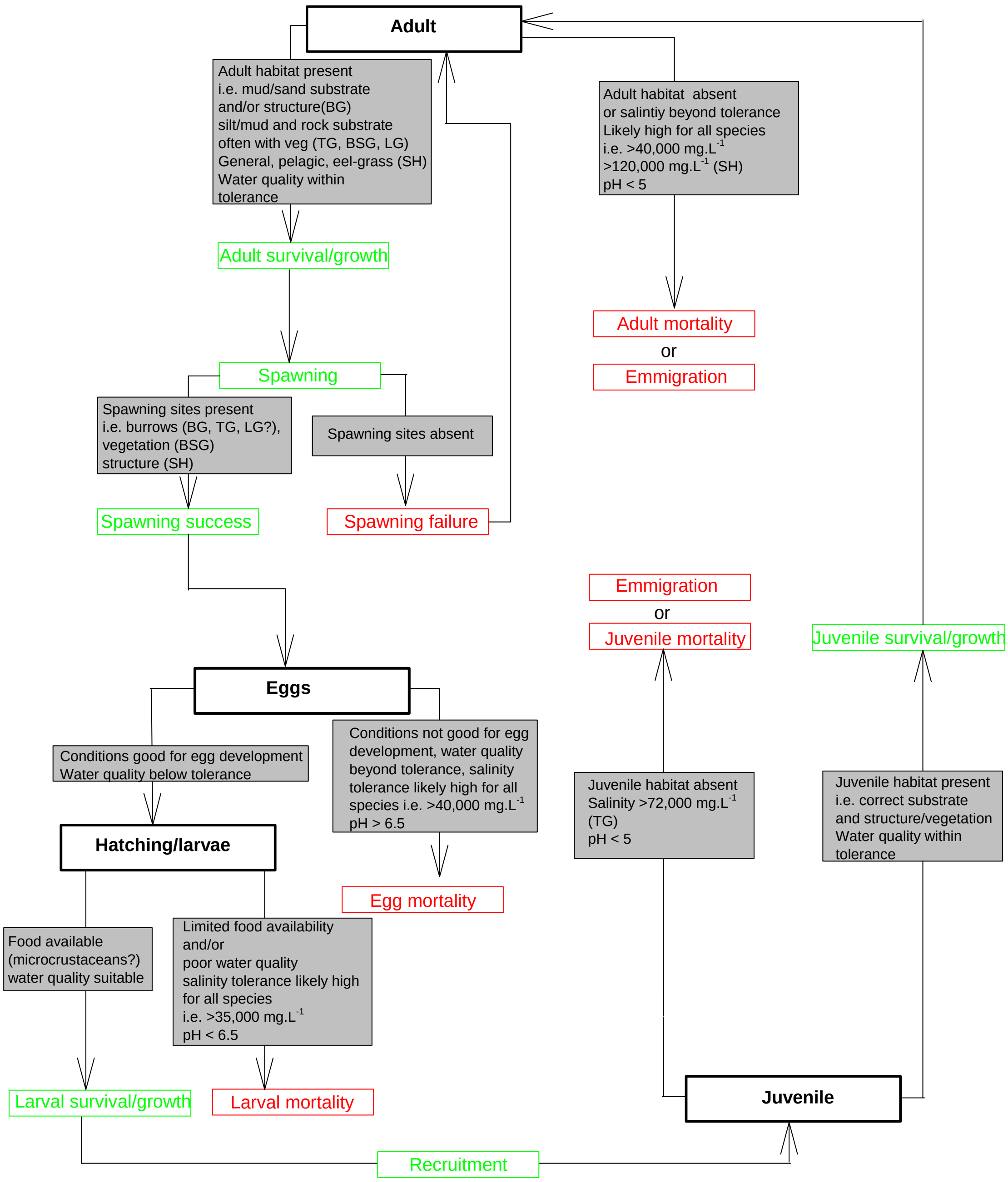

Figure 17. Lifecycle of small-bodied estuarine species, bridled goby (BG), Tamar river goby (TG), blue-spot goby (BG), lagoon goby (LG) and small-mouthed hardyhead (SH). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

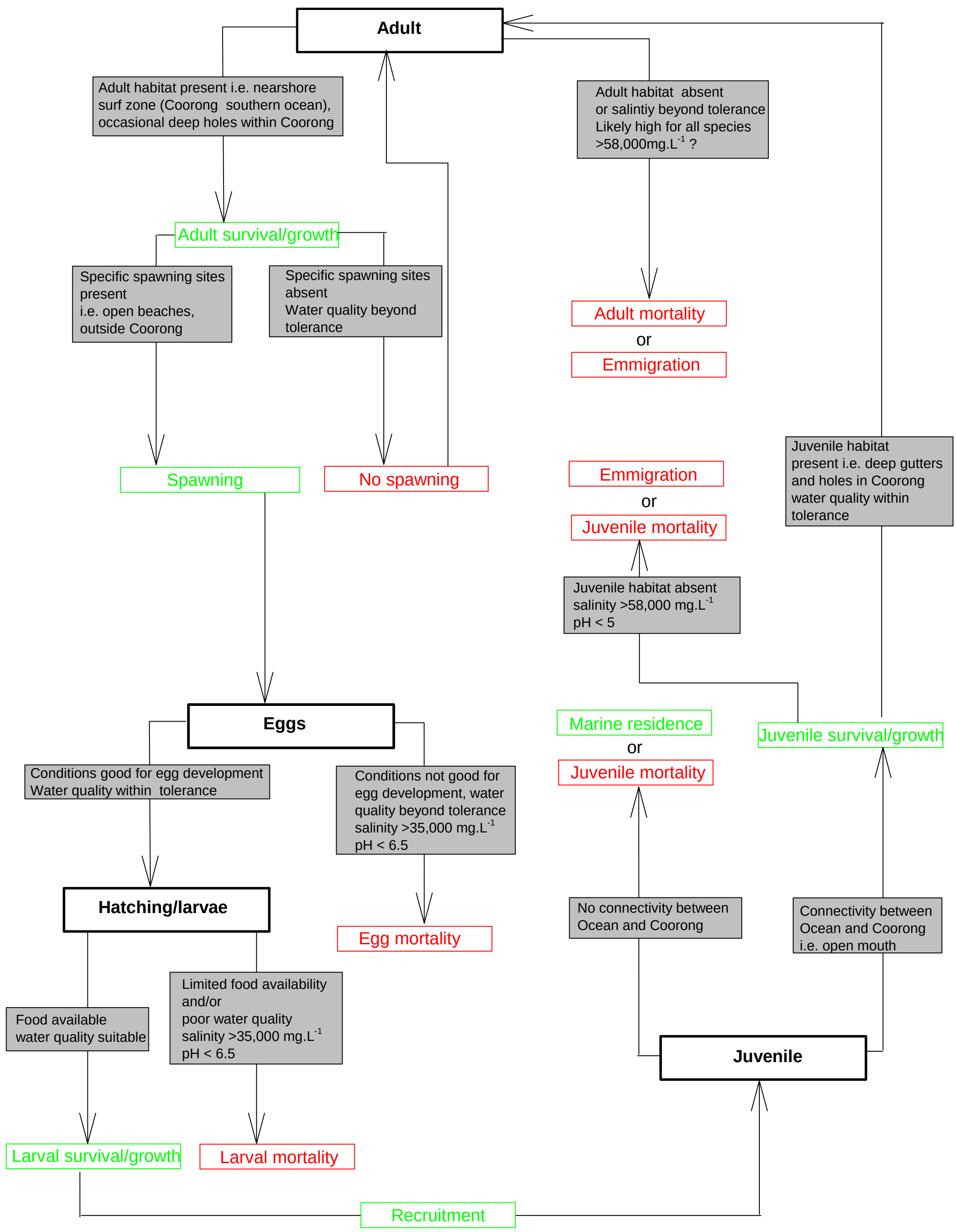

Figure 18. Lifecycle of the marine species, mulloway. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

