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Biological Review of the Freshwater Fishes of the Mount Lofty Ranges

Dale McNeil and Michael Hammer

February 2007

A Report to the: **Adelaide & Mount Lofty Ranges NRM Board, SA Department of Water, Land and Biodiversity Conservation & SA Murray River NRM Board**

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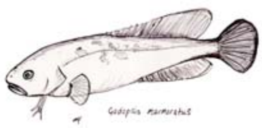

Aquasave

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Executive Summary

This report outlines the baseline knowledge regarding native fish in the Mount Lofty Ranges near Adelaide in South Australia. The report collates existing knowledge regarding the distribution, general biology and life history of all native fishes found in the region and provides a comprehensive review of the factors influencing the long term sustainability of these species across their range.

The report generalises knowledge gained from these species outside of the Mount Lofty Ranges and also presents that knowledge that has so far been obtained specifically from fish and habitats from within the Mount Lofty Ranges. Matrices are presented for each species in lieu of often confusing conceptual model diagrams, that summarise knowledge regarding the key factors that are important for successful spawning, recruitment to the population and long-term survival of adults to reproductive and highly fecund ages.

A discussion of the factors most important for the long-term sustainability is presented and includes discussion of key knowledge and knowledge gaps, as well as outlining research and management priorities. This report provides a baseline summary of the native fish populations within the Mount Lofty Ranges and outlines and discusses strategies for assessing and monitoring the sustainability and general health of native fish populations in the long term.

1 Introduction

South Australia has naturally limited aquatic habitat and subsequently ever-increasing urban, agricultural and industrial development places significant and competing demands on water dependent ecosystems. The Mount Lofty Ranges (MLR) is one of the few areas of the state to have topographic elevation and regular seasonal rainfall resulting in an extensive network of streams, providing diverse aquatic habitat.

Freshwater fish form a significant component of the aquatic biodiversity in the MLR. Recent surveys suggest that native fish populations remain in some areas despite the impacts of urban development and anthropogenic reduction of stream flows, riparian and instream habitat and migrational barriers, and that management of these key threats is essential for achieving the long term sustainability of these populations. The current report reviews current information that will support the development of an ongoing monitoring and assessment program assessing the sustainability and flow ecology of native fish in the MLR.

The project has been initiated and funded by the Adelaide & Mount Lofty Ranges Natural Resource Management Board, in conjunction with the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC) and the South Australian Murray River Natural Resource Management Board with the intention of developing a better understanding of the factors that sustain native fish populations in the MLR. This paper aims specifically to collate existing knowledge (relevant to MLR fish species) and develop a conceptual understanding of factors that are important for maintaining sustainable fish populations in the MLR. This in turn will inform important stream management decisions and processes such as the provision of environmental flows, restoration of riparian and instream habitat and connectivity and the management of exotic fish species. Furthermore, the report aims to identify specific data and knowledge gaps for different species and provide direction for future investment in research, monitoring and assessment effort.

The scope of this report includes:

1. An introduction to the local freshwater fish fauna as identified through various historical collections and distributional studies in the MLR.
2. A summary of the general biology of these species incorporating SA, interstate and general literature.
3. Species matrices that outline key components for sustainability in the MLR including research and management priorities & directions.
4. Development of a long term monitoring strategy for assessing sustainability of native species in the MLR.
5. Discussion of key aspects of native fish sustainability in the MLR.

1.1 Description of the Mount Lofty Ranges

The Mount Lofty Ranges stretch roughly north-south along the eastern edge of the city of Adelaide, abutting the Flinders Ranges in the north and terminating at the Fleurieu Peninsula (Fig. 1a & 2a). It has a maximum elevation of 710m at Mount Lofty, with an average elevation of 200-400m above sea level. The study area experiences a Mediterranean type climate with hot, dry summers, and rainfall predominantly concentrated within winter and spring (prevailing low pressure systems from the south-west). Yearly average rainfall is variable in different sections of Ranges, but most areas receive between 450-750mm mean annual rainfall, with patches near Mt Lofty and on the Fleurieu receiving up to 900-1100mm (Fig. 1b).

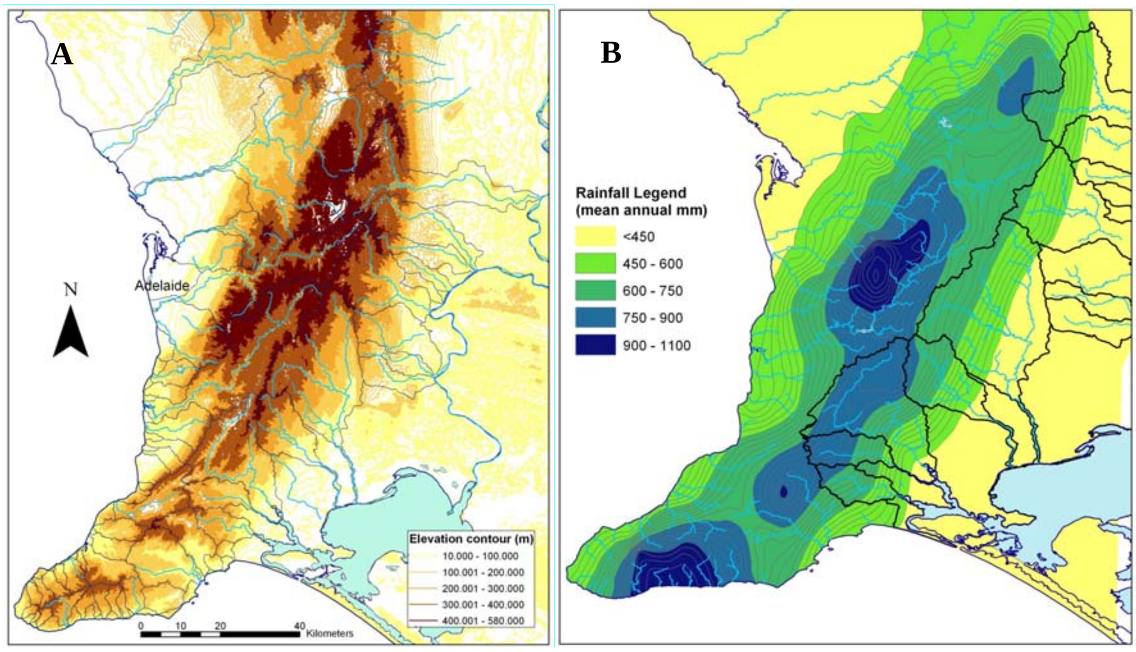


Figure 1 a: Topographical map and b: Annual rainfall distribution map for the Mount Lofty Ranges showing major streams and rivers.

There is a strong and continuing land use and development pressure on the aquatic habitats of the MLR. The area hosts several large population bases in Adelaide (over one million people), regional (Clare, Gawler, Mt Barker, Strathalbyn, Murray Bridge, Victor Harbour) and rural centres. Land clearance in most of the region has been extensive (~90%) (e.g. Kraehenbuehl 1996), although some areas of the southern Fleurieu and Adelaide Hills are more intact. Water resource development is significant, firstly for the supply of potable water (numerous major reservoirs and pipelines), but increasingly with dams for irrigation and stock supply, which has escalated dramatically in the last 15-20 years (e.g. Savadamuthu 2002). Hence flow volumes and regimes in many areas have been altered (e.g. Marne River Environmental Flows Technical Panel 2003). Many lowland reaches are now engulfed by urban development, and unfettered stock access to riparian areas is still commonplace.

1.2 Aquatic habitat and hydrology in the MLR

Broad hydrological separation in the Mount Lofty Ranges follows a general east-west divide. Catchments drain toward two major drainage divisions: (1) the Murray-Darling Drainage Division or Murray-Darling Basin which includes streams in the Eastern MLR (EMLR) that drain towards the Lower River Murray or Lake Alexandrina (via wetlands), and (2) the South Australian Gulf Division - streams on the western slopes of the range (*WMLR*) that drain toward the Gulf of St Vincent and habitats on a small section of the Southern Fleurieu Peninsula (*SFP*) that discharge directly into the Southern Ocean between Goolwa and Cape Jervis (Fig. 2b).

Aquatic habitats in the MLR are defined here as those in the MLR proper (i.e. above the ~100m elevation contour as the hills or slopes) plus connected freshwater habitats influenced by stream flow originating in the ranges (i.e. lowland plains and terminal wetlands/estuarine interfaces). Catchment management falls under the jurisdiction of the Adelaide and Mount Lofty Ranges (WMLR & SFP) and the SA Murray-Darling Basin (EMLR) NRM Boards (Fig. 2c)

Aquatic habitats in the region consist predominantly of small streams (generally less than 10m wide), with a few larger streams including the lower reaches of the Onkaparinga and Torrens rivers. These streams are either perennial (very limited in number: e.g. Sixth, Brownhill and Tookayerta creeks) or more often intermittent or seasonal in flow reflecting the local Mediterranean type climate. Nevertheless sections of permanent base flow, springs and permanent pools are scattered throughout most systems. In the southern MLR, swamps are another often independent feature of several catchments being perched or forming upper tributary areas (see Harding 2005).

There is considerable variation in geomorphic and hydrological characteristics across and within catchments, further compounded by differing patterns and intensity of regional land use. Hence, any general patterns in fish biology and ecology need qualification for local conditions at a catchment or individual habitat scale. For example, the hydrological signature or flow components of different MLR streams have general similarities, but patterns differ considerably in magnitude, timing and interannular variability and also in regard to hydrological development (e.g. especially below reservoirs).

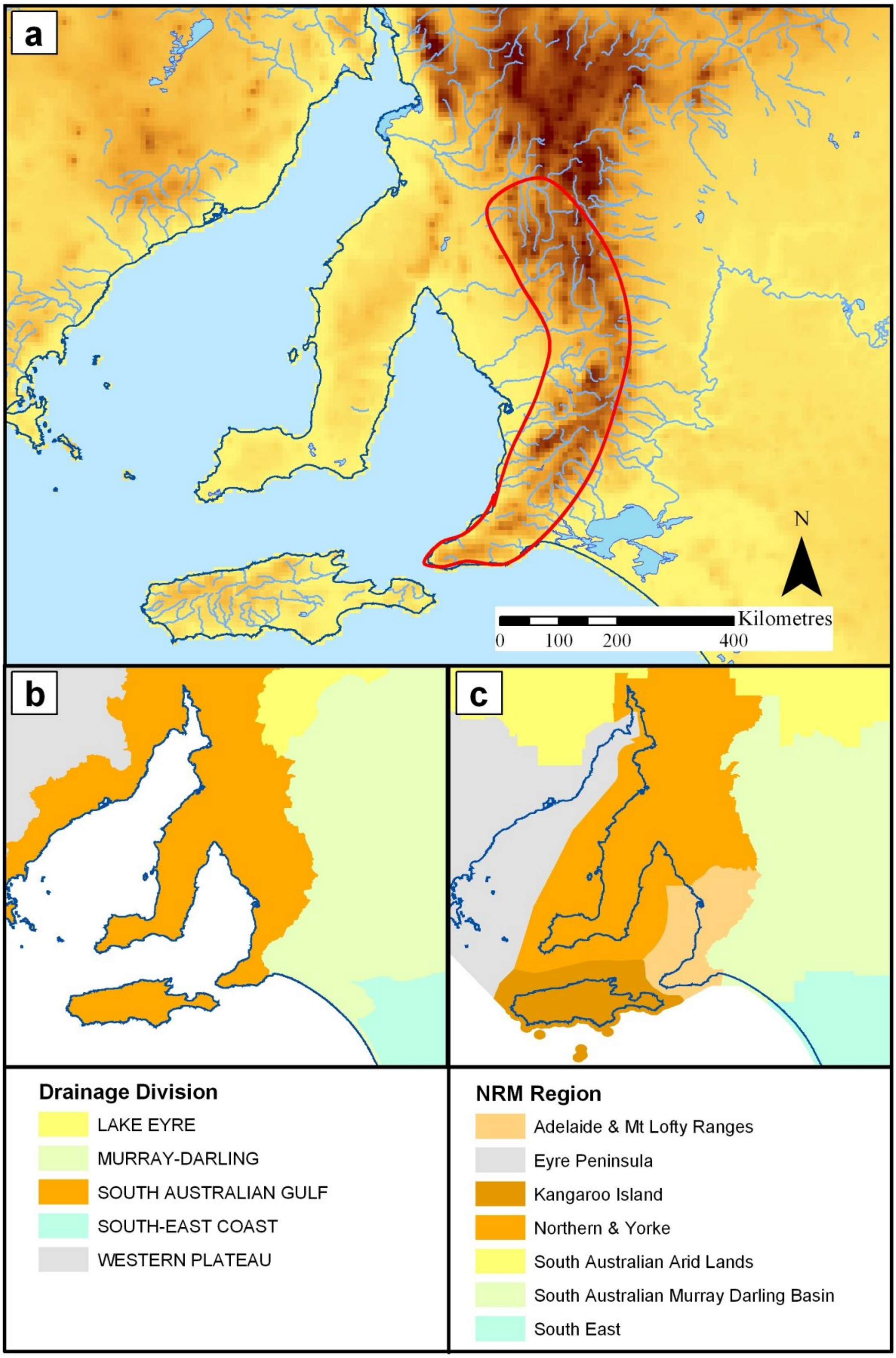


Figure 2. Map of the Mount Lofty Ranges (a: red outline) showing Drainage Divisions (b) and Natural Resource Management (NRM) regions (c).

2 Fishes of the MLR

The aim of this section is to describe the fish species that occur in the Mount Lofty Ranges and to outline the status and distributional knowledge regarding each. For the present report, freshwater fish are defined as species that complete their lifecycle inland (obligate freshwater species and select euryhaline taxa) or those that spend considerable time in freshwater for particular life stages (i.e. diadromous species) (*sensu* Hammer and Walker 2004). Thus, some estuarine species that occur in the region such as black bream, jumping (flat-tail) mullet and Tamar goby are not discussed in detail but future programs should consider these and other estuarine species as well as the linkages between freshwater and estuarine/marine habitats, particularly in relation to flow ecology (e.g. Gillanders and Kingsford 2002).

Overall 30 native and nine exotic species are recorded in the MLR, with several of these of conservation concern at the national and state level (Table 1a). In addition, some species native to the Murray-Darling Basin (*via* South Australia River Murray and or interstate hatcheries) have been translocated to sites where they do not naturally occur in different sections of the MLR, especially WMLR. This is further complicated by the uncertainty regarding some possible translocations where historical data is insufficient to clarify wether populations are translocated or natural (i.e. dwarf flatheaded gudgeon in WMLR). For some species a recorded presence is based on a single observation or stocking (e.g. Barramundi, brook trout). Others were present historically but have not been found in recent times (e.g. southern purple-spotted gudgeon). All species recorded in the MLR, along with notes on their local ranges, are outlined in Tables 1a and b.

Distinct faunas are found across the different geographic regions of the MLR. The EMLR possesses the most native species (*n* = 30), however, many are only recorded in terminal wetlands and reflect a broader species pool present in the Murray-Darling Basin. The SFP (*n* = 17) supports a small component of species otherwise restricted to the Murray-Darling Basin, most likely due to geographic proximity and historic drainage connectivity, plus shares numerous coastal species with WMLR. The WMLR has the lowest number of native species (*n* = 13) and high numbers of alien species (exotic and translocated native species) (Table 1a).

The known current and historic distribution of native and exotic fish species in the MLR, as based on verified surveys and museum records, is shown in Figures 3(a-w) and 4(a-f) respectively. Sources of data and data coverage for this section are described in detail later (see Section 6.0: Data Sources) but note (1) positive records reflect the level of survey data for a region and are not necessarily indicative complete distribution, and (2) records span the early 1900's to present and some sites may no longer have extant populations. The species groups used for this section are based upon our current understanding of taxonomy and genetic diversity as it relates to populations in the MLR. The taxonomy of several currently recognised single species, especially mountain galaxias (Raadik 2001), carp gudgeons (Bertozzi *et al.* 2000; Unmack 2000) and smelt (Hammer *et al.* unpublished), are uncertain (Table 1b) and these species may contain a number of separate groups and/or hybrids. The biological information presented in Section 3 are summarised for the traditional species (or summarised across species complexes i.e. carp gudgeons), but cryptic diversity within currently recognised 'single' species may harbour biological differences, which could influence sustainability differentially across geographically separate populations.

Table 1a. List of native and exotic (in red) species recorded in the Mount Lofty Ranges by *region* [*EMLR* = Eastern Mount Lofty Ranges, *SFP* = Southern Fleurieu Peninsula (Goolwa to Cape Jervis), *WMLR* = Western Mount Lofty Ranges north of Cape Jervis. *Records*: 1 = verified records, but limited in number, 2 = species present but which have declined with no recent records, 3 = recent records, at a few or more locations, 0 = presumed to exist based on unverified records or nearby records plus suitable habitat, * = translocated, ? = unknown if native or translocated (or both). *Conservation status*: National (Nat.): VU=Vulnerable (*EPBC Act 1999*); State: P = protected (*Fisheries Act 1982*), E = Endangered, V = Vulnerable, R = Rare (DEH 2004)]

Species	**Scientific name**	**Nat.**	**State**	***EMLR***	***SF***	***WMLR***
Pouched lamprey	*Geotria australis*		E	1	0	3
Shortheaded lamprey	*Mordacia mordax*		E	1	0	3
Shortfinned eel	*Anguilla australis*		R	1	0	0
Freshwater catfish	*Tandanus tandanus*		P, V	1		3*
Bony herring	*Nematalosa erebi*			3		
Smelt	*Retropinna semoni*			3	0	
Climbing galaxias	*Galaxias brevipinnis*		V	1	3	3
Common galaxias	*Galaxias maculatus*			3	3	3
Mountain galaxias 1	*Galaxias olidus*		R	3	0	3
Mountain galaxias 2	*Galaxias* sp. 1		R	3	3	
Murray rainbowfish	*Melanotaenia fluviatilis*		R	2/3		3*
Smallmouthed hardyhead	*Atherinosoma microstoma*			3	3	3
Murray hardyhead	*Craterocephalus fluviatilis*	VU	E	2		
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*		R	3		
Chanda perch	*Ambassis agassizii*		P, E	2		
River blackfish	*Gadopsis marmoratus*		P, E	3	0	0
Murray cod	*Maccullochella peelii peelii*	VU	R	2		1*
Murray-Darling golden perch	*Macquaria ambigua ambigua*			2/3		1*
Southern pygmy perch	*Nannoperca australis*		P, E	3	3	
Yarra pygmy perch	*Nannoperca obscura*	VU	P, E	3		
Silver perch	*Bidyanus bidyanus*		P, V	2		1*
Congolli	*Pseudaphritis urvillii*		R	3	3	3
Midgley's carp gudgeon	*Hypseleotris* sp. 1			3		3*
Murray-Darling carp gudgeon	*Hypseleotris* sp. 3		R	3	3	
Hybrid forms	*Hypseleotris* spp.			3	3	
Southern purple-spotted gudgeon	*Mogurnda adspersa*		P, E	2		2
Flathead gudgeon	*Philypnodon grandiceps*			3	3	3
Dwarf flathead gudgeon	*Philypnodon* sp. 1		R	3	3	3?
Western bluespot goby	*Pseudogobius olorum*			3	3	3
Lagoon goby	*Tasmanogobius lasti*			3		
Goldfish	*Carassius auratus*			3	1	3
Common carp	*Cyprinus carpio*			3	1	3
Tench	*Tinca tinca*			3		3
Rainbow trout	*Oncorhynchus mykiss*			3	3	3
Brown trout	*Salmo trutta*			3	3	3
Brook trout	*Salvelinus fontinalis*					1
Gambusia	*Gambusia holbrooki*			3	3	3
Redfin	*Perca fluviatilis*			3	3	3
Barramundi	*Lates calcarifer*					1
Total native				**30**	**17**	**13**
Total alien				**7**	**6**	**15**

Table 1b. General distribution of fish species within the MLR and information regarding the nature of observational data. (Sanger 1986; Musyl and Keenan 1992, 1996; Waters *et al.* 2000; Hammer 2001)

Species	MLR Distribution	Taxonomy
Pouched lamprey	Records from major systems in SAG (Gawler, Torrens, Onkaparinga) and the Murray (Hindmarsh Island, Finniss, Bremer).	Some confusion in reports for adults of *Mordacia* and *Geotria*, but keys are reliable.
Shortheaded lamprey	Records from major systems in SAG (Gawler, Torrens, Onkaparinga) and Murray (Hindmarsh Is.).	As above.
Shortfinned eel	At west end of Aust. distribution, occasional records Murray (e.g. Bremer) and KI - so could also occur SAG.	
Freshwater catfish	Historically lower Finniss and Marne, general Murray dist. overlaps with terminal wetlands. Introduced Field, Torrens and Wakefield systems (SAG).	**Species complex.** Multiple species, one wide spread form in MDB and some east coast locations - not formally recognised (e.g. Musyl and Keenan 1996).
Bony herring	General Murray distribution overlaps with terminal wetlands.	
Smelt	General Murray distribution overlaps with terminal wetlands, penetrates lower sections of Finniss R (and Marne historically). Probable erroneous report from Onkaparinga.	**Species complex** of 5 species on mainland Australia (previously considered to be one: Hammer *et al.* in review). Lower Murray fish represent a distinct genetic grouping of a wider SE Aust taxon (occurs Murray, coastal Vic and Tas.)
Climbing galaxias	Coastal populations from west of Murray mouth to Onkaparinga Catchment. Landlocked in Onkaparinga, Torrens, Gawler systems. Old single record for EMLR (Angas R), likely occasional migrants to this area.	*Likely species complex*. Initial genetic evidence to suggest Australian and New Zealand fish are not con-specific (Waters *et al.* 2000) and distinction within mainland and Tasmanian fish (Raadik *et al.* in prep). Can be confused with mountain galaxias and river blackfish, but keys reliable.
Common galaxias	Lower ends of most/all catchment sin MLR. Landlocked in Onkaparinga and Torrens.	Can be confused with other galaxias (and less likely smelt), especially when juvenile.
Mountain galaxias 1	Mostly western MLR (Bungala to Gawler system) plus Finniss and Tookayerta Catchments of EMLR (see Figure).	**Species complex** in SE Aust (Raadik *el al.* in prep). inc two species plus high genetic sub-structure in the MLR. Currently use genetic markers to separate from mountain galaxias 2. Keys to be developed.
Mountain galaxias 2	EMLR and Hindmarsh R (SF) -see Figure.	As above.
Murray rainbowfish	General Murray distribution overlaps with terminal wetlands, but not L. Alexandrina (historically lower Finniss). Introduced to lower Torrens.	
Smallmouthed hardyhead	Coastal estuaries (SAG, SF). Lower Lakes distribution overlaps with terminal wetlands.	Can be confused with other freshwater hardyheads, but distinctive. In estuaries can be confused with similar *A. elongata*.
Murray hardyhead	Terminal wetlands historically (Finniss, Angas, Marne).	Can (and often has) be confused with other freshwater hardyheads, but distinctive (reliable keys).
Unspecked hardyhead	Distribution in Murray and Lower Lakes overlaps with terminal wetlands.	As above.
Chanda perch	Terminal wetlands historically (Finniss, Marne).	Taxonomy of the group is unclear, specific status of fish in the MDB needs clarification within a broader review.
River blackfish	Historically Murray and widespread EMLR, severely contracted range to small areas in four catchments (Tookayerta, Angas, Bremer and Marne). Unverified presence in SAG.	**Species complex**. A northern (MDB) and southern form have long been recognised but not described (e.g. Sanger 1986). Can be confused with climbing galaxias (e.g. anecdotal reports by public).
Murray cod	Historically lower Bremer, Finniss and Marne rivers.	

Table 1b continued….

Murray-Darling golden perch	Lower Finniss and Bremer rivers, historically Finniss. Introduced SAG.	Note distinctive species in MDB, Lake Eyre Basin and subspecies in Fitzroy River (Musyl and Keenan 1992). Most information collected for 'golden perch' refers to MDB fish, so possibility for confusion is less likely.
Southern pygmy perch	In EMLR (three catchments: Tookayerta, Finniss, Angas) and terminal wetland associated with Lake Alexandrina, also Inman Catchment (SF).	**Species complex**. 2 species in SE Aust. with a distinct lineage (sub-species) in MDB (Hammer 2001). Can be confused with Yarra pygmy perch, but distinctive (reliable keys). Also highly genetic distinct local sub-populations.
Yarra pygmy perch	Highly restricted to Lower Finniss R wetlands and Hindmarsh island in MDB.	Can be confused with southern pygmy perch, but distinctive (reliable keys).
Silver perch	Historically in Lower Finniss, Bremer and Marne rivers/terminal wetlands.	
Congolli	Widespread coastally in SAG and SF systems, tribs of Lake Alexandrina (EMLR).	
Midgley's carp gudgeon	Terminal wetlands associated with Murray. Introduced Torrens.	**Species complex**. Local species verified with molecular markers, keys partially reliable (Bertozzi *et al.* 2000; Hammer and Adams unpublished).
Murray-Darling carp gudgeon	Stream and terminal wetland habitats of EMLR and Inman (SF).	As above.
Hybrid forms	Stream and terminal wetland habitats of EMLR and Inman (SF).	As above.
Southern purplespotted gudgeon	Historically lower Finniss and possibly Bremer systems and broader Murray overlap with Terminal wetlands (EMLR), also records from Onkaparinga and Torrens catchments.	
Flathead gudgeon	Widespread in EMLR streams and wetlands; lower Hinhmarsh R (SF); lower stream habitat from Onkaparinga to Light Catchments (SAG).	Can be confused with dwarf flathead gudgeon but distinctive (semi-informative keys).
Dwarf flathead gudgeon	Patchy distribution in EMLR streams and wetlands; lower Hindmarsh R (SF); Onkaparinga and Torrens catchments (unknown if native, introduced or both).	Can be confused with flathead gudgeon but distinctive (semi-informative keys).
Western bluespot goby	Estuaries and some landlocked populations such as Gawler and Torrens systems (SAG & SF); broader Lower Lakes dist. overlaps with terminal wetlands (EMLR).	Similar to other gobies but keys (need marine and freshwater) are reliable.
Lagoon goby	Broader Lower Lakes dist. overlaps with terminal wetlands (EMLR). Only verified records for SAG are on Kangaroo Is.	Similar to other gobies but keys (need marine and freshwater) are reliable.
Goldfish	Widespread patchy dist in MLR.	Carp x goldfish hybrids occur.
Common carp	Widespread patchy dist in MLR.	Carp x goldfish hybrids occur.
Tench	Restricted presence: recent records from Gawler and Onkaparinga systems (SAG); Angas catchment (EMLR).	
Oriental weatherloach	Not present yet. Potential invasive species (e.g. occurs upstream in MDB).	
Rainbow trout	Patchy distribution in region. Stocked.	
Brown trout	Patchy distribution in region. Stocked.	
Brook trout	Stocked historically. No recent records.	
Gambusia	Widespread in region, less common in SF and wetter areas of EMLR.	
Redfin	Widespread in region.	
Barramundi	Single record from Torrens Lake (SAG).	

*Orange donates exotic species

2.1 Native Fish Distribution Maps

Diadromous and euryhaline species

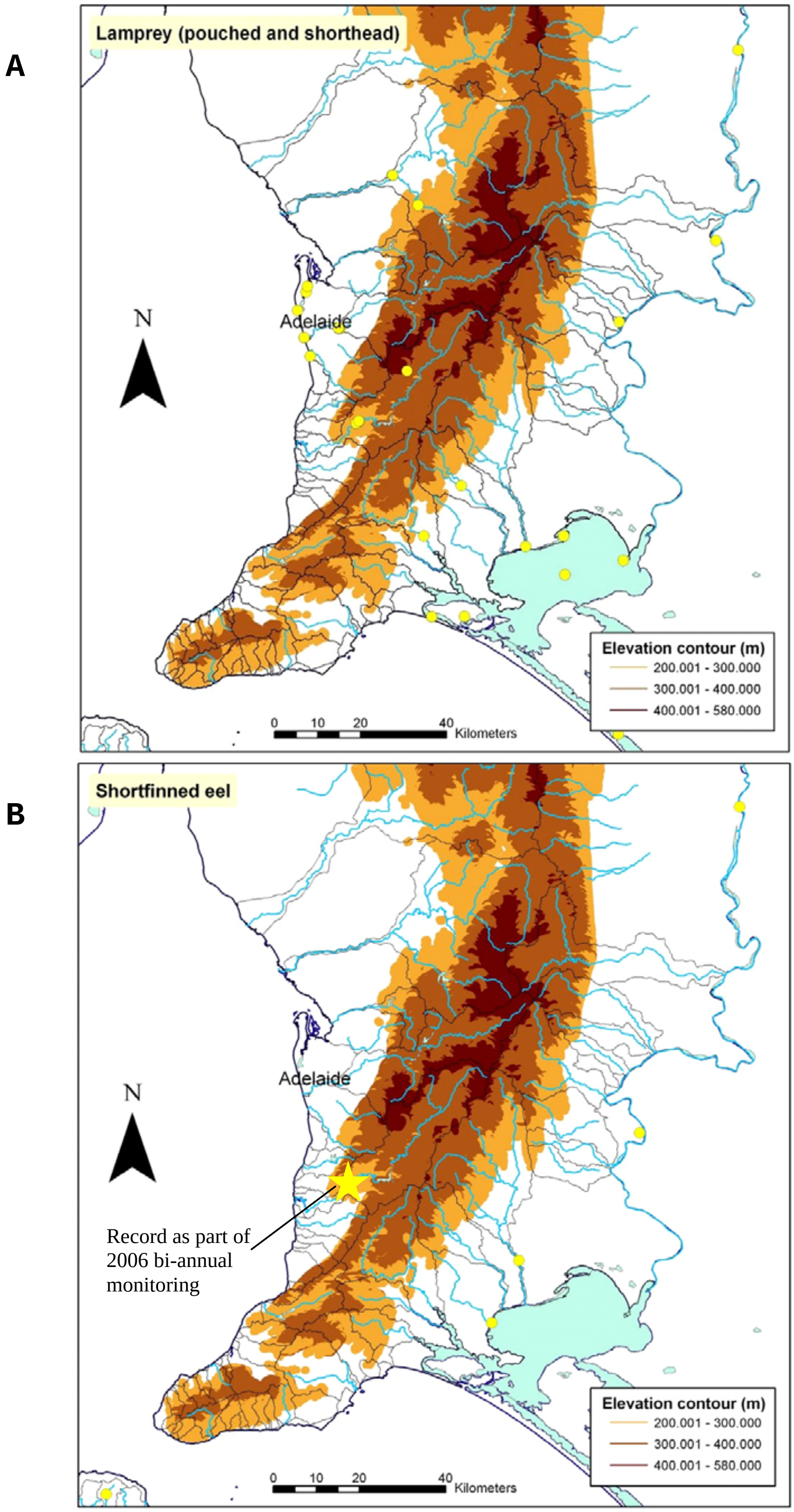
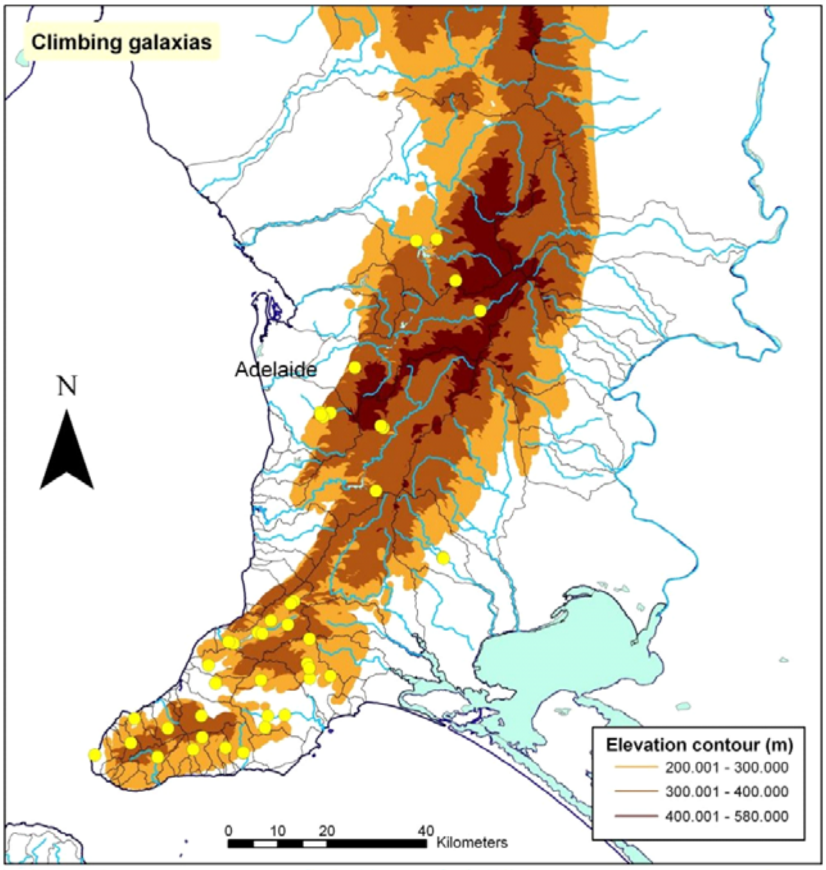


Figure 3A-B. Native fish species distributions in the MLR, lamprey (A) and shortfinned eel (B)

C



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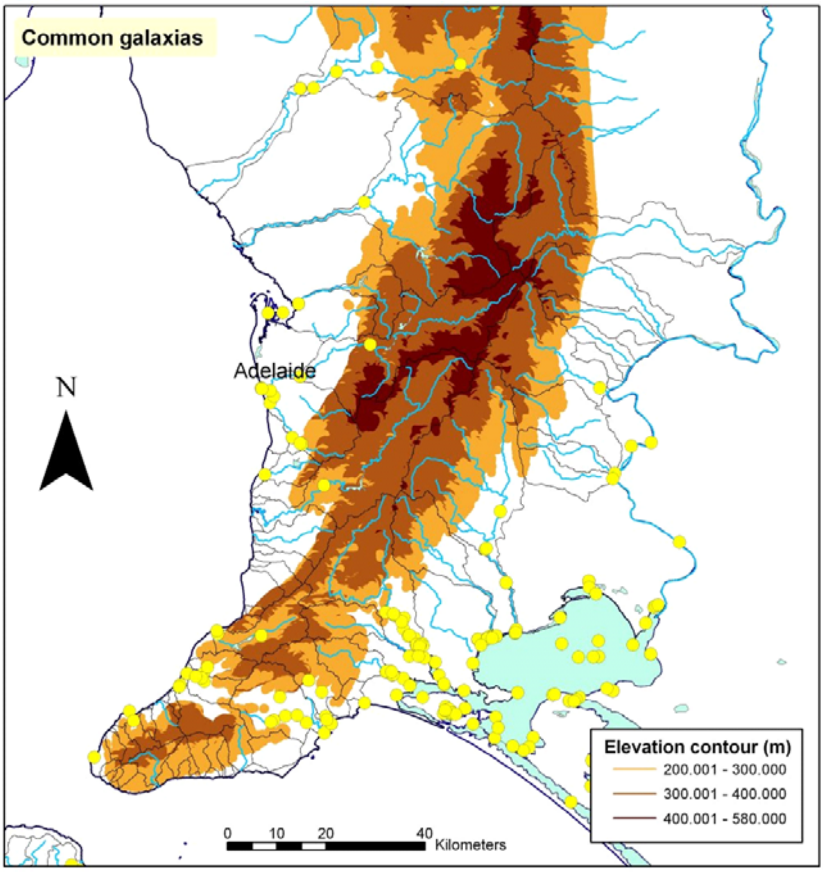


Figure 3C-D. Native fish species distributions in the MLR, climbing galaxias (C) and common galaxias (D).

