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Ecology, Monitoring, Conservation

River Torrens Water Quality Improvement Trial 2014–15: Fish Monitoring, autumn 2015

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Executive summary

The River Torrens is a highly modified and regulated system flowing through the heart of the city of Adelaide, South Australia. A long history of urban development since European settlement has dramatically impacted its catchment and resulted in reduced aquatic biodiversity, with only half of the 16 indigenous freshwater fish species now occurring. Concerted efforts to improve biodiversity, such as the installation of three fish ladders (to improve connectivity), enhancement of localised aquatic habitat, provision of environmental flows and dilution flows through Torrens Lake to ameliorate the risk of cyanobacteria blooms, have recently been implemented to address these impacts. The monitoring of fish communities over recent years has provided useful assessment of the effectiveness of these restoration efforts; hence the autumn 2015 study continues this ongoing assessment.

Overall, native fish communities continued to improve, with broad recruitment of native species and consolidation of the range of diadromous species; although numbers of the introduced eastern gambusia have rapidly increased across Breakout Creek and management of this highly invasive species will be paramount. Diadromous species, whose movement into the Lower Torrens en masse was detected during spring 2014 monitoring, have consolidated this range expansion and even greater movement is anticipated during 2015. The dilution flows over the 2014−15 summer (along with other recent summers) did not appear to have any negative impact on downstream native fish populations, even possibly contributing to increased native fish abundance and diversity – although the sampling regime is insufficient to prove causation with certainty. Finally, the impact of the May 2014 fish kill continues to diminish and the fish species (with the exception of adult freshwater catfish) have recovered to levels comparable to those observed prior to the event.

The outcomes of recent monitoring highlight positive changes in the fish community following restoration of a heavily altered urban river system, and a considerable engagement opportunity exists to showcase these benefits and garner community support. Continued restoration efforts are necessary, including further enhancement of habitats of the Lower Torrens, and accompanying monitoring will be important to document changes to the fish community.

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1 Introduction

1.1 Background

Waterways flowing through urban centres – which account for half of the world's rivers – represent some of the most degraded aquatic ecosystems (Walsh *et al.* 2005; Gurnell *et al.* 2007; UNFPA 2007). River Torrens is a highly modified and regulated system that flows through the heart of Adelaide, a major city populated by over 1.2 million people, in the Western Mount Lofty Ranges (WMLR), South Australia (Daniels and Hodgson 2010). The river once resembled a series of interconnected aquatic habitats, transitioning from a small flowing upland freshwater stream, interspersed with many deep and permanent pools, to an expansive estuary wetland, which under high flows discharged both northwards into the Port River estuary, and southwards towards the Patawolonga Creek (Holmes and Iversen 1976).

However, activities following European settlement, (e.g. the alteration of upstream flow regimes through construction of dams, weirs and reservoirs; construction of the Breakout Creek ocean outfall, draining and bypassing of the estuary wetland, clearance or substantial modification of riparian vegetation throughout the catchment, and increased nutrient and pollution inputs associated with urban development) have dramatically impacted the catchment and reduced aquatic biodiversity (Daniels and Hodgson 2010). In particular, freshwater fish – forming a significant component of aquatic biodiversity in the region – have been severely impacted, with the loss of species, declines in range and abundance and greater pervasiveness of alien (and translocated) species now occurring (Hicks and Hammer 2004).

There is increasing recognition of the need to restore urban waterways (Walsh 2000; Feminella and Walsh 2005), not only to improve ecological function and connectivity but to also enhance social and economic values (Findlay and Taylor 2006). In the Torrens catchment, concerted restoration efforts have recently been implemented to address over a century of cumulative detrimental impacts associated with urbanisation and flow modification (Table 1). Restoration efforts include the installation of three fish ladders (to improve connectivity), enhancement of localised aquatic habitat, provision of environmental flows, and dilution flows through Torrens Lake to ameliorate the risk of cyanobacteria blooms.

Table 1. Recent restoration efforts influencing the study region (between Tapleys Hill Rd to Second Creek outlet) of the Torrens catchment.