5 Current condition

Water levels in the Lower Lakes are currently *c.* -0.9 m AHD, over 1.5 m lower than typical operating levels (*c.* 0.75 m AHD). There has been a substantial loss of off-channel wetland habitats in both the Lower Murray and Lower Lakes and submerged vegetation has largely vanished, whilst the remaining water has become disconnected from fringing emergent vegetation (Marsland and Nicol 2009). Concurrently, receding water level has resulted in increased salinities in the Lower Lakes due to evapo-concentration. This is most notable in areas of the Goolwa channel where salinities reached >10,000 $mg.L^{-1}$. Additionally, there has been no freshwater released to the Coorong since March 2007 and there has been no connectivity between the Lower Lakes and Coorong. This has resulted in widespread marine and hyper-marine salinities throughout the Coorong (DWLBC 2009). Thus, the current condition of the site is likely altered from a pre-2006 state (see Phillips and Muller 2006).

Several projects undertaken by several different agencies have sampled fish populations in the Lower Murray, Lower Lakes and Coorong Lagoons within the last 3 years. These include various projects targeting small-bodied species in the Lower Murray and Lower Lakes including Bice and Ye (2007), Bice *et al.* (2008), Hammer (2008), Bice *et al.* (2009) and Wedderburn and Barnes (2009). The current status of large-bodied freshwater species in the Lower Murray is largely interpreted from data from the Murray-Darling Basin Authorities 'Sea to Hume' fishways program (Baumgartner *et al.* 2008a; SARDI Unpublished data) and Native Fish Monitoring conducted by SARDI Aquatic Sciences and funded by PIRSA Fisheries (Ye and Zampatti 2007; SARDI Unpublished data). Data on fish assemblages of the Coorong are taken from Bice *et al.* (2007), Jennings *et al.* (2008a) and Noell *et al.* (2009). A recently initiated project monitoring fish assemblages in the Goolwa channel area as part of the 'Goolwa water level management project' provides further data on current condition (SARDI Unpublished data). The data collected by these programs provides insight on current condition but is not definitive. Thus, the information presented in this section is a combination of data collected in the aforementioned projects and predictions on distribution and abundance by the author (Table 7).

Whilst the current status of individual species within sub-units of the study region is presented in Table 7, the general status of fish communities may be simply described. In general, fish assemblages in the Lower Murray and Lower Lakes are currently dominated by species with generalist habitat requirements (e.g. Australian smelt), alien species (e.g. common carp) and those with wide physico-chemical tolerance levels (e.g. bony herring), whilst species with specialised habitat requirements have declined (e.g. Yarra pygmy perch).

Due to a loss of off-channel wetlands in the Lower Murray, Murray hardyhead have decreased in distribution and abundance in this region and southern purple-spotted gudgeon are present in severely decreased abundance (Bice *et al.* 2009). A loss of similar habitats in the Lower Lakes has resulted in similar decreases in distribution and abundance of southern pygmy perch and potential local extirpation of Yarra pygmy perch (Hammer 2008; Bice *et al.* 2009). Large-bodied native species are present in the Lower Murray but recruitment of some species has been diminished in recent years (Ye and Zampatti 2007; SARDI Unpublished data). The status of most large-bodied native species in the Lower Lakes is largely unknown.

The lack of connectivity between the Lower Lakes and Coorong has drastically impacted diadromous fish populations. In 2006/07 significant numbers of juvenile congolli and common galaxias and adult short-headed lamprey were sampled at the barrage fishways migrating upstream into the Lower Lakes (Bice *et al.* 2007). In 2007/08 and 2008/09 following the cessation of freshwater inflows into the Coorong and loss of connectivity, the abundance of upstream migrating juvenile congolli and common galaxias was reduced by >95% (Jennings *et al.* 2008a; SARDI Unpublished data). Additionally, no short-headed lamprey were collected over this period.

With the cessation of freshwater inflows to the Coorong, salinities have increased such that the Murray Estuary now typically exhibits marine salinities with salinity increasing to hypermarine through the North and South Lagoons. As such, fish assemblages in the Murray Estuary have changed from a diverse mixture of freshwater, diadromous and estuarine species to an assemblage characterised by estuarine and opportunistic marine species (Jennings *et al.* 2008a; Noell *et al.* 2009). Only two species (i.e. small-mouthed hardyhead and yellow-eyed mullet) can now be considered abundant in the North Lagoon and small-mouthed hardyhead are the only species present in the South Lagoon (Noell *et al.* 2009).

Table 7. A summary of current condition of fish communities in different geographical units of the study region, based upon data from research projects conducted in the last three years and predictions by the author.

Species	Scientific name	River Murray	Lower Lakes		Coorong		
			Lake Alexandrina	Lake Albert	Murray Estuary	Northern Lagoon	Southern Lagoon
Large-bodied native freshwater species							
Silver perch	*Bidyanus bidyanus*	Present in low abundances	Unknown, likely rare	Unknown, likely rare	Absent	Absent	Absent
Golden perch	*Macquaria ambigua*	Present	Present. Commercial fishery still operating	Unknown, likely rare	Absent	Absent	Absent
Murray cod	*Macquaria peelii peelii*	Present, poor recent recruitment	Unknown, likely rare and poor recruitment	Unknown, likely rare and poor recruitment	Absent	Absent	Absent
Bony herring	*Nematalosa erebi*	Present and abundant	Present and abundant	Present and abundant	Absent	Absent	Absent
Eel-tailed catfish	*Tandanus tandanus*	Present	Unknown, likely rare	Unknown, likely rare	Absent	Absent	Absent
Common small-bodied native freshwater species							
Carp gudgeon complex	*Hypseleotris* spp.	Present and abundant	Present	Likely present	Absent	Absent	Absent
Flat-headed gudgeon	*Philypnodon grandiceps*	Present and abundant	Present and abundant	Present	Absent	Absent	Absent
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Present	Present	Likely present	Absent	Absent	Absent
Australian smelt	*Retropinna semoni*	Present and abundant	Present and abundant	Present and abundant	Absent	Absent	Absent
Murray rainbowfish	*Melanotaenia fluviatilis*	Present and abundant	Absent	Likely absent	Absent	Absent	Absent
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Present and abundant	Present	Likely absent	Absent	Absent	Absent
Rare or endangered small-bodied native freshwater species							
Murray hardyhead	*Craterocephalus fluviatilis*	Present at one off-channel wetland but current status unknown	Present from *c.* 3 remaining sites	Known from just one remaining site	Absent	Absent	Absent
Southern purple-spotted gudgeon	*Mogurnda aspersa*	One site remaining? Very low abundance,	Absent	Absent	Absent	Absent	Absent
Southern pygmy perch	*Nannoperca australis*	Absent	Only 2 remaining sites in the region. Low abundance	Absent	Absent	Absent	Absent
Yarra pygmy perch	*Nannoperca obscura*	Absent	Potentially extirpated from local area. Has not been recorded since 2007	Absent	Absent	Absent	Absent

Table 7 continued.