E

F

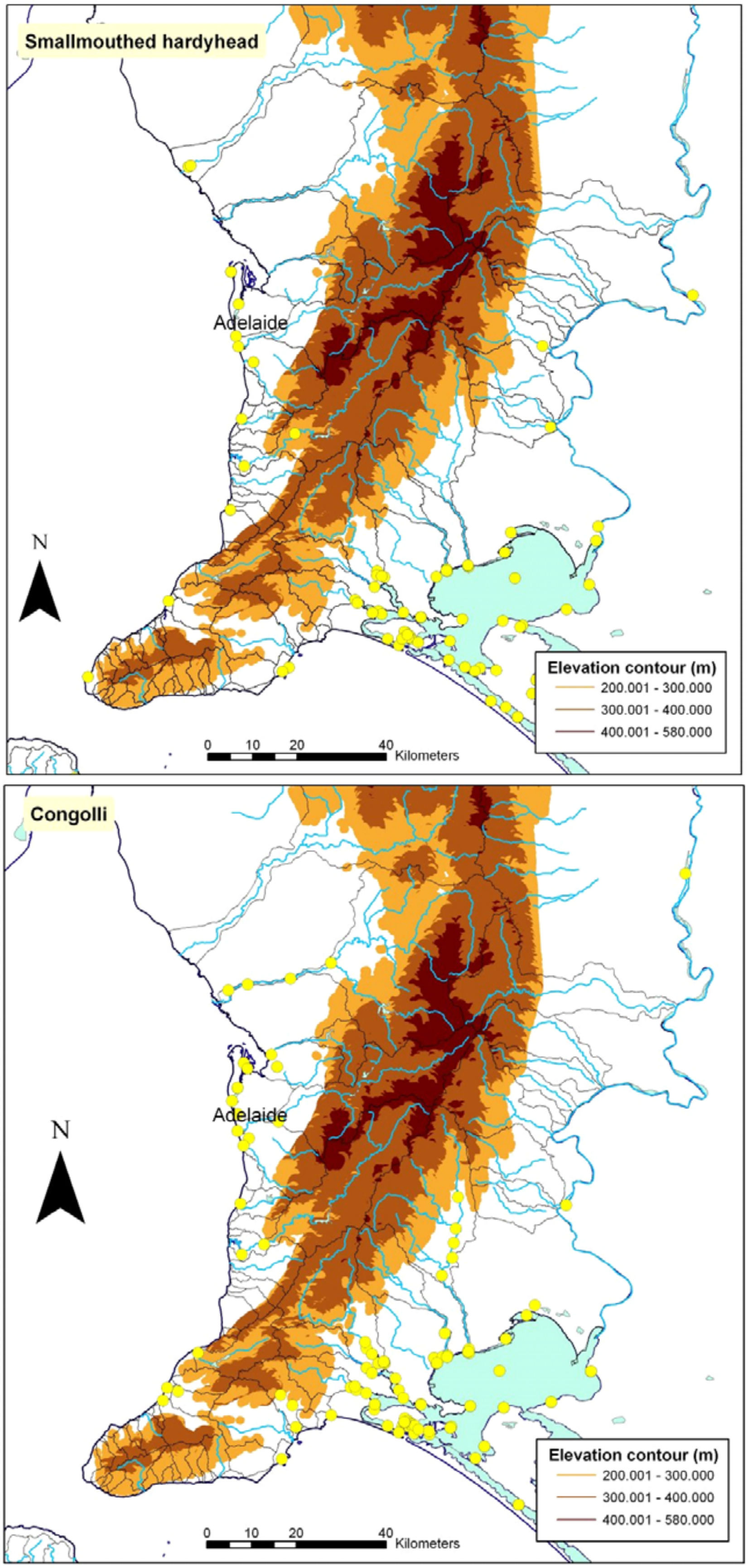
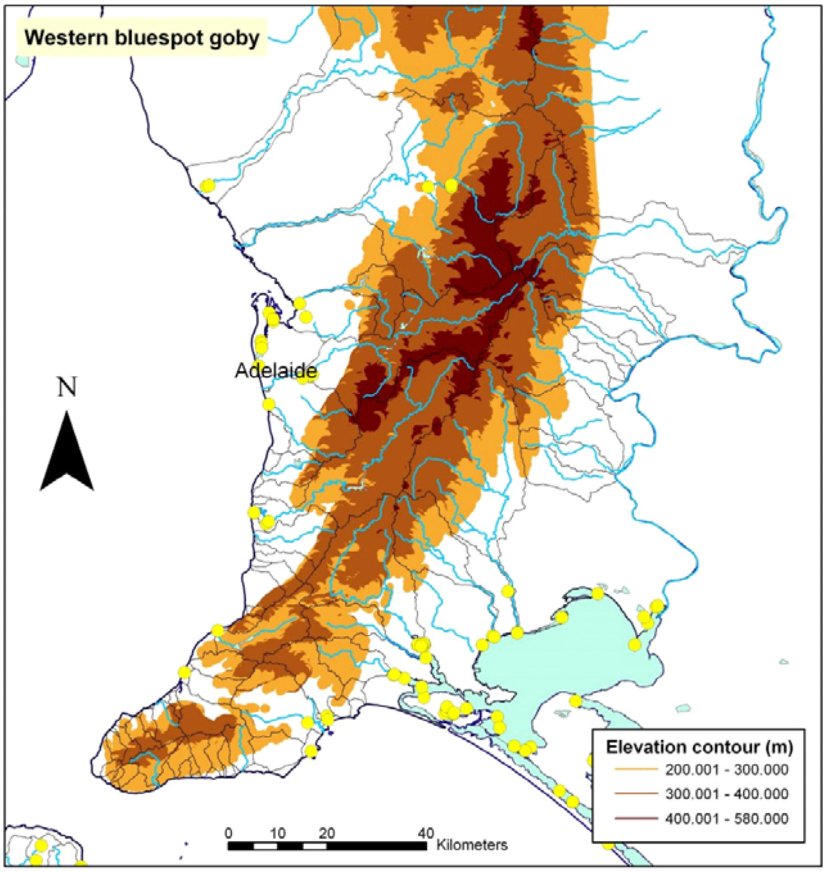


Figure 3E-F. Native fish species distributions in the MLR, smallmouth hardyhead (E) and congolli (F).

G



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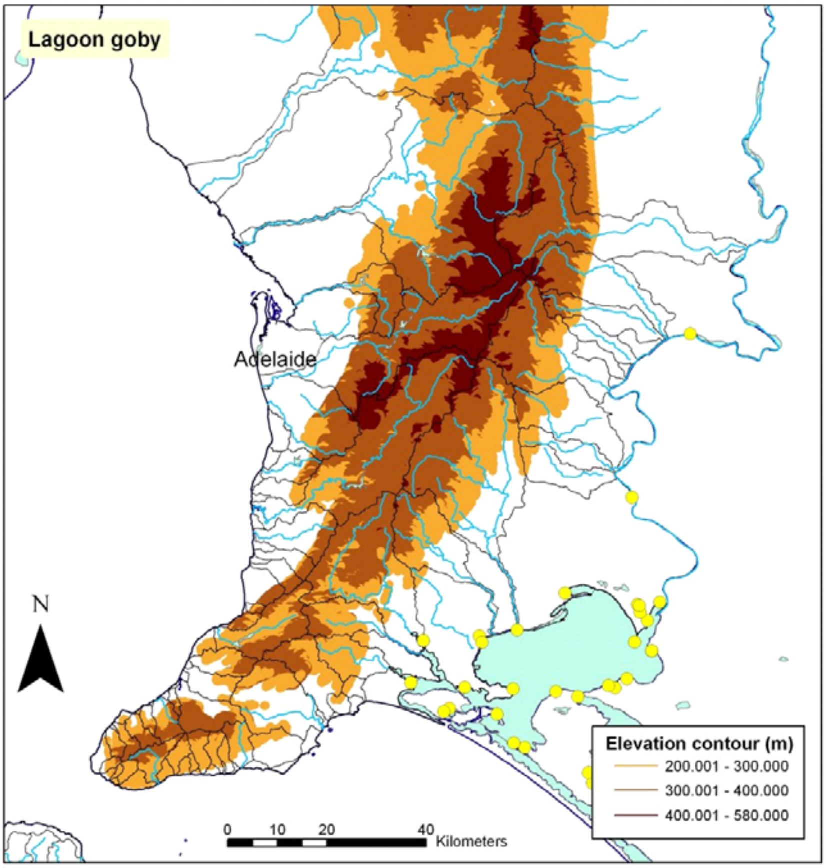
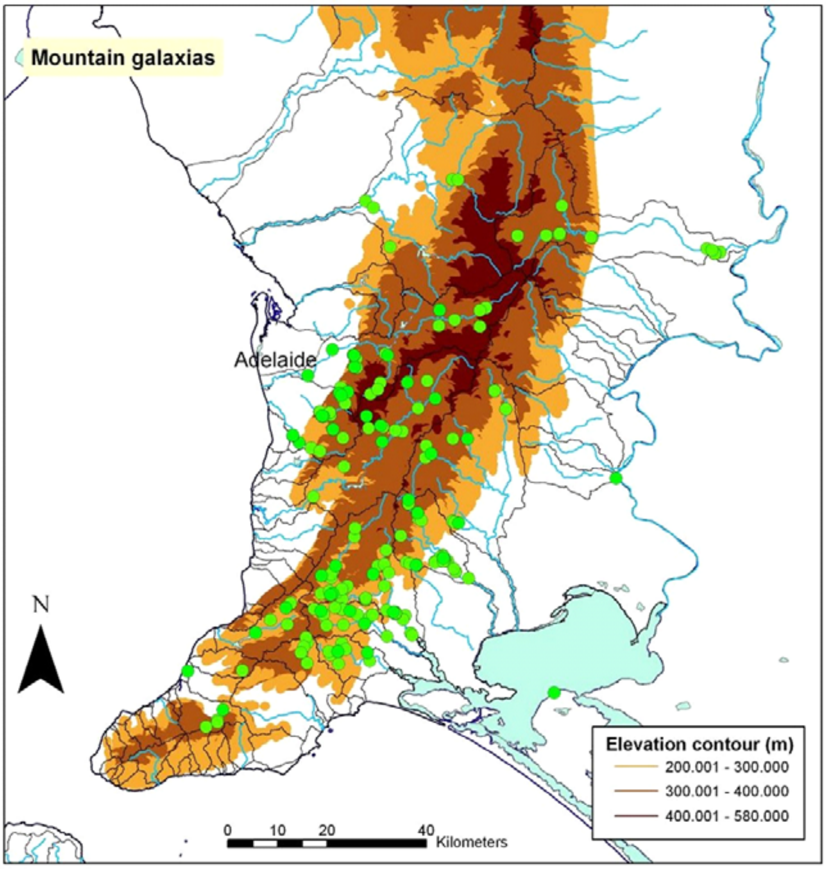


Figure 3G-H. Native fish species distributions in the MLR, western bluespot goby (G) and lagoon goby (H).

Obligate freshwater species –stream species

I



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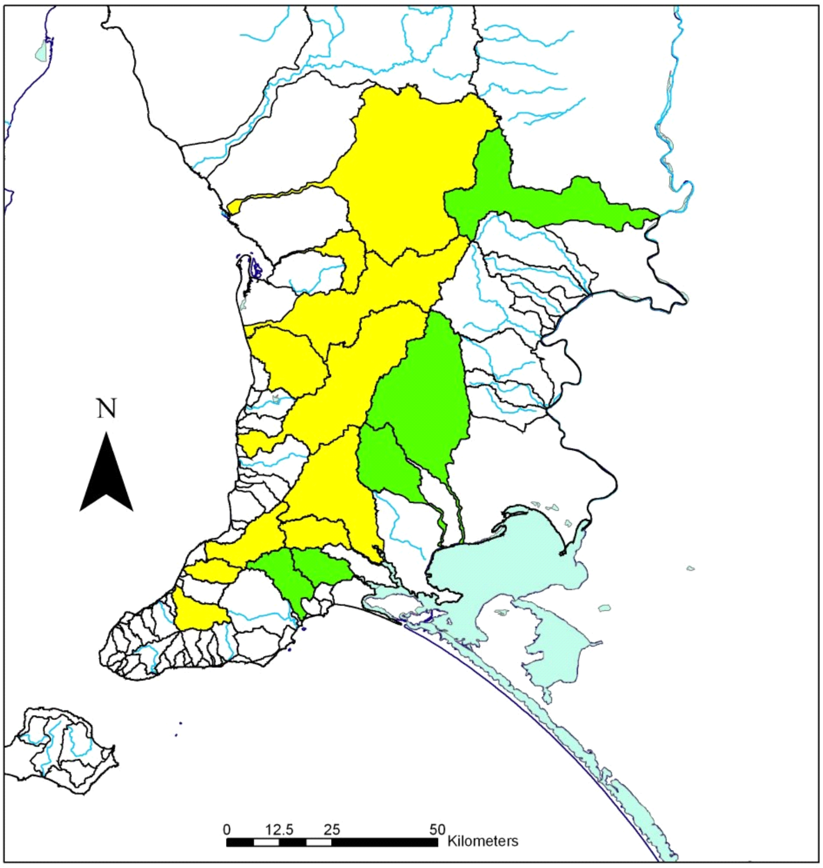
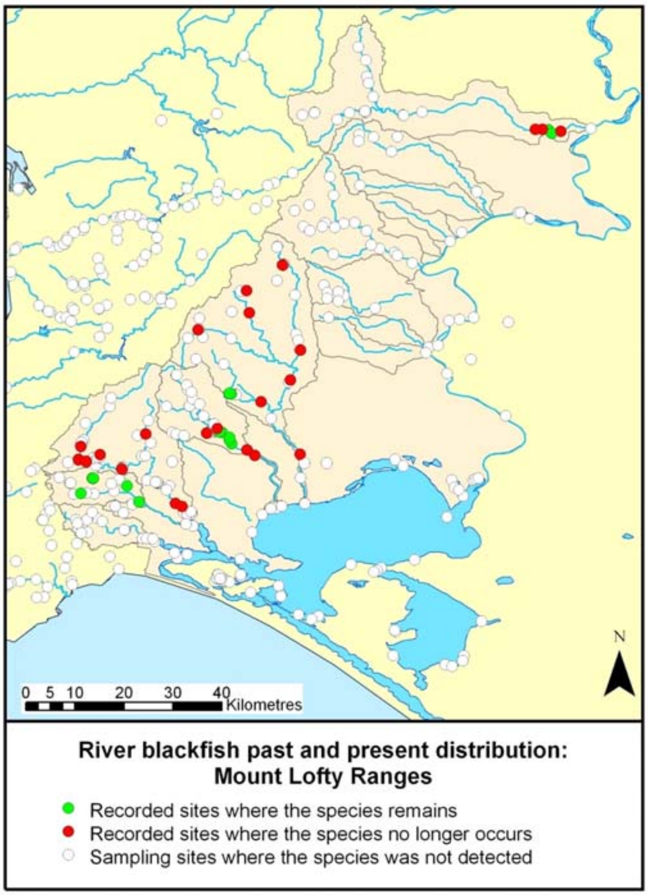


Figure 3I-J. Native fish species distributions in the MLR, (I) mountain galaxias, (J) including two genetically different sub-groups (Raadik *et al*. in prep). See also Hammer (2004).

K



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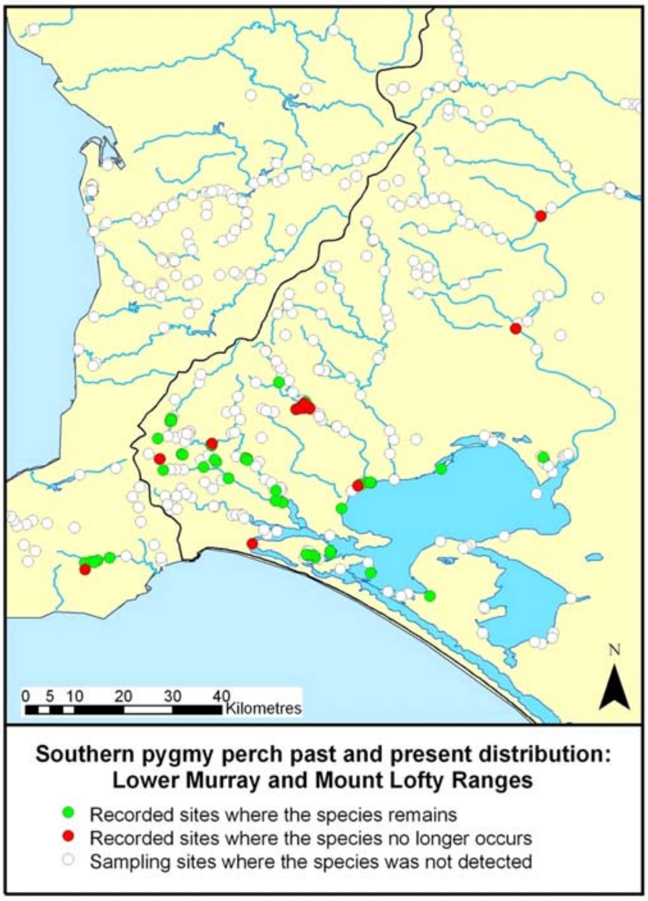

Figure 3K-L. Native fish species distributions in the MLR, river blackfish (K) and southern pygmy perch (L).

M

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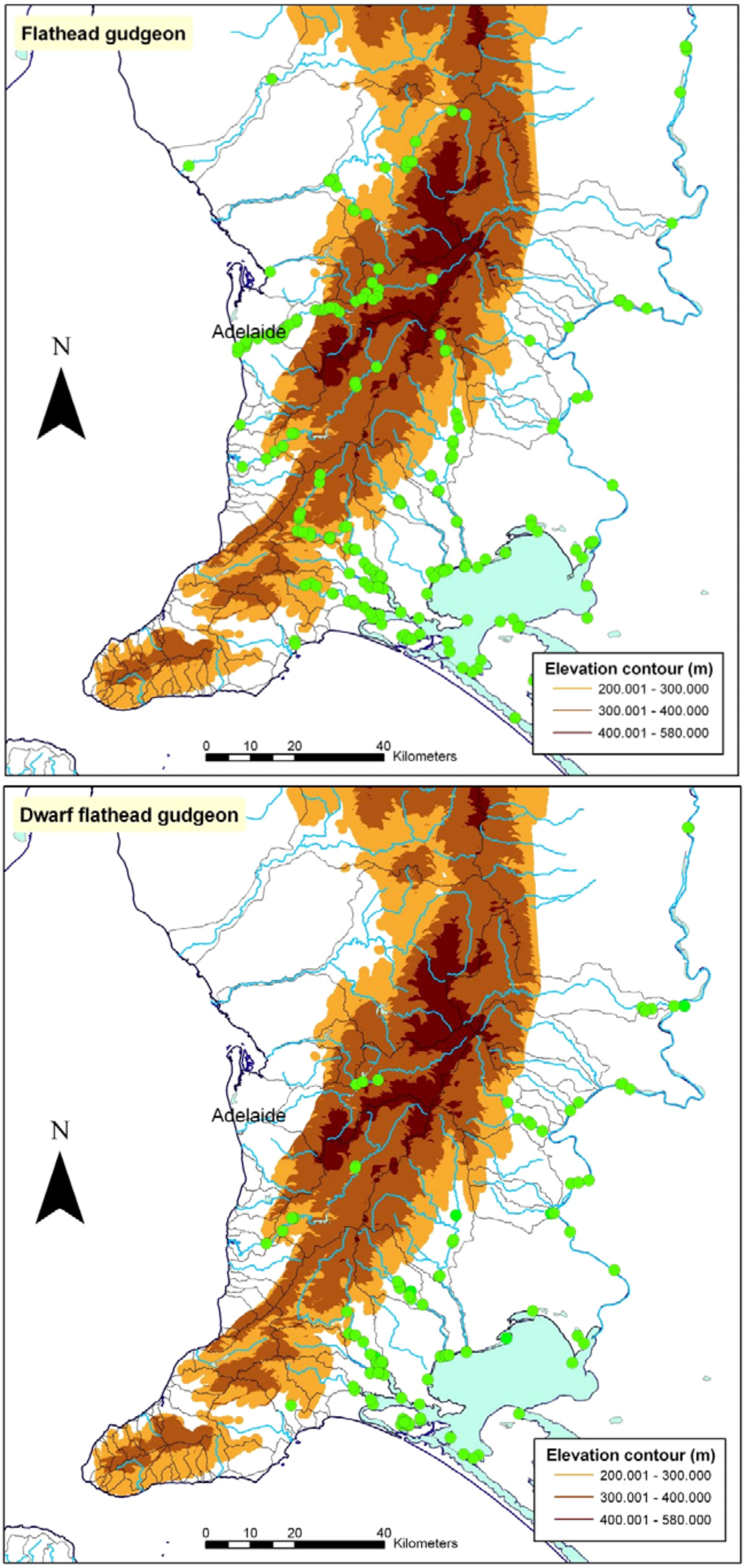
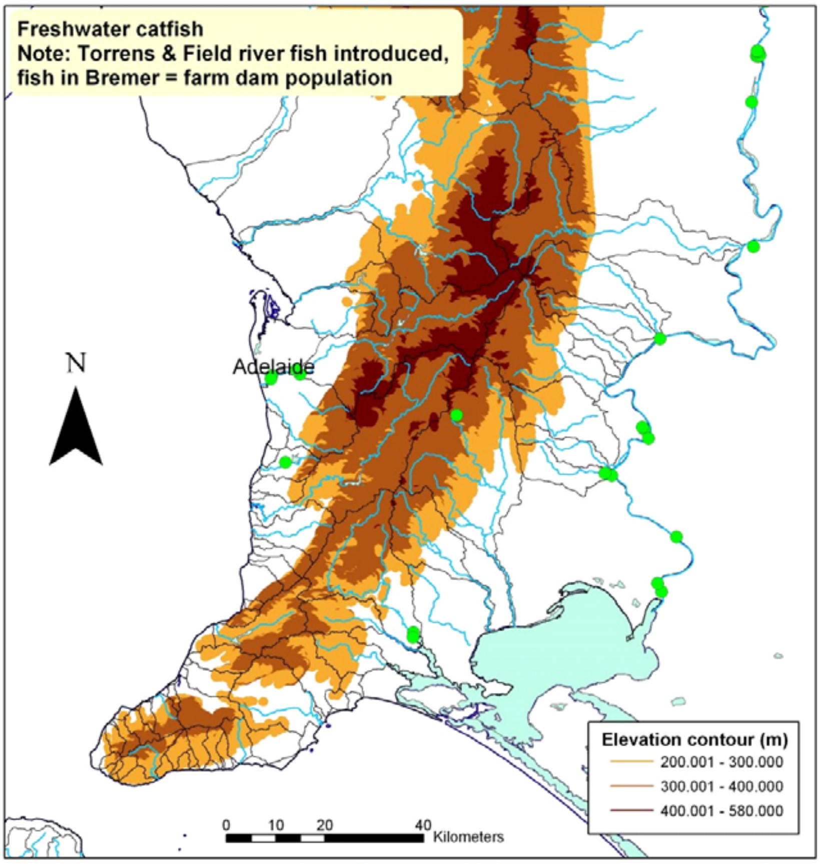


Figure 3M-N. Native fish species distributions in the MLR, flathead gudgeon (M) and dwarf flathead gudgeon (N).

M



N

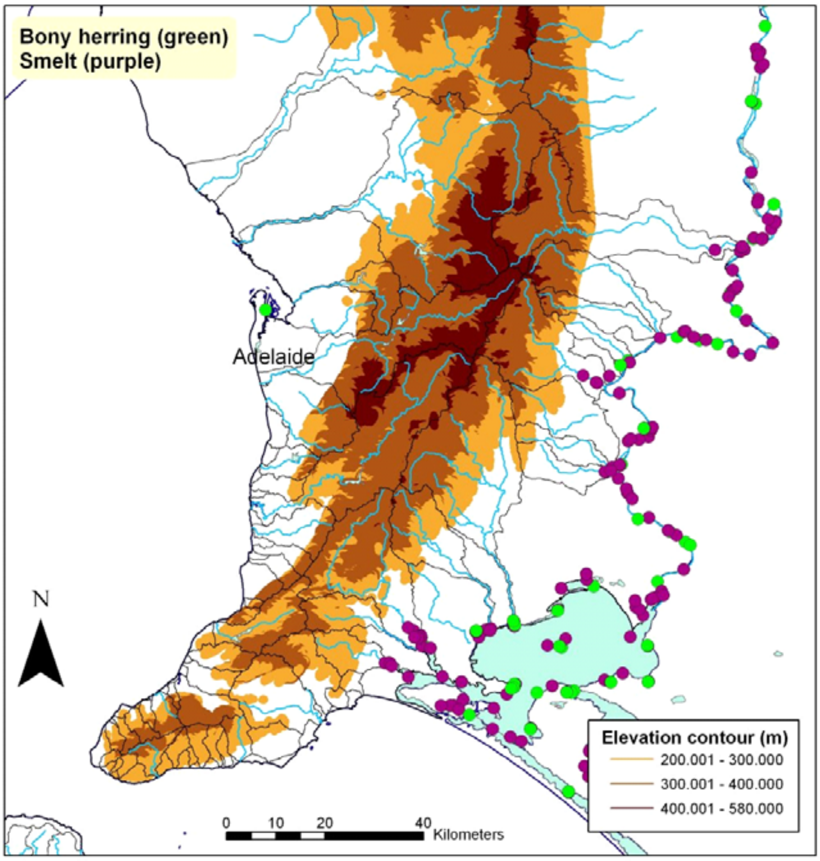
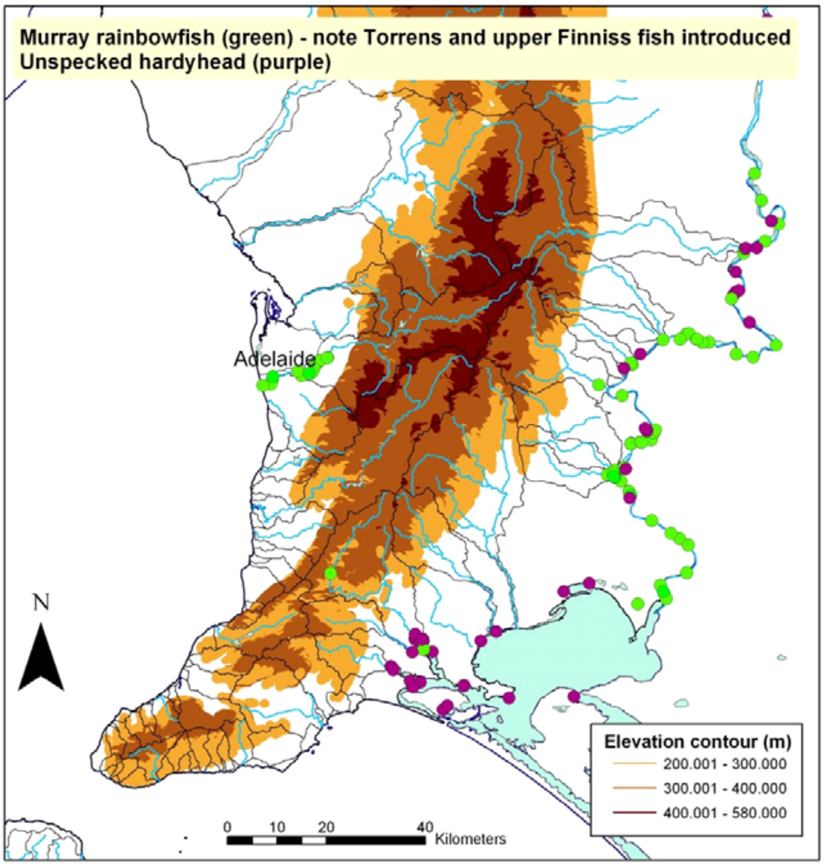


Figure 3M-N. Native fish species distributions in the MLR, freshwater catfish (M) and bony herring & smelt (N).