Period	Reach	Action	Assessed
2005	Breakout Creek outlet weir	Installation of fish ladder	McNeil *et al*. (2010)
2005−2007	Above Henley Beach Rd weir (stage 1)	Habitat restoration	McNeil *et al*. (2012); Schmarr *et al*. (2013); Whiterod (2014a; b); present study
2010−2013	Between Tapleys Hill Rd and Henley Beach Rd weirs (stage 2)	Habitat restoration, including installation of two weirs (to manage water levels) and associated fish ladders	Whiterod (2014a; b); present study
2011−ongoing	Upper catchment, but with downstream influence	Implementation of environmental flows trial	SARDI, *unpublished data*
2011−ongoing	Torrens Lake with downstream influence	Dilution flows for cyanobacteria management	McNeil *et al*. (2012); Schmarr *et al*. (2013); Whiterod (2014a; b); present study

Freshwater fish are considered useful indicators of environmental change (Fausch *et al.* 1990) and hence monitoring patterns of distribution, abundance and population demographics provides valuable data for assessing the effectiveness of restoration efforts (McNeil and Hammer 2007; Hammer 2011). Assessment of the Breakout Creek outlet weir fish ladder, for instance, highlighted the successful ascent of nine species (McNeil *et al.* 2010), including diadromous species; those species having both freshwater and marine phases of their life cycle (McNeil *et al*. 2012; Schmarr *et al.* 2013). Dilution flow monitoring of the lower River Torrens in autumn and spring 2014 highlighted that the two recently installed fish ladders (on Tapleys Hill Road and Stage 2 weirs) are facilitating fish passage, but questions over their effectiveness remain given observed fish aggregations downstream (Whiterod 2014a; b). Most notably, a substantial number of juvenile common galaxias were recorded in spring 2014 across the lower Torrens River, representing an almost ten-fold increase in numbers since early summer 2012 (i.e. before completion of fish ladders).

Assessment of the influence of dilution flows over summer 2011−12 and 2012−13, highlighted recruitment responses in native and alien fish species, suggesting limited or no downstream influence of the unseasonal flows (McNeil *et al.* 2012; Schmarr *et al.* 2013). Consistently, monitoring of the 2013−14 summer dilution flows indicated that the flows did not negatively impact downstream native fish populations (Whiterod 2014a; b). This monitoring also highlighted that the fish kill in May 2014 clearly impacted the resident fish community with some recovery occurring, but ongoing assessment required.

The present study details autumn 2015 monitoring (but also draws on the outcomes of complimentary autumn and spring 2014 sampling) with the aim of providing assessment of the (a) effectiveness of fish ladders in Breakout Creek, and (b) ongoing impact of the dilution flows over the 2014−15 summer and (c) recovery from the May 2014 fish kill upstream of Henley Beach Road.

1.2 Fish species of the study region

The River Torrens catchment historically supported 16 indigenous freshwater fish species across freshwater generalist, freshwater specialist, diadromous and estuarine functional groups as well as least 12 marine vagrants (Hicks and Hammer 2004; McNeil *et al.* 2010; McNeil *et al.* 2011). The contemporary (1999−2014) fish fauna upstream of the Breakout Creek weir is 23 fish species, including just eight indigenous species with 14 non-indigenous species along with shortfinned eel *Anguilla australis*, which was first recorded in the catchment in 2007. Within the study region (Tapleys Hill Road weir to Second Creek outlet weir), 13 species were recorded between 1999 and 2014: six indigenous species (including mountain galaxias *Galaxias olidus* first recorded in the study region in spring 2014), three River Murray translocations and three alien species (Table 2).

Table 2. Contemporary (1999−2014) fish species recorded in the study region of the River Torrens catchment, and downstream of Breakout Creek outlet weir. State cconservation status abbreviated as EN=Endangered, VU=Vulnerable, and RA=Rare (Hammer *et al.* 2009). Translocated native species represented by *.