Species	Scientific name	River Murray	Lower Lakes		Coorong		
			Lake Alexandrina	Lake Albert	Murray Estuary	Northern Lagoon	Southern Lagoon
Exotic freshwater species							
Goldfish	*Carassius auratus*	Present	Present	Present	Absent	Absent	Absent
Common carp	*Cyprinus carpio*	Abundant	Abundant	Abundant	Absent	Absent	Absent
Eastern gambusia	*Gambusia holbrooki*	Abundant	Abundant	Likely abundant	Absent	Absent	Absent
Redfin perch	*Perca fluviatilis*	Present	Present	Present	Absent	Absent	Absent
Diadromous species (*anadromous, ^catadromous)							
Pouched lamprey*	*Geotria australis*	?	No adults recorded for 2 years	?	No adults recorded for 2 years	Absent	Absent
Short-headed lamprey*	*Mordacia mordax*	Ammocoetes recently recorded in region.	No adults recorded for 2 years	?	No adults recorded for 2 years	Absent	Absent
Common galaxias^	*Galaxias maculatus*	Present	Present. Potentially limited recruitment due to lack of connectivity	Present. Potentially limited recruitment due to lack of connectivity	present	Absent	Absent
Short-finned eel^	*Anguilla australis*	Some recent records of individuals	Some recent records of individuals	?	Absent	Absent	Absent
Estuary perch^	*Macquaria colonorum*	Absent	Absent	Absent	Absent	Absent	Absent
Congolli^	*Pseudaphritis urvillii*	Present, low abundances	Present. Likely limited recruitment due to lack of connectivity	Present. Likely limited recruitment due to lack of connectivity	Present, low abundances	Present, low abundances	Absent
Estuarine species							
Yellow-eyed mullet	*Aldrichetta forsteri*	Absent	Present, low abundances	?	Abundant	Abundant	Absent
Black bream	*Acanthopagrus butcheri*	Absent	Present, low abundances	?	Present	Absent	Absent
Bridled goby	*Arenogobius bifrenatus*	Absent	Present	Likely present, low abundances	Present	Absent	Absent
Tamar goby	*Afurcagobius tamarensis*	?	Present	Likely present	Present	Present	Absent
Bluespot goby	*Pseudogobius olorum*	?	Present	Likely present	Present	Absent	Absent
Lagoon goby	*Tasmanobius lasti*	?	Present	Likely present	Present	Present, low abundances	Absent
Greenback flounder	*Rhombosolea tapirina*	Absent	Present, low abundances	Likely present	Present	Present	Absent
Small-mouthed hardyhead	*Atherinosoma microstoma*	Likely present, low abundances	Abundant	Likely abundant	Abundant	Abundant	Present
Marine species							
Mulloway	*Argyrosomus japonicus*	Absent	Absent	Absent	Present, moderate abundance	Absent	Absent

6 Key Knowledge gaps

The information presented in this review summarises all up-too-date knowledge on the selected species yet; significant gaps remain in the understanding of the functioning of the Lower Lakes and Coorong system and individual species ecology. Whilst there are many gaps in current understanding, the following represent the most important in terms of fish ecology.

The status of large-bodied freshwater species (e.g. Murray cod, silver perch, catfish) in the Lower Lakes

The majority of recent (last five years) research effort in the Lower Lakes has centred on small-bodied fish; particularly species of conservation significance (i.e. southern pygmy perch, Yarra pygmy perch and Murray hardyhead) (see Bice and Ye 2007; Bice *et al.* 2008; Hammer 2008; Bice *et al.* 2009). Consequently sampling gear types are selective for small-bodied species and are ineffective for sampling large-bodied species. There is, however, some data from the commercial fishery but this primarily pertains to the status of golden perch and common carp which are actively targeted within this fishery. Other large-bodied native species, namely silver perch, eel-tailed catfish and Murray cod are protected under the *Fisheries Management Act* (2007) and thus are not targeted by commercial fishermen. Silver perch and eel-tailed catfish are of a similar size to golden perch and therefore are sometimes caught as by-catch but due to the large size of Murray cod (often > 1 m in length) this species must be specifically targeted in order to be captured. Hence the status of Murray cod within the Lower Lakes is unknown.

Within the Lower Murray, historical fishery data suggest a strong correlation between recruitment of Murray cod and river flow (Ye *et al.* 2000). It has been suggested that a lack of significant river flows in the last 20 years has resulted in limited recent recruitment as evidenced by a population that is dominated by large, old (primarily ≥ 15 years) fish (Ye and Zampatti 2007). This is also potentially the case in the Lower Lakes.

Movement patterns of fish between Lake Alexandrina and Lake Albert, and between the Lower Lakes and the Lower Murray River

The movement patterns of some freshwater species (e.g. golden perch and common carp) in other areas of the MDB are relatively well known (O'Connor et al. 2005; Stuart and Jones 2006) but the movement patterns of fish between Lake Alexandrina and Lake Albert and between Lake Alexandrina and the Lower Murray are unknown. Recent work at the Murray Barrages (see Bice *et al.* 2007; Jennings *et al.* 2008a; Jennings *et al.* 2008b) has generated an understanding of the movement of diadromous fishes between the Coorong and Lower Lakes and a current study being undertaken by SARDI Aquatic Sciences and funded by the SA MDB NRMB is investigating the movement patterns of congolli within Lake Alexandrina.

Knowledge of fish movement within the Lower Lakes and between the Lower Lakes and Lower Murray is fundamental to the management of the system. As part of current management several instream barriers to fish movement have been constructed in the last two years, including the blocking bank that separates Lake Alexandrina and Lake Albert, which represents a complete barrier to movement between these water bodies. Additionally, a regulator has been built at Clayton, further segmenting Lake Alexandrina and obstructing fish movements. Given the current propensity for environmental systems and the Lower Lakes in particular, to be managed with engineering solutions, knowledge of the movement patterns of fish, especially native species, is perhaps more important now than ever before.

The tolerance of native species to changes in pH and heavy metal concentrations

The impact of reduced pH is discussed generally in this review but species-specific information is lacking. Additionally, as pH is decreased, ASS may also release a variety of heavy metals and other metalloids which may be directly toxic to fish. The toxicity of these metals differs by orders of magnitude at different pH and therefore providing values for toxicity that are meaningful is difficult. Nonetheless, as with pH, very little data is available on the heavy metal tolerance limits of native species. The risk posed by heavy metals released as a result of the oxidation of ASS is real and thus a lack of knowledge on their affect on native species is significant.

7 Conclusion

With continued drought predicted in south-eastern Australia, inflows to the Lower Lakes are likely to remain below average. This will result in further decreases in water levels and an increasing risk of acidification from acid sulfate soil exposure. Hence, there is a dire need to manage the system in order to mitigate the risks posed by acidification.

The information and conceptual models presented in this report will provide the basis for assessing the likely impacts of proposed management options for the Lower Lakes on the resident fish communities. When used in conjunction with water quality modelling data these conceptual models will assist in predicting potential changes to the fish community.