O



P

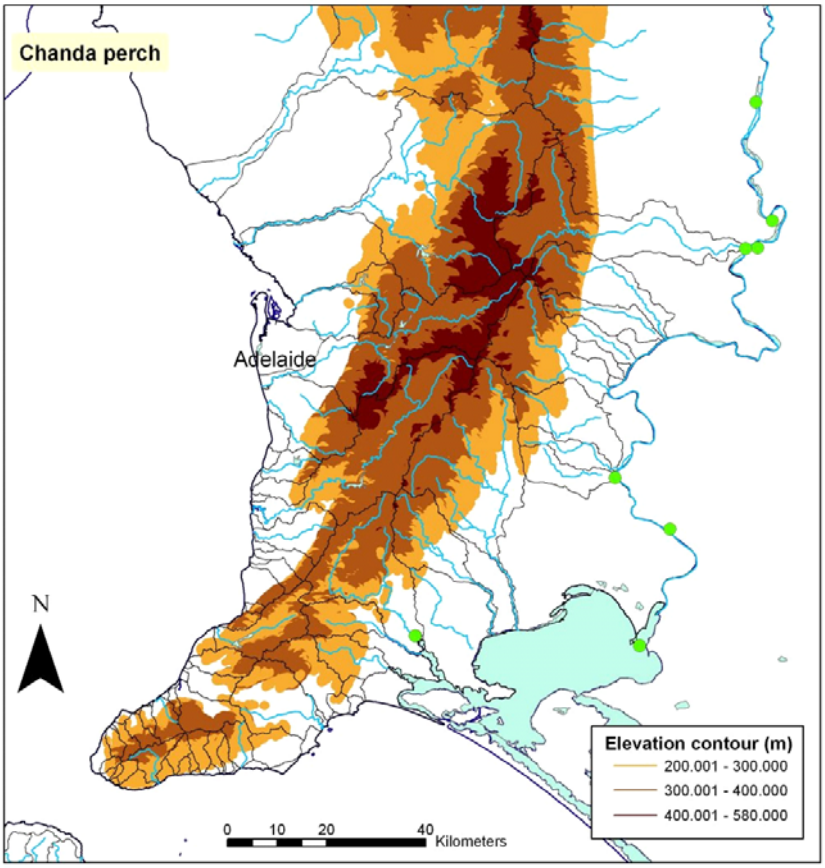
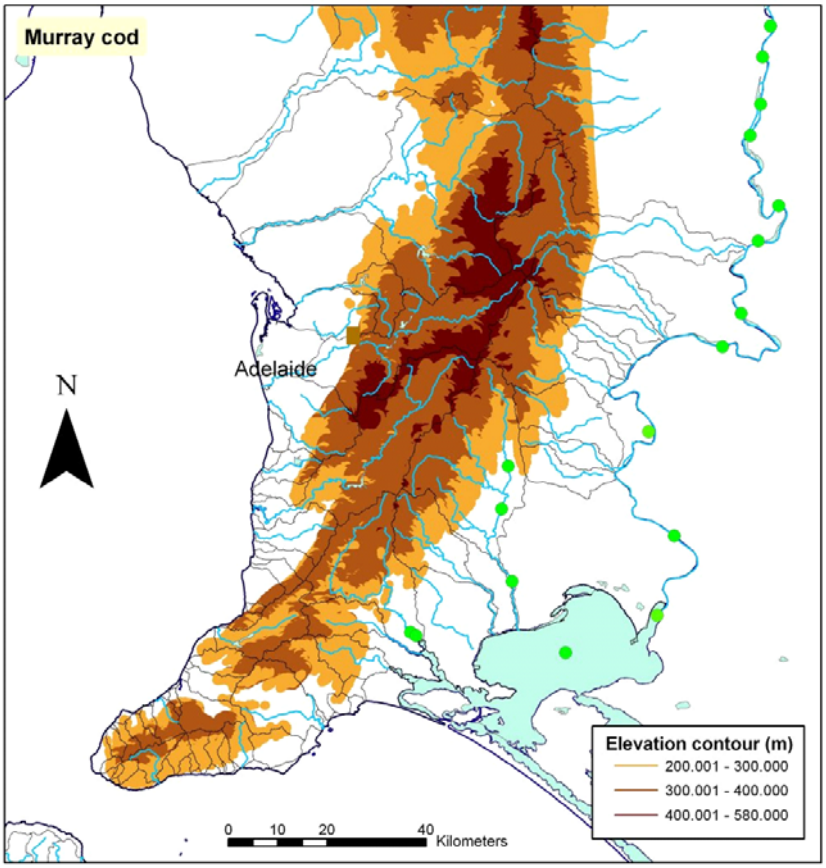


Figure 3O-P. Native fish species distributions in the MLR, Murray rainbowfish & unspecked hardyhead (O) and chanda perch (P).

Q



R

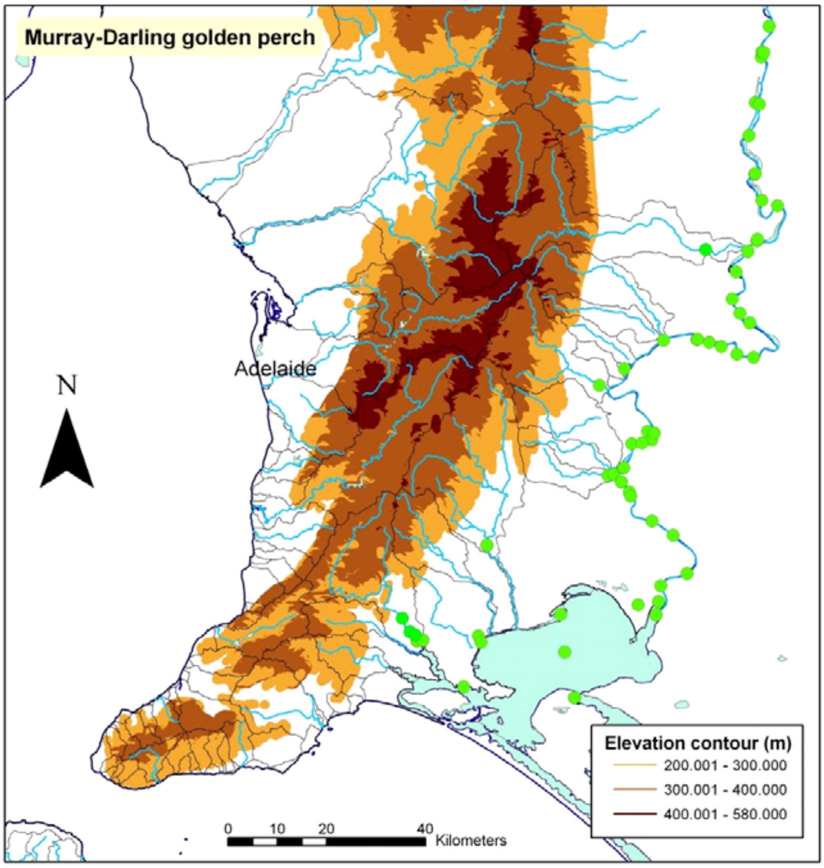
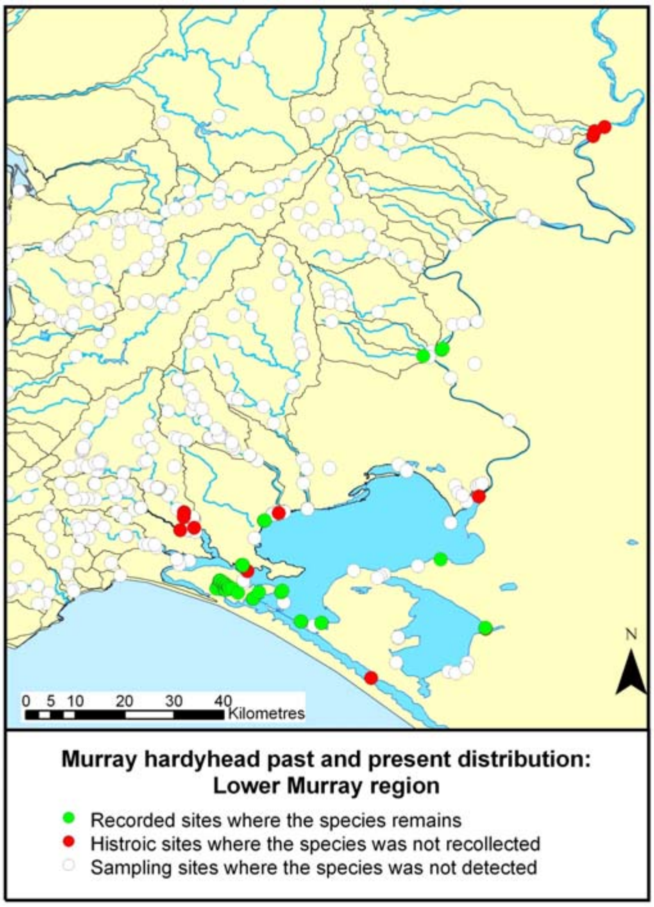


Figure 3Q-R. Native fish species distributions in the MLR, Murray cod (Q) and Murray-Darling golden perch (R). Various translocations into farm dams not shown, also suspected introductions into WMLR streams.

S



T

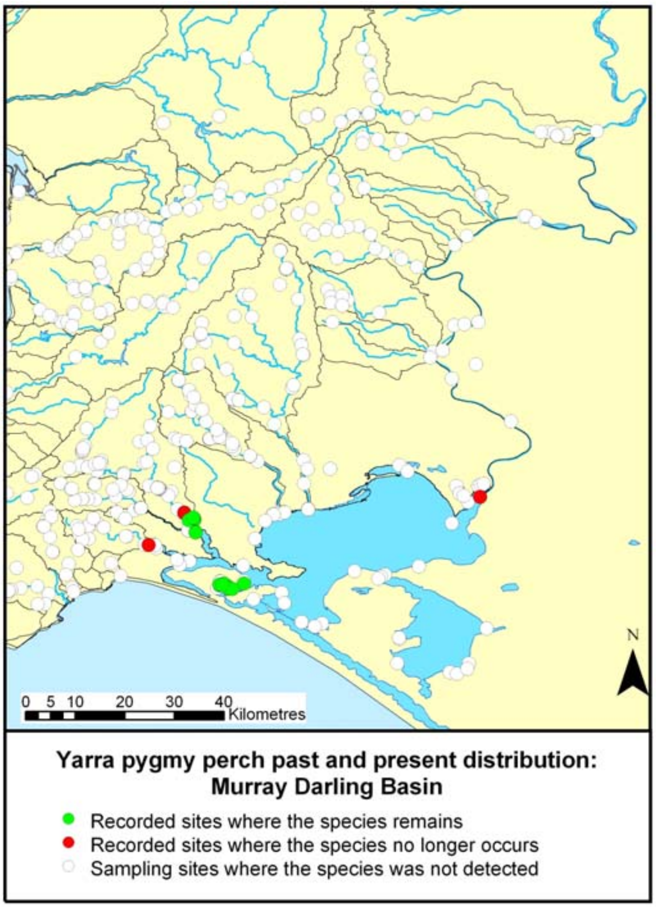
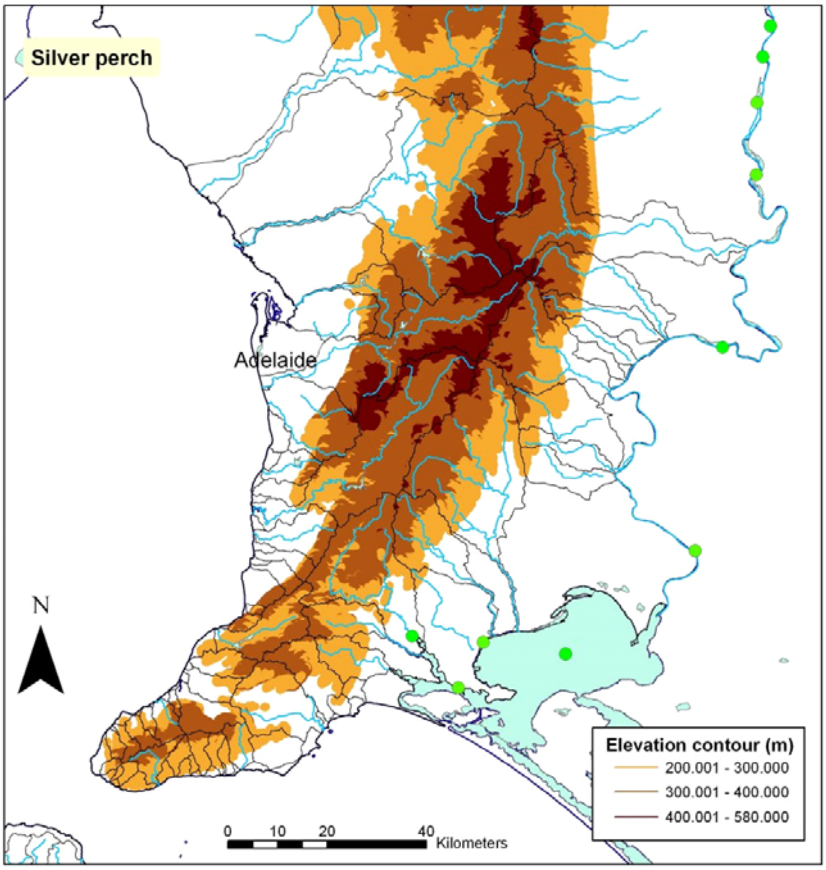


Figure 3S-T. Native fish species distributions in the MLR, Murray hardyhead (S) and Yarra pygmy perch (T).

U



V

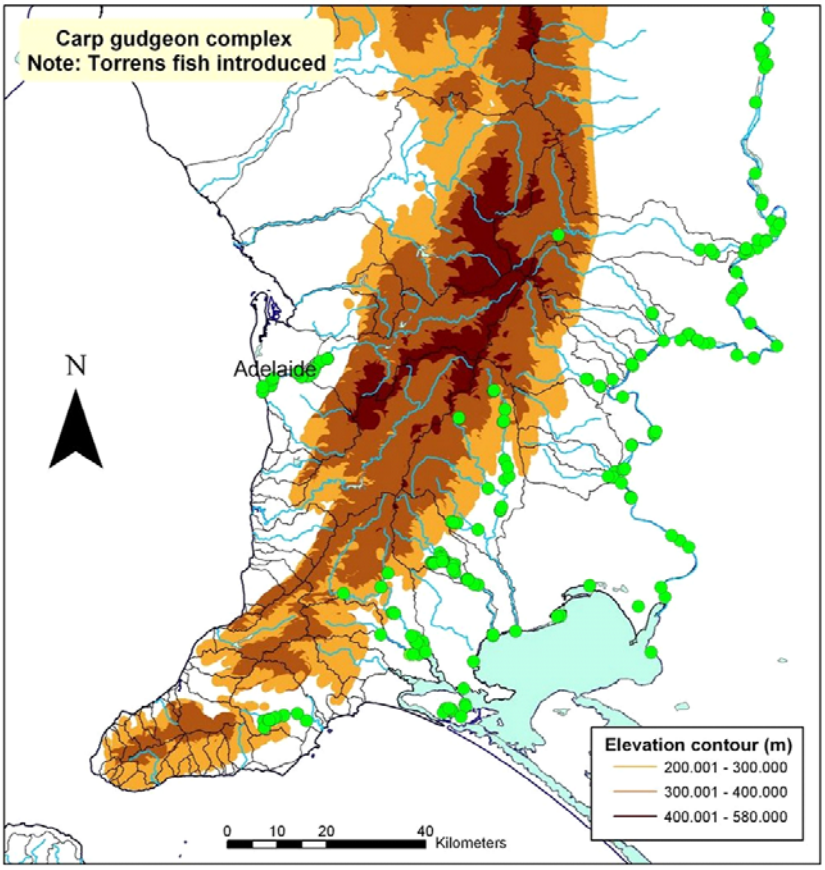


Figure 3U-V. Native fish species distributions in the MLR, silver perch (U) and carp gudgeon (species complex) (V).

W

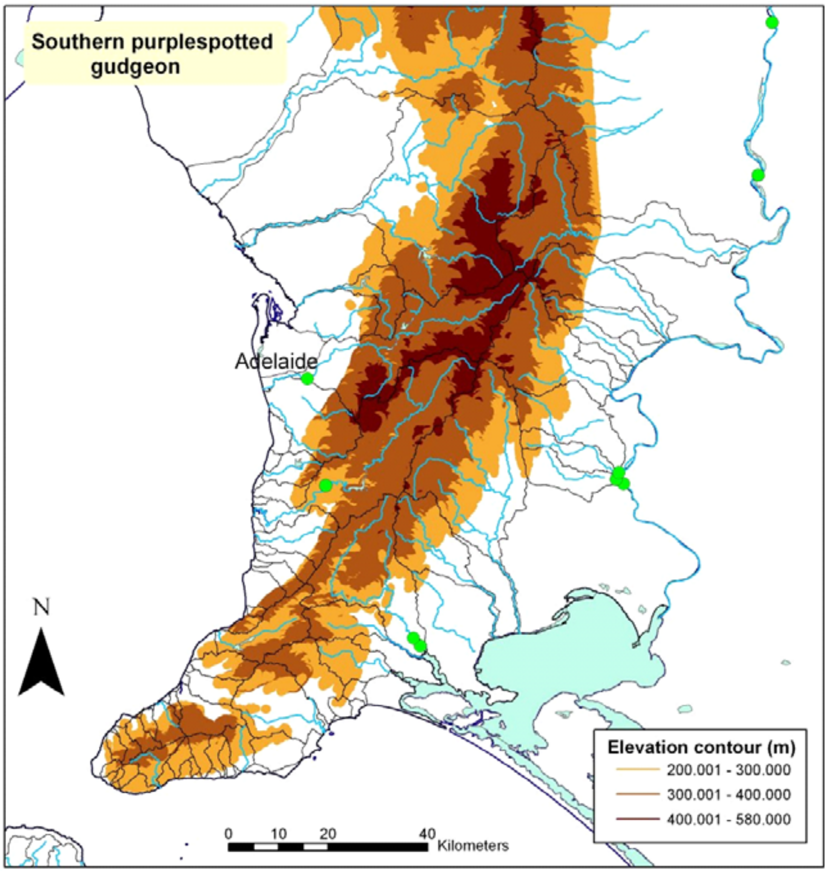
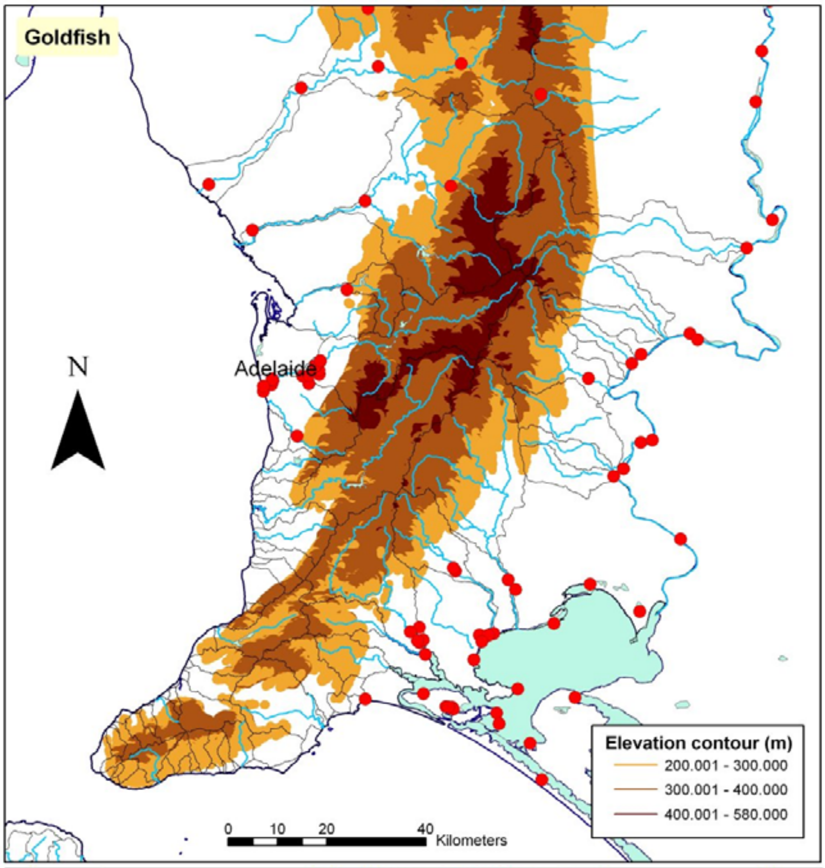


Figure 3W. Native fish species distributions in the MLR, southern purplespotted gudgeon.

2.2 Exotic Fish Distribution Maps

A



B

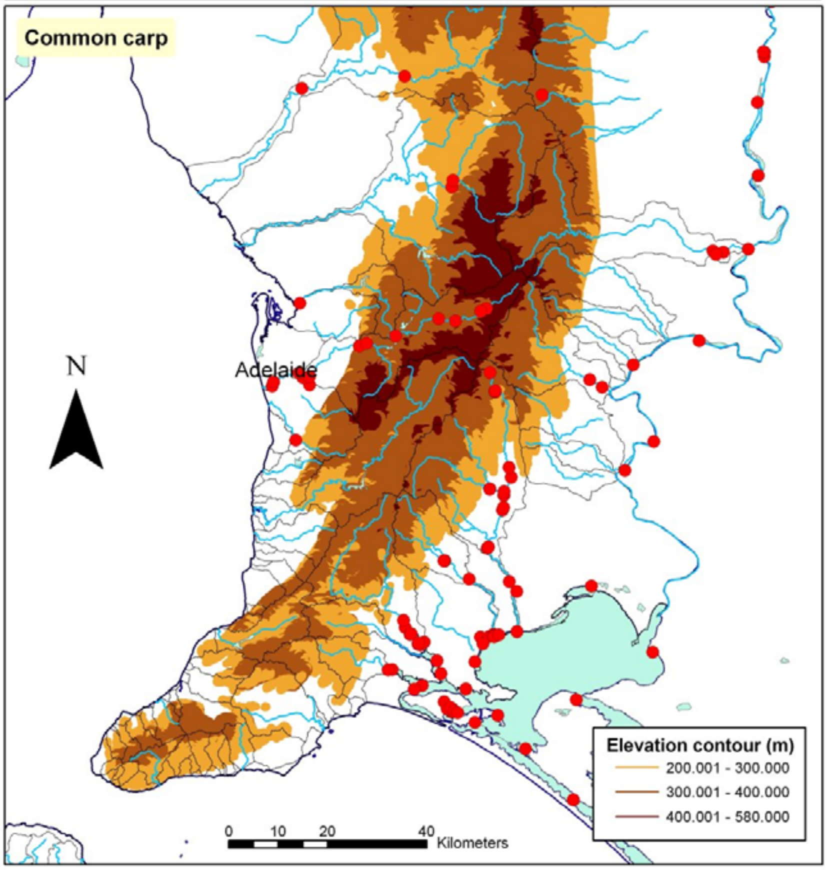


Figure 4A-B. Exotic fish species distribution in the MLR, (A) goldfish and (B) common carp.

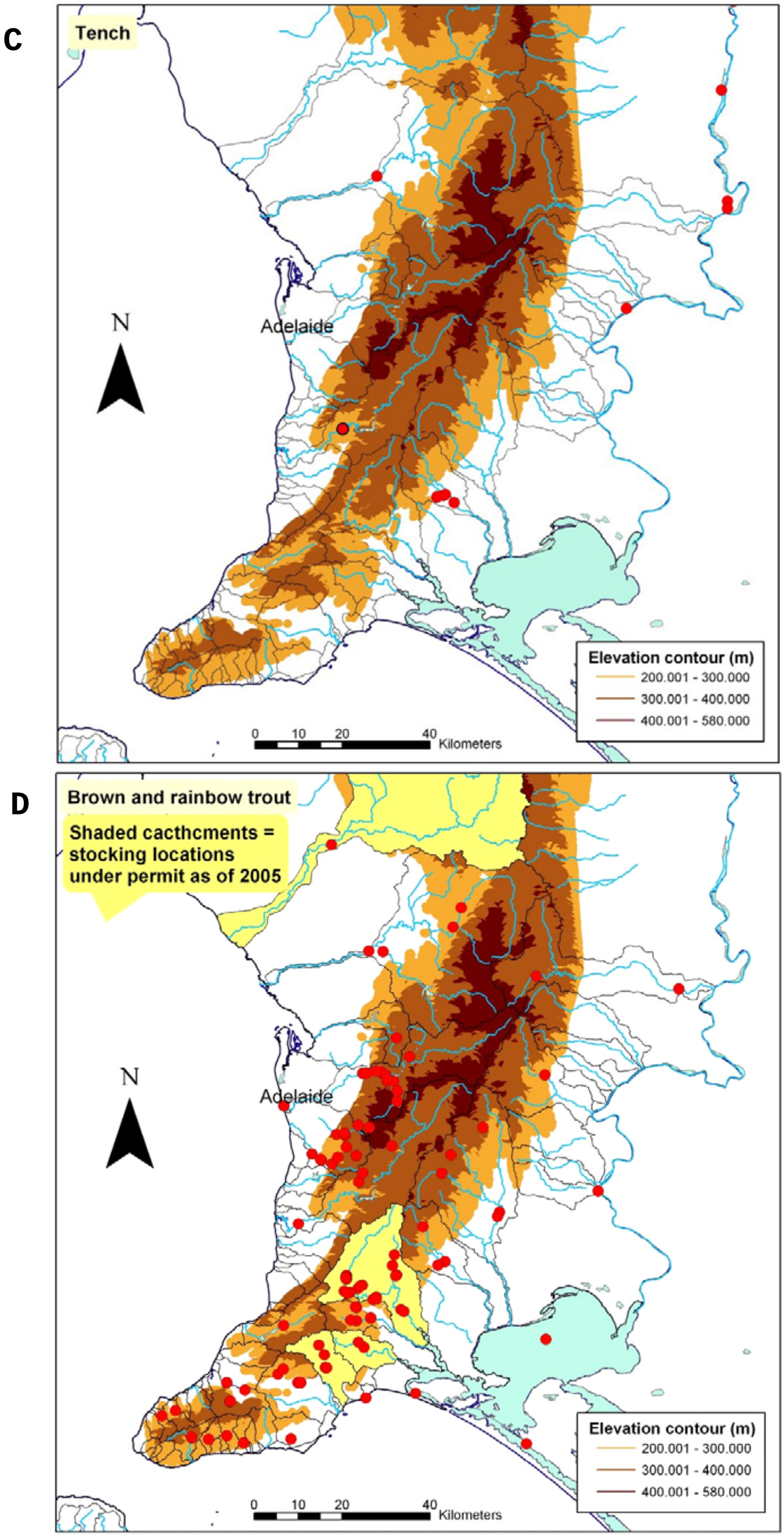
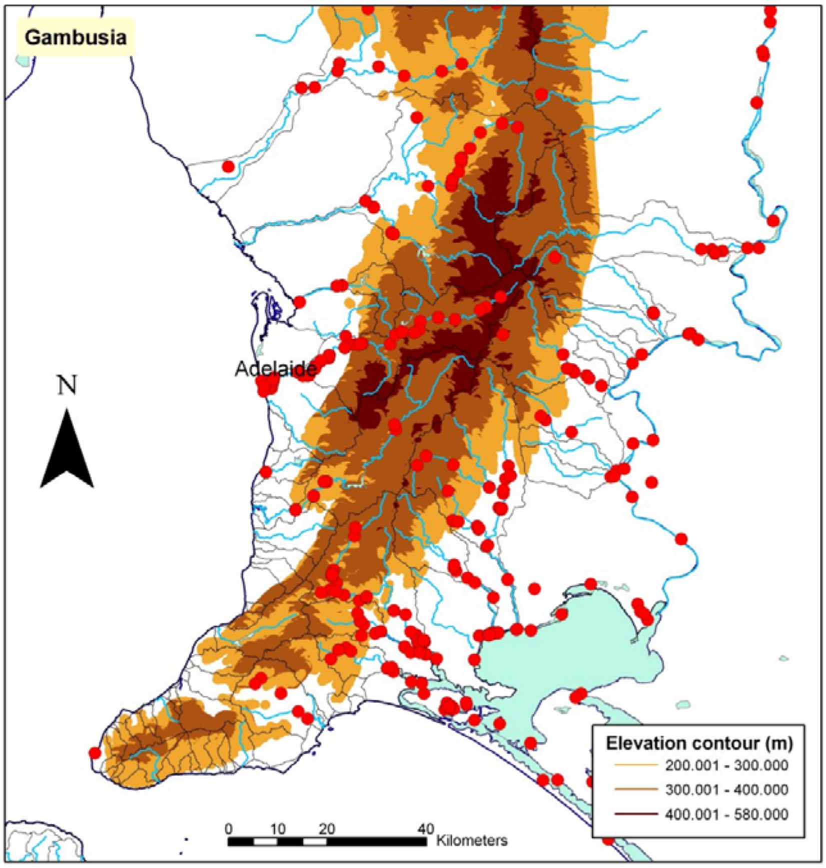


Figure 4C-D. Exotic fish species distribution in the MLR, (C) tench and (D) rainbow & brown trout.

E



F

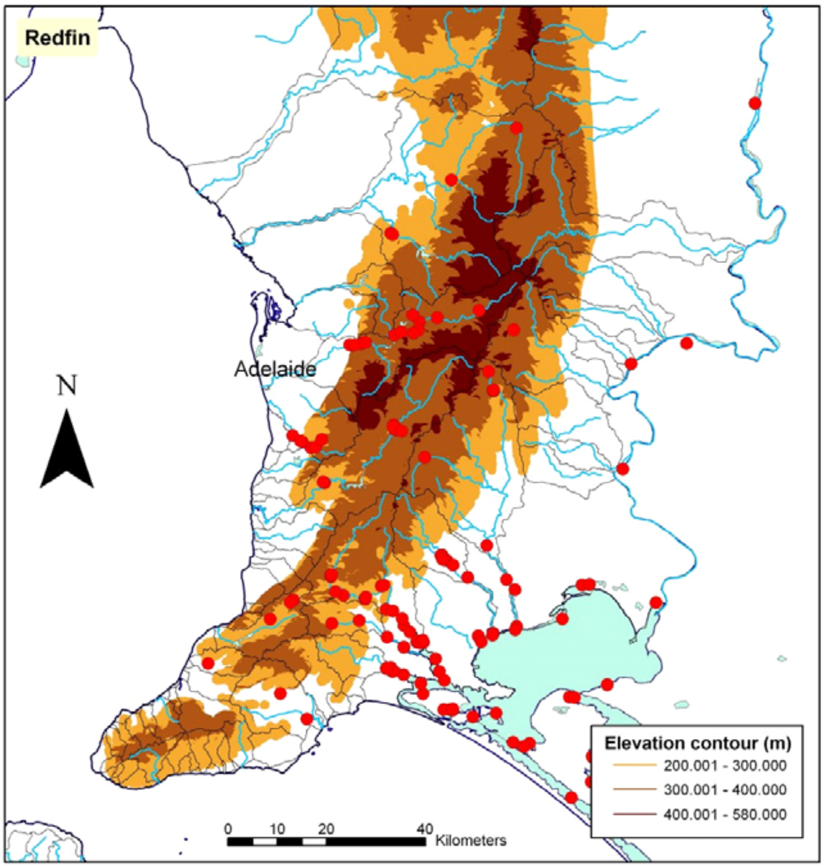


Figure 4E-F. Exotic fish species distribution in the MLR, (E) gambusia and (F) redfin.