Functional Group	Species	Scientific name	Action plan status	Study region	ds outlet weir
Freshwater generalist	Carp gudgeon*	*Hypseleotris spp.*		x	x
	Flathead gudgeon	*Philypnodon grandiceps*		x	x
	Murray rainbowfish*	*Melanotaenia fluviatilis*		x	x
Freshwater specialist	Freshwater catfish*	*Tandanus tandanus*	EN	x	x
	Mountain galaxias	*Galaxias olidus*	VU	x	
Diadromous	Climbing galaxias	*Galaxias brevipinnis*	RA		x
	Common galaxias	*Galaxias maculatus*		x	x
	Congolli	*Pseudaphritis urvillii*	VU	x	x
	Pouched lamprey	*Geotria australis*	EN	x	x
	Shortheaded lamprey	*Mordacia mordax*	EN		x
	Shortfinned eel	*Anguilla australis*	RA	x	
Estuarine	Black bream	*Acanthopagrus butcheri*			x
	Jumping mullet	*Liza argentea*			x
	Smallmouth hardyhead	*Atherinosoma microstoma*			x
	Tamar goby	*Afurcagobius tamarensis*			x
	Yellow-eyed mullet	*Adrichetta forsteri*			x
	Western bluespot goby	*Pseudogobius olorum*		x	x
Alien	Gambusia	*Gambusia holbrooki*		x	x
	Common carp	*Cyprinus carpio*		x	x
	Goldfish	*Carassius auratus*		x	x

A total of 18 freshwater species (as well as a number of marine vagrants) have been recorded downstream of the Breakout Creek outlet weir, six of which (diadromous species climbing galaxias *Galaxias brevipinnis* and five estuarine species) have not been recorded across the study region in recent times (McNeil *et al.* 2010; McNeil *et al.* 2011)

1.3 Project hypotheses

The overarching aims of the project are to assess the (a) effectiveness of fish ladders in Breakout Creek, (b) impact of the dilution flows over the 2014−15 summer, and (c) recovery after the May 2014 fish kill upstream of Henley Beach Road.

In doing so, the following hypotheses will be tested:

Relating to aim (a):

- Diadromous fishes would be facilitated in moving upstream of the Breakout Creek fish ladder towards the city weir;
- In-channel barriers between Breakout Creek and the city weir may serve as barriers to upstream fish movements resulting in aggregations below barriers;

Relating to aim (b):

- Flows may induce spawning and/or recruitment responses that are measurable by assessing fish population structure;
- Freshwater inflows into the relatively poorer water quality environment of the Torrens Lake will result in aggregations of spawning common carp and lead to increases in common carp abundance, biomass and distribution; and,

Relating to aim (c):

- The abundance, distribution and structure of fish populations in the area affected by the May 2014 fish kill will be impacted.

2 Methods

2.1 Study region

The River Torrens catchment is a prominent and relatively large system (≈620km^2) originating in the WMLR before flowing westward across the Adelaide plains, discharging into Gulf St Vincent near West Beach. This project focused on a region in the River Torrens catchment between Second Creek outlet and the Tapleys Hill Road weir (Figure 1).