8 References

Alber M (2002) A conceptual model of estuarine freshwater inflow management. *Estuaries* **25**, 1246-1261.

Aquaculture SA (2003) 'Mulloway aquaculture in South Australia.' PIRSA, FS No. 35/03, Adelaide.

Arthington AH and Marshall CJ (1999) Diet of the exotic mosquitofish, *Gambusia holbrooki*, in an Australian lake and potential for competition with indigenous species. *Asian Fisheries Science* **12**, 1-16.

Bacher G and Garnham J (1992) 'The effect of salinity to several freshwater aquatic species of southern Victoria.' Freshwater Ecology Section, Flora and Fauna Division, Department of Conservation and Environment. EPA Report SRS 92/003.

Balcombe SR and Humphries P (2006) Diet of the western carp gudgeon (*Hypseleotris klunzingeri* Ogilby) in an Australian floodplain lake: the role of water level stability. *Journal of Fish Biology* **68**, 1484-1493.

Barletta M, Barletta-Bergan A, Saint-Paul U and Hubold G (2005) The role of salinity in structuring fish assemblages in a tropical estuary. *Journal of Fish Biology* **66**, 45-72.

Barnett C and Pankhurst N (1999) Reproductive biology and endocrinology of greenback flounder *Rhombosolea tapirina* (Gunther 1862). *Marine and Freshwater Research* **50**, 35-42.

Baumgartner LJ (2007) Diet and feeding habits of predatory fishes upstream and downstream of a low-level weir. *Journal of Fish Biology* **70**, 879-894.

Baumgartner LJ, Stuart IG and Zampatti BP (2008a) Day and night changes in the structure of fish assemblages on the lower Murray River prior to fishway construction. In 'The Sea to Hume Dam: Restoring Fish Passage in the Murray River'. (Ed. J Barrett) pp. 12-20. (Murray-Darling Basin Commission, Canberra)

Baumgartner LJ, Stuart IG and Zampatti BP (2008b) Synthesis: what have we learnt about fish passage in the Murray-Darling Basin. In 'The Sea to Hume Dam: Restoring Fish Passage in the Murray River'. (Ed. J Barrett) pp. 76-85. (Murray-Darling Basin Commission, Canberra)

Bice C, Hammer M, Wilson P and Zampatti B (2009) 'Fish monitoring for the 'Drought Action Plan for South Australian Murray-Darling Basin threatened freshwater fish populations': Summary for 2008/09. Report to the South Australian Department for Environment and Heritage.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Bice C, Jennings P and Zampatti B (2007) 'Fish movement and recruitment in the Coorong and Lower Lakes: 2006/07 progress report.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 48pp. SARDI Publication No. 2007/000555-1. SARDI Research Report Series No. 232.

Bice C, Wilson P and Ye Q (2008) 'Threatened fish populations in the Lower Lakes of the River Murray in spring 2007 and summer 2008.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 32pp. SARDI Publication number F2008/000801-1.

Bice C and Ye Q (2006) 'Monitoring threatened fish communities on Hindmarsh Island, in the Lower Lakes of the River Murray, South Australia in 2005.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication Number RD06/0004-1.

Bice CM and Ye Q (2007) 'Monitoring threatened fish communities on Hindmarsh Island, in the Lower Lakes of the River Murray, South Australia, in the summers of 2006 and 2007 with reference to baseline data from 2005.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 47pp. SARDI Publication Number F2007/000551-2.

Bice CM and Ye Q (2009) 'Risk assessment of proposed management scenarios for Lake Alexandrina on the resident fish community.' Report to the South Australian Department for Environment and Heritage. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 129pp. SARDI Publication Number F2009/000375-1.

Blanch SJ, Walker KF and Ganf GG (2000) Water regimes and littoral plants in four weir pools of the River Murray, Australia. *Regulated Rivers: Research & Mangement* **16**, 445-456.

Boys C and Thoms M (2006) A large-scale, hierarchical approach for assessing habitat associations of fish assemblages in large dryland rivers. *Hydrobiologia* **572**, 11-31.

Cadwallader PL (1979) Distribution of native and introduced fish in the Seven Creeks river system, Victoria. *Australian Journal of Ecology* **4**, 361-385.

Cadwallader PL and Backhouse G (Eds) (1983) 'A guide to freshwater fishes of victoria.' (Victorian Government printing house: Melbourne)

Castonguay M, Plourde S, Robert D, Runge JA and Fortier L (2008) Copepod production drives recruitment in a marine fish. *Canadian Journal of Fisheries and Aquatic Sciences* **65**, 1528-1531.

Cech JJJ, Mitchell SJ and Massingill MJ (1979) Respiratory adaptations of Sacramento blackfish, *Orthodon microlepidotus* (Ayres), for hypoxia. *Comparative Biochemistry and Physiology* **63**, 411-415.

Cheshire K and Ye Q (2008) 'Larval fish assemblages below Locks 5 and 6, in the River Murray, South Australia from 2005 to 2007: with reference to water manipulation trials ' South Australian Research and Developement Institute, Aquatic Sciences, Adelaide, pp 42. SARDI Publication Number F2007/000705-1

Chessman B and Williams W (1974) Distribution of fish in inland saline waters in Australia. *Australian Journal of Marine and Freshwater Research* **25**, 167-172.

Chubb C, Potter I, Grant C, Lenanton R and Wallace J (1981) Age structure, growth rates and movements of sea mullet, *Mugil cephalus* L. and yellow-eye mullet, *Aldrichetta forsteri* (Valenciennes), in the Swan-Avon River system, Western Australia. *Australian Journal of Marine and Freshwater Research* **32**, 605-628.

Clarkson R and Childs M (2000) Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin Big-River fishes. *Copeia* **2000**, 402-412.

Clements J (1988) 'Salmon at the Antipodes. A History and Review of the Trout, Salmon and Char, and Introduced Coarse Fish in Australia.' (John Clements, Ballarat, Australia)

Clunie P, Ryan T, James K and Cant B (2002) 'Implications for rivers from salinity hazards: Scoping study. Report for the MDBC-project R2003.' Arthur Rylah Institute, Heidleberg, Victoria, Australia.

Connolly R (1994) A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. *Australian Journal of Marine and Freshwater Research* **45**, 1033-1044.

Craig G and Baksi W (1977) The effects of depressed pH on flagfish reproduction, growth and survival *Water Research* **11**, 621-626.

Crawshaw L (1979) Responses to rapid temperature change in vertabrate ectotherms. *American Zoologist* **19**, 225-237.

CSIRO (2008) 'Water availability in the Murray-Darling Basin.' Report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia, 67pp.

DEH (2000) 'Coorong and Lakes Alexandrina and Albert Ramsar Management Plan.' Department of Environment and Heritage, Adelaide.

DEH (2009) 'Supplementary Environmental Impact Statement for the temporary weir near Pomanda Island.' The Department for Environment and Hertage, Adelaide. Reference number 2007/3484.

DWLBC (2008) 'DWLBC Unpublished data. Department of Water Land and Biodiversity Conservation.'

DWLBC (2009) 'DWLBC Unpublished data. Department of Water Land and Biodiversity Conservation.'

Ebner B (2006) Murray cod an apex predator in the Murray River, Australia. *Ecology of Freshwater Fish* **15**, 510-520.