3 Biology and Life History of MLR Fishes

This section provides information summarizing various fish biology and life history characteristics for MLR fish species. This has been presented in tabulated form to summarise the current knowledge for each species. This is especially useful for aspects such as spawning and migration calendars, where managers and researchers might need to access species information based on a distinct calendar period. In the case of other biological information such as reproductive biology, habitat use, flow requirements and water quality tolerances; these charts present summary information for all species in a single table. Where possible, all charts differentiate between SA specific data as compared to information collected or generalized from interstate data to alert for knowledge gaps under local environmental conditions.

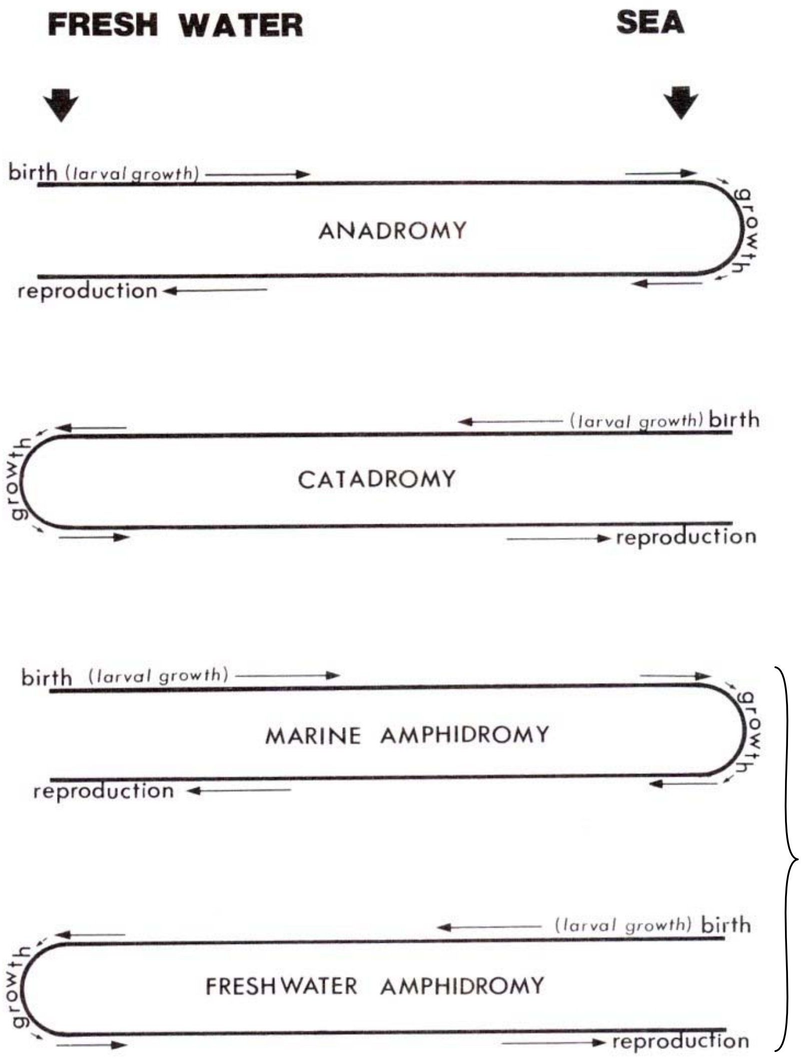
For all biological and life history data, it must be remembered that geographically separate populations are likely to possess differing biological and life history characteristics and therefore knowledge inferred from interstate or from other catchments and drainages must be considered as 'hypothesised' knowledge only. In many cases there will be little variation across populations (i.e. blackfish spawn in hollow logs across their range), whilst some characteristics may vary greatly between populations (i.e. natural and landlocked populations of common and climbing galaxias will possess very different reproductive strategies even within the same catchment).

3.1. Life History Modes

Three main life history modes are evident for local species: (1) obligate freshwater fishes – these complete their lifecycle inland, and can be further sub-divided to consider species occurring in select (e.g. stream) *vs.* more general (e.g. wetland) habitats, (2) diadromous species – have a determined migration between fresh and salt water, and can be subdivide by the types of movement they undertake (i.e. anadromous, catadromous, amphidromous: see Fig. 5), (3) euryhaline fishes that can complete their lifecycle in either fresh or salt water. Potamodromous species are those known to make determined movements within freshwater systems for particular lifecycle stages.

This section outlines the general reproductive characteristics for each species including spawning behaviour, egg and larval characteristics and spawning habitat (Table 2). Literature reports vary in the actual interpretation of 'spawning'. These vary from perceived spawning periods, actual investigation of spawning period to observations related to spawning (e.g. fish condition may indicate imminent spawning, the presence of larvae that spawning has or is occurring). For this analysis all aspects are combined with some distinction between the types of observations presented.

The section also contains calendars outlining the spawning period and timing of migrational movements for each species, separated into three life history guilds; obligate freshwater native species (Table 3), diadromous native species (Table 4) and exotic species (Table 5). Table 6 documents required migrations as part of the species lifecycle including the larger and determined movements of diadromous and potamodromous species.



Spend most of their lives in the sea and migrate to fresh water to breed as adults

Spend most of their lives in the fresh water and migrate to the sea to breed as adults

Migration to or from freshwater is not for the purpose of breeding but occurs regularly at some life cycle stage

Figure 5. Schematic representation of different forms of diadromy. Figure and text adapted from McDowall (1988).

Table 2. Biological information for freshwater fishes of the MLR. [*Life history strategy*: C; catadromous, A; anadromous, FAm; freshwater amphidromous, E; euryhaline (species comfortable in fresh and salt water), F; complete lifecycle in fresh water (obligate freshwater species), P; potamodromous. *Reproductive strategy*: n; parental care – guard eggs and/or build a nest, a; use structure by attaching or distributing eggs within (e.g. aquatic vegetation), no parental care, r; distribute demersal eggs randomly, p; spawn surface drifting (pelagic) eggs, l; bear live young. [Literature source abbreviations: K = Koehn and O'Conner (1990), M = McDowall (1996) and S = SKM (2003). Observations in or near the MLR in South Australia are included in bold. Note matching migration and spawning period calendars in Tables 4.2a-f]

	Species	Life history	Spawning mode	Spawning site/notes	Source
Natives	Pouched lamprey	A	r	Small headwater streams (Tas., SE Aust).	S
	Shortheaded lamprey	A	r or n	Depressions in mud or shallow flowing habitats (SE Aust.).	K
	Shortfinned eel	C	p?	Migrates to ocean (vicinity of Coral Sea) to spawn.	M
	Freshwater catfish	F	n	Builds a nest from rocks, guarded by male. Located in flooded and shallow portions of main rivers or quieter backwaters (SE Aust.).	K, M & S
	Bony herring	F	p	No general requirements (e.g. spawns over sandy margins of L. Alexandrina); not aligned to flooding **(SA Lower Murray)**.	Puckridge and Walker (1990)
	Smelt	F	r	Distribute over vegetation or become attached to vegetation, debris or sediment (SE Aust.).	M, S.
	Climbing galaxias	Fam	a	Thought to spawn on riparian vegetation -requires multiple lateral connections (water rises in autumn/winter) (Vic.).	M, S.
	Common galaxias	C/Fam or F	a	Spawns in lower river or estuary on fringing vegetation, possibly requires consecutive large tidal or water level rises (SE Aust. and NZ).	K, M & S
	Mountain galaxias complex	F	a	Clutches of eggs found in flowing riffles near normal adult habitat, under boulders/large rocks (coastal Vic.).	S
	Murray rainbowfish	F	a	Adhesive eggs laid onto aquatic vegetation (MDB).	S
	Smallmouthed hardyhead	E	a	On submerged surfaces and vegetation - on fyke net rope! **(Upper SE SA)**	Hammer unpub.
	Murray hardyhead	F	a	Possibly occurs amongst aqautic vegetation onto which eggs with adhesive filaments are attached (SE Aust).	M
	Unspecked hardyhead	F	a	Attached to aquatic vegetation and surfaces (SE Aust).	S
	Chanda perch	F	a	Scattered in vicinity of cover or attached to plants (SE Aust.).	S
	River blackfish	F	n	Eggs spawned in hollows and guarded by male: woody debris (Vic.), but also probably undercut banks, root mass where hollows absent (SE Aust., **SA EMLR**).	K, M, S & Khan *et al.* (2004); Hammer (2004)
	Murray cod	F	n	Eggs spawned in nest guarded by male- in hollows, depressions or solid surfaces; may make small migrations then return to home range (MDB).	K, M & S
	Golden perch	P	p	Normally migrates prior to spawning, flow related. Eggs randolmyl distributed. Pelaigic non-adhesive.	K, M & S
	Southern pygmy perch	F	a	Among macrophytes or randomly scattered near structure (SE Aust.). Spawning adults found in inundated stream edges **(SA EMLR)**.	K, M & S; Hammer unpub.
	Yarra pygmy perch	F	a	Eggs scattered over submerged vegetation in ponds.	Hammer unpub.
	Silver perch	F	p	Migrates prior to spawning, flow related?semi-bouyant pelaigic eggs.	
	Congolli	A/E	r?	Spawning site unknown. Large fish appear to be all female (SA Lower Lakes).	Piddington (1964)
	Carp gudgeon complex	F	n	Utilise structure, male guards eggs (SE Aust).	K, M & S
	Sth. purple-spotted gudgeon	F	n	Utilise structure, male guards eggs (SE Aust).	K, M & S
	Flathead gudgeon	F	n	Utilise structure, male guards eggs (SE Aust).	K, M & S
	Dwarf flathead gudgeon	F	n	Probably utilise structure, male guards eggs (aquarium observations).	S; Hammer unpub.
	Western bluespot goby	E	n	Spawning sites found under rocks exposed at low tide **(SA Port R.)**	Hammer unpub.
	Lagoon goby	E	n	Unknown, probably in caves or under structure given aquarium behaviour.	Hammer unpub.
Exotics	Goldfish	F	a	Demersal ahesive eggs laid on aquatic vegetation, & rocks	M
	Common carp	F	a	Demersal adhesive ggs laid on vegetation/structure, highly fecund	M
	Tench	F	a	Few, poisonous eggs laid on submerged vegetation	M
	Oriental weatherloach	F	r	Eggs deposited on aquatic vegetation or mud	M
	Rainbow trout	F	n	Eggs buried under gravel in fast flowing reches	M
	Brown trout	F	n	Eggs buried under gravel in fast flowing reches	M
	Brook trout	F	n	Eggs buried under gravel in fast flowing reches	M
	Gambusia	F	l	Bear live young in summer in low flow areas	M
	Redfin	F	a	Unpalatable eggs, demersal/adhesive laid in ribbons on vegetation/structure	M
	Barramundi	F/E		Unlikely to reproduce successfully in temperate waters	

Table 3. Annual spawning calendar for obligate freshwater fish species of the MLR. (A) Stream specialists, (B) Wetland specialists/generalists. [K = Koehn and O'Conner (1990), M = McDowall (1996) and S = SKM (2003). Observations in or near the MLR in South Australia are included in bold].

Ripe (yellow)	Ripe fish noted
Spawning (green)	Spawning period
Larvae (blue)	larvae collected

A

OF fishes (stream)	J	F	M	A	M	J	J	A	S	O	N	D	**Where**	**Source**
Mountain galaxias							Spawning	Spawning	Spawning	Spawning	Spawning		SE Aust	K
	Spawning	Spawning	Spawning						Spawning	Spawning	Spawning	Spawning	SE Aust	M
						Ripe	Ripe	Spawning	Spawning	Larvae			Qld	S
									Spawning	Spawning	Spawning		NSW	K
								Larvae	Larvae	Larvae	Larvae		Broken R (MDB Vic)	S
								Spawning	Spawning	Spawning			Coastal Vic	S
			Ripe	Ripe	Ripe	Ripe							**SA Marne & Angas (EMLR)**	Hammer (in prep)
								Ripe					**SA Hindmarsh (SF)**	Hammer (in prep)
				Ripe	Ripe				Larvae	Larvae			**SA Brownhill Ck (SA)**	Hammer (in prep)
River blackfish	Spawning								Spawning	Spawning	Spawning	Spawning	SE Aust	M
	Spawning										Spawning	Spawning	SE Aust	K
	Spawning										Spawning	Spawning	Coastal Vic	S
											Spawning	Spawning	Wimmera	S
										Larvae	Larvae		Broken R (MDB Vic)	S
												Ripe	LSE SA	Hammer *et al.* (2000)
										Ripe	Spawning		**SA Angas R**	Lloyd (1987)
Southern pygmy perch							Spawning	Spawning	Spawning	Spawning	Spawning		SE Aust	K
										Spawning	Spawning	Spawning	Tas	S & M
									Spawning	Spawning			NSW	K
									Ripe		Ripe		SE SA	Hammer unpublished
									Spawning	Spawning	Spawning		**SA Tookayerta**	Lloyd (1987)
	Ripe												**SA Inman (SF)**	Hammer unpublished
			Larvae	Larvae									**SA Tookayerta**	Hammer (2005)
Flathead gudgeon	Spawning	Spawning	Spawning							Spawning	Spawning	Spawning	SE Aust	K & S
	Spawning	Spawning							Spawning	Spawning	Spawning	Spawning	MDB	K
	Larvae	Larvae	Larvae	Larvae				Larvae	Larvae	Larvae	Larvae	Larvae	Broken R (MDB Vic)	S
										Larvae	Larvae	Larvae	Murray, Vic.	S
	Spawning	Spawning										Spawning	**SA Lower Murray**	Lloyd (1987)
	Larvae	Larvae	Larvae						Larvae	Larvae	Larvae	Larvae	**SA Lower Murray**	Cheshire (2005)
Dwarf flathead gudgeon				?			?			?			unknown	K, M & S
	Spawning	Spawning							Spawning	Spawning	Spawning	Spawning	**SA Lower Murray**	Lloyd (1987)
									Ripe	Ripe			**SA Lower Lakes**	Hammer unpublished
Carp gudgeon complex	Spawning	Spawning										Spawning	SE Aust	K
	Spawning	Spawning								Spawning	Spawning	Spawning	SE Aust	S
	Larvae	Larvae	Larvae	Larvae						Larvae	Larvae	Larvae	Broken R & Murray	S
	Spawning	Spawning									Spawning	Spawning	**SA Lower Murray**	Lloyd (1987)
	Larvae	Larvae	Larvae						Larvae	Larvae	Larvae	Larvae	**SA Lower Murray**	Cheshire (2005)

Ripe fish noted (Y)
Spawning period (G)
larvae collected (B)

B

OF fishes (LS/wetland)	J	F	M	A	M	J	J	A	S	O	N	D	**Where**	**Source**
Freshwater catfish	G	G	G							G	G	G	SE Aust	K, M & S
Bony herring										G	G	G	Vict	K
	B	B	B						B	B	B	B	**SA Lower Murray**	Cheshire (2005)
	B	B											Vic MDB	S
	G											G	**SA Lower Murray**	Puckridge & Walker (1990)
Smelt	G	G							G	G	G	G	SE Aust.	M
	B	B	B	B				B	B	B	B	B	Broken R (MDB Vic.)	S
	B	B	B						B	B	B	B	**SA Lower Murray**	Cheshire (2005)
									G	G	G		**SA Lower Murray**	Lloyd (1987)
								G	G	G	G	G	**SA Lower Murray**	Leigh (2002)
	B	B							B	B	B	B	**SA Chowilla region**	Zampatti & Leigh (2006)
Murray Rainbowfish	G									G	G	G	Vict.	M
	B	B								B	B	B	Broken R (MDB Vic.)	S
	G	G									G	G	**SA Lower Murray**	Lloyd (1987)
	B	B	B							B	B	B	**SA Chowilla region**	Zampatti & Leigh (2006)
Murray hardyhead	G	G	G										Vict.	K
	G	G							G	G	G	G	Vict.	Ellis (2005)
	G	G											**SA Lower Murray**	Lloyd (1987)
Unspecked hardyhead	G	G								G	G	G	SE Aust.	M & S
	G	G								G	G	G	**SA Lower Murray**	Lloyd (1987)
											B	B	**SA Lower Murray**	Cheshire (2005)
												Y	**SA Lower Murray**	Hammer unpublished
	B	B	B								B	B	**SA Chowilla region**	Zampatti & Leigh (2006)
Chanda perch											G	G	SE Aust.	K & M
Murray cod									G	G	G	G	MDB	M & S
	B										B	B	Broken R (MDB Vic.)	S
	B	B									B	B	**SA Lower Murray**	Cheshire (2005)
										B	B	B	**SA Chowilla region**	Zampatti & Leigh (2006)
MD golden perch	G	G	G	G					G	G	G	G	MDB	M & S
	B	B								B	B	B	**SA Lower Murray**	Cheshire (2005)
	G	G	G								G	G	MDB	K
	B	B										B	**SA Chowilla region**	Zampatti & Leigh (2006)
Yarra pygmy perch									G	G			Vict.	K, M & S
									G	G	G		SE SA	Hammer (2005 & unpublished)
									Y				**SA Lower Finniss**	Wedderburn and Hammer (2003)
Silver perch										G	G	G	MDB	K & S
	G	G								G	G	G	MDB	M
	B	B									B	B	**SA Lower Murray**	Cheshire (2005)
Purple-spotted gudgeon	G	G										G	SE Aust.	K & M
	G	G							G	G	G	G	**SA L. Murray/Finniss R**	Blewett (1929)

Table 4. Annual spawning calendar for diadromous and estuarine fish species of the MLR. [Literature source abbreviations: K = Koehn and O'Conner (1990), M = McDowall (1996) and S = SKM (2003). Observations in or near the MLR in South Australia are included in bold]

Yellow	Ripe fish noted
Green	Spawning period
Blue	larvae collected

(Y = yellow, G = green, B = blue)

Diadromous fishes	J	F	M	A	M	J	J	A	S	O	N	D	**Where**	**Source**
Pouched lamprey										G	G	G	Southern Aust.	K & S
										G	G		SW WA	M
Shortheaded lamprey								G	G	G	G		SE Aust.	K
								G	G	G			SE Aust.	S
Shortfinned eel				?			?			?			Aust.	K, M & S
Climbing galaxias			G	G	G	G	G	G					Aust and NZ	M
				Y									NE Tas.	Hammer unpublished
					G	G							Vic.	K
					G	G							Coastal Vic.	S
			Y										**SA Hindmarsh R (SF)**	Hammer unpublished
			Y										**SA Kangaroo Is.**	Hammer unpublished
Common galaxias			G	G	G	G							Coastal SE Aust.	K, M
					G	G	G						Coastal Vic.	S
			Y	Y	Y								**SA EMLR, Lower Lakes**	Hammer unpublished
Congolli									G	G	G	G	SE Aust.	K
											G	G	Tas.	K
								Y	Y	Y			Central Vic.	K
				G	G	G	G	G					SE Aust.	S
					Y	Y	Y	Y					**SA Lower Lakes (biology)**	Piddington (1964)
					G	G	G	G	G				**SA Lower Lakes (fishers)**	Piddington (1964)
	B									B			**SA Lower Lakes**	Lloyd (1987)

Euryhaline fishes	J	F	M	A	M	J	J	A	S	O	N	D	**Where**	**Source**
Smallmouthed hardyhead	G	G							G	G	G	G	SE Aust.	K
										B			SE Aust.	M
	G											Y	SE SA	Hammer unpublihsed
											Y		**SA Lower Lakes**	Hammer unpublihsed
									G	G	G	G	**SA Coorong**	Molsher *et al.* (1994)
Western bluespot goby									G	G	G		SE Aust.	K
									Y				SA Wakefield R	Hicks and Sheldon (1998)
											G	G	**SA Port River & Gawler R**	Hammer unpublihsed
Lagoon goby											Y		**SA Lower Lakes**	Wedderburn & Hammer (2003)
								Y					**Lake George**	SARDI unpublished

Table 5. Annual spawning calendar for exotic introduced fish species of the MLR. SA data in bold. [Literature source abbreviations: K = Koehn and O'Conner (1990), M = McDowall (1996) and S = SKM (2003). Observations in or near the MLR in South Australia are included in bold]

Yellow	Ripe fish noted
Green	Spawning period
Blue	larvae collected

(Y = yellow, G = green, B = blue)

Obligate freshwater fishes	J	F	M	A	M	J	J	A	S	O	N	D	**Where**	**Source**
Goldfish	G	G										G	SE Aust.	M
	G	G										G	**SA Lower Murray**	Loyd (1987)
Carp									G	G	G	G	SE Aust.	M
	G	G	G	G	G				G	G	G	G	**SA Lower Murray**	Smith & Walker (2004)
									B	B	B	B	**SA Lower Murray**	Cheshire (2005)
									B	B	B	B	**SA Chowilla region**	Zampatti & Leigh (2006)
Tench	G	G							G	G	G	G	SE Aust.	M
Rainbow trout								G	G	G			SE Aust.	M
								G	G				**SA Sixth Ck (SAG)**	Morrissy (1967)
			Y										**SA Angas R (EMLR)**	Hammer (2004)
Brown trout				G	G	G	G	G					SE Aust.	M
					G	G							**SA Sixth Ck (SAG)**	Morrissy (1967)
				Y	Y								**SA EMLR**	Hammer unpublished
Gambusia	G	G	G	G						G	G	G	SE Aust.	M
	G	G	G	G	G						G	G	**SA Lower Murray**	Loyd (1987)
Redfin									G	G	G		SE Aust.	M
								G	G				SW WA	Morgan *et al.* (2002)
				Y	Y								**SA EMLR**	Hammer unpublished

Table 6. Annual calendar showing migrational movements of MLR fish species. SA data in bold. [Literature source abbreviations: K = Koehn and O'Conner (1990), M = McDowall (1996) and S = SKM (2003). Observations in or near the MLR in South Australia are included in bold]

Migration into estuary (est)
Upstream (us) migration
Downstream (ds) migration

Species	Migration type	J	F	M	A	M	J	J	A	S	O	N	D	Where	Source
Pouched lamprey	Upstream migrants							us	us	us	us	us		SW WA	M
										us	us	us		tas	K
										us	us	us		**SA Torrens & Murray**	SA Musem, Hammer (2005)
	Downstream migrants							ds	ds	ds	ds			SE Australia	K
								ds	ds	ds	ds			SW WA	M
Shortheaded lamprey	Upstream migrants								us	us	us	us	us	SE Australia	K
										us	us	us		Tas	M & K
		us										us	us	Tas	S
		us	us						us	us	us	us	us	Yarra R Vic	Zampatti *et al.* (2003)
									us	us	us	us		Vic	M
										us	us	us		**SATorrens & Murray**	SA Museum; Higahm *et al* (2005)
	Downstream migrants								ds	ds	ds	ds		SE Australia	K
Shortfinned eel	Glass eels into estuary					est	est	est	est	est	est			SE Australia	K
						est	est	est	est	est				NSW	S
				est	est	est	est	est	est	est	est	est	est	Tas	k & S
						est	est	est						Central Vic	K
								est	est	est	est			Western Vic	K
	Elvers upstream	us									us	us	us	SE Australia	K & M
		us	us						us	us	us	us	us	Yarra R Vic	Zampatti *et al.* (2003)
		us	us								us	us	us	Tas	K & S
	Adults to estuary	ds	ds	ds	ds	ds					ds	ds	ds	SE Australia	K
										ds	ds	ds	ds	SE Australia	S
Climbing galaxias	Juveniles us from sea									us	us	us	us	SE Australia	K & M
											us	us		Yarra R Vic	Zampatti *et al.* (2003)
		us									us	us	us	Tas	K
	Larvae swept to sea			ds	ds	ds	ds	ds	ds					SE Australia	M
Common galaxias	Juveniles us from sea									us	us	us		Aust	M
								us	us	us	us	us	us	Aust	S
		us	us									us	us	Tas	K
		us	us						us	us	us	us	us	Yarra R Vic	Zampatti *et al.* (2003)
											us	us		Central Vic	K
										us	us			**SA Torrens**	Hammer (2005); Matthews (2004)
	Adults ds to spawn			ds	ds	ds								Aust	M
						ds	ds	ds						Vic	K
	Larvae swept to sea				us	us	us							Aust	M
							us	us	us					Vic	K
Congolli	Juveniles us from sea	us	us								us	us	us	Tas	K
										us	us			Tas	K
														Yarra R Vic	Zampatti *et al.* (2003) - not caught
	Adults ds to spawn				ds	ds	ds	ds	ds					Aust	S
					ds	ds	ds	ds						Vic	K
										ds	ds			Tas	K
MD golden perch	Adults us to spawn									us	us	us	us	**SA**	Reynolds (1983)
	Larvae swept ds	ds	ds	ds	ds							ds	ds	MDB	K

3.2. Habitat associations

A detailed study of fish-habitat associations has not yet been conducted for the MLR and has not been comprehensively studied for most native species, although knowledge can be gleaned from a diverse range of ecological papers and reports. In temperate Australia, there is a need to better understand how physical habitat actually relates to fish assemblage and population structure (Koehn 1987). Many types of finer scale structural habitats that are potentially important for fish species have not yet been assessed in relation to their value as fish habitat (e.g. the role of complex woody debris such as *Acacia* and *Leptospermum* debris, smaller branches, leaf litter, bark etc). This may be particularly important for some poorly understood MLR species such as larval lampreys and climbing galaxias. An assessment of fish-habitat associations in the Lower River Murray is currently being conducted by SARDI and will be especially relevant to the lowland sections of the EMLR. Habitat use, as with many life history traits, is considered to vary greatly across geographical ranges even within a single species (Humphries *et al.* 1999; Growns *et al.* 2004), and therefore the extension of data from elsewhere in Australia to MLR fish and habitats should be made with care.

In many cases, native species may be found in association with specific habitats that may not be their naturally preferred habitat. For example, mountain galaxias and climbing galaxias are associated with small headwater streams (SE Australia) and Murray galaxias (Ovens River Victoria) are found to be associated with poor quality floodplain habitats, however, these species are likely to prefer very different habitats (larger streams and deep pools, large, high quality billabongs respectively), and are only restricted to marginal habitats through the predation pressure applied by introduced trout and redfin perch (Closs and Lake 1994; McDowall and Fulton 1996; McNeil 2004). In the EMLR, river blackfish persist within a few remaining pools left after water abstraction and hydrological modification, and would almost certainly occupy other habitats preferentially had they not become desiccated (Hammer 2002c, 2004). As a result we must also be cautious when inferring habitat preferences from distributional field observations without considering other factors.

It is also acknowledged that ontogenic shifts in habitat use occur between juvenile and adult fish within a species. Murray-Darling golden perch and redfin perch both utilise macrophyte habitats when very small, moving to deeper water and woody cover as they get larger (McNeil *et al.* 2001; Shirley 2002; McNeil unpublished data), with similar patterns also occurring for example with carp gudgeons (Stoffels and Humphries 2003). Habitat information (Table 7) has, therefore, been summarised distinctly for juvenile and adult fish where possible. Two important components of overall 'habitat' (water quality tolerance and flow) have been addressed separately in Section 3.4 and 3.5 below. It should be remembered, however, that both of these components are intricately linked to more physical or geomorphic aspects of fish habitat.

Scale dependant factors are also important in addressing fish habitat preferences. Whilst broad scale habitat preferences such as 'wetland' or 'stream' habitats are easily generalised across broad geographical scales, other habitat associations such as macrophyte beds (and individual macrophyte species) or fine woody debris are specific to very small spatial scales. Different habitat components and scales must therefore be considered together for purposes of assessing species habitat associations or estimating, preserving or rehabilitating available habitat.

Table 7. Broad and fine scale habitat associations for freshwater fishes of the MLR. [Note: (1) habitat type ‘swamp’ refers to species known to occur in Fleurieu Swamps, (2) diadromous species move through additional habitat types as part of their lifecycle. The data source is a collation of SA references unless otherwise stated (main data source: Lloyd 1987; Wedderburn and Hammer 2003; Hammer 2004, 2005c, 2006c), where no SA data was available interstate data was used with geographic context highlighted in brackets (source: Koehn and O'Conner 1990; McDowall 1996; SKM 2003)]

	Species	MLR habitat type	Habitat association-adult	Habitat association-juvenile
Natives	Pouched lamprey	**Stream**	Little known in freshwater. Structure?	Ammocetes prefer shaded silty areas in slow water (Aust.).
	Shortheaded lamprey	**Stream**	Little known in freshwater. Structure?	Soft sediments along river edge (low velocity) (Vic.). Permanent flow?
	Shortfinned eel	Stream/wetland	Variable, but associated with structure such as woody debris (Vic.).	Estuaries (glass eel), elvers slowly move into stream habitat (but not all) (SE Aust).
	Freshwater catfish	Wetland	Slow flowing areas of larger rivers and anabranches (Lower Murray and Vic).	
	Bony herring	Wetland	Open water pelagic species.	Open water.
	Smelt	Lower stream/wetland	Open water pelagic species.	Open water and wetlands.
	Climbing galaxias	**Stream/swamp**	Mid-upper catchment areas. Permanent pools, spring fed, high percentage of riparian vegetation cover.	Pelagic larvae - at sea or lentic waterbody (e.g. reservoir). Estauries into freshwater (Vic.).
	Common galaxias	L. stream/wetland/estuary	Generalist, lowland habitats. Probably benefits from fringing emergent or riparian vegetation.	Pelagic larvae. Estuaries into freshwater. Need cover form predators? Negative influence of artificial barriers.
	Mountain galaxias 1	**Stream/swamp**	Higher elevations. Generally shallow flowing areas. High structural integrity or heterogeneity, especially when exotic predators present (if the native species is not otherwise excluded).	In adult habitat (pools).
	Mountain galaxias 2	**Stream**	Higher elevations (except a few spring fed lowland areas such as Marne). Pool habitat, requires high heterogeneity in habitat.	
	Murray rainbowfish	Wetland	Submerged and emergent aquatic vegetation.	Shallow backwaters and sheltered littoral habitats (Vic.)
	Smallmouthed hardyhead	Wetland/estuary	Generalist, shallow habitat.	
	Murray hardyhead	Wetland	Submerged and emergent aquatic vegetation.	
	Unspecked hardyhead	Wetland	Submerged and emergent aquatic vegetation.	
	Chanda perch	Wetland	Submerged and emergent aquatic vegetation or structure (historic SA and Qld).	
	River blackfish	**Stream/swamp**	Mid catchment. Deep permanent pools, cool flowing water, fringing emergent macrophytes.	Littoral edge habitat, with high structural integrity (Vic.).
	Murray cod	Lower stream/wetland	Structural integrity (snags).	Structure in littoral edges of main channel (Vic.)
	Golden perch	Lower stream/wetland	Structural integrity (snags), also open water or river edges.	Variable, near structure (Vic.).
	Southern pygmy perch	**Stream/swamp/ wetland**	High structural integrity and/or habitat heterogeneity -e.g. submerged and emergent vegetation, fine woody debris, algae, rocks, dense swamp.	Shallows amongst emergent vegetation.
	Yarra pygmy perch	**Wetland**	Submerged and emergent aquatic vegetation.	Shallow still water amongst macrophytes (Vic.)
	Silver perch	Lower stream/wetland	Varied habitat in larger rivers and anabranches (Lower Murray and Vic).	Backwater and floodplain areas (MDB).
	Congolli	L. stream/wetland/estuary	In-stream structure in streams, but also sandy and mud habitat.	Estuarine areas (Vic and Tas).
	Midgley's carp gudgeon	Wetland	Structural integrity (snags, submerged and emergent vegetation).	Shallow ponded habitats (MDB).
	Murray-Darling carp gudgeon	**Stream and wetland**	Structural integrity (snags, emergent vegetation, stream banks).	
	Hybrid forms	Stream and wetland	Structural integrity (snags, emergent vegetation, stream banks).	
	Sth. purple-spotted gudgeon	Lower stream/wetland	Structural integrity (snags, submerged aquatic vegetation).Also flow heterogeneity (e.g. still side stream pools).	
	Flathead gudgeon	Stream/wetland/upper est.	Generalist, often near structure.	Pools and littoral areas (Vic.)
	Dwarf flathead gudgeon	Stream and wetland	Structure (rock, vegetation, river banks).	
	Western bluespot goby	Wetland/estuary	Shallow areas, exposed or with aquatic vegetation.	
	Lagoon goby	Wetland/estuary	Sandy and rocky habitat.	
Introduced	Goldfish	Stream and wetland	Generalist, often slow flowing or stagnant habitat, vegetation.	
	Common carp	Stream and wetland	Generalist, often slow flowing or stagnant habitat.	Wetlands & floodpalin habitats
	Tench	Stream and wetland	Deeper pools in Angas catchment only	
	Rainbow trout	Stream and wetland	Prefers permanent flow and deep pools, cool oxygenated	Cooler flowing streams
	Brown trout	Stream	Prefers permanent flow and deep pools, cool oxygenated water.	Cooler flowing streams
	Brook trout	Stream	Prefers permanent flow and deep pools, cool oxygenated water.	Cooler flowing streams
	Gambusia	Stream and wetland	Generalist, most habitats, low flow. Often close to surface and at edge.	Adult habitats
	Redfin	Stream and wetland	Low flow generalist. Often near structure, but also open areas.	Adult habitats, wetlands, littoral habitats
	Barramundi	Lower stream	Isolated introduction.	