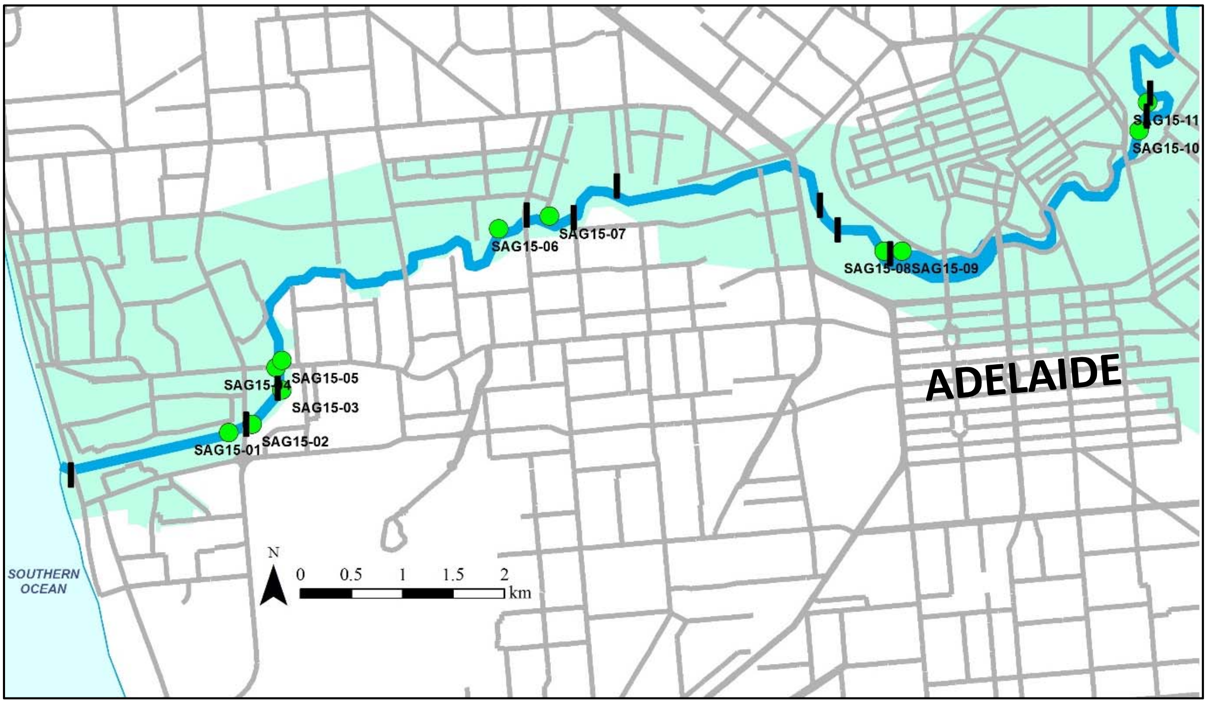

Figure 1. Study region of the River Torrens catchment (light green), highlighting sampling sites (with Aquasave-NGT site code, green dots), weirs (black bars) and major roads (grey).

Across the study region, separate upstream and downstream sites distinguished the five sites detailed in the project brief, and ongoing assessment of the additional May 2014 fish kill site (upstream of Henley Beach Road weir) continued. In total, 11 sites were sampled between 30 March and 1 April 2015 (Table 3).

Table 3. Summary of sampling sites and methodology.

Site Code	Date	Waterway	Location	Easting	Northing	Fyke nets	
						Single	Double
SAG15-01	30-Mar-15	Breakout Creek	Tapleys Hill Rd weir (downstream)	273104	6131680	3	1
SAG15-02	30-Mar-15	Breakout Creek	Tapleys Hill Rd weir (upstream)	273332	6131762	3	1
SAG15-03	30-Mar-15	Breakout Creek	Stage 2 weir (downstream)	273627	6132096	3	1
SAG15-04	30-Mar-15	Breakout Creek	Stage 2 weir (upstream)	273568	6132317	3	1
SAG15-05	31-Mar-15	Breakout Creek	Henley Beach Rd weir (upstream)	273624	6132386	3	2
SAG15-06	31-Mar-15	River Torrens	Holbrooks Rd weir (downstream)	275751	6133674	3	1
SAG15-07	31-Mar-15	River Torrens	Holbrooks Rd weir (upstream)	276248	6133797	3	1
SAG15-08	01-Apr-15	River Torrens	City weir (downstream)	279533	6133457	3	1
SAG15-09	01-Apr-15	River Torrens	Torrens Lake	279705	6133456	3	
SAG15-10	01-Apr-15	River Torrens	Second Creek outlet (downstream)	282029	6134636	3	
SAG15-11	01-Apr-15	River Torrens	Second Creek outlet (upstream)	282116	6134911	3	

2.2 Flow summary

The flow regime prevailing in the River Torrens downstream of Torrens Lake (Holbrooks Road gauging station, A5040529) between July 2014 and May 2015 is presented in Figure 2. There was reasonable winter flows (peaking at 37,319 ML/day on the 10 July 2014) before low spring flows were experienced. Summer flows were equally low, except for a moderate, atypically high flow event (peaking at 18,249 ML/day) in mid-January 2015 and three dilution flow pulses through Torrens Lake (16–20 December 2014; 16–20 February 2015; 28 February to 4 March 2015) ranging between 550, 673 and 575 ML in total, respectively. A number of moderate peaks in flow were experienced after this autumn monitoring (during April 2015).