Echelle A, Echelle A and Hill L (1972) Interspecific interactions and limiting factors of abundance and distribution in the Red River pupfish, *Cyprinodon rubrofluviatilis*. *American Midland Naturalist* **88**, 109-130.

Eckert J and Robinson R (1990) The fishes of the Coorong. *South Australian Naturalist* **65**, 5-30.

Edgar G and Shaw C (1995a) The production and trophic ecology of shallow-water fish assemblages in southern Australia. I. Species richness, size-structure and production of fishes in Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, 53-81.

Edgar GJ and Shaw C (1995b) The production and trophic ecology of shallow-water fish assemblages in southern Australia II. Diets of fishes and trophic relationships between fishes and benthos at Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, 83-106.

Ellis I (2005) 'Ecology and breeding seasonality of the Murray hardyhead *Craterocephalus fluviatilis* (McCulloch), Family Atherinidae, in two lakes near Mildura, Victoria.' Murray-Darling Freshwater Research Centre, Lower Basin Laboratory, Mildura.

Ferguson G and Ward T (2003) 'Mulloway (*Argyrosomus japonicus*) Fishery.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 63pp.

Ferguson GJ, Ward TM and Geddes MC (2008) Do recent age structures and historical catches of mulloway, *Argyrosomus japonicus* (Scianidae), reflect freshwater inflows in the remnant estuary of the Murray River, South Australia? *Aquatic Living Resources* **21**, 145-152.

Fielder D and Bardsley W (1999) A preliminary study on the effects of salinity on growth and survival of mulloway *Argyrosomus japonicus* larvae and juveniles. *Journal of the World Aquaculture Society* **30**, 380-387.

Finlayson BL and McMahon TA (1988) Australia vs the world: a comparative analysis of streamflow characteristics. In 'Fluvial Geomorphology of Australia'. (Ed. RF Warner) pp. 17-39. (Academic Press, Sydney)

Fitzpatrick R, Shand P, Marvanek S, Merry R, Thomas M, Raven M, Simpson S and McClure S (2008) 'Acid sulfate soils in subaqueous, waterlogged and drained soil environments in Lake Albert, Lake Alexandrina and River Murray below Blanchtown (Lock 1): properties, distribution, genesis, risks and management.' CSIRO Land and Water Science. Report 46/08.

Fromm P (1980) A review of some physiological and toxicological responses of freshwater fish to acid stress. *Environmental Biology of Fishes* **5**, 79-93.

Garner P (1996) Microhabitat use and diet of 0+ cyprinid fishes in a lentic, regulated reach of the River Great Ouse, England. *Journal of Fish Biology* **48**, 367-382.

Geddes MC (1987) Changes in salinity and in the distribution of macrophytes, macrobenthos and fish in the Coorong Lagoons, South Australia, following a period of River Murray flow. *Transactions of the Royal Society of South Australia* **108**, 173-181.

Gee J and Gee P (1991) Reactions of gobioid fishes to hypoxia: Bouyancy control and aquatic surface respiration *Copeia* **1**, 17-28.

Gehrke PC (1992) Diel abundance, migration and feeding of fish larvae (Eleotridae) in a floodplain billabong. *Journal of Fish Biology* **40**, 695-707.

Gehrke PC, Brown P, Schiller CB, Moffat DB and Bruce AM (1995) River regulation and fish communities in the Murray-Darling River system, Australia. *Regulated Rivers: Research & Management* **11**, 363-375.

Gill H and Potter IC (1993) Spatial segregation amongst goby species within an Australian estuary, with a comparison of the diets and salinity tolerance of the two most abundant species. *Marine Biology* **117**, 515-526.

Goecker ME, Valentine JF, Sklenar SA and Chaplin GI (2009) Influence from hydrological modification on energy and nutrient transference in a deltaic food web. *Estuaries and Coasts* **32**, 173-187.

Gomon M, Bray D and Kuiter R (Eds) (2008) 'Fishes of Australia's Southern Coast.' (Reed, New Holland, Sydney)

Gray C and McDonall V (1993) Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces: Sciaenidae) in the Hawkesbury River, south-eastern Australia. *Australian Journal of Marine and Freshwater Research* **44**, 401-409.

Guo P, Mather B and Capra M (1995) Salinity tolerance and osmoregulation in the silver perch, *Bidyanus bidyanus* Mitchell (Teraponidae), an endemic Australian freshwater teleost. *Marine and Freshwater Research* **46**, 947-952.

Haddy J and Pankhurst N (1998) Annual change in reproductive condition and plasma concentrations of sex steroids in black bream, *Acanthopagrus butcheri* (Munroe) (Teleostei: Sparidae). *Marine and Freshwater Research* **49**, 389-397.

Haddy J and Pankhurst N (2000) The effects of salinity on reproductive developement, plasma steroid levels, fertilisation and egg survival in black bream *Acanthopagrus butcheri*. *Aquaculture* **188**, 115-131.

Hall D (1984) The Coorong: biology of the major fish species and fluctuations in catch rates 1976-1984. *SAFIC* **8**, 3-17.

Hammer M (2004) 'The Eastern Mt Lofty's Fish Inventory: Distribution and Conservation of Freshwater Fishes of Tributaries to the Lower River Murray, South Australia.' Native Fish Australia (SA) Inc. and River Murray Catchment Water Management Board.

Hammer M (2005) 'Recovery monitoring for the Southern Pygmy Perch in the Mount Lofty Ranges, 2001-2005 review.' Native Fish Australia (SA) Inc, Adelaide.

Hammer M (2007) 'Report on urgent conservation measures and monitoring of southern purple-spotted gudgeon on the River Murray, South Australia. Report to the South Australian Murray-Darling Basin Natural Resource Management Board.' Aquasave Consultants.

Hammer M (2008) 'Status review of wild and captive populations of Yarra pygmy perch in the Murray-Darling Basin.' Aquasave Consultants, Adelaide.

Hardie S (2000) 'Examination of fish and invertebrate fauna in seven lakes in the Swan Hill-Kerang Region, Northern Victoria.' Department of Natural Resources and Environment, Victoria.

Hart P, Bailey P, Edwards R, Hortle K, James K, McMahon A, Meredith C and Swadling K (1991) A review of the salt sensitivity of the Australian freshwater biota. *Hydrobiologia* **210**, 105-144.

Hart P, Hutchinson W and Purser G (1996) Effects of photoperiod, temperature and salinity on hatchery-reared larvae of the greenback flounder (*Rhombosolea tapirina* Gunther, 1862). *Aquaculture* **144**, 303-311.

Hart P and Purser G (1995) Effects of salinity and temperature on eggs and yolk sac larvae of the greenback flounder (*Rhombosolea tapirina* Gunther, 1862). *Aquaculture* **136**, 221-230.

Higham J, Ferguson G and Ye Q (2005a) 'Lakes and Coorong yellow-eye mullet (*Aldrichetta forsteri*) fishery.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication Number RD04/0162. 49pp.

Higham J, Hammer M and Geddes MC (2002) Fish and Invertebrates. In 'The Murray Mouth: Exploring the implications of closure or restricted flow' pp. 53-64. (A report prepared for the Murray-Darling Basin Commission, Department of Water, Land and Biodiversity Conservation)

Higham J, Ye Q and Smith B (2005b) 'Murray Darling Basin Drought Monitoring: 'Monitoring small-bodied fish in the Lower Murray during and after drought conditions in

2003-2004.' Project Final Report to the Department of Water, Land and Biodiversity Conservation.