3.4. Water Quality Tolerances

For any fish species to survive in any given area, they must be able to tolerate the general physical and chemical characteristics present. There is a high degree of variability across physicochemical gradients, both temporally and spatially. Seasonal, climate driven variation is stronger in Australian systems than almost anywhere in the world (Puckridge *et al.* 1998) and the complexity of stream habitats result in patchiness in water quality even over relatively small spatial scales (McNeil 2004). It is necessary for fish species to be able to tolerate all conditions present within any given habitat in order to persist. Fish often persist within 'refuge' habitats where local patchiness allows some comparatively benign areas to persist in which less tolerant fish may survive until conditions improve (McNeil 2004; Closs *et al.* 2006).

There is, however, very little accurate and comparative data to indicate what range of conditions can be tolerated by native fish species. Much knowledge has been gleaned from field surveys where local physicochemical measurements were taken along with fish assemblage data. This provides us with some level of understanding, but laboratory based trials that are accurate and comparative remain the best way of estimating species tolerances. Even less studied is the range of sub-lethal conditions that will impact upon immune responses, growth rates or reproductive success, in populations that are able to survive within environmentally harsh habitats. It is generally acknowledged that Australian native species must be fairly tolerant of high temperatures, low oxygen and high salinity to have survived the harsh and variable Australian climate [recent investigations, however, highlight the comparatively excellent tolerance of introduced exotic species to these conditions (McNeil 2004)]. To best understand the interaction between species tolerance and ecological distributions is to combine laboratory estimates with targeted ecological assessment. As yet, very few such studies have been attempted for inland Australia (McNeil 2004; Closs *et al.* 2006).

Furthermore, anthropogenic changes to aquatic systems have resulted in habitats that are variously warmer, colder, saltier, more ephemeral, nutrient rich and toxic than even the harsh climate of Australia could provide historically. Recent increases in surface and groundwater abstraction, the construction of reservoirs for storage and broad scale land clearing for agriculture and urbanisation continue to extend the environmental harshness of aquatic refuge habitats. In the MLR, cold-water pollution (from storage releases), increased water temperatures & hypoxia (due to riparian clearing & water abstraction), increased nutrient and toxin loads (through agriculture and urbanisation) all lead to poor water quality within stream habitats, particularly during summer when fish survive predominantly within isolated refuge pools. The specific nature of environmental harshness within refuge habitats in the MLR, and the abilities of local species to survive are not yet known and warrant a detailed assessment.

Although the ongoing monitoring program and short term flow response projects (see Section 4) will collect some physical and chemical data for long-term sites, this data will not cover the temporal or spatial scales required to understand the variability or impacts across the MLR. Collection of this data, combined with estimated species tolerances will allow the identification of likely water quality impacts on MLR fish populations. For the current summary, extant information has been collated where possible from general reviews of fish biology and habitat use (Koehn and Morison 1990; SKM 2003), supplemented by a small amount of recently obtained data from south-eastern Australia (Gee and Gee 1991; Clunie *et al.* 2002)(Hart *et al.* 1991; Ryan *et al.* 1999) and some scant local records from the MLR.

Table 8. Physio-chemical tolerances related to fishes recorded in the MLR. Maximum water conductivity (Max EC MLR) is an indication of the highest autumnal value adults have been recorded under in the MLR –it does not necessarily imply high tolerance (i.e. rare observation, few individuals) (source: Wedderburn and Hammer 2003; Hammer 2004, 2005c, 2006c). These are supplemented with data from laboratory trials and field observations from SA and interstate. (K&O=Koehn & O'Connor 1990, SKM=SKM 2003, H=Hart et al 1991, Cl=Clunie et al. 2002, McN=McNeil 2004, R=Ryan et al. 1999).

	Species	Salinty (mg/l) Adult	Salinity (mg/l) egg/juvenile	Max EC MLR	Temp max.	DO/hypoxia	Source
Natives	Pouched lamprey			Sensative once acclimated to freshwater	28.3	Highly tolerant ammocoetes	K&O, SKM
	Shortheaded lamprey				30	Ammocetes rarely found in stagnant or highly eutrophic waters (general: Potter 1974).	
	Shortfinned eel	13400		High tolerance	wide ranging	Tolerant	K&O, Cl
	Freshwater catfish	44000(1hr); 17800(LC50)		4660	38	Tolerant (1h+ at 90-2% saturation)	K&O, SKM, O&R, R
	Bony herring	24,600; 35000		5000	38		SKM
	Smelt	59000(LC50)		2910	28	Moderate tolerance <2mg/L, ASR-poor	McN, SKM, H
	Climbing galaxias	35000		4000	23		K&O, SKM, O&R
	Common galaxias	30000; 62000(LC50)	49000; 6000(LC50)	4000 (adults)	24.5		H, Cl
	Mountain galaxias 1	1500	1500	9020	32		Cl
	Mountain galaxias 2			9660			
	Murray rainbowfish	30,000	17,000egg, 12,000fry (LC50)	2050	28		K&O, SKM, O&R
	Smallmouthed hardyhead	108000 (LC50)		marine			
	Murray hardyhead	45900, 110,000			28		SKM, O&R, Cl
	Unspecked hardyhead	69100, 43,700 (LC50)		5210,	36		O&R
	Chanda perch				poss. high	poss. high	SKM
	River blackfish	10000	6000, 12000	8890	28	Low	SKM
	Murray cod	15,700 (LC50)				13% saturation (2h+).	O&R
	Golden perch	33,000 (LC50)	8300	8030	37	13% saturation (2h+). Use larger billabongs-wetland habitats	O&R, R, McN
	Southern pygmy perch	10000		8490	38	Tolerant below 1mg/L (short periods), ASR.	McN, K&O, SKM
	Yarra pygmy perch			3010	30		SKM
	Silver perch	16000(LC50)	24600, 9000 (LC50-eggs)		38	>2mg/l	SKM, O&R
	Congolli	35,000; 17000(LC50)		22000 (estuary)	20		SKM, Cl, H
	Carp Gudgeon (complex)	26000; 50,000 (LC50)		1980		Tolerant below 1mg/L (short periods), ASR, eggs vulnerable	McN, K&O, Cl, H
	Sth. purple-spotted gudgeon	35,000; 17,100(LC50)			34		O&R, K&O
	Flathead gudgeon	24600; 40000(LC50)		>25000 (estuary)		Tolerant below 1mg/L (short periods), ASR.	McN. G&G
	Dwarf flathead gudgeon			33000 (EMLR)			
	Western bluespot goby			marine			
	Lagoon goby			2500 (>30000 KI)			
Introduced	Goldfish	8800; 19176(LC50)		12300		Tolerant below 1mg/L (short periods), ASR.	McN, Cl
	Common carp	12800(LC50)	9000(LC50)	12300		Tolerant below 1mg/L (short periods), ASR.	McN, Cl
	Tench	11,600(2 hours)		7090		5-13% saturation (2 hours)	R
	Oriental weatherloach					Extremely tolerant (anoxia), airbreathing.	McN
	Rainbow trout	35000(LC50)	3000(LC50)	8000		Not found in hypoxic habitats	Cl
	Brown trout	35000(LC50)	3000(LC50)	5090, mostly <3000		Not found in hypoxic habitats	Cl
	Brook trout					Not found in hypoxic habitats	
	Gambusia	59000(30 days), 15000(LC50)		33000	44	Tolerant <1mg/L, efficient use of ASR	McN, H
	Redfin	17500; 8000(LC50)		8030		Moderate tolerance <2mg/L, ASR-poor	McN, Cl, H
	Barramundi	31000	94000				H

3.5. Environmental water requirements

None of the MLR fish species are able to survive for any period of time in the absence of surface water and therefore the maintenance of aquatic habitats through stream-flow is the principal factor influencing fish populations. Indeed, flow regulation in the MLR has been directly responsible for the complete desiccation of certain stream reaches resulting in the near or total removal of fish populations within a reach (e.g. Hammer 2002c; Hammer 2004, 2005a). In such situations, subsequent flows must be able to re-connect remnant habitats to isolated populations so that fish can re-populate the re-inundated reaches. If such refuge populations are not available for a given species, then it will remain permanently extinct within that reach.

This pattern of cyclical desiccation and re-inundation is naturally common across many ephemeral Australian streams (Koehn & O'Connor 1990) and some MLR fish appear well adapted for these conditions (i.e. mountain galaxias in Victoria: Closs and Lake 1996). In the MLR, however, flow patterns have been greatly altered, due to large storages and increasing abstraction. As result, many natural aspects of flow variability, including baseflow and small to medium sized flow pulses have been lost to many stream reaches. Additionally, other impacts such as habitat alteration limit the number and availability of source or refuge populations.

These aspects of flow variability are essential for: (1) determining the ultimate extent of available habitat at multiple scales (e.g. habitat [water] present in a stream reach; the wetted presence of certain habitat type i.e. fringing emergent vegetation), (2) linking habitat components (linear connection of pools and broader habitat types such as marine and freshwater; lateral connections to habitat), thus driving population processes such as migration, recolonisation and particular biological responses or cues, and (3) maintaining refuge habitats of appropriate water quality and habitat complexity where populations can persist throughout low flow periods (and potentially recolonise following re-inundation).

At the extremes of the natural flow range, both high and low flow periods are also essential for shaping fish populations. Very high flows are required to provide floods which reset and re-structure habitats and ecological processes. Alternatively, low flow periods may provide important evolutionary pressure within refuge habitats that are advantageous to native fish over poorly adapted introduced species (Closs and Lake 1994; Bunn and Arthington 2002; McNeil 2004).

Environmental flow releases are planned for major streams of the MLR beginning in 2007 (with 2006 flows postponed due to drought). It is therefore an objective of the 'fish sustainability project' to identify key flow components for fish species sustainability and to this end, the current review attempts to identify key flow relationships for the MLR (Table 9). Flow related components of life history, migration and spawning; habitat requirements and water quality impacts are implicit throughout the biological summary tables above (Table 2-8), including indications as to seasonality and/or timing of flows. For example, for diadromous species migration might require a suitable period of linear connectivity and potentially of a certain water quality (olfactory cues) to attract and allow upstream migration into catchments. Obligate freshwater fishes with a restricted range require long-term presence of suitable habitat and habitat heterogeneity (linear and vertical connectivity). They also require particular types of flow to link with biological processes such as spawning or a water level rise to allow movement and mixing within populations. The intent here is not, however, to define environmental water requirements for individual species, as this requires detailed thought and investigation specific to particular management units and conditions, but rather to outline information that can potentially be used in such assessments (e.g. see Sheldon *et al.* 1999; SKM *et al.* 2002; Marne River Environmental Flows Technical Panel 2003).

Table 9. Species-flow relationships and information for native MLR fish species. [Literature source for interstate summary unless otherwise stated is Koehn and O'Conner (1990), McDowall (1996) and SKM (2003). Observations in or near the MLR in South Australia are included in bold]. (Hale 1928; Reynolds 1983; Puckridge and Walker 1990; Molsher et al. 1994; Ye et al. 2000; Hammer 2001, 2002a; Leigh 2002; Wedderburn and Hammer 2003; Hammer 2004; Rowntree and Hammer 2004; Hammer 2005a, b)

Species	Flow relations	Demographic data	Population dynamics (refuges & recolonisation)	SA Source
Pouched lamprey	Migratory, potential larval requirements for permanent flow and oxygenation (SE Aust.).	Lifecycle model well established (SW WA).	Unknown attractants to catchments.	
Shortheaded lamprey	As above.	Lifecycle model well established (SE Aust.)	Unknown attractants to catchments.	
Shortfinned eel	Migratory.	Lifecycle model well established (SE Aust.)	Western end of larval migration - opportunistic based on currents? Attractants to catchments?	
Freshwater catfish	Higher density in lotic *v* lentic habitat of Torrens weir -sediment flushing required?	Lifecycle model well established (SE Aust.)		Rowntree and Hammer (2004)
Bony herring		Initial model developed through assessment for lower Murray tracked potential cohorts through time, no age data **(SA Lower Murray).**		Puckridge and Walker (1990)
Smelt	Recorded in flooded edge habitat avoiding high velocities during flow (Finniss).	Lifecycle model (including age data and tracking of recruits) developed for **Lower Murray SA.**		Leigh (2002)
Climbing galaxias	Migratory. Spawns during floods.	Migrating juveniles 40-50mm (SE Aust.). Length-age relationships or assessments of adult population structure not reported.	Several disjunct populations within range, some indication of inhabitation of adults at mid-catchment refuges.	
Common galaxias	Migratory. Flooding for spawning.	Lifecycle model well established for recruitment, differs in landlocked and coastal populations (SE Aust.). Larger adults aged? (not cited in reviews but as there is considerable biology reported on the species could occur)?	Unknown attractants to catchments.	
Mountain galaxias 1	Spawns in riffles (Vic). Recorded avoiding high velocity in flooded shallows **(Finniss)**.	Lifecycle model could be based on a biological investigation of spawning and age structure (from length data only) for a coastal Victorian population (O'Conner and Koehn 1991).	Isolated populations in many catchments.	Hammer (2004).
Mountain galaxias 2	Probably spawns in riffles. Recorded recolonising dry habitat **(Marne Catchment)**	Above may be applicable.	Isolated populations in many catchments.	Hammer in prep.

Table 9 continued….

Species	Flow relations	Demographic data	Population dynamics (refuges & recolonisation)	SA Source
Murray rainbowfish		Not reported.		
Smallmouthed hardyhead		Lifecycle model established for **Coorong.**		Molsher *et al.* (1994)
Murray hardyhead	Colonisation of newly flooded habitats - flow related variability and disturbance?	Appears to be an annual species (population monitoring at Victorian saline lakes: Ellis 2005).	Disjunct populations.	Wedderburn and Hammer (2003)
Unspecked hardyhead		Not reported.		
Chanda perch		Not reported for MDB.		
River blackfish	Remains only in areas of cool, well oxygenated and permanent habitat. Imersion of shallow litoral areas for juveniles **(EMLR)**.	Length-age relationships little reported, especially for 'northern' *marmoratus* (i.e. in MDB). Koehn *et al.* (1994) tracked a recruitment event over a year from autumn (coastal Vic.).	Highly restricted occurrence including several small refuges.	Hammer (2004, in prep)
Murray cod	Flood appears to promote enhanced recruitment.	Length age relationships developed (MDB) and reviewed with relation to **Lower Murray SA**.		Ye *et al.* (2000)
MD golden perch	Migratory. Flood appears to promote enhanced recruitment.	Length age relationships developed (MDB) and reviewed with relation to **Lower Murray SA**.	Immature fish (~1 yo) found to move upstream.	Reynolds (1983); Ye (2004)
Southern pygmy perch	Lateral connectivity - moved outward to avoid flood dislodgment (EMLR).	Seminal study including some ageing undertaken in northern Tasmania (Humphries 1995). Assessment of local patterns and comparison to Tas. undertaken **(EMLR).**	Highly restricted occurrence including several small refuges.	Hammer (2001, 2005)
Yarra pygmy perch	Occurs in areas of L. Alex with distinct water quality - possibly flow related in lower Finniss (e.g. tannin, regular flushing - water quality and silt removal).	Long-term assessment of demographic structure in **USE SA**, but no detailed biological investigation.	Occurs in small habitat pockets.	Hammer (2005).
Silver perch	Spawns during floods, river flow an important stimulus for Silver Perch migration (MDB).	Lenght age relationships developed (MDB).		
Congolli	Migratory - upstream and downstream movments.	Not reported in detail.		
Carp gudgeon	Congregations observed below instream barriers suggesting a migratory urge **(SE SA).**	Unstudied (note taxonomic confusion)	Occurs in small refuges in some catchments.	Hammer (2002)
Sth. purple-spotted gudgeon	?	Not reported MDB.	Prone to sudden appearance and disappearance **(Finniss SA).**	Hale (1928)
Flathead gudgeon	Low flow recruitment	Not reported.		
Dwarf flathead gudgeon	Low flow recruitment	Not reported.		
Western bluespot goby	?	Not reported.		
Lagoon goby	?	Not reported.		

4 Population Sustainability

A workshop held in September 2005 to address the conceptual modelling of fish population sustainability in the MLR identified a range of key life stages and associated several ecological parameters that were important to sustaining recruitment to each of these stages. Three life history stages were outlined, (1) adult, (2) larvae and (3) juvenile. Population sustainability depends on effective recruitment to and or survival of each of these stages (spawning being the recruitment process between adults and larvae). Food and habitat (physical and chemical) were identified as key components in supporting each of these stages, however, additional complexity was identified for the spawning phase. In particular, population parameters (sex ratios, adult pre-condition) and environmental cues (physical, chemical, flow) were seen as essential for adults to spawn effectively and for larvae to be produced and survive.

Whilst larval and juvenile phases are relatively short (usually complete within a single season), adults must survive until reproductively mature. This may take between one and three years depending on the species and requires that habitat, flow, food and water quality conditions must be maintained for longer periods of time. Therefore, there are varying management timeframes appropriate for different life history stages. Whilst short-term manipulation of flows may be necessary for sustaining spawning, recruitment to adult populations and survival to breeding age require long-term management of stream ecosystems.

The purpose of this section is to populate this generalised conceptual model for sustainability with species-specific information that exists for MLR fish species. Although different 'guilds' of fishes can be identified for fish species present in the MLR in regard to reproduction (Growns *et al.* 2004), life history (obligate freshwater, diadromous) and habitat specificity (wetland, riverine, and stream specialists or generalists), we will attempt to address species individually. This will allow us to gain a more detailed understanding of the particular scenario for each species. For example, although spring flows may be essential for the sustainability of all diadromous species in the MLR, the particular utility of spring flows is different between, for example lampreys (allowing adults to enter freshwater to breed) and common galaxias (allowing larval recruitment to adult habitats). It is anticipated that this approach will be better at informing prioritisation for management and future research than generalised models. As such, information will be collated within a sustainability matrix, as opposed to commonly used flow charts. This has greatly reduced the need for arrows within the present report.

Individual matrices are provided below for all fish species of the MLR (Figs 10A-Q) utilising biological information predominantly summarised previously (Figs 2-9). Knowledge gaps may be identified through empty boxes, or where the information is not comprehensive or inferred from interstate literature. In many cases, much or even all of the information provided on any topic may be wholly summarised from information gained outside of the MLR and is likely to require some level of verification for MLR populations. To this end, knowledge will be identified as: (1) no knowledge identified (black text), (2) requires verification for MLR (blue text), (3) low confidence or comprehensiveness (Maroon text). The complete absence of information indicates that no knowledge was detected within the literature used for the current review, however it must be acknowledged that some of information and data may exist within reports not included. Population models, demographic and temporal data sets, for both MLR and interstate data relevant to MLR species, are generally limited. The methods used for this review did not necessarily pick up these limitations, as they may not have been covered in the data sources. Hence, there is still a need for extra searching and collaboration with interstate researchers to obtain and incorporate unpublished and agency reports and data sets. It is anticipated that information contained in this review will be updated on an ongoing basis as part of the long term reporting for the MLR sustainability project.

The level of local verification required will vary for different parameters, for example, seasonal cues for seaward migration are likely to vary between eastern states and the MLR whilst structural habitat preferences are likely to vary less (this caution is repeated ad-nauseum throughout this report but is relevant across a range of concepts). A thorough review of fish ecology in streams of Mediterranean type climates is beyond the scope of this review, but would be of great value in understanding and developing patterns in local ecology and data (e.g. responses to disturbance, recolonisation and migration, exotic species invasion and persistence).

A summary of management and research priorities are outlined at the bottom of these species matrices based on the information presented. These priorities are intended to outline the principal issues that are likely to exist for each species in the MLR and to provide information regarding strategies for addressing these issues. It should be remembered that these priorities are somewhat subjective and do not exclude alternative prioritisation of research or management issues. As future knowledge gaps and management actions are addressed, these priorities are likely to change significantly and should also be updated regularly (as part of the long term monitoring project). It is anticipated that the priorities outlined below will allow the identification of some major or generally applicable research and management issues that will be addressed within the Discussion (Section 5.0). This information may be used to identify those management actions or research areas that may provide the strongest or broadest benefits to overall fish sustainability across the MLR fish species.

4.1 Native species matrices

Table 10A-J. Factors important for maintaining sustainable populations of key fish species of the MLR-model of interactive factors. [No knowledge identified (*blank*) (2) requires verification for MLR (*blue text*), (3) low confidence/comprehensiveness (*Maroon text*)]

	Reproduction	Recruitment	Adult Survival	
Pouched lamprey (*Geotria australis*)		Ammocoete larvae burrow into soft substrates and remain for ~3 years. Substrate organic material and chlorophyll related to burrow density.	Marine. Adults die in upstream reaches following spawning.	Food
	Adults migrate from sea in late winter-summer to spawn in headwater streams. Migration upstream may take up to 16 months. Nests in stony substrates.	Organic material and macrophytes important for burrowing phase, may be restricted to areas of permanent flow and high habitat quality. Migrate downstream to sea, late July after metamorphosis (Feb-July).	Spent adults die in freshwater following spawning. Parasitic phase is unknown, host fish are unknown	Habitat
		Temperature influences density of larval burrows. Ammocoetes very tolerant to hypoxia. Intolerant of very high temperatures (30oC+)	Marine	Water Quality
	Spawning occurs in higher flow headwaters Oct-Nov. Adults may not be able to migrate upstream through extremely turbulent water.	Prefer lower flow habitats for burrows.	Marine	Flow
	Barriers to upstream migration. Loss/deterioration of upstream spawning sites.	Loss of burrowing habitat. Reduced organic input (riparian vegetation) and macrophytes, increased temperatures around burrowing sites, i.e. Deforestation and flow alteration	Loss of adult marine host species. Survival through upstream spawning migration.	Key Threats

Research	Targeted species research: (1) radio tracking of adult upstream migrants to identify instream barriers, spawning sites and larval nests. (2) Assessment of larval nesting habitats, extent and condition. (3) Identify specific target flows for migration. (4) Investigate marine parasitic phase, host species abundances etc. (4) Impact of climate change.
Management	(1) Removal of migrational barriers. (2) Environmental flow programs for larval habitat and provision of appropriately timed flows for spring/summer migrations to/from the sea.

	Reproduction	Recruitment	Adult Survival	
Shorthead lamprey (*Mordacia mordax*)	Larvae (Ammocoete) burrow into sand or silt in lower flow areas of streams and rivers.		Feed parasitically on marine fish for 1-2 years. Burrow in sand when not feeding.	**Food**
	Adults move into freshwater (late winter-summer) to spawn. Have a strong climbing ability. Utilise burrows & stony substrates during daylight and migrate upstream at night. Nests in sand, gravel or pebble substrates.	Ammocetes occur in perennial, high quality habitat (e.g. sound riparian and instream structre). Downstream migrants move to the sea Aug-Nov.	Marine. Spent adults die in freshwater following spawning.	**Habitat**
	Increased temperature stimulates migration into freshwater. Wide range of salinity tolerance.	Larvae are unable to survive salt water.	Marine.	**Water Quality**
	Reduced flows stimulate migration into freshwater. Spawning occurs in higher flow headwaters.	Require permanent habitats. Downstream migration associated with high river flows.	Marine.	**Flow**
	Barriers to upstream migration	Barriers to downstream migration	Reduced stocks of marine host species.	**Key Threats**

Research	Targeted species research: (1) radio tracking of adult upstream migrants to identify instream barriers, spawning sites and larval nests. (2) Assessment of larval nesting habitats, extent and condition. (3) Identify specific target flows for migration, (4) Investigate adult parasitic phase, host species abundance impacts etc. (4) Impacts of climate change.
Management	(1) Removal of migrational barriers. (2) Environmental flow programs for larval habitat and provision of appropriately timed flows for spring/summer migrations to/from the sea.

	Reproduction	Recruitment	Adult Survival	
Shortfinned eel (*Anguilla australis*)			Carnivorous, fish, insects, crustaceans, molluscs etc.	**Food**
	Downstream migrations in spring/summer/autumn to the Coral Sea for Mass spawning.	Migration of juveniles along SE coast and into freshwater. Mass migration of glass eels upstream into adult habitats all year, specific to region (i.e. winter in Tas, spring summer on mainland).	Wetlands, swamps, creeks, streams. Adults live 10-20years. Reproduce once only in marine habitats.	**Habitat**
	12°C triggers spawning runs.		Tolerant of high salinity, temperature, turbidity and low oxygen.	**Water Quality**
	Downstream adult migration triggered/assisted by high flows.	High flows inhibit upstream migration.	Utilise a range of flow conditions.	**Flow**
	Migrational barriers, predation of juveniles.	Migrational barriers, predation of juveniles.	Migrational barriers, predation of juveniles.	**Key Threats**

Research	(1) Establish endemicity and distribution across MLR. (2) Recruitment to Murray mouth and to WMLR streams (ocean current patterns, cues, barriers etc). (3) Water quality and flow impacts on elver upstream migration.
Management	(1) Establish endemicity and distribution. (2) Removal of migrational barriers.

Freshwater catfish (*Tandanus tandanus*)	Reproduction	Recruitment	Adult Survival	
		Juveniles feed on zooplankton and insect larvae, especially chironomids.	Benthic carnivores. Eat carp gudgeons, shrimp, molluscs, worms and a wide range of aquatic and terrestrial insects and insect larvae.	**Food**
	Circular nests built into gravel or course sand, often amongst dense macrophyte beds late spring-summer. Nests 0.6-2.0 meters in diameter.	Juveniles probably remain close to adult habitats, no migrational movements for spawning.	Found sluggish waters and lakes, associated with aquatic vegetation. Remain within confined reach as adults. Sexual maturity at three years.	**Habitat**
	Adults aerate eggs within nests.		Inhabit turbid streams. Tolerate very high, but not low temperatures.	**Water Quality**
	Rise in flow may induce spawning. If low flows expose nest it is abandoned.		Utilise low flow habitats.	**Flow**
	Destruction of eggs in nests through water quality or predation of eggs/ larvae.	Loss of macrophyte cover. Predation.	Loss of macrophyte cover. Cold water pollution. Potential competition with exotic carp.	**Key Threats**

Research	(1) Determine impacts of sedimentation, water quality and predation on eggs in nests. (2) Dependence of larvae and juveniles on macrophytes and related food sources, competition and predation. (3) Impact of flow on spawning and recruitment.
Management	Rehabilitation of slow flow areas and macrophyte cover (lower EMLR streams and wetlands). Introduced Torrens population ideal study candidate for threatened Murray species.

	Reproduction	Recruitment	Adult Survival	
Bony herring (*Nematalosa erebi*)			Omnivorous, algae, insects, crustaceans & detritus.	**Food**
	Spawn in schools in shallow backwaters in spring and summer. Mature after 1-year high number of small eggs.	Smaller fish in littoral habitats.	Open water schools (large masses), lowland rivers and wetlands.	**Habitat**
	At least 20^{o}C.	At least 28^{o}C. Die on mass under low temperatures.	Linked to turbid waters. Up to 38^{o}C. Considered tolerant. Sensitive to cold water.	**Water Quality**
		Larvae found in backwaters and fast flowing anabranches.	Schools in moderately flowing or still waters.	**Flow**
			Highly abundant key species for supporting riverine food webs.	**Key Threats**

Research	(1) Spawning behaviour, habitats, (2) Water quality tolerance of adults, eggs and larvae (3) Role within riverine food webs- importance as a food source for cod, callop, cormorants, pelicans etc.
Management	Do well under current management in Murray

Smelt (*Retropinna semoni*)	Reproduction	Recruitment	Adult Survival	
			Zooplankton, especially cladocerans.	**Food**
	Spawn in Spring scattering eggs over streambed and/or aquatic vegetation. Adults reproductive within 1 year.	Backwaters, billabongs, littoral riverine habitats.	Large pelagic schools in open water. Use billabongs, wetlands and main river channels. Adults survive for 2+ years. Widespread within coastal and inland SE-Aus (but many species).	**Habitat**
	15-18^{o}C		May use salt water. Tolerate turbidity, salinity over 8800mg/l. Sensitive to severe hypoxia, disappear from environmentally harsh billabongs over summer. Tolerate <28^{o}C	**Water Quality**
	Spawning success independent of flooding. Larvae may be washed to sea.	Schools of juveniles migrate upstream in response to small flow increases. May be diadromous populations in EMLR.	Found in still and fast flowing waters.	**Flow**
	Predation, migratory barriers.	Predation, migratory barriers.	Predation, migratory barriers.	**Key Threats**

Research	(1) Habitat use, water quality tolerance of eggs & larvae. (2) Does migration exist for smelt in the EMLR?
Management	Do well under present management regime in Murray.

	Reproduction	Recruitment	**Adult Survival**	
Climbing galaxias (*Galaxias brevipinnis*)	Pelagic larvae feed at sea or in lakes.		Aquatic & terrestrial invertebrates	**Food**
	Adults migrate to estuaries to spawn, upstream into tributaries in lakes during autumn-winter. Marine (lacustrine) following hatching. Stay at sea for 6 months.	Migration upstream from the sea or lakes landlocked populations. Enter stream mouths on rising tides after ~6months during spring.	Prefer flowing rocky or silt based pools and riffles. Prefer good riparian vegetation and stream canopy.	**Habitat**
		Migrating juveniles will avoid high turbidity. (BDWD)	Prefer cooler temperatures. Data deficient.	**Water Quality**
	Spawn during high flow events in flooded estuaries-tributaries. Eggs laid on banks above limits of regular stream flow.	Connectivity required in spring–summer for larvae and juveniles re-entering freshwater. Can overcome barriers to migration such as weirs, falls etc.	Prefer lower flows when predation is absent.	**Flow**
	Riparian vegetation removal.	Predation and habitat restriction in prime habitats by redfin and trout.	Predation and habitat restriction in prime habitats by redfin and trout.	**Key Threats**

Research	(1) Assessment of local species biology: [(a) Identify distribution in MLR (b) Identify spawning sites, habitat requirements, timing & behaviours for MLR (assess landlocked populations and use of MLR reservoirs for spawning) (c) Assess timing and duration of flows for spawning and recruitment/migration (landlocked and sea-run) (e.g. does diadromy still exist in the MLR)]. (2) Impacts of climate change.
Management	(1) Promote research. (2) Removal of instream barriers/restoration of estuarine linkages. (3) Protection/restoration of instream and riparian habitat. (4) Environmental flows for spawning and migration.