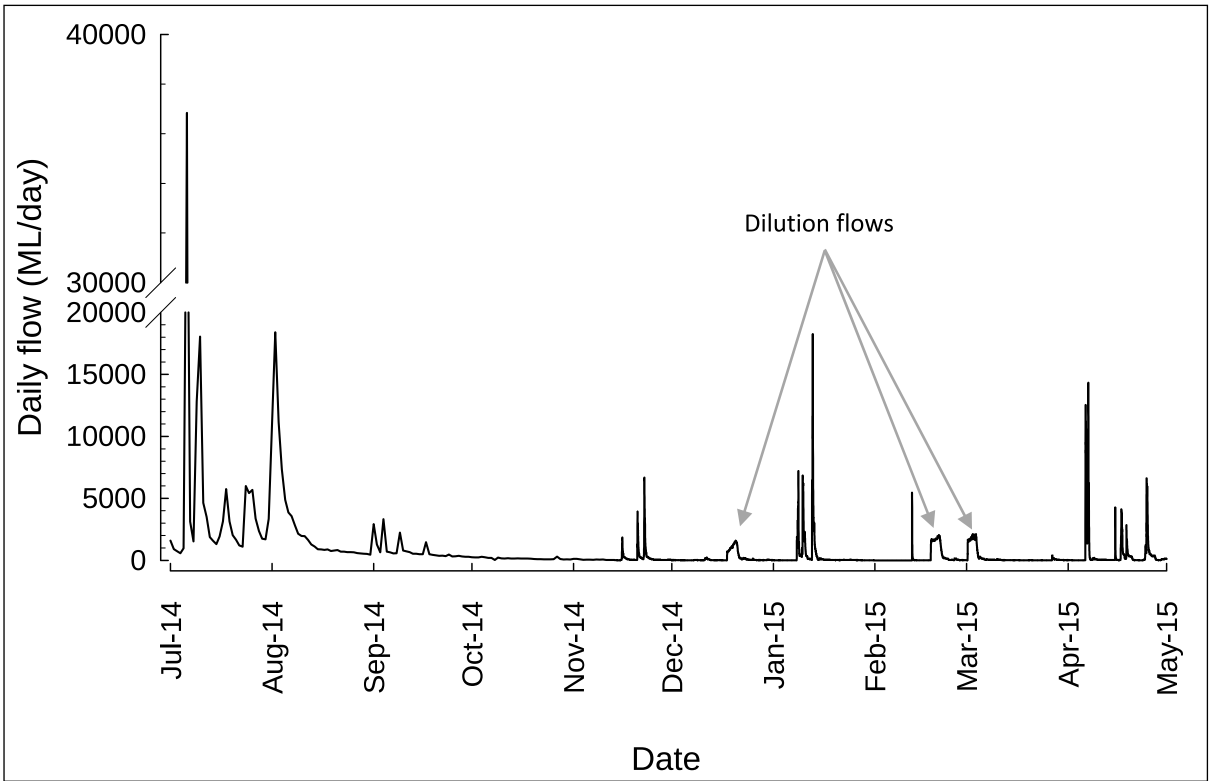

Figure 2. Mean daily flow (ML/d) for the Torrens River @ Holbrooks Road (A5040529) between July 2014 and May 2015 (source: Water Data Services) (note: the break in daily flow between 20,000 and 30,000 ML/day).

2.3 Field sampling

Fish monitoring followed the previously established flow dilution methodology (McNeil *et al.* 2012; Schmarr *et al.* 2013), which has been employed over autumn and spring 2014 sampling (Whiterod 2014a; b). This was designed to determine presence and relative abundance of fish species and provide information on population structure and fish condition (i.e. diseases). At each sampling site, three small single-winged fyke nets were employed and for sites below city weir, a directionally set double-winged fyke net – either upstream or downstream of the associated weir structure (depending on site) – was also used to sample upstream movement (Table 3). At the additional site used to investigate the fish kill, three small fyke nets and two double-winged fyke nets were employed. All fyke nets were set overnight with a buoyed cod end (to enable surface access for air-breathing by-catch) and targeted the widest variety of aquatic microhabitats across a 50m reach at each site.