Hortle M (1978) The ecology of the sandy, *Pseudaphritis urvillii,* in south-east Tasmania. Honours thesis, University of Tasmania.

Hortle ME and White RWG (1980) Diet of *Pseudaphritis urvillii* (Cuvier & Valenciennes) (Pisces: Bovichthyidae) from south-east Tasmania. *Australian Journal of Marine and Freshwater Research* **31**, 533-539.

Howell T, Laurenson LJ, Myers JH and Jones PL (2004) Spatial, temporal and size-class variation in the diet of estuary perch (*Macquaria colonorum*) in the Hopkins River, Victoria, Australia. *Hydrobiologia* **515**, 29-37.

Humphries P (1995) Life history, food and habitat of Southern pygmy perch, *Nannoperca australis*, in the Macquarie River, Tasmania. *Marine and Freshwater Research* **46**, 1159-1169.

Humphries P, King A and Koehn J (1999) Fish, flows and floodplains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes* **56**, 129-151.

Humphries P, Serafini LG and King AJ (2002) River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47**, 1307-1331.

Jackson G and Pierce B (1992) Salinity tolerance of selected adult Murray-Darling Basin fishes. *Newsletter of the Australian Society for Fish Biology* **22**, 35.

Jasim B (1988) Tolerance and adaptation of goldfish, *Carrasius auratus L.* to salinity. *Journal of Biological Sciences Research (1012-344X)* **19**.

Jenkins GP (1987) Comparative diets, prey selection and predatory impact of co-occurring larvae of two flounder species. *Journal of Experimental Marine Biology and Ecology* **110**, 147-170.

Jennings P, Zampatti B and Bice C (2008a) 'Fish movement and recruitment in the Coorong and Lower Lakes 2007/08 Progress Report.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 47pp

Jennings P, Zampatti B, Stuart IG and Baumgartner LJ (2008b) Fish passage at the Murray barrages. In 'The sea to Lake Hulme: Restoring fish passage in the Murray River' pp. 62-77. (Murray-Darling Basin Commission, Canberra. MDBC publication No. 32/08)

Jones KA, Hara TJ and Scherer E (1985) Behavioural modifications in arctic char (*Salvelinus alpinus*) chronically exposed to sublethal pH. *Physiological Zoology* **58**, 400-412.

Kailola P, Williams M, Stewart P, Reichelt R, McNee A and Grieve C (Eds) (1993) 'Australian Fisheries Resources.' (Bureau of Resource Sciences, Department of Primary Industries and Energy and the Fisheries Research and Development Corporation: Canberra)

Karimov B and Keyser D (1998) The effect of salt composition on the salinity tolerance of mirror carp (*Cyprinus carpio* L.) during early ontogeny. *Archive of Fishery and Marine Research* **46**, 225-239.

Khan TA (2003) Dietary studies on exotic carp (*Cyprinus carpio* L.) from two lakes in western Victoria, Australia. *Aquatic Sciences* **65**, 272-286.

King A (2005) Ontogenetic dietary shifts of fishes in an Australian floodplain river. *Marine and Freshwater Research* **56**, 215-225.

Koehn J and Harrington D (2006) Environmental conditions and timing for the spawning of Murray cod (*Maccullochella peelii peelii*) and the endangered trout cod (*M. macquariensis*) in southeastern Australian rivers. *Rivers Research and Applications* **22**, 327-342.

Koehn JD (2004) Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. *Freshwater Biology* **49**, 882-894.

Koehn JD and O'Connor WC (1990) 'Biological information for the management of native freshwater fish in Victoria.' Department of Conservation and Environment, Freshwater Fish Management Branch & Arthur Rylah Institute for Environmental Research, North Melbourne.

Krebs JM and Turingan RG (2003) Intraspecific variation in gape-prey size relationships and feeding success during early ontogeny in red drum, *Scianops ocellatus*. *Environmental Biology of Fishes* **66**, 75-84.

Kroon F (2005) Behavioural avoidance of acidified water by juveniles of four commercial fish and prawn species with migratory life stages. *Marine Ecological Progress Series* **285**, 193-204.

Kupschus S and Tremain D (2001) Associations between fish assemblages and environmental factors in nearshore habitats of a subtropical estuary. *Journal of Fish Biology* **58**, 1383-1403.

Kurth D (1957) An investigation of the greenback flounder, *Rhombosolea tapirina* Gunther. PhD Thesis, University of Tasmania

Lake JS (1967) Rearing experiments with five species of Australian freshwater fishes. 1. Inducement of spawning. *Australian Journal of Marine and Freshwater Research* **18**, 137-153.

Larson HK and Hoese DF (1996) Family Gobiidae, subfamilies Eleotridinae and Butinae. In 'Freshwater Fishes of south-eastern Australia'. (Ed. RM McDowall) pp. 200-219. (Reed Books: Sydney)

Lassalle G, Crouzet P and Rochard E (2009) Modelling the current distribution of European diadromous fishes: an approach integrating regional anthropogenic pressures. *Freshwater Biology* **54**, 587-606.

Lazzaro X (1987) A review of planktivorous fishes: Their evolution, feeding behaviours, selectivities and impacts. *Hydrobiologia* **146**, 97-167.

Lieschke JA and Closs GP (1999) Regulation of zooplankton composition and distribution by a zooplanktivorous fish in a shallow, eutrophic floodplain lake in south east Australia. *Archives of Hydrobiology* **146**, 397-412.

Lintermans M (2007) 'Fishes of the Murray-Darling Basin: An introductory guide.' (Murray-Darling Basin Commission, Canberra)

Llewellyn LC (2006) Breeding and development of the endangered purple-spotted gudgeon *Mogurnda aspersa* population from the Murray-Darling. *Australian Zoologist* **33**, 480-510.

Lloyd LN and Walker KF (1986) Distribution and conservation status of small freshwater fish in the River Murray, South Australia. *Transactions of the Royal Society of South Australia* **110**, 49-57.

Lucas M and Baras E (2001) 'Migration of Freshwater Fishes.' (Blackwell Sciences, Oxford)

Lui LC (1969) Salinity tolerance and osmoregulation in *Taenomembrus microstomus* (Gunther, 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. *Australian Journal of Marine and Freshwater Research* **20**, 157-162.

Maheshwari BL, Walker KF and McMahon TA (1995) Effects of regulation on the flow regime of the River Murray, Australia. *Regulated Rivers: Research & Management* **10**, 15-38.

Mallen-Cooper M and Stuart IG (2003) Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* **19**, 697-719.

Marsland KB and Nicol JM (2009) 'Lower Lakes vegetation condition monitoring - 2008/09.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 45pp. SARDI Publication Number F2009/000370-1.

Matthews W (1998) 'Patterns in Freshwater Fish Ecology.' (Kluwer Academic Publishers, Massachusetts, USA)

May H and Jenkins G (1992) Patterns of settlement and growth of juvenile flounder *Rhombosolea tapirina* determined from otolith microstructure. *Marine Ecological Progress Series* **79**, 203-214.