Common galaxias (*Galaxias maculatus*)	Reproduction	Recruitment	Adult Survival	
	Feed at sea. Pelagic larvae.	Cease feeding during inland migration. Resume feeding in freshwater after reaching adult habitat	Benthic and drift feeders, insects, crustaceans & molluscs, some surface animals.	Food
	Adults move down to estuaries to spawn during autumn. Landlocked populations may use large lakes in a similar manner and move upstream into tributaries to spawn in groups of 2-4. Eggs laid on bank vegetation in estuaries or tributary streams (landlocked).	Larvae will live in marine habitats for 5-6 months before re-migrating to adult habitats as whitebait	Found at lower elevations. Adults are found in streams, rivers and wetlands Can survive in small pools largely bereft of structure (apart from benthic interstices) over summer. Survival to spawning needs to be 1, 2 or 3 years, adults usually die after spawning.	Habitat
	Eggs tolerate wide range of salinity and temperature.	Migrating juveniles will avoid high turbidity.	Relatively tolerant to wide ranges in salinity, temperature, oxygen & turbidity. Preference for temperatures around 20^{o}C.	Water Quality
	Connectivity between freshwater and marine habitats is required during spawning period. Larvae carried out to sea/lakes in floodwaters. Reproduction timed with moon phase and tidal patterns. Eggs left on exposed vegetation in first flood/high tide and require a second inundation of bank vegetation. Eggs hatch on re-immersion.	Connectivity between freshwater and marine habitats is required during spring when juveniles migrate upstream. Larvae utilise high flows and associated chemical cues to select rivers for re-entry to freshwater in shoals during high tide in daylight. Juveniles can migrate under high flow velocities and will use fishways and ramps. (Davies *et al.* 2003)	Adults require refuge pools with reasonable water quality to persist over summer.	Flow
	No connectivity between marine and freshwater habitats.	No connectivity between marine and freshwater habitats.	Predation in prime habitats, desiccation of refuge riffles.	Key Threats

Research	(1) Investigate impact of barriers and use of fishways (2) Determine spawning & migration patterns for MLR. (3) General biology such as determined length-age relationships.
Management	(1) Removal of instream barriers/restoration of estuarine linkages and lowland stream habitat. (2) Provision of autumn/spring flows reaching the sea to facilitate spawning and larval recruitment including migration.

	Reproduction	Recruitment	Adult Survival	
Mountain galaxias (*Galaxias olidus*)			Aquatic insects, crustaceans, molluscs, worms, spiders.	Food
	Adults (1+) may move upstream toward headwaters to spawn in winter-spring but possibly all year round. Eggs are laid around adult habitat beneath rocks. Larvae persist in adult habitats. (Possibly paired mating units??)	Juveniles recruited direct to adult habitats. Movement is restricted to small local ranges.	Adults survive within small pools and riffles where trout & redfin are absent. Associated with riparian vegetation and instream habitat, leaf litter, debris, macrophytes and cobbles. Can persist in larger pools released from predation in ephemeral streams with little structural habitat.	Habitat
			Can tolerate moderately high and very low temperatures and poor water quality (fatal to trout). Data deficient (e.g. no temperature or oxygen upper limits known).	Water Quality
			Prefer more permanent flowing water or pools with good water quality. Some populations appear to prefer high flow-riffle habitats.	Flow
	Siltation, reduced leaf litter (riparian deforestation), loss of riffle habitats resulting from flow modification.	Predation of recruits to prime habitats such as larger pools.	Habitat restricted by predation. Loss of riffle habitats due to flow regulation. Clearing of riparian vegetation. Predation by trout and redfin perch.	Key Threats

Research	(1) Determine distribution, taxonomic status and genetic uniqueness of different populations. (2) Undertake research on local biology, especially (a) flow relationships for spawning and recruitment and (b) juvenile and adult tolerances. (3) Impacts of climate change. (4) Assess predation impacts.
Management	(1) Promote research on biology and environmental relationships (2) Reduce predation impacts in larger streams (3) maintain/enhance habitat values in headwater streams (4) Restoration of lowland stream reaches (i.e. Lower Onkaparinga/tributaries)

Murray rainbowfish (*Melanotaenia fluviatilis*)	Reproduction	Recruitment	Adult Survival	
	Eggs laid on macrophytes Oct-Jan.		Insects, micro crustaceans, algae	**Food**
	Aquatic macrophytes. Larvae attach to plants before free swimming.	Larvae found in weir pools, flowing creeks and shallow ponds.	Pelagic schooling <30 individuals. Prefer clear water, low flow and sunlight. Associated with thick vegetation and habitat complexity.	**Habitat**
	Warming of shallow floodwaters implicated in spawning initiation. Eggs and fry tolerant of high salinity.	<28°C. Moderately salt tolerant.	Cold water pollution results in fungal and bacterial infections. Avoid murky water. Tolerant of warm temperatures <28°C. Tolerant of very high salinity.	**Water Quality**
	Low flow.	Low flow.	Avoid fast flowing waters. Prefer backwaters, billabongs and wetlands.	**Flow**
	Destruction/loss of macrophyte habitats, loss of warm water habitats.	Destruction/loss of macrophyte habitats, loss of warm water habitats.	Destruction/loss of macrophyte habitats, loss of warm water habitats.	**Key Threats**

Research	(1) Interactions with other species, native and introduced. (2) Reasons for decline in EMLR.
Management	Translocation impacts within the MLR.

Smallmouthed hardyhead (*Atherinosoma microstoma*)	Reproduction	Recruitment	Adult Survival	
			Small crustaceans and insects.	**Food**
	Submerged structures and macrophytes.	New recruits found in October.	Mostly estuarine, will inhabit coastal lakes and lagoons. Form large schools. Associated with macrophyte beds (especially *Zostera*). Life cycle probably only 1 year.	**Habitat**
			Supposedly intolerant of freshwater but found in freshwater habitats.	**Water Quality**
				Flow
	Destruction of estuarine habitats (i.e. Murray Estuary).	Destruction of estuarine habitats (i.e. Murray Estuary).	Destruction of estuarine habitats (i.e. Murray Estuary).	**Key Threats**
Research	(1) Investigate use of and distribution within freshwater habitats. (2) Determine the impact of the loss of estuarine habitat on the species.			
Management	Do well under current management in Murray and Adelaide region.			

Murray hardyhead (*Craterocephalus fluviatilis*)	Reproduction	Recruitment	Adult Survival	
	Spawning in January-February in lake and floodplain habitats.			**Food**
	Assumed to be in macrophyte beds.	Larvae found in lake margins and low flow floodplain habitats.	Lower Lakes wetlands, salt lakes and floodplains, especially in well vegetated areas. Some adults in river channel and higher flow habitats.	**Habitat**
		Tolerant of very high salinity.	Tolerant of high salinity.	**Water Quality**
	Predominantly low flow habitats.	Predominantly low flow habitats.	Predominantly low flow habitats.	**Flow**
	Destruction/alteration of wetland and floodplain habitats. (e.g. loss of ephemerality).	Destruction/alteration of wetland and floodplain habitats. (e.g. loss of ephemerality).	Destruction/alteration of wetland and floodplain habitats. (e.g. loss of ephemerality).	**Key Threats**

Research	(1) Basic biology and population dynamics with respect to submerged macrophytes and water quality (Lower Lakes wetlands). (2) Impacts of introduced predators. (3) Reasons for decline in Lower Finniss River.
Management	(1)Maintenance of wetland and low flow habitats. (2) Carefully monitored habitat restoration programs.

Unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*)	Reproduction	Recruitment	Adult Survival	
	Larvae feed immediately on spawning.	Form schools appearing Sept-March		**Food**
	Spawn from Oct-Feb in warm water (<23°C) amongst macrophyte beds, sand, gravel or rocks	In schools or amongst macrophytes.	Lowland rivers, lakes, wetlands and billabongs, schooling in open water adjacent to macrophyte beds.	**Habitat**
		Tolerant of very high temp (<38°C)	Tolerant of high temperature (<38°C) and salinity 61,000+).	**Water Quality**
		Inhabit low and high flow areas but predominantly low flow.	Inhabit low and high flow areas but predominantly low flow.	**Flow**
				Key Threats

Research	Basic biology and recruitment.
Management	Does well under current management of the Murray.

Chanda perch (*Ambassis agassizii*)	**Reproduction**	**Recruitment**	**Adult Survival**	
			Micro-crustaceans and insects.	**Food**
	Spawn in spring-summer probably over macrophyte beds or structure.		Very rare, large population decline. Utilise a wide range of habitats, associated with habitat structure such as macrophytes, woody debris. Form stationary schools around cover.	**Habitat**
	Spawning occurs <23°C.		Probably tolerant of low oxygen and high temperature.	**Water Quality**
	Spawn in low flow habitats but associated with summer water level rises.		Inhabit slow flowing floodplain habitats and rivers/creeks.	**Flow**
	Probably extinct locally.	Probably extinct locally.	Probably extinct locally.	**Key Threats**

Research	(1) Continue to examine presence within the MLR. (2) Determine factors involved with (likely) extinction (i.e. predation, habitat loss etc). (3) Basic life history and biology (collaborative with interstate agencies). (4) Determine impacts and effectiveness of re-introduction to MLR (including genetic comparison to donor sources from local historic material)
Management	(1) Feasibility and risk assessment for possible translocation to restore populations in the MLR. (2) Restoration/preservation of floodplain habitats. (3) Predator control.

River blackfish (*Gadopsis marmoratus*)	**Reproduction**	**Recruitment**	**Adult Survival**	
			Adults feed on small fish and invertebrates, especially yabbies.	**Food**
	Reproduce at 1-4 years during spring-summer. Spawn in pairs with eggs laid in guarded 'nests' inside hollow logs, between boulders etc. Low fecundity.		Benthic and nocturnal, with limited home ranges in pools and rivers (occasionally billabongs). Associated with structure (emergent vegetation, woody debris, undercut banks, rocks).	**Habitat**
	Spring rise in water temperature triggers spawning.		Prefer higher water quality habitats. Data deficient.	**Water Quality**
	Eggs laid in low-0 velocity sites.	Juveniles present in moderately flowing habitats, potentially using low flow microhabitats such as leaf litter, emergent vegetation, and rock interstices.	Adults present in low-moderately flowing habitats, avoid high velocities. Require reasonable flows to maintain habitat permanency and water quality.	**Flow**
	Loss of flow and deterioration in water quality. Loss of woody debris, siltation of spawning sites or nests. Low fecundity likely to slow recovery from impacts.	Predation by trout or redfin. Sedimentation known to kill juvenile fish. Restricted home range impedes wide recolonisation during higher flows.	Desiccation of refuge habitats. Poor water quality due to reduced flows. Strong competition for space and food from introduced trout and redfin.	**Key Threats**

Research	(1) Research local species biology – recruitment processes, tolerances, demographic relationships. (2) Identify and map key areas for targeted flow restoration. (3) Undertake research on hydrology at positive sites. (4) Ongoing monitoring and distribution mapping (e.g. Onkaparinga Catchment, southern Fleurieu).
Management	A priority species for management. (1) Restoration of stream flows essential for maintaining/restoring habitat range and water quality (i.e. restrict or reduce water abstraction from key reaches). (2) Restoration of structural habitat especially hollow logs and stream banks for spawning. (3) Reduce predation pressure/competition from introduced species. (4) Development of emergency contingency plans for highly restricted populations.

	Reproduction	Recruitment	Adult Survival	
Murray cod (*Maccullochella peelii peelii*)	Copepods and cladocerans for larvae.	Flood born food items important for larvae/juveniles. Chironomid and other insect larvae for juveniles.	Fish, large insect larvae, birds, eggs, lures.	**Food**
	Spawning migrations occur in late winter/early spring. Eggs deposited on a range of substrates and structures, Sept-Feb. Adults return downstream to home sites following spawning. Male guards nest (data deficient for MLR)	Larvae recorded spring and summer in main channel.	Flowing waters, around woody debris, possibly preferring hollow snags. Maturity takes 4-5 years.	**Habitat**
	Rising temp triggers spawning		Found between 10-37^{o}C, moderately tolerant of salinity, potentially intolerant of low oxygen.	**Water Quality**
	Elevated flows trigger spawning migration (with temp increase).	Floodwaters thought to provide food for larval/juvenile development	Found in sluggish flowing water but require some flow. Will move out of drying pools if drawdown is gradual.	**Flow**
	Loss of hydrologic variation through regulation. Loss of spawning structures such as woody debris.	Flood born food sources reduced through river regulation.	Habitat degradation, especially snags, water quality problems and geomorphic changes (loss of pool depth).	**Key Threats**
Research	(1) Water quality tolerances 2) Larval food/habitat requirements and recruitment. (3) Biological requirements for small stream populations.			
Management	(1) Restoration of woody debris habitats 2) Provision of appropriately timed flows (3) Removal of migratory barriers 4) Feasibility study and risk assessment for reestablishment in Bremer River. (5) Controls on new introductions within and outside natural range (to prevent ecological and genetic impacts).			

Species	Reproduction	Recruitment	Adult Survival	
Murray-Darling golden perch (*Macquaria ambigua*)	New larvae feed on zooplankton after 5 days.	Insect larvae and crustaceans	Insect larvae and crustaceans small fish.	**Food**
	Extensive upstream migrations for spawning occur Sept-Dec. Spawning occurs Spring –March in still backwaters and floodplains. Post spawning migrants move downstream in Autumn-Winter.	Pelagic larvae swept downstream. Juveniles found in anabranches and inundated floodplains/backwaters. Associated with macrophyte beds. Juveniles migrate into upstream habitats.	Found in rivers, anabranches and floodplain habitats (preferring larger billabongs). Utilise large woody debris. Lower Reaches of Finniss, Bremer, Marne.	**Habitat**
	Temperature increases trigger spawning migrations. Young fish impacted by poor water quality such as low oxygen and high dissolved organic carbon.		Tolerant of moderately high salinity and temperature conditions.	**Water Quality**
	High flows and floods trigger spawning migrations. Eggs and larvae drift on downstream currents. Attractant flows for movement into EMLR habitats?	Larvae swept with flow downstream but juveniles found to move back upstream utilising small rises in flow level.	Found in rivers and anabranches over a range of flow conditions with a preference for lower flows.	**Flow**
	Barriers to spawning migration. Destruction of eggs/larvae going over weirs/through structures.	Barriers for dispersal and movement of young recruits back into upstream areas. Lack of flow variation for juvenile movement and recruitment to upstream areas.		**Key Threats**

Research	(1) Use of MLR streams and wetlands for spawning and juvenile development. (2) Population response to resnagging/habitat restoration. (3) Otolith microchemistry to determine origin of if fish in Bremer River.
Management	(1) Removal of migratory barriers, (2) Restoration of appropriate flows to encourage natural return to EMLR habitats. (3) Restoration of woody debris habitats (4) Impact of translocated populations in WMLR. (5) Controls on new introductions within and outside natural range (to prevent ecological and genetic impacts).

	Reproduction	Recruitment	Adult Survival	
Southern pygmy perch (*Nannoperca australis*)		Zooplankton-crustaceans.	Aquatic and terrestrial insects and crustaceans. Predominantly benthic invertebrates or plant epifauna (Humphries 1995).	**Food**
	Spawning occurs over structure (vegetation, leaf litter) or substrate Sept-Jan. Spawning occurs over short bursts of 3-4 days but may have many events/season. Prefer open water or macrophyte habitats once hatched. Low fecundity.	Direct to adult habitats.	Adults prefer slower flowing areas such as stream pools or billabongs and wetlands. Associated with macrophytes and woody debris.	**Habitat**
	Temperatures above 16°C associated with spawning.		Inhabit very harsh, shallow pools. Limited salinity tolerance.	**Water Quality**
	Spawning occurs in low-0 flow.	Require flow dependant riparian macrophyte habitat.	Prefer low flow habitats; require connectivity for dispersal and recolonisation. Will disperse widely and recolonise floodplains during flood events. Require flow dependant riparian macrophyte habitat.	**Flow**
	Destruction of instream habitat. Flow regime change, especially habitat drying. Low fecundity may slow population responses.	Loss of lateral connectivity and linkage to riparian vegetation, loss of macrophyte and riparian cover and diversity and competition from mosquitofish, predation from redfin perch and trout.	Flow regime change, particularly habitat loss (especially unnatural drying). Competition from mosquitofish, predation from redfin perch and trout, heightened by loss of submerged structure and riparian cover	**Key Threats**
Research	(1) Response to environmental flows (loss and gain) & habitat restoration (2) Impact of predation (especially redfin) (3) Egg & larval habitat & water quality tolerance.			
Management	(1) Restoration of environmental flows, especially low flows and base flow (habitat presence and quality, flow regime suitable for macrophytes) (2) Maintenance/restoration of refuge pool habitats (3) Control of introduced predators in refuge reaches.			

	Reproduction	Recruitment	Adult Survival	
Yarra pygmy perch (*Nannoperca obscura*)			Carnivorous-small invertebrates.	**Food**
	Sept-Oct, eggs scattered over submerged vegetation.		Streams, swamps, lakes and wetlands, in sheltered sections amongst dense macrophytes.	**Habitat**
	Spawns between 16-24°C.		Occur in fresh and brackish waters.	**Water Quality**
			Found in slow flowing or still water habitats. In areas with regular flow (e.g. stream discharge or through flow) (Lower Murray)	**Flow**
			Lowered water levels and loss of wetland habitat due to low to nil Murray inflows. Loss of wetland habitats, especially macrophyte beds. Loss of wetland processing due to river regulation. Predation by redfin.	**Key Threats**
Research	(1) Basic life history and biology, environmental tolerances etc. (2) Determine essential wetland habitat characteristics, especially factors governing submerged macrophyte density in wetland habitats.			
Management	(1) Develop action/recovery plan to address immediate (e.g. predation, habitat drying Lower Lakes) and longer term risks. (2) Promote investigation of this poorly known, but nationally threatened species (2) Determine population status and sustainability. (3) Identify key threats.			

	Reproduction	Recruitment	Adult Survival	
Silver perch (*Bidyanus bidyanus*)		Floodplains provide zooplanktonic food source for larvae/juveniles.	Aquatic insects, molluscs, worms and algae.	**Food**
	Spawning migration upstream October -April	Juveniles migrate upstream, downstream and laterally. May use floodplain habitats.	Main river channels, anabranches and big floodplain lakes. Associated with macrophytes.	**Habitat**
	Warmer temperatures trigger migrations (with flow rise). Spawning occurs in flooded backwaters. Larvae require moderate salinity for survival.	Wide range of temperature tolerance. High salinities lethal.	Tolerate moderate salinities and oxygen.	**Water Quality**
	Spawning migrations follow peak floods.	Small rises in water level trigger juvenile movements.	A range of flow conditions, potentially prefer lower flowing/sluggish waters.	**Flow**
	Barriers to spawning migration, loss of spawning cues due to river regulation.	Barriers to recruitment into adult habitats.		**Key Threats**
Research	(1) Identify threatening processes (2) Identify spawning habitats and population structure/recruitment within the EMLR.			
Management	(2) Removal of migratory barriers. (2) Restoration of appropriately timed flows for migratory facilitation.			

Congolli (Pseudaphritis urvilii)	Reproduction	Recruitment	Adult Survival	
				Food
	Females reproduce ~ 4-6 years old. Spawning takes place around estuaries-marine habitats in August-October (although observed spawning in May in the Onkaparinga 2006). Males present around estuary and lower stream reaches.	Juveniles remain around tidal zone for 9-12 months and gradual move upstream in spring-summer.	Male-female habitat separation. Males remain around estuaries with females utilising lowland freshwater habitats (decreasing upstream). Prefer slower flowing waters with general habitat preferences.	Habitat
	Tolerant of salt and fresh water	Tolerant of salt and fresh water	Tolerant of salt and fresh water, utilise low water quality habitats.	Water Quality
	High flow induces downstream migration of females to estuaries in April-July. Males move into estuarine fringes away from freshwater flow influence.	Low flows stimulate upstream migration of juveniles.	Prefer slower flows, limited ability for dealing with high velocity flows.	Flow
	Removal of connectivity between freshwater and estuarine habitats. Flows essential for breeding, reconnecting males with females.	Loss of connectivity between freshwater and estuarine habitats.	Desiccation of lowland freshwater reaches will remove females.	Key Threats

Research	(1) Research on biology – identify spawning behaviour/biology, migration, habitat requirements and flow requirements in MLR (2) Identify population structure and habitat use for males versus females (3) Assess their use of fishways and swimming ability.
Management	(1) Removal of instream barriers/restoration of estuarine linkages. (2) Restoration of lowland stream reaches (i.e. Lower Torrens/Break Out Creek).

	Reproduction	Recruitment	Adult Survival	
Carp gudgeon (*Hypseleotris spp.*)			Zooplankton, insect larvae, especially chironomids.	**Food**
	Deposit eggs on aquatic vegetation and twigs during summer in littoral areas, backwaters, wetlands and billabongs. Male builds and guards nest.	Found in low flow habitats. Some migration upstream occurs in rivers and anabranches after moderate inundation of floodplain.	Highly abundant in lakes, backwaters, anabranches, billabongs and rivers especially where physical structure and aquatic macrophytes are present/abundant.	**Habitat**
	Spawn above 21°C. Eggs vulnerable to low oxygen.		Tolerant of low oxygen, moderately high temperature and salinity.	**Water Quality**
	Utilise low flow areas.	Upstream migration in response to flows.	Prefers low flow habitats but present also in higher flow areas.	**Flow**
	Loss of floodplain habitats and macrophytes.	Loss of floodplain habitats and macrophytes.	Loss of floodplain habitats and macrophytes. Introduced predators i.e. redfin.	**Key Threats**
Research	(1) Taxonomic resolution providing targeted ecological studies, (2) Trophic importance, role as food source for larger native fish. (3) Impact of introduced predators especially redfin.			
Management	(1) Environmental flows and habitat protection in EMLR streams. (2) Assess the impact of translocated populations into the MLR			

Southern purplespotted gudgeon (*Mogurnda adspersa*)	Reproduction	Recruitment	Adult Survival	
	Zooplankton	Zooplankton, insect larvae.	Ambush predator, feeds on small fish, worms, insect larvae.	**Food**
	Spawn in Spring-Summer on rocks, debris and macrophytes.		Low flow habitats associated with dense macrophyte beds or riparian structure. Historically present in pool habitat with submerged aquatic vegetation.	**Habitat**
	Spawn between 20-34°C.		Tolerant of moderately high salinity and temperatures. Appear to be inactive in winter.	**Water Quality**
	Fry unable to actively swim.		Prefer slow flowing habitats.	**Flow**
			Loss of macrophyte habitats, altered flow, introduced predators (i.e. redfin). Mostly unknown but have certainly occurred resulting in widespread extinction.	**Key Threats**

Research	(1) Continue to examine distribution of species in lower Murray and MLR. (2) Assess key threats/requirements and the potential for rehabilitation/re-introduction of species. (3) Assess the impact of introduced mosquitofish and redfin perch
Management	(1) Assessment of translocation potential back into MLR including genetic comparison to local and source populations. (2) Feasibility study and risk assessment for reestablishment in Finniss River

	Reproduction	Recruitment	Adult Survival	
Flathead gudgeon (*Philypnodon grandiceps*)			Sit and wait predator	**Food**
	Egg clusters attached to structure and guarded/fanned by males.	Larvae are facultative drifters recruiting direct to adult (low flow) habitats.	Adults are predominantly benthic and widely distributed in slower flowing pools, runs, estuaries and wetlands. Emerge from cover (rocks/vegetation) after dark. May be favoured by river regulation and degredation.	**Habitat**
			Will persist in low water quality habitats, tolerant of high temp & salinity and low O2.	**Water Quality**
		Some recruitment variability at large scales, may not recruit well in high flows.	Prefers low flow habitats.	**Flow**
	Predation by redfin perch, competition & predation with mosquitofish	Predation by redfin perch.	Predation by redfin perch, desiccation of refuge pools or removal of refuge habitats.	**Key Threats**

Research	(1) Assess general biology, habitat use, spawning and feeding ecology (2) Investigate impact of predation
Management	(1) Reduce impact of predation (2) Restoration of stream habitats

Dwarf flathead gudgeon (*Philypnodon* sp.)	Reproduction	Recruitment	Adult Survival	
				Food
			Pools or low flow areas in streams and wetlands. Often found near emergent macrophytes on mud, silt or rocky substrates.	**Habitat**
			Utilise similar habitats to the highly tolerant *P. grandiceps*.	**Water Quality**
			Seem to prefer lower flow habitats such as pools.	**Flow**
	Lack of species knowledge.	Lack of species knowledge.	Lack of species knowledge.	**Key Threats**

Research	(1) Assess the endemicity of this species to MLR (i.e. possibly translocation via Murray pipeline) (2) Assess general biology, habitat use, spawning and feeding ecology
Management	(1) Restoration of stream habitats (2) Reduce translocation potential from inter-basin pipelines.

	Reproduction	Recruitment	Adult Survival	
Western bluespot goby (*Pseudogobius olorum*)				**Food**
	Spawns in upper reaches s of estuary in brackish water. Spawn in early-late spring laying eggs beneath solid structure, male guards nest.		Estuaries and coastal lakes and wetlands, associated with abundant macrophytes. Occurs inland in the North Para system. Benthic on muddy or rocky substrates.	**Habitat**
			Can tolerate fresh and saline water.	**Water Quality**
				Flow
			Reduced quality of estuarine areas. Loss of permanent pool habitats in North Para (e.g. decline in the condition and pool permanency of Walker Creek)	**Key Threats**

Research	(1) General biology and life history, abundance and distribution
Management	(2) Protect inland habitat in North Para Catchment

	Reproduction	Recruitment	Adult Survival	
Lagoon goby (*Tasmanogobius lasti*)				Food
	Spawns in estuaries, probably beneath structures.		Estuaries and coastal lakes and wetlands, benthic on sandy or rocky substrates.	Habitat
				Water Quality
				Flow
				Key Threats
Research	(1) General biology and life history, abundance and distribution (2) Assesses and determine presence in WMLR (e.g. confirm unverified records from Patawalonga Creek.			
Management				

4.2 Priorities for maximising sustainability

A number of key management recommendations were presented as part of the species sustainability matrices above. These recommendations are made to assist in the prioritisation of management actions targeting specific species although it is understood that not all actions, or indeed species are a management priority within the MLR. These recommendations however, can collectively suggest some general areas toward which management priority may provide outcomes for a range of species and therefore promote the sustainability of a range of native fish populations.

Overall, five key points were commonly identified as a priority management concern across a number of native species. Of the 29 species/groups outlined above, the most generally applicable management priority identified concerned habitat rehabilitation, which was identified for 12 species. The restoration of appropriate flow regimes was a priority for 10 species. The removal of migratory barriers was identified as a key management priority for 9 native species. Predation from introduced fishes was identified as a key management concern for 7 native species, and the issue of translocation (either as a management option to promote species sustainability or as an impact through the past translocation of native species) identified for six.

It is appropriate that each of these management priorities be addressed briefly:

Habitat Rehabilitation: This applies to a range of rehabilitation actions that include the restoration of instream and riparian vegetation communities, the maintenance of stream pools and low flow refuges and the restoration of physical structures such as snags, hollow logs and benthic structure (e.g. rocky interstices, leaf litter etc). Human landscape alteration for agriculture and urban development has resulted in the loss of much of the complex habitat structure that native fish rely on for various stages of their life history. Complex habitat structure can be essential for spawning, predator avoidance, feeding and the maintenance of appropriate water quality, all of which are essential components of species sustainability. The rehabilitation of stream habitats is in its infancy in SA, although recent interstate efforts have begun to identify the most important and cost effective methods for maximising ecosystem benefits provided by rehabilitation investment. Although this is an emerging science investment in habitat rehabilitation is likely to have a broad benefit to native fish populations, particularly if works are targeted towards specific habitats for specific fish species. NRM boards, as well as emerging management groups such as the Torrens Taskforce' are in a position to prioritise and direct restoration investment within target catchments.

Removal of migratory barriers: Native fish were divided into two classes under this priority, each of which has different implications for the MLR. One class is a suite of Murray-Darling freshwater obligates that undergo large-scale migrations along the main river channel of up to 1000kms. This involves both upstream and downstream movement of adults, downstream carriage of eggs and larvae and subsequent recruitment migrations of juveniles into adult habitats, in both directions as well as laterally into anabranches, wetlands and floodplain habitats. This issue is largely acknowledged under the Living Murray Initiative and the Native Fish Strategy under the Murray Darling Basin Commission (MDBC). As such, there is scope for NRM groups to integrate and co-ordinate management activities and investment with the MDBC to maximise investment outcomes both within the MLR and across the MDB.

The second group impacted by migrational barriers are the diadromous fish that require access between marine and freshwater habitats in order to sustain populations. This is further exasperated by the fact that many of these species in the MLR require access between the sea and high altitude upland stream habitats. This requires the assessment of a large number of dams and weirs, many of which are enormous water storages that cannot be removed and implementing fish ladders or fishways to provide fish passage can be expensive and logistically complex. A further implication of these large water storages is that populations above the weir may form landlocked populations that utilise the water storages to replace the marine phase of the life history cycle. The actual use of MLR reservoirs for this purpose is a key knowledge gap in understanding the sustainability of these species, although it is likely that at least two galaxiid species are doing so. This results in a dichotomy between landlocked and sea-run populations that serves to isolate the two with potential genetic repercussions. The assessment and provision of fish passage between the sea and upland reaches of the MLR is a key issue for native fish and can only be redressed through concerted management of physical stream infrastructure, requiring a high degree of inter-departmental co-operation across state agencies. Small local barriers may also be issues for obligate freshwater fishes such as mountain galaxias, inhibiting movement related to recolonisation, gene flow and general population processes. Monitoring to determine the presence and potential impacts (both negative impacts as above but also positive such as barriers separating native species from introduced predators) is required to provide a plan of action for smaller barriers.

Restoration of flow regime: Restoration of stream flows is already acknowledged as a key component of stream health in the MLR and recent management effort has resulted in the provision of environmental flows for the Torrens, Onkaparinga and South Para Rivers. The present report is a direct result of the efforts of the flow management group within DWLBC and NRM boards and underpins the importance of flow regime in sustaining native fish populations. In its extreme, flow is the most essential of all requirements for fish sustainability as the prevention of flow results in the subsequent removal of all fish. Although the reinstitution of flow regime is common across a number of species, the specific flow requirements for each species is likely to be quite different and needs to be addressed in detail for each species and possibly even for different reaches across a species' range. In general however, the flow requirements of each species will be aligned to the natural climatic pattern. Autumnal and spring flows that are required to allow migration of diadromous fish represent the natural flow regime under which these species evolved and are therefore the most appropriate aspects of the flow regime to be re-instated. Further research is needed before flow patterns can be most effectively tailored to facilitate individual species and their specific flow requirements. It must also be outlined that restoration of flow regime must go hand in hand with other management actions (especially those outlined here) to be most effective.

The specific components of habitat and flow restoration that are most important or beneficial for fish, is an emerging problem to which scientific attention is only recently been directed. Recently developed research programs such as the MDBC funded "Riparian restoration experiment", based at Monash University, are beginning to uncover what components of stream rehabilitation works actually provide the most benefit to fish communities. It is a further recommendation that stream restoration in the MLR should seek to collaborate and form partnerships with such projects to ensure efficiency and effectiveness in rehabilitation investment.

Introduced predators: The introduction of fish from overseas has been common in the past and a range of these species have become established in the MLR. Whilst the impacts of many of these species are complex or poorly understood, the impact of large piscivorous predators on smaller native species is likely to be direct and severe. Of the introduced species present Redfin perch and the two trout species (rainbow and brown) are large bodied predators that are well known to consume large numbers of native fish species when introduced into foreign catchments (Closs *et al.* 2006, McDowall 2006). It is well established that large trout are able to eat all native fish within stream pools and thus completely exclude native fish from their prime habitats. This predatory relationship is complicated by variation in the climatic conditions the presence of alternative food sources such as invertebrates, and the availability of microhabitat refuges (such as shallow riffles) (e.g. McIntosh 2000). As a result, the presence of these predators does not always lead to the complete extinction of prey species.

Over extended periods however, the consumption of most adults along with the restriction of prey fish to marginal and often impoverished habitats will have a profound impact on population structure and sustainability of prey fish species. Recent review in the EMLR has suggested spatial segregation between redfin and trout (present in deeper pools) and native prey species (present in riffles or predator free pools). The specific impact that this has on native fish sustainability is a major knowledge gap and a principle target for future research. At the time of writing, University of Adelaide and SARDI aquatic sciences have a number of projects aimed to address this issue. An ARC funded project commenced in 96/97 to address the role of trout and trout stocking on MLR fishes, led by Dr Bronwyn Gillanders. MDBC and Federal DEH funding has also been sought to review the impacts of redfin nationally and to study the effectiveness and impacts of trout and redfin removal on native fish populations in the EMLR. It is recommended that a close collaboration between the NRM boards, DWLBC, SARDI and UA will maximise the usefulness and applicability of these projects to NRM objectives in the MLR.

Predation of eggs larvae and aggressive competition from introduced gambusia are also likely to impact heavily on native fish species. These impacts are also included in the aforementioned DEH tender (as are tench) and will therefore review Australia-wide impacts will be summarised in the near future. The predatory role of gambusia and the competitive impact of the species need to be studied for all MLR species, particularly for the pygmy perches, galaxiids and gudgeons, which share similar habitats and food resources to the gambusia. Being livebearers, this species is able to persist in low numbers over the cooler months and then explode their population with high numbers of live juveniles, whilst native species rely on the survival of free-swimming larvae to facilitate recruitment. Qualitative evidence suggests that this species suffer from high flows, which may have implications for their management within the MLR where larger flushing flows may be provided under the EWP process.

Although the management priorities identified above were specifically aimed at predation, it should be noted that substantial impacts might also occur due to tench, carp, goldfish and an imminent invader, the oriental weatherloach (ETA: 10-15 years). These impacts include predation of eggs and benthic larvae, destruction of macrophyte habitat and significant changes to sediment activation and water quality. There is significant investment aimed toward carp control through the MDBC, the Invasive animals CRC (IACRC) and other organisations that will be directly applicable to the MLR. Particularly relevant is the use of carp separation cages (CSC) that can trap carp whilst allowing native fish to pass through. Such structures are likely to be most effective in the EMLR where large numbers of carp are able to move from the river through terminal wetlands and into stream reaches. There is great value in considering the application of such control methods to the MLR.

Translocation: The translocation of native (Australian) species into catchments or drainages from which they are not endemic has occurred commonly throughout Australia, with at least 53 native species translocated across Australian catchments (Lintermans 2004). IN the MLR the issue of translocation is somewhat complex due to the lack of detailed distributional data available prior to 2000. As a result, the presence of MDB species in the WMLR is poorly understood and some may be the result of inter-basin water transfers whilst others are clearly due to human dispersal and stocking. Species that have been translocated into WMLR habitats include Murray rainbowfish, silver perch, freshwater catfish, carp gudgeons and Murray cod. There is also the possibility that dwarf flathead gudgeon is an inter-basin transfer, however the species was only recently discovered and therefore its historical presence in the WMLR is unknown (Hammer and Walker 2004). For all of these species, however, the impact of their transferral is not known. A clear state policy on translocation of native species has been called for (Fulton 2004). New translocations of native species are still occurring, but should be discouraged and treated with great care pending legislation.

The opposing issue has also arisen for two species believed to have become extinct in the MLR, the purple spotted gudgeon and the chanda perch. There is potential for trial translocation to occur to re-establish populations of these species within the MLR, within their historical ranges. This may be trialled within isolated dams or reaches so as to first assess the impacts of their re-introduction and to establish wether the factors responsible for their initial extinction will inhibit any attempt to re-institute populations. There is also a range of factors that need to be addressed including the genetic impact of such translocations. For management priority, there are two separate issues with translocation; firstly that the translocation of new species between drainages or catchments should be discouraged and avoided and secondly; re-introduction of extinct species to the catchment may be conducted using translocated populations from other areas. Any attempt to translocate native species requires detailed research and assessment on the potential impacts on native fish and ecosystem function.

4.3 Research Priorities

A number of research priorities were also provided in the species sustainability matrices based on the knowledge gaps identified therein. A detailed breakdown of these research directions will not be provided here as each is species specific and needs to be assessed independently in each instance. There were however, a number of recurring research areas that were common across many of the MLR fish species. Most significantly, basic biology, habitat use and spawning/recruitment processes are little known for a large number of MLR species and outline a general need for basic research on native fish species. This basic knowledge of local species is essential in maximising the effectiveness of management approaches, which need to be specifically tailored to benefit local species. Equally, the impact of predation on native species was identified as a major research priority and as discussed under management priorities, knowledge of species impacts and of the impacts of potential control techniques, are required before effective management actions can begin.

A proportion of species also require targeted research to identify flow requirements for migration, spawning and maintenance of habitat. This theme is central to the MLR flows program and it is clear that the specific flow requirements be assessed to allow maximally beneficial flow provisions to be obtained and released. This applies especially to diadromous species for which appropriate timing, duration and volume of flows are essential for sustaining populations in the long term.

Finally, there was poor knowledge as to the distribution of many species within the MLR. Fish surveys conducted since 2000 have provided much detail about the species of the MLR and identified a number of populations of rare or threatened species. The extent of these species, however, remains poorly understood and this knowledge is essential for the sustainable management of fish species. It is suggested that distributional monitoring be continued in the long term with sites assessed every three years at least in order to maintain a sound distributional database for MLR fish species. This is best directed toward populating and maintaining a spatial database across a wide range of MLR streams, and can be conducted as part of existing stream monitoring programs such as waterwatch. It should be qualified, however, that such monitoring should be highly reliable and collected by trained staff, maintaining catalogued photo verification and voucher specimens to confirm species identification.

Whilst the following monitoring and assessment strategy goes a long way to address issues of basic biology and population structure, there is a strong linkage here to post-graduate opportunities. Whilst a high quality professional capacity is required for delivering the majority of monitoring and research needs, some basic biology and ecology (including flow requirements and predation impacts) can be partially addressed in research degrees such as honours and PhD projects. It is strongly recommended therefore that management bodies consider small amounts of investment to direct such research projects to priority knowledge gaps for MLR fish species. Supervision of local student projects can be ably handled through Adelaide and Flinders Universities in conjunction with research groups such as SARDI and are a relatively economic approach to filling knowledge gaps. The provision of an annual scholarship or award to support student projects focussing on MLR stream issues is an effective way of maintaining a steady research focus on MLR streams whilst attracting high quality candidates to the cause.

4.4 Monitoring for sustainability

A large number of variables and factors influence the ability for stream fish to persist in a self-sustaining population. Furthermore, the definition of sustainability is not a consistent or explicate objective across habitats or across species. For the present paper, the term sustainability will refer to "The long term maintenance of genetically diverse and structurally sound species population across the natural range of appropriate habitats." The basic principle of sustainability is that healthy populations of all native fish species should be able to survive and reproduce successfully within their natural habitats. The overall aim of the sustainability project is to ensure that well informed management decisions are able to protect all native fish species from localised and general extinction through addressing key threats and maintaining or rehabilitating essential ecosystem components.

This section provides an outline for long term monitoring of fish populations in the MLR to address wether or not fish populations are being maintained under current management and/or being impacted by progressive management actions such as providing environmental flow releases for ecosystem benefit. The scale of the monitoring proposal has been set to ten years to allow for the collection of data across a range of climatic and seasonal variability. The scale of the strategy has also been restricted to a level that can be realistically provided within current general funding constraints. Important monitoring and assessment components outside of the current monitoring project funding will be appropriately addressed and qualified. This section will therefore provide a prioritisation of monitoring components, although actual priorities for investment for addressing knowledge gaps must be set in line with management and investment priorities in an adaptive framework.

Monitoring Components

Bi-annual, seasonal sampling of key sites

This monitoring approach addresses long term trends in fish population dynamics by sampling key sites repeatedly in autumn and spring of each year. This approach is maximised over longer timeframes due to the naturally high variability in population dynamics between seasons and between years [Australia's inland streams are among the most variable in the world (Puckridge *et al.* 1998)]. By sampling both before and after summer, this approach also provides an assessment as to the impact of harsh summer conditions on the fish population each year. These conditions are likely to play a key role in naturally structuring native fish populations in such ephemeral Mediterranean climate streams. Furthermore, the ongoing sampling will assess key population parameters such as recruitment and seasonal (spring/autumn) spawning events. Each sampling event will also provide detailed information regarding species composition, population size structure and abundance.

It is recommended that autumn and spring samples be carried out each year for at least ten years. Information recorded from these samples must include sound assessment of the below components.

Species Assemblage Data
A high degree of sampling effort is required to confidently obtain species assemblage data. In particular, it will be rarer or less abundant fish that may be missed if the

sampling effort is inadequate. A wide range of gear types is also recommended for this purpose. Different netting techniques will sample certain species or habitats more effectively. A complete 'set' of sampling gear (for maximising assemblage data) should include box traps, small meshed (~6mm) fyke nets and larger meshed fyke nets (~15-20mm). These passive methods are very effective in smaller streams and should be set overnight (preferentially for 24 hours to neutralise diel bias). Gill nets may also be used in deeper pools (and for larger fish species) but are highly destructive unless constantly checked. Netting techniques should be supplemented with active methods such as seining, dip-netting, and spotlighting. Electrofishing is an excellent technique for providing quantitative data although a number of limitations exist. Backpack electrofishing is recommended for sampling smaller shallow streams where salinity and turbidity are relatively low, but cannot be used in deeper pools. Combinations of backpack electrofishing in shallower areas and fixed netting in deeper pools is likely to maximise the catch efficiency. Deeper pools may be sampled using boat or bank mounted electrofishing techniques, but these are often impractical for use in MLR streams where boat and/or car access to sites is often difficult. Any additional techniques, (even line fishing) are recommended for maximising the assemblage data.

Abundance Data (catch per unit effort)

Abundance data is captured from methods outlined above; however, great care must be taken in ensuring when combining or comparing data from different gear types. Different gear types represent a different degree of effort (i.e. different sized nets sample different volumes of stream habitat, a net that is good at catching large redfin may be bad at catching small redfin etc.). Indeed all gear types will possess some bias that makes them directly incompatible with any other gear type. Complex algorithms are often utilised to allow such comparisons across gear types. Alternatively, abundance data should be taken from a single gear type and compared only to data from the same gear type. This may be different for each species (i.e. large fyke data for redfin perch, box traps for pigmy perch), but this needs to be clearly qualified. Ideally, a single gear type that is equally good at sampling the entire fish population should be used. Fish biology is considerably behind the scientific world in regard to understanding and quantifying sampling efficiency and effort. A prominent knowledge gap within this methodological section is that a comparison of netting types in sampling different species and habitats has not been conducted (see Balcombe and Closs 2000).

Demographic Data

Length analysis is often used as a surrogate for fish age and can provide important information as to the distribution of age classes within a population. Young of the year fish recruit into a population at a small size and will often take one or more years before they reach adult size (after which length becomes a poor determinate of age as adults bulk out laterally or dorso-ventrally as opposed to caudally). A key benefit of conducting length-frequency analysis is to determine the recruitment of small size classes to the population and the incorporation of those size classes into the adult population as years pass. Similarly, the presence of very large (and more fecund) individuals can be important for some species [for example, all large congolli appear to be female (SARDI unpublished data) and the lack or disappearance of larger size classes could be disastrous for a population]. The nature of length frequency analysis necessitates that large sample sizes be used to get a representative picture of the population (as for assemblage data) particularly as upper size classes may be relatively rare. The long term monitoring framework presented here affords an effective basis for collecting sound demographic data.

Whilst length frequencies provide data on the appearance of small size classes, or the persistence of older classes, more dedicated techniques must be employed to gain a definite knowledge of fish age. This can be particularly important for fish that may reach large adult size rapidly, resulting in overlap across adult age classes. If such a fish doesn't reach reproductive maturity until the third year, it is necessary to find out what proportion of that adult size class is available to breed (and is therefore at least 3 years old). Otolith analysis uses rings formed in the ear bones of fish, to accurately estimate age. The process of matching known aged fish to length frequency data provides a detailed age population model that, once conducted can be used to validate ongoing analysis of length frequency. It is recommended that age/length analysis should be conducted for all MLR fish species to inform the ongoing assessment of length frequency data. The skills and equipment required for this are present within Adelaide University and SARDI.

Sex and reproductive condition
All processed fish should be checked for signs of reproductive development including gonad enlargement, egg development or excretion, sperm excretion, breeding colouration etc. Ripeness is relatively easy to assess through physically 'milking' fish and observing egg or sperm ejaculate. Eggs and developed gonads can be identified visually in some species. Sex determination can be difficult for some species when not in breeding condition. Where sufficient data can be collected, sex ratios and size/sex distributions should be analysed from long term monitoring data and is an important component of flow response sampling

Site Selection

MLR streams may be generalised into three basic habitat types, (1) Pools: deeper sections of lower flow, become isolated refuges for stream fish during low/no flow periods, (2) Riffles: shallow reaches where water is highly turbulent and flowing, usually with some emergent rocks or substrate areas and (3) Runs: These are deeper areas of high, predominantly laminar flow. The distinction between riffles and runs can depend entirely on the flow level (i.e. a riffle may become a run during high flows). Both habitats are essentially meandering, higher flow reaches that link pools and are more prone to drying under low flow conditions.

Each site for long-term monitoring consists of three replicate pools, linked by riffle reaches (see figure 11). It is recognised that geomorphic variation rarely presents such a discrete series of pools and riffles and that in many cases, some smaller pools or extended riffle areas may be present within a site area but not included in sampling. As a general rule, all pools within a site should be located within a 1km stretch of stream where possible. Pools are most effectively sampled using combinations of net types, whilst riffles are often too shallow and are most effectively sampled using backpack electrofishing (and supplementary methods such as dip netting, spotlighting etc). Each site therefore contains three replicate pools sampled identically, with at least four riffle/run reaches sampled using backpack electrofishing shots. Each shot (unit of electrofishing effort) consists of 120 seconds of sampling, and extra shots may be added to maximise the sampling area.

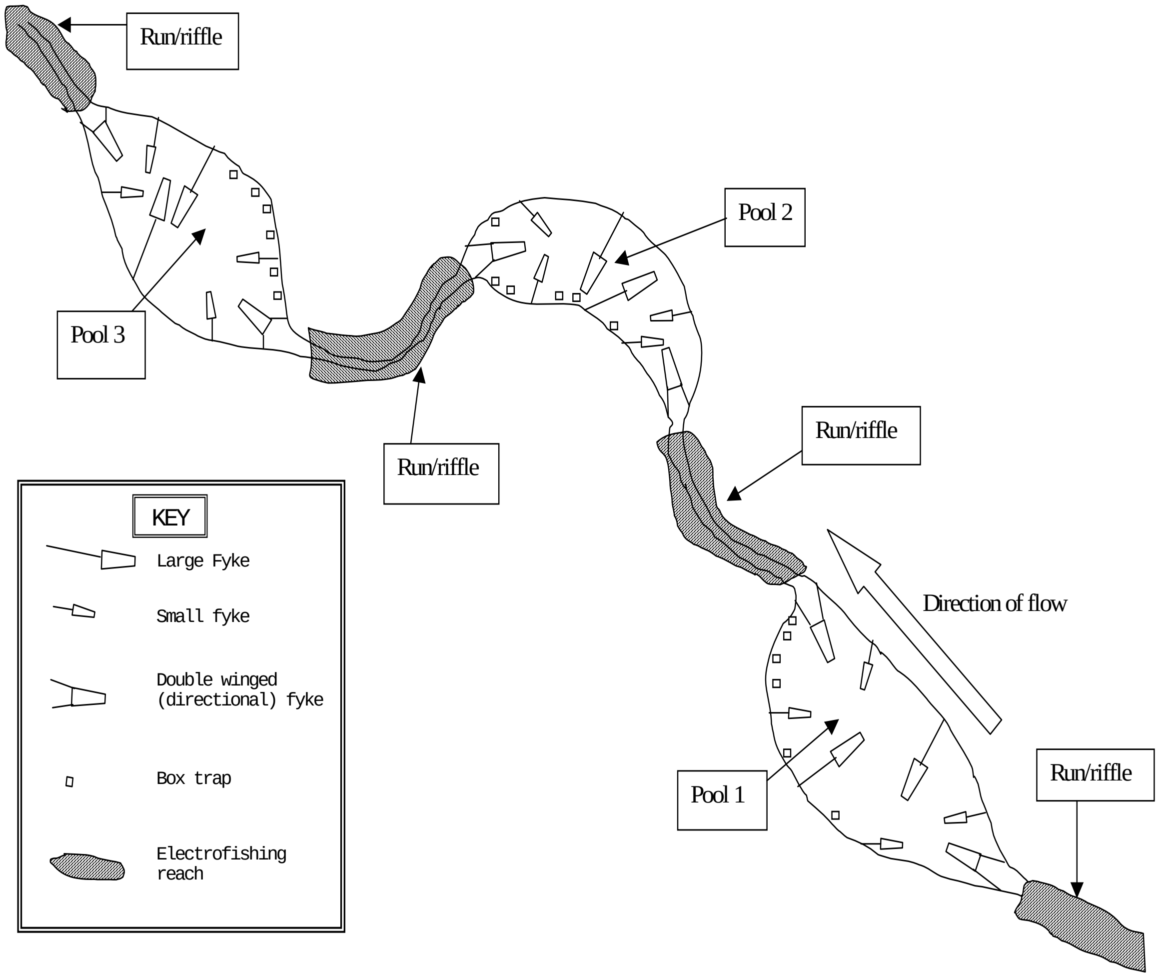


Figure 6. Generalised sampling design for long term monitoring sites in MLR stream.

Flow Response Sampling

One of the central themes to the MLR monitoring program is the role of stream flows in sustaining native fish populations. Fish are one of the key faunal groups used for the formulation of flow targets because so many aspects of their life history are intrinsically linked to flow patterns (some more than others). If flows are inappropriate then there is likely to be a strong response in population structure and process. Furthermore, the restoration of stream flow components is often designed to elicit a particular response (i.e. breeding migration) or facilitate a process (i.e. enticement of larvae out of marine habitats). Ongoing monitoring in the MLR should therefore maintain a component of flow response sampling married closely with the release and calibration of environmental flows. This will provide important information that will enlighten the recruitment patterns observed elsewhere (e.g. length frequency analysis). For example lack of juvenile recruitment may be linked to a failure to respond to flow cues, or conversely spawning may occur satisfactorily in response to flows but recruitment doesn't occur (perhaps due to barriers or lack of food or habitat). The extra level of information, therefore, enables more powerful inferences to be developed through the long-term site monitoring data.

An important tool in the assessment of breeding movements and migration is the use of direction (double winged) fyke nets. These nets may be set so that only upstream or downstream moving fish are caught. Furthermore they may be linked to sample both upstream and downstream movement whilst completely blocking a stream. Directional nets have been included in the sampling design for long-term sites to sample fish moving into pools from either upstream or downstream. This effectively tailors the long-term site design to detecting upstream and downstream movements that are likely in response to flows.

The identification of breeding condition is an essential part of flow response sampling. The presence of ripe males and females can indicate wether movements are clearly linked to reproductive events as opposed to movements related to normal ranging, recolonisation or feeding behaviours.

Distributional range sampling

Whilst comprehensive biological and population structure patterns can be gained only through repeated, detailed investigations such as the long-term monitoring sites, these provide little information about what is happening in areas outside of the long-term monitoring sites (i.e. at larger spatial scales). Information regarding the distribution and range of fish species needs to be addressed using a wide reaching survey technique that targets as many as possible sites for less intensive sampling. To some degree, this type of sampling has been utilised in the MLR to gain the majority of baseline inventory and longer-term site monitoring on native fish (Hammer 2004, 2005a, 2006b). Whilst this technique is limited in providing detailed biological data, it is essential for understanding the distribution and habitat use of native fish in the MLR. Aside from these recent inventory surveys, much of the distributional data used for the present review is outdated with no recent searches conducted at those sites. Distributional data should be refreshed at least every decade to ensure that range contractions or extinctions are not occurring unobserved.

A sound understanding of species distributions and habitat use is essential for addressing the nature of sustainability for many MLR fish species. For example, small remnant populations are responsible for recolonisation of streams after disturbance (such as drought, flood or over-abstraction). If a stream reach was allowed to dry completely, knowledge of the potential sources of recolonisation is vital to any management response. If it is well known that remnant populations persist within permanent headwater streams, subsequent reconnection of habitats may be adequate for re-establishing the population. If it is known that those habitats do not contain remnants, then it may be necessary to provide flow releases to prevent the stream population from dying out. A complete lack of information may result in a large waste of water and money, or result in population extinction through an incorrect response. Knowledge of population extent is therefore important in informing management decisions about fish sustainability.

As discussed previously, there is potential under this component to include data collected during other broad monitoring programs such as Waterwatch. As long as training and strict protocols for sampling and identification were adhered to, such programs may be effective in providing additional, low cost distributional data that can be combined within a common distributional database.

5 Discussion

The baseline information indicates that a wide range of native freshwater fish species are extant within the MLR, and that at least some appropriate habitats remain to support populations of most resident native fishes, although this varies greatly across and within catchments. Species that remain common across the MLR include common galaxias, congolli, flathead and dwarf flathead gudgeons. There are numerous other species which are either highly restricted and/or threatened with local extinction (especially river blackfish and southern pygmy perch) or other species which are wide spread but patchily distributed and are under threat of local declines, especially mountain galaxias and climbing galaxias. Furthermore, at least two native species (southern purple-spotted gudgeon and the chanda perch) are believed to have become extinct within the region. The overall status of the regional biota suggests that severe impacts are present, or have been imposed historically which need to be remediated where possible.

The current MLR fish sustainability project, developed through the environmental water provisions process by DWLBC and the Adelaide-MLR and Murray NRM boards, will provide the first detailed assessment of biological information for native fish across the region. The long term monitoring framework and the knowledge gaps, research and management requirements detailed within this report outline an approach for achieving sustainable native fish populations across the MLR. In general, there is a requirement to collect sound knowledge regarding the distribution, abundance and population structure of native fish communities and as well as identifying the complex requirements for habitat, flow regime and migrational movement.

These factors are strongly species specific and largely inferred from populations outside of the MLR. There is therefore a need to develop strong linkage projects to address priority knowledge gaps. Whilst some of this can be achieved through post-graduate projects at local universities, there is a strong need for well funded programs to address some of the larger scale priority problems such as those relating to flow and longitudinal connectivity, restoration of habitat, and the control of introduced predators, all of which have been identified as key knowledge and management priorities.

Some native species (i.e. climbing galaxias, southern pygmy perch, river blackfish) have been identified from few, or geographically isolated reaches that lie outside of the scope of the current fish sustainability project in the WMLR. The need for targeted investment to assess the sustainability of these species has been strongly heralded throughout this report. The same issue applies to the assumed status of extinct species in the MLR. Without a comprehensive search, potential remnant populations of southern purple-spotted gudgeon and other regionally threatened, but unknown populations, may continue to decline. This issue is highlighted by the recent discovery of a species previously unknown to the MLR, the Yarra pygmy perch. In layman's terms, it is important to know what fish are in the places we haven't looked properly.

Although long term monitoring for the flows project focuses on the WMLR, many of the fish species, habitats and processes are common to the EMLR (SA MDB). The native fish fauna of the EMLR differs from that in the west due to the natural presence of Murray-Darling species such as the Murray cod, golden perch, silver perch, freshwater catfish, smelt, southern pygmy perch, Yarra pygmy perch, bony herring, carp gudgeon, Murray rainbowfish, and Murray and unspecked hardyheads (some translocated populations of these species are present in the WMLR).

For many of native species of the EMLR, sustainability requires the effective management of lowland reaches and terminal wetlands in the Murray system. The management of these lowland areas depend largely on the provision of adequate volumes and the quality of water for maintaining aquatic habitats and this is further complicated by the lack of large storages from which flow provisions can be easily obtained. Although the species assemblage differs between east and west, the issues that impact upon the sustainability of native fish populations remain similar. Provision of flows for maintaining habitat and facilitating spawning and movement, the restoration of riparian and instream habitats and the control of introduced predators are still the principal management priorities in the east as in the west and research is required to address knowledge gaps within these areas for effective management to occur.

5.1 MLR Fish and stream habitats

Although the MLR fish fauna is representative of the inland and coastal communities of the Great Dividing Range, this natural isolation renders the MLR a highly sensitive geographical (and genetic) isolate of these populations and as such, specific sustainability issues need to be addressed.

Current and longer term exposure (e.g. natural selection and genetic drift) to specific climatic, flow and habitat conditions of the MLR may cause local fish populations to display very different ecological patterns and responses to eastern, interstate populations. As such, MLR species are likely to possess 'divergent biology'. This requires that management actions (such as flow or habitat restoration) may be specifically tailored for the MLR. For example, MLR populations of southern pygmy perch are genetically and biologically different to eastern populations, where they are considered to be widespread and of low conservation priority (Hammer 2001, 2002b, 2005a). Further, in the MLR and lower Murray, there are five specific genetic isolates that are highly impacted and in decline, and that occur in specific and quite different environmental units.

As an 'edge' population of the south eastern Australian fish fauna, MLR populations hold particular genetic value that may prove essential in the recovery or adaptation to change for national populations. Hence from the above example we now know that MLR populations of southern pygmy perch are extremely important for conserving the overall diversity of the species and that the spatial scale for management is at the individual catchment level. Subsequently, management (e.g. environmental water requirements programs) is dependent on local information.

5.2 Biological guilds as management units

Although a species by species approach is ideal for managing fish populations (see section 4.1), there are some considerations that are generally different between 'guilds' of fish based on their overall biology:

Obligate freshwater stream species: Stream specialist species have a tendency to remain within localised habitats and juveniles are recruited locally (Humphries 1995). As a result, localised impacts are more likely to effect whole populations, which are less likely to recover (or recover very slowly) from local disturbance (i.e floods, introduced predators, desiccation) or extinction. Furthermore, local populations are less likely to mix and therefore are more likely to form genetic isolates whose conservation may be important for the species in general. Alternatively, these species are most likely to benefit from local scale management such as revegetation or rehabilitation of stream reaches, or predator control exercises.

Three of these species stand out as priorities for concern. Southern pygmy perch, mountain galaxias and river blackfish, all possess vulnerable life cycle characteristics and restricted ranges, which makes populations extremely vulnerable within and across catchments (Koehn & O'Connor 1990). For example, southern pygmy perch have very low fecundity and low dispersal ability (Humphries 1995, Growns 2004), river blackfish have very specific habitat and spawning requirements (Koehn & O'Connor 1990) and mountain galaxias are in direct competition for habitat with introduced predators (Closs and Lake 1996).

Obligate freshwater wetland species: A sub group of the obligate freshwater species are restricted to lowland riverine and wetland habitats, where populations rely strongly on stream flows to drive wetland food webs and ecological processes. Many of the Murray's fish species rely on these wetlands for larval production and/or survival (e.g. King *et al.* 2003). This management unit is particularly relevant to the EMLR where species including Yarra pygmy perch, Murray-Darling golden perch, Murray cod, smelt and southern purple-spotted gudgeon have some dependence on adequate stream flows from the MLR for their biology, to maintain wetland health and support fish populations. Although it is beyond the scope of the current project an assessment should be made as to the importance of EMLR stream in maintaining the fish community of the Lower River Murray and Lower Lakes. This aspect could be potentially relevant to the MDBC 'Living Murray' and 'Native Fish Strategy' initiatives.

Diadromous species: This group of species contains congolli, common galaxias, broadfinned galaxias, shortfinned eel and the lampreys, all of which utilise freshwater, estuarine and/or marine habits for part of their life cycle. As a result, longitudinal connectivity is absolutely essential for these populations to flourish. This aspect is so important that most of these species have evolved, to varying degrees, adaptations for scaling or climbing instream barriers. There is no evidence, however, to suggest that these species are able to navigate many of the structures on the scale present in the MLR. In combination to connectivity, flow regime is an essential component in the life cycle of these species. All require specifically timed flows to complete their reproductive or recruitment cycles. Furthermore, these flows must be allowed to reach the sea to facilitate migrations of larvae, juveniles or adults moving in and out of the freshwater systems.

Two general periods are especially important for high flow events, being autumn/winter and spring. Autumn/winter flows are important for spawning of both species of galaxiids, in egg deposition, development and in washing their larvae out to sea (Koehn and O'Connor 1990). Spring flows are essential for recruiting larvae back into freshwater from the sea. Lampreys require mostly spring/summer flows for both upstream and downstream migrations to/from the sea. Congolli are thought to spawn in estuaries in response to spring flows but ripe males and females have both been observed in the Onkaparinga in freshwater during autumnal flows. Eels appear to move in and out at various times. Consideration must also be given to landlocked populations of diadromous species (i.e. common and broadfinned galaxias), that may present distinct management concerns to sea-run populations. The emphasis on large flows should not just be about flow volume, but also the nature of a flow event with steady rise and fall to for example attract or prime species for migration and to allow migration to preferred habitat rather than being trapped along the way with receding levels.

Whilst flows and connectivity are particularly important for management of these diadromous species, it is easy to neglect their freshwater habitat requirements. All species are linked to particular freshwater habitats and with riparian and instream vegetation, thus, management of this guild requires broad consideration of issues along the entire stream length. Management directed for these species is most likely, therefore to also address many issues applicable to other guilds.

Estuarine and marine species: Whilst not considered in the present review, a number of estuarine fish species have been found to migrate into the lower reaches of freshwater systems. A range of gobies, mullet and estuary perch utilise freshwater habitats in the coastal streams of the MLR, if barriers are absent. Although the nature of their freshwater incursions is not fully understood, it is clear that consideration of predominantly estuarine fish (and potentially marine fish) be made when addressing riverine management. Furthermore, flow management in particular is an important, yet mostly neglected, component of estuarine and near-shore ecosystems. Seagrass communities along the Adelaide coast are highly impacted by freshwater flow patterns (Westphalen *et al.* 2005), and river flows are considered to be important in setting ecosystem processes within these marine systems. The implications of different flow regimes and volumes upon these habitats is as yet unknown but may be an important management consideration given the potential for negative impact of flows. A further linkage to marine research is the fundamental lack of knowledge regarding the adult marine phase of the lampreys, both parasitic and free living. Clearly many marine fish (i.e. reduction in marine hosts) and habitat issues will be brought to bear upon lampreys.

5.3 Other management and knowledge priorities for sustainability

Refuge habitats: The over-riding priority for adult survival of most species is the maintenance of refuge habitats so adults can survive periods of low flow (natural or enforced). Refuge habitats must possess the appropriate structural habitats for species inhabitation, requiring that substrate, macrophyte, woody debris (including leaf litter and bark) and riparian habitat be maintained. Another important component of refuge habitat is water quality condition and the presence/abundance of introduced species.