May RC (1974) Larval mortality in fishes. In 'The early life history of fish'. (Ed. JHS Blaxter) pp. 3-19. (Springer-Verlag, Berlin)

McDonald DG (1983) The effects of H^+ upon the gills of freshwater fish. *Canadian Journal of Zoology* **61**.

McDowall RM (Ed.) (1996) 'Freshwater fishes of south-eastern Australia.' (Reed: Sydney)

McNeil D (2004) Ecophysiology and behaviour of Ovens River floodplain fish: hypoxia tolerance and the role of the physicochemical environment in structuring Australian billabong fish communities. PhD thesis, Latrobe University, Australia.

McNeil D and Hammer M (2007) 'Biological review of the freshwater fishes of the Mount Lofty Ranges.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 104pp. Publication number: F2006/000335.

McNeil D and Westergaard S (In Prep).

McNeil DG and Closs GP (2007) Behavioural responses of a south-east Australian floodplain fish community to gradual hypoxia. *Freshwater Biology* **52**, 412-420.

MDBC (2006) 'The Lower Lakes, Coorong and Murray Mouth Icon Site Environmental Management Plan 2006-2007.'

Medeiros ESF and Arthington AH (2008) The importance of zooplankton in the diets of three native fish species in floodplain waterholes of a dryland river, the Macintyre River, Australia *Hydrobiologia* **614**, 19-31.

Meredith S, Gawne B, Sharpe C, Whiterod N, Conallin A and Zuwkowski S (2002) 'Dryland Floodplain Ecosystems: influence of flow patterns on fish production.' Murray-Darling Basin Research Centre, Mildura, report no. 1/2002.

Merrick JR and Schmida EG (1984) 'Australian freshwater fishes: Biology and Management.' (Griffen Press: Netley, South Australia)

Mol JH (1995) Ontogenetic diet shifts and diet overlap amoung three closely related neotropical armoured catfishes. *Journal of Fish Biology* **47**, 788-807.

Molsher RL, Geddes MC and Paton DC (1994) Population and reproductive ecology of small-mouthed hardyhead *Atherinosoma microstoma* (Gunther) (Pisces: Atherinidae) along a salinity gradient in the Coorong, South Australia. *Transactions of the Royal Society of South Australia* **118**, 207-216.

Morgan DL, Hambleton SJ, Gill HS and Beatty SJ (2002) Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*) (Percidae) in Western Australia *Marine and Freshwater Research* **53**, 1211-1221.

Neira F and Potter I (1994) The larval fish assemblage of the Nornalup-Walpole estuary, a permanently open estuary on the south coast of Western Australia. *Australian Journal of Marine and Freshwater Research* **45**, 1193-1207.

Newton GM (1996) Estuarine icthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary. *Marine and Freshwater Research* **47**, 99-111.

Nielsen D, Brock M, Rees G and Baldwin D (2003) Effects of increasing salinity on freshwater ecosystems in Australia. *Australian Journal of Botany* **51**, 655-665.

Noell CJ, Ye Q, Short DA, Bucater LB and Wellman NR (2009) 'Fish assemblages of the Murray Mouth and Coorong region, South Australia, during an extended drought period.' CSIRO: Water for a Healthy Country National Research Flagship and South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Norriss J, Tregonning J, Lenanton R and Sarre G (2002) 'Biological synopsis of the black bream, *Acanthopagrus butcheri* (Munroe) (Teleostei: Sparidae) in Western Australia with reference to information from other southern states: Fisheries Research Report.' Department of Fisheries, Western Australia, Perth.

Nunn A, Harvey J and Cowx I (2007) Variations in the spawning periodicity of eight fish species in three English lowland rivers over a 6 year period, inferred from 0+ year fish length distributions. *Journal of Fish Biology* **70**, 1254-1267.

O'Brien T and Ryan T (1999) Impact of saline drainage on key Murray-Darling Basin fish species: Final report to the Murray-Darling Basin Commission. NRMS Project R5004.

O'Connor JP, O'Mahony DJ and O'Mahony JM (2005) Movements of *Macquaria ambigua*, in the Murray River, south-eastern Australia. *Journal of Fish Biology* **66**, 392-403.

Packer RK and Dunson WA (1970) Effects of low environmental pH on blood pH and sodium balance in brook trout. *Journal of Experimental Zoology* **174**, 65-72.

Partridge G and Jenkins G (2002) The effect of salinity on growth and survival of juvenile black bream (*Acanthopagrus butcheri*). *Aquaculture* **210**, 219-230.

Pen LJ and Potter IC (1992) Seasonal and size-related changes in the diet of perch, *Perca fluviatilis* L., in the shallows of an Australian river, and their implications for the conservation of indigenous teleosts. *Aquatic Conservation: Marine and Freshwater Ecosystems* **2**, 243-253.

Phillips B and Muller K (2006) 'Ecological Character Description of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance.' Department of Environment and Heritage.

Pollard DA (1973) The biology of a landlocked form of a normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). V. Composition of diet. *Australian Journal of Marine and Freshwater Research* **24**, 281-295.

Potter I and Hyndes G (1994) The composition of the fish fauna of a permanently open estuary on the southern coast of Australia, and comparisons with a nearby seasonally closed estuary. *Marine Biology* **121**, 199-209.

Potter I, Ivantsoff W, Cameron R and Minnard J (1986) Life cycles and distribution of atherinids in the marine and estuarine waters of southern Australia. *Hydrobiologia* **139**, 23-40.

Potter IC and Hyndes GA (1999) Characteristics of the icthyofaunas of southwestern Australian estuaries, including comparisons between holarctic estuaries and estuaries elsewhere in temperate Australia: A review. *Australian Journal of Ecology* **24**, 395-421.

Preece R and Jones H (2002) The effect of Keepit Dam on the temperature regime of the Namoi River, Australia. *River Research and Applications* **18**, 397-414.

Puckridge J, Sheldon F and Walker K (1998) Flow variability and the ecology of large rivers. *Marine and Freshwater Research* **49**, 55-72.

Puckridge J and Walker KF (1990) Reproductive biology and larval development of a gizzard shad, *Nematalosa erebi* (Gunther) (Dorosomatinae: Teleostei), in the River Murray, South Australia. *Australian Journal of Marine and Freshwater Research* **41**, 695-712.

Robins JB, Halliday IA, Staunton-Smith J, Mayer DG and Sellin MJ (2005) Freshwater-flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach. *Marine and Freshwater Research* **56**, 343-360.

Rowland S (1996) Development of techniques for the large-scale rearing of the larvae of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson, 1845). *Marine and Freshwater Research* **47**, 233-242.

Rowntree J and Hammer M (2007) 'Assessment of fishes, aquatic habitat and potential threats at the proposed location of the Wellington Weir, South Australia ' Report to the Department of Environment and Heritage, South Australia. Aquasave Consultants.

Ruby SM, Aczel J and Craig G (1977) The effects of depressed pH on oogenesis in flagfish *Jordanella floridae*. *Water Research* **11**, 757-762.

SARDI (Unpublished CPUE Lakes and Coorong data).

SARDI (Unpublished data).

Sarre G, Platell M and Potter I (2000) Do the dietary compositions of *Acanthopagrus butcheri* in four estuaries and a coastal lake vary with body size and season and within and amongst these water bodies? *Journal of Fish Biology* **56**, 103-122.