Water Quality: Water Quality must be maintained to a level that is not toxic to the species. Variability in species tolerances to poor water quality means that species are individually adapted to surviving poor water quality. This is not to say that maintaining maximum water quality is the best management tool for maintaining species diversity or promoting sustainable populations of native species. In fact, recent work suggests that large predators such as redfin perch may be more susceptible than native prey species (McNeil 2004). This means that some level of water quality deterioration or natural variability (within the limits of native tolerance limits) could be favourable for native species. The fine-tuning of summer baseflow releases in the MLR may be able to be adapted to allow deterioration with subsequent relief over summer. The application of flows for maintaining and maximising native fish benefits of refuge habitats during summer is largely untried and requires detailed attention that may be within the scope of the MLR flows project.

Spawning sites: The spawning sights of fishes in the MLR are largely unknown. The majority of information on this topic was inferred from studies to the east that in themselves are often not comprehensive. Much information is likely to be gained from the long term monitoring project, although it is necessary to investigate smaller headwater streams that are not covered under the project (but may be covered in broad scale distributional surveys or monitoring programs such as those for southern pygmy perch and in the Marne River -EMLR). Dedicated spawning site searches carried at appropriate times at appropriate habitats (guided by observations from interstate literature) may be required for key species.

Exotic species: The impact of most exotic species found in the MLR are currently under desktop review by the federal government as part of broader projects (Department of Environment and Heritage, Department of Agriculture, Fisheries and Forestry). Detailed reports outlining environmental, social and economic impacts, as well as management and research priorities will be available by the end of 2007. The key exotic species in the MLR are the introduced predatory fish, brown trout, rainbow trout and redfin perch, plus the smaller gambusia. The three larger species have moved into the niche of keystone predators in MLR streams being common (and in some cases continually stocked) in cooler higher altitude stream reaches of the MLR, especially WMLR and Southern Fleurieu. Native fish fauna in MLR are generally adapted to smaller and less actively aggressive predators such as galaxiids and gudgeons (and in some areas river blackfish) as opposed to these large sized, highly aggressive visual predators. For example redfin perch have been found to be more active and aggressive than similar sized native golden perch (Shirley 2002).

Although recent reviews appear to have underestimated the impact that trout species have on structuring native fish populations (Fulton 2004), others document a pervasive worldwide impact of trout across a wide range of galaxioid fishes (McDowall 2006). Local evidence clearly shows that trout exclude mountain galaxias from certain stream habitat and often only persist in areas that are inhospitable to or inaccessible to trout (Closs and Lake 1994; Hammer 2004, 2005c; 2006c; McNeil unpublished data). Redfin have been linked to the decline or fragmented distribution of several native species in the MLR (Wedderburn 2000; Hammer 2001; Wedderburn and Hammer 2003; Hammer 2004, 2005c; Smith and Hammer 2005; Hammer 2006c). The impact of redfin perch in structuring populations of flathead gudgeons in the South Para is being investigated by Phillipa Wilson through an honours project (2006/07) at the University of Adelaide and should provide important information regarding redfin predation impacts in the MLR. The role of predatory exotics is central to the sustainability of native fish populations. Many environmental flow objectives are targeted towards stimulating native fish to move into main river channels for spawning and migration. If these habitats are predominantly saturated with exotic predators they are likely to feed heavily on native fish moving into or through pools.

Species at highest risk of trout and redfin predation impact are:

- Southern pygmy perch- *excluded from refuge pools*
- Mountain and climbing galaxias- *excluded*
- Yarra pygmy perch- *reduced abundance from predation*
- River blackfish- *impacted by predation and competition in restricted habitat*
- Common galaxias - *predation and impacted colonisation*
- Gudgeon species- *predation*

Non-predatory introduced species:

- Gambusia: *strong competition for food, aggressive towards small natives, dominate/defend macrophyte habitats important for spawning of natives*
- Tench: *largely unknown*
- Carp: *Low numbers in much of the MLR, use wetlands to spawn, increase turbidity and change ecosystem processes* (SARDI, the IACRC and SA MDB NRM board are co-operating in trials for carp control in wetlands of the Murray that may provide applicable technology for carp control in the MLR).
- Goldfish: *Largely unknown, utilise macrophyte habitats*
- Brook trout: *only single record otherwise impacts as for other trout*
- Oriental weatherloach: *has not been recorded in the MLR but is an imminent invader, spreading rapidly down the Murray* (e.g. as it spread down the Murray system from Victoria: Koster et al. 2002).

Translocated species:

- Murray-Darling golden perch, Murray cod, silver perch, freshwater catfish: *large predators (smaller natives and invertebrates); potential disease risk*
- Carp gudgeons and Murray rainbowfish: *compete for food and habitat with small natives; disease risk*
- Barramundi: *single record, unlikely to survive winter temperatures in temperate Australia; disease risk*

As the impacts of introduced fish in the MLR are likely to be diverse and somewhat complex, it is recommended that efforts be made to conduct an impact assessment and prioritisation exercise to initiate management and control activities in the MLR. Control of priority species is largely untried in SA and careful planning is required before control programs can be undertaken. It needs to be acknowledged that some of the species threatening native fish sustainability are valued by some sectors of the community and therefore control activities need to consider commercial and social issues.

5.4 Considering climate change

A major future consideration for the sustainability of fish habitat and populations in the MLR relates to the predicted impacts of climate change, especially considering the largest predicted regional impacts are for areas with Mediterranean type climates such as the MLR. This has been highlighted during the present drought where threatened species such as southern pygmy perch and blackfish have been restricted to isolated single pools within entire stream catchments.

Exact predictions of climate change are difficult given large temporal variations in climatic conditions, and with variations for different parts of the state, but the overall trend based on average seasonal and annual conditions suggests South Australia will become hotter and drier, with a change in the nature of rainfall events (McInnes *et al.* 2003). Notably, in time the prevailing low pressure systems from the south west which produce rainfall in the southern areas of the state, are projected to decrease in number but increase in intensity resulting in less rain and fewer rain events. This will be most pronounced during spring when most native fish require higher rainfall to facilitate spawning, migration or habitat quality. The northern half of the state is predicted to become warmer (e.g. between 1-6 ºC) with an increasing frequency and magnitude in summer rainfall events (e.g. more floods). A summary of predicted changes in rainfall and temperature are contained in Figure 7.

Recent reports have identified that freshwater biodiversity is likely to be impacted most severely across all aspects of natural resource management in the Mount Lofty Ranges (Figure 8). This high vulnerability relates to extreme exposure, sensitivity, and a lack of adaptive capacity given projected climate impacts and is therefore of the utmost concern to the long-term sustainability of native freshwater fish in the region (Bardsley 2006).

The results of such change in climate could mean aquatic habitats which are increasingly influenced by disturbance events of large floods and longer periods of drought, and which have overall warmer water temperatures and lower average flows (the later could also result in increased concentrations of salt, nutrients and pollutants). This pattern is likely to be further exacerbated in developed regions as humans react to secure water supply with cumulative additions to existing abstractions (e.g. dams, groundwater pumping) with smaller flows particularly susceptible. All fishes will be vulnerable to changes in their habitat extent and conditions, but those living in currently cooler and currently more predictable seasonal environments will be hardest hit (e.g. cool water species from the Mount Lofty Ranges).

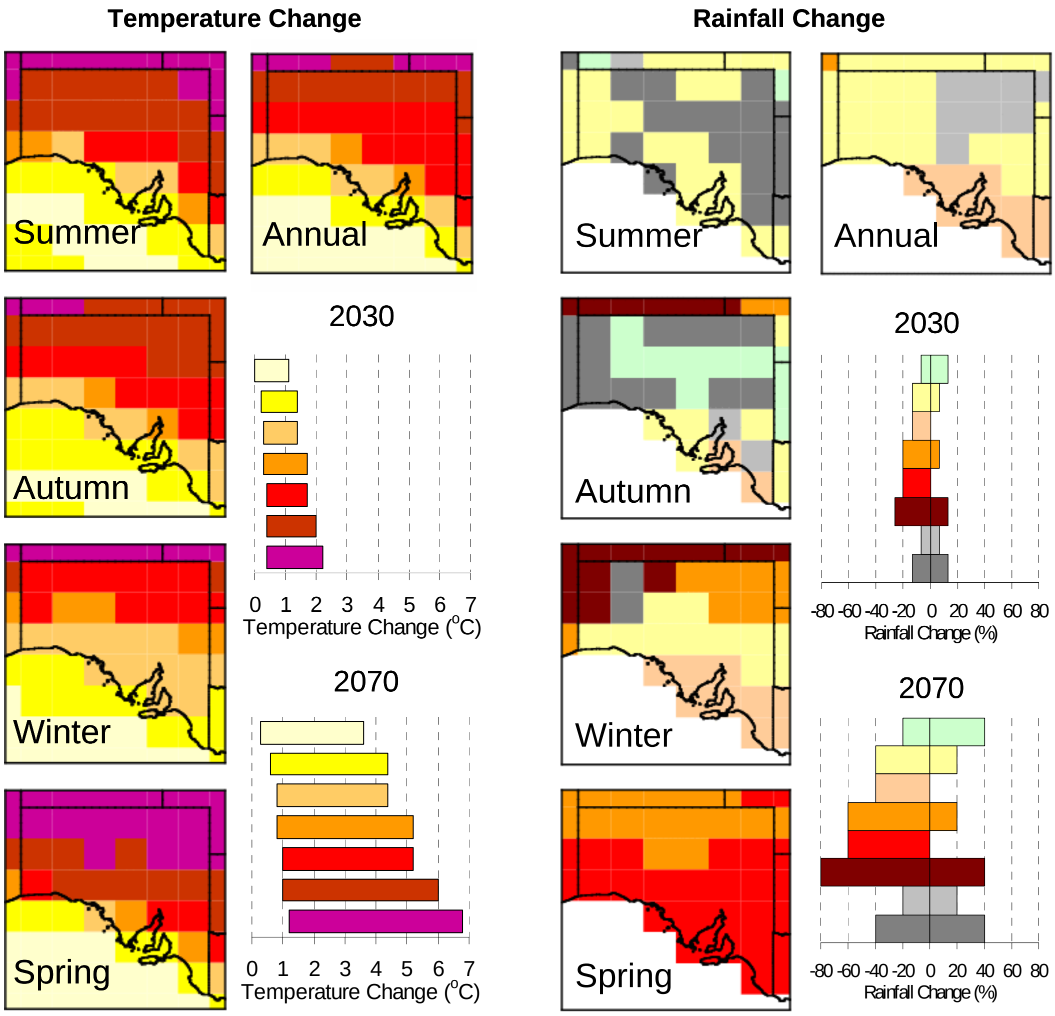


Figure 7: CSRIO projections of (a) average seasonal and annual warming ranges (oC) for around 2030 and 2070 relative to 1990 and (b) average seasonal and annual rainfall change (%) for 2030 and 2070 relative to 1990. The coloured bars show ranges of change for areas with corresponding colours in the maps (reproduced from McInnes et al. 2003).

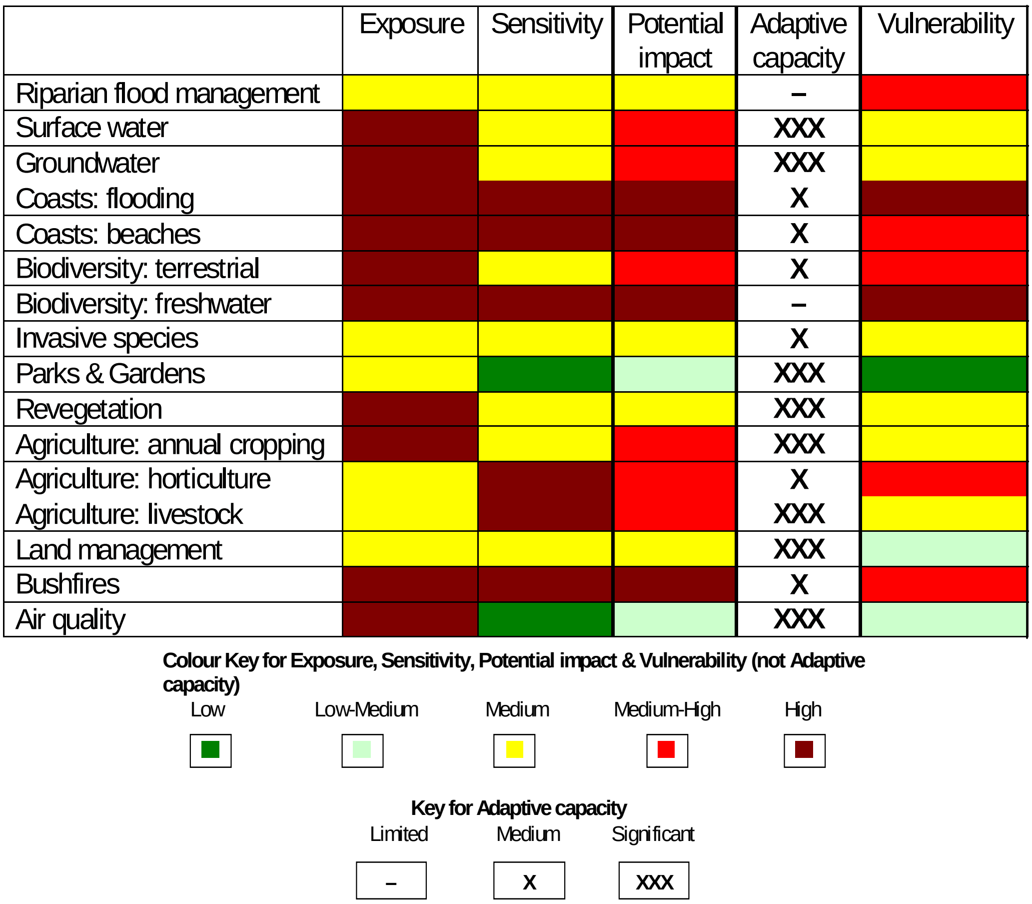


Figure 8: Summary of the likely severity of climate change in impacting various components of natural resource management under predicted conditions for the Mount Lofty Ranges (reproduced from Bardsley 2006).

Given that accurate tolerance estimates are not known for almost all of the MLR freshwater fishes (see Table 8), the actual levels of impact at which species may be affected, impacted or become extinct are also not yet known. A targeted study, aimed at estimating species tolerances to high temperature, salinity and hypoxia will provide this vital information and can be utilised in relation to the CSIRO predictive models to gain a projected understanding of how native fish sustainability will be impacted by climate change in the MLR. This action is highly recommended and was identified as a research and investment priority for the SA Murray-Darling NRM Board (Dalby and O'Connor 2006).

The ability of fishes and other biota to cope and ultimately adapt to climate change will depend on the characteristics of particular species and ecosystems, some level of management and probably in many cases, chance. In a sense we have a small window of time currently to repair some historic and current damage to systems and ensure populations are in a healthy and as wide spread range across different habitats as possible, to prepare for the future. Thus the best prescription for climate change is to sensibly manage and protect systems from external influences (e.g. habitat damage) but place a particular emphasis on environmental water allocations that achieve a buffer for future change.

5.4 General Conclusions

The MLR possess a unique and highly valuable native fish fauna that is worthy of protection and careful management. This requires, however, that managers embark on programs to gain knowledge and develop strategies that are effective in enhancing population sustainability. This can be effectively undertaken utilising linkages and partnerships between local universities, research institutes and government and NRM agencies. Clear direction is required and therefore it is essential that NRM planning processes and investment strategies make provision for the development of such programs and that external state and federal funds are sought to expand current and ongoing management activities.

This report has outlined the need for the expansion of knowledge and investment if native fish populations are to be managed for sustainability. There remains a distinct lack of locally derived biological knowledge for native fish species and for many species there is a complete lack of knowledge regarding their local distribution, status or biology. Finally, the ongoing management and sustainability of MLR native fish species is inextricably linked with the rehabilitation of riverine systems and processes. Clearly, benefits to native fish should be considered and incorporated into rehabilitation programs, as native fish sustainability is predominantly dependant on effective management of stream and riverine habitats.

6 Data sources

This section documents the information sources and methodology used for reviewing information. A two-pronged method was used to (a) document actual data collected in the MLR region by reviewing primary data sources and (b) draw on information more broadly in southeastern Australia by utilising reviews.

There has been a lack of historical data collected, with intensive studies at basic information levels such as distribution only appearing in the last 6 or so years. Targeted long-term ecological monitoring has been badly neglected and most biological information needs to be inferred from interstate studies. The sources of available information and the data they contain are described below. Some historical sampling locations are collated in maps presented in Figure 9.

6.1 Local Data Sources

South Australian Museum (SAM): Specimens lodged provide basic information on species distributions in the region, with the potential for identifying trends of decline through time (records span late 1800's to present). There are around 350 records; these are patchy in space and time (Fig. 9). Identification can be assigned with confidence as specimens exist (and can be verified if required), location details are of varying spatial certainty. The accuracy of the collection records is being improved through constant revision as part of various programs (e.g. Fish Inventories and the Action Plan for freshwater Fishes in South Australia in preparation).

Regional 'Fish Inventory' program: Native Fish Australia (SA) has since 2001 being undertaking extensive surveys across the state to better document distribution of native and exotic fishes. The general methodology has a sufficient spatial intensity in the MLR to identify broader habitat associations, the character of remaining habitat and fish related environmental parameters. Some trends over short and longer temporal scales are evident through sampling sites targeted for where other data exists (previous surveys, museum records, oral history). Length frequency information is gathered opportunistically as part of the program, and links with longer term monitoring for environmental flows in the EMLR (see below). Relevant survey coverage includes: EMLR streams and connected wetland habitats (Wedderburn and Hammer 2003; Hammer 2004; Hammer *et al.* 2005), southern Fleurieu Peninsula (Hammer 2006c), and SAG - Bungala, Torrens and Patawalonga catchments (Hammer *et al.* 2004; Rowntree and Hammer 2004; Hammer 2005c).

EMLR fish monitoring: Involved demographic data and flow/habitat related observations over last 4-5 years at selected stream nodes for environmental flows/threatened species fish monitoring for the River Murray Catchment Water Management board (now SAMDB NRM board). Focus on the Marne River catchment and sites across other EMLR catchments with southern pygmy perch and river blackfish (Hammer 2002c; Conallin and Hammer 2003; Hammer 2005a)– program currently under review for expansion in the future. Other unpublished biological data held by the Michael Hammer collected as supplementary observations during the Inventory and EMLR sampling is also included here.

Mid north ecology reports: A series of surveys to inform the development of river management plans, and developed stream index of biotic integrity (IBI) scores for sites.

Broad scale coverage across the Gawler, Wakefield, Light and Broughton catchments with some supplementary biological information (Hicks and Sheldon 1998; Hicks and Sheldon 1999a, b, c). Surveys were not vouchered, with minor issues with confirming the presence of mountain galaxias in more northern catchments (Broughton, Light).

Onkaparinga environmental flows project: As part of assessing Environmental Water Requirements in the Onkaparinga Catchment a targeted fish survey was undertaken in 2001-2002 (SKM 2002). Interesting data was collected from different areas of the catchment. No vouchers were retained from the study and several data (taxonomic) issues subsequently remain.

Ecology of small fish of the River Murray: select sites in a few catchments (Marne, Angas, lower Finniss and Tookayerta) were sampled as part of a broader investigation of the autoecology and conservation status of small fishes of the South Australian section of the Murray-Darling Basin. The official reference for this work is a peer reviewed paper (Lloyd and Walker 1986), however significant citation is also made to the raw data and additional detail of his masters thesis (Lloyd 1987). A range of specimens was left with SAMA verifying the data collected.

SARDI: SARDI has conducted a number of studies of fish and aquatic ecology that have various levels of relevance to the MLR. Many of these studies focus on the River Murray (including the main river channel, creeks and anabranches, floodplain systems and wetlands) as well as the Lower lakes and Coorong (Ye *et al.* 2000; Leigh 2002; Smith and Walker 2004a; Smith and Walker 2004b; Ye 2004; Bice and Zampatti 2005, Cheshire 2005, Smith *et al.* 2006, Zampatti & Leigh 2006). Many of these studies are directly relevant to understanding the species and ecology of the lowland EMLR fish fauna, but have varying relevance to patterns in the WMLR. SARDI has also conducted investigations into the ecology of streams in the WMLR, focussing on wetland, aquatic and riparian vegetation communities. SARDI also lead the current project to collect baseline knowledge and develop a long term monitoring and assessment framework for sustainable fish populations in the MLR.

6.2 Miscellaneous studies

Distribution

General fishes of the region (Zietz 1902; Scott *et al.* 1974; Hammer and Butler 2000; Sim *et al.* 2000; Hammer and Butler 2001a, b; Carter and Pierce undated).

Various other surveys or reviews on the (a) Onkaparinga (Branden *et al.* 1974; Edmeades 1999; Hammer 2006a), (b) Torrens (Zietz 1887; Tyler *et al.* 1976; Cappo *et al.* 1979; Hassell and Partners *et al.* 1979; Edmeades 1999; Hicks and Hammer 2004; Mathews *et al.* 2004; Gray *et al.* 2005; Hicks and McEvoy 2005) and (c) Gawler (Hammer 2000; Hicks 2000) catchments.

Sites in the EMLR as part of broader studies (Bertozzi 1990; Bertozzi *et al.* 2000; Wedderburn 2000) and review of recent distribution info for exotic and native species in SA MDB (Smith and Hammer 2005).

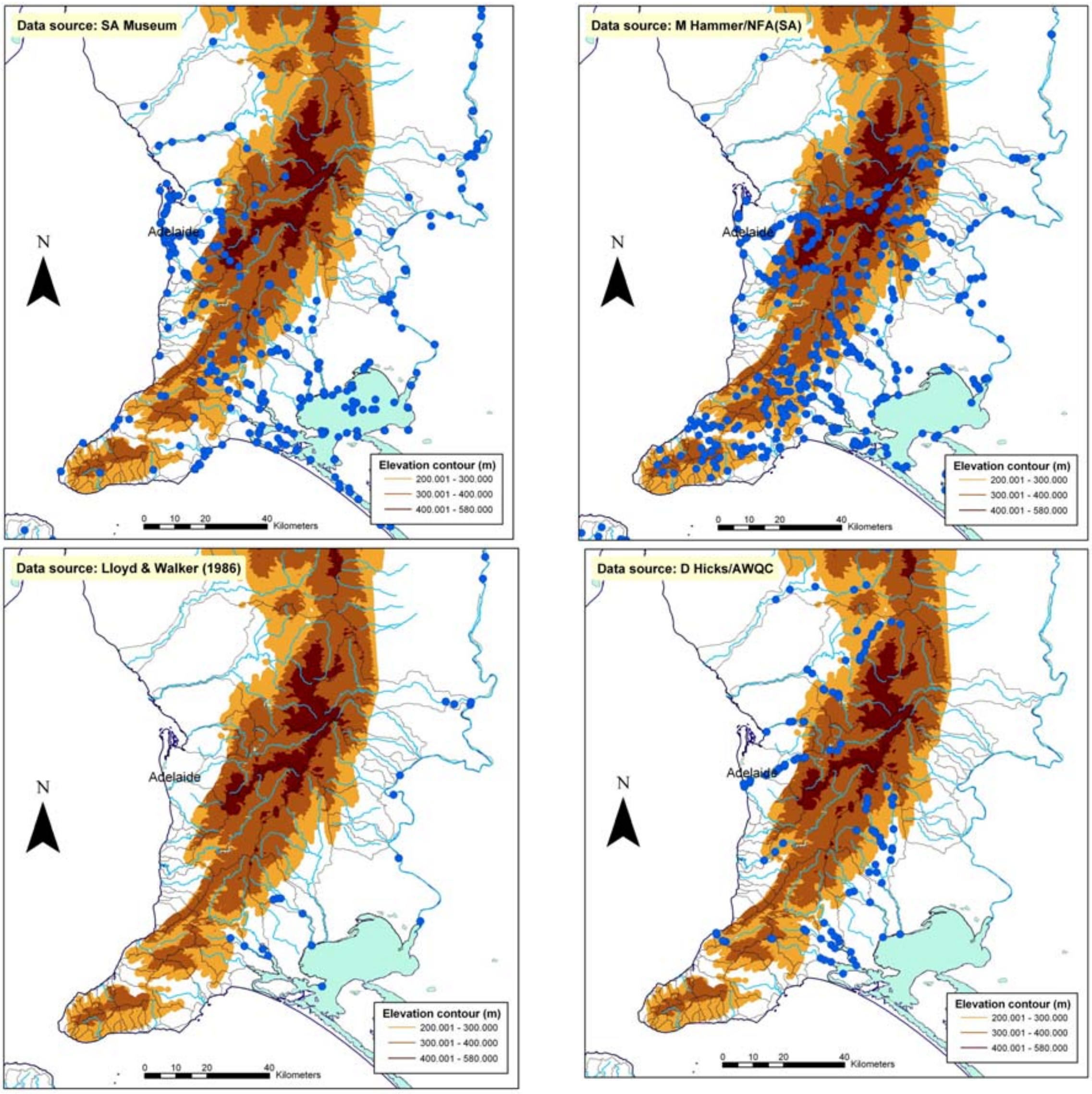


Figure 9. Some historical sampling locations in the MLR region used for species distribution data.

Biology

Observations on: *Mogurnda* and other fishes of the lower Finniss River (Nettlebeck 1926; Hale 1928; Blewett 1929; Rutherford 1991) and congolli (Hale 1920; Piddington 1964; Cheshire 2005a).

A specific study on southern pygmy perch in the MLR (Hammer 2001).

Biological studies for various relevant species in close proximity to study region e.g. Lower Murray, Lower Lakes and Coorong (Reynolds 1983; Puckridge and Walker 1990; Molsher *et al.* 1994; Vilizzi and Walker 1999; Ye *et al.* 2000; Leigh 2002; Smith and Walker 2004a; Smith and Walker 2004b; Ye 2004; Bice and Zampatti 2005).

Environmental engineering studies to gain understanding of management issues with experimental testing of local fish: mountain galaxias and flow gauging weirs (Cantone et al. 2002), common galaxias and fish passage on the lower Torrens (Davies et al. 2003).

Investigation of trout ecology in the MLR with field sites in various catchments (e.g. Finniss, Bremer, Light, Broughton) and main study area in Sixth Ck, Torrens Catchment. Some supplementary observations on galaxias decline (Morrissy 1967).

Investigation of impact of acid mine drainage on fish in the SE MLR (Hicks 1997).

Bryan Pierce (formerly SARDI) did conduct research in the area (see Pierce 1997), however the nature and extent of this remains unclear due to a lack of publications.

6.3 General (Non-MLR) Data Sources

Three primary sources were used to provide a general summary of information (see below). Extensive revision of information used in the three reviews was not undertaken due to time constraints (reference to primary data sources would be the better determination and acknowledges the actual authors who contributed the information). Any new or key references not included in these sources known to the authors were included (see below).

Review of information for management of native freshwater fishes in Victoria: The publication (Koehn and O'Conner 1990) collates data from SE Australia relevant to species occurring in Victoria, many of which also occur in the MLR (but see taxonomy in Section 4). As it was based on information published up to the late 1980's it is a bit outdated but nevertheless serves an excellent conceptual framework and data source.

Fishes of south –eastern Australia: An edited book with chapters on the various fish familles of south eastern Australia, with summaries of the 'model' life history for species (McDowall 1996). Again various authors contributed to the different chapters and each chapter sites key or general references forming the primary data sources.

Review of Habitat Associations of Native Fish in the Murray Darling Basin: A fairly comprehensive literature review for fish species of the MDB including different life stages (SKM 2003). A weakness is that it generally does not incorporate information from South Australia, but this aspect is of less importance considering the approach of this review.

Other references

Several new studies covering habitat use and biology of river blackfish, southern pygmy perch, mountain galaxias and Murray hardyhead were important to include (Bond and Lake 2003; Khan *et al.* 2004; Ellis 2005) along with systematic studies (e.g. Sanger 1986; Musyl and Keenan 1992, 1996; Bertozzi *et al.* 2000; Waters *et al.* 2000; Hammer 2001).

7.0. References

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Appendix 1

*Example field images of MLR Fish species**

Pouched lamprey – River Torrens, City Weir (SAG)

Shorthead lamprey – Boundary Creek (adjacent EMLR)

Shortfinned eel – Onkaparinga River (SAG); tail fin alignment (inset)

Climbing galaxias – Southern Fleurieu Peninsula (SF)


Common (top) and mountain (lower) galaxias – Finniss River


Juvenile (whitebait) common galaxias – River Torrens (SAG)

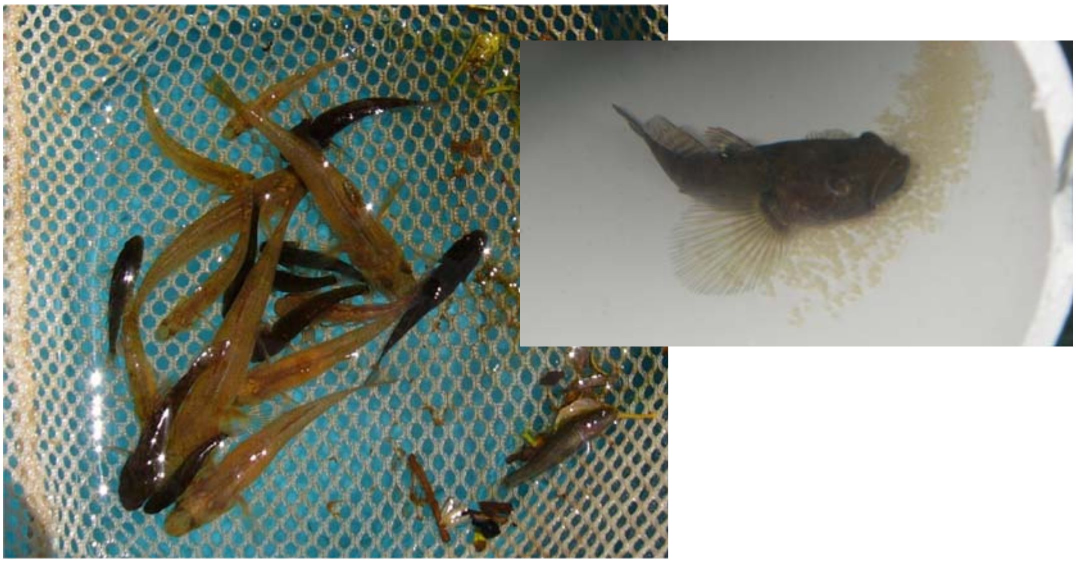

River blackfish – Marne River (EMLR)


Southern pygmy perch– Inman River Catchment (SF)

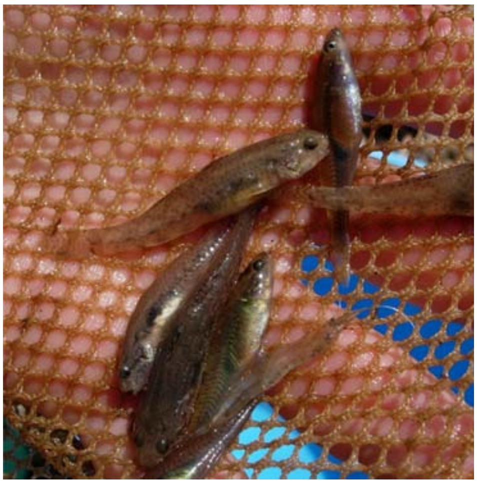
Yarra pygmy perch – Lower Finniss River wetlands (EMLR)

Congolli –Middleton Creek (SF)

Murray-Darling carp gudgeon - Inman River Catchment (SF)



Flathead and dwarf flathead gudgeon – Torrens Gorge (WMLR); male flathead gudgeon guarding eggs (inset)



Western bluespot goby and Murray-Darling carp gudgeon –Inman River (SAG)

Western bluespot goby, Torrens River (SAG)

Murray Catfish, Torrens River (SAG, Translocated)

Murray Rainbowfish- Torrens River (SAG-translocated)

***All Photos taken by the authors**