Sarre G and Potter I (1999) Comparisons between the reproductive biology of black bream *Acanthopagrus butcheri* (Teleostei: Sparidae) in four estuaries with widely differing characteristics. *International Journal of Salt Lake Research* **8**, 179-210.

Shaw M and Jenkins GP (1992) Spatial variation in feeding, prey distribution and food limitation of juvenile flounder *Rhombosolea tapirina* Gunther. *Journal of Experimental Marine Biology and Ecology* **165**, 1-21.

Sim T and Muller K (2004) 'A Fresh History of the Lakes: Wellington to the Murray Mouth, 1800's to 1935.' River Murray Catchment and Water Management Board, South Australia.

SKM (2003) 'Review of the habitat associations of native fish in the Murray-Darling Basin. Final report for Murray-Darling Basin Commission project R2105.' Sinclair Knight Merz PTY LTD, Armadale, Victoria.

Sloane RD (1984) Distribution, abundance, growth and food of freshwater eels (*Anguilla* spp.) in the Douglas River, Tasmania. *Australian Journal of Marine and Freshwater Research* **35**, 325-329.

Smith B and Walker KF (2004) Reproduction of the common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries. *Transactions of the Royal Society of South Australia* **128**, 249-257.

Smith BB and Fleer D (2007) 'Final report on the 'fish' and 'water quality' components of the 2006 River Murray Wetlands Baseline Survey. Final report to the Mid-Murray locan action planning committee.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Aquatic Sciences Publication Number RD 04/0245-3.

Sternberg D, Balcombe S, Marshall J and Lobegeiger J (2008) Fodd resource variability in an Australian dryland river: evidence from the diet of two generalist native fish species. *Marine and Freshwater Research* **59**, 137-144.

Stewart J, Hughes J, Gray C and Walsh C (2005) 'Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters ' Primary Industries Science and Research, Cronulla, Final Report Series No. 73 FRDC Project 2001/027.

Stoffels RJ and Humphries P (2003) Ontogenetic variation in the diurnal food and habitat associations of an endemic and an exotic fish in floodplain ponds: consequences for niche partitioning. *Environmental Biology of Fishes* **66**, 293-305.

Stuart IG and Jones M (2006) Movement of common carp, *Cyprinus carpio*, in a regulated lowland Australian river: implications for management. *Fisheries Management and Ecology* **13**, 213-219.

Taylor MD, Fielder DS and Suthers IM (2006) Spatial and ontogenetic variation in the diet of wild and stocked mulloway (*Agyrosomus japonicus*, Sciaenidae) in Australian estuaries. *Estuaries and Coasts* **29**, 785-793.

Thomson JM (1957) Biological studies of economic significance of yellow-eye mullet, *Aldrichetta forsteri* (Cuvier & Valenciennes) (Mugilidae). *Australian Journal of Marine and Freshwater Research* **8**, 1-13.

Trippel EA and Chambers RC (1997) The early life history of fishes and its role in recruitment processes. In 'Early Life History and Recruitment in Fish Populations'. (Eds RC Chambers and EA Trippel) pp. 21-32. (Chapman and Hall, London)

Von Westernhagen H (1988) Sublethal effects of pollutants on fish eggs and larvae. In 'Fish Physiology. Part A. Eggs and Larvae'. (Eds W Hoar and D Randall) pp. 253-346)

Walker D (2002) 'What is possible: hydrology and morphology. In 'The Murray Mouth: exploring implications of closure or restricted flow.' A report prepared for the Murray-Darling Basin Commission and Department of Water Land and Biodiversity Conservation.

Walker J, Ghalambor C, Griset O, McKenney D and Reznick D (2005) Do faster starts increase the probability of evading predators? *Functional Ecology* **19**, 808-815.

Walker KF (1992) A semi-arid lowland river: the River Murray, Australia. In 'The rivers handbook'. (Eds PA Calow and GE Petts). (Blackwell Scientific: Oxford)

Walker KF and Thoms MC (1993) Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research & Management* **8**, 103-119.

Wedderburn S and Barnes T (2009) 'Condition monitoring of threatened fish species at Lake Alexandrina and Lake Albert (2008-2009). Report to the Murray-Darling Basin Authority and the South Australian Murray-Darling Basin Natural Resources Management Board.' Adelaide University, Adelaide.

Wedderburn S and Hammer M (2003) 'The Lower Lakes Fish Inventory: Distribution and Conservation of Freshwater Fishes of the Ramsar Convention Wetland at the Terminus of the Murray-Darling Basin, South Australia.' Native Fish Australia (SA) Inc., Adelaide.

Wedderburn SD, Walker KF and Zampatti BP (2007) Habitat separation of *Craterocephalus* (Atherinidae) species and populations in off-channel areas of the lower River Murray, Australia. *Ecology of Freshwater Fish* **16**, 442-449.

Wedderburn SD, Walker KF and Zampatti BP (2008) Salinity may cause fragmentation of hardyhead (Teleostei: Atherinidae) populations in the River Murray, Australia. *Marine and Freshwater Research* **59**, 254-258.

Werner EE and Hall DJ (1988) Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. *Ecology* **69**, 1352-1366.

Whiterod N and Walker K (2006) Will rising salinity in the Murray-Darling Basin affect common carp (*Cyprinus carpio* L.)? *Marine and Freshwater Research* **57**, 817-823.

Whitfield A (1990) Life-history of fishes in South African estuaries. *Environmental Biology of Fishes* **28**, 295-308.

Whitfield AK (1999) Icthyofaunal assemblages in estuaries: A South African case study. *Reviews in Fish Biology and Fisheries* **9**, 151-186.

Williams MD and Williams WD (1991) Salinity tolerances of four species of fish from the Murray-Darling River system. *Hydrobiologia* **210**, 145-160.

Williams W (1987) Salinization of rivers and streams: An important environmental hazard. *Ambio* **16**, 180-185.

Willis S, Laurenson L, Mitchell B and Harrington D (1999) Diet of larval and juvenile black bream, *Acanthopagrus butcheri*, in the Hopkins River estuary, Victoria, Australia. *Proceedings of the Rpyal Society of Victoria* **111**, 283-295.

Woodward G and Malone B (2002) Patterns of abundance and habitat use by *Nannoperca obscura* (Yarra pygmy perch) and *Nannoperca australis* (Southern pygmy perch). *Proceedings of the Royal Society of Victoria* **114**, 61-72.

Ye Q (2005) 'Golden perch (*Macquaria ambigua*). Fishery assessment report to PIRSA Fisheries 2004.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Aquatic Sciences Publication Number RD04/0167, No. 71.

Ye Q, Jones K and Pierce B (2000) 'Murray cod (*Maccullochella peelii peelii*), Fishery Assessment Report to PIRSA for Inland Waters Fishery Management Committee.' South Australian Fisheries Assessment Series 2000/17.

Ye Q and Zampatti B (2007) 'Murray cod stock status - the Lower River Murray, South Australia. Stock Status Report to PIRSA Fisheries.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 32pp. SARDI Publication Number F2007-000211-1.

Zampatti B, Nicol J, Leigh S and Bice C (2005) '2005 progress report for the Chowilla fish and aquatic macrophyte project.' South Australian Research and Developement Institute, Aquatic Sciences, Adelaide. SARDI Publication Number RD04/0167.