The dimensions of nets were as follows:

- **Single-winged fyke net** - single 3m wing, 4mm mesh, 3m funnel, 0.6m high; and,
- **Double-winged fyke net** - double 5m wing, 4mm mesh, 3m funnel, 0.6m high.

All sampled fish were identified to species level (Allen *et al.* 2002), counted and observed to obtain general biological information (reproductive condition and external disease or parasites). Total length (TL, mm) was recorded for the first 20 individuals for each species per net. Records of other fauna opportunistically sampled were noted.

At each site, environmental descriptors, covering differing aspects of underwater cover, edge vegetation, pool condition, flow and water quality were recorded to aid the interpretation of results and assist with broader condition assessment (see Appendix 1. Habitat descriptors). All monitoring was conducted in accordance with PIRSA Ministerial Exemption no. ME9902705.

3 Results

3.1 Fish community

3.1.1 Summary

Some 19,324 fish across 11 species (eight native, three alien) were recorded across the 11 sites sampled across the study region in autumn 2015 (Table 4). The catch again included River Torrens endemics (flathead gudgeon *Philypnodon grandiceps*, congolli *Pseudaphritis urvillii*, common galaxias *Galaxias maculatus*, and western bluespot goby *Pseudogobius olorum*); translocated Murray-Darling Basin species (carp gudgeon *Hypseleotris spp.*, Murray rainbowfish *Melanotaenia fluviatilis* and freshwater catfish *Tandanus tandanus*); and alien species (eastern gambusia *Gambusia holbrooki* and common carp *Cyprinus carpio* and goldfish *Carassius auratus*). Although present in spring 2014, mountain galaxias *Galaxias olidus* was not recorded in the study region in autumn 2015. The fish catch was numerically dominated by four species: flathead gudgeon (5729 fish), eastern gambusia (5436 fish), carp gudgeon (3991 fish) and Murray rainbowfish (3656 fish), which accounted for 97% of total numbers. Rarer species included western bluespot goby (8 fish), goldfish (5 fish) and dwarf flathead gudgeon (1 fish).

Table 4. Summary of fish catch from autumn 2015.

		Fish species										
Site code	Location	Carp gudgeons	Common galaxias	Congolli	Dwarf flathead gudgeon	Flathead gudgeon	Freshwater catfish	Murray rainbowfish	Western bluespot goby	Common carp	Gambusia	Goldfish
SAG15-01	Tapleys Hill Rd weir (downstream)	140	25			208	1	222		6	3274	
SAG15-02	Tapleys Hill Rd weir (upstream)	454	24	5		372	5	263		1	337	2
SAG15-03	Stage 2 weir (downstream)	736	4	2		438	23	38			623	1
SAG15-04	Stage 2 weir (upstream)	1401	76			2068		401			745	1
SAG15-05	Henley Beach Rd weir (upstream)	992	104			648	9	530		8	270	
SAG15-06	Holbrooks Rd weir (downstream)	74		1		28	58	601		3		
SAG15-07	Holbrooks Rd weir (upstream)	68	5	2		75	7	1008		1	65	
SAG15-08	City weir (downstream)	27	23			86	30	1				
SAG15-09	Torrens Lake	45			1	75	3	51			53	
SAG15-10	Second Creek outlet (downstream)	20	8				10	338	8		51	
SAG15-11	Second Creek outlet (upstream)	34				1731	52	203		3	18	

In the following sections, the outcomes of monitoring are presented in the context of functional groups (which provide links to the hypotheses of the study), with special mention of the species that are endemic and translocated.

3.1.2 Diadromous species

A total of 269 common galaxias were recorded across the study region during the present monitoring. A small number of individuals were again recorded upstream of Torrens Lake but the majority of fish (261 fish, size range 51−96mm) were observed from city weir to Breakout Creek. Whilst down considerably from spring 2014, the number of common galaxias represents a more than ten-fold increase from autumn 2014 (24 fish) indicating that the peak in juveniles has corresponded to greater establishment of sub-adults and adults of the species. The progression of spring 2014 juveniles into sub-adults and adults in autumn 2015 is clearly evident in Figure 3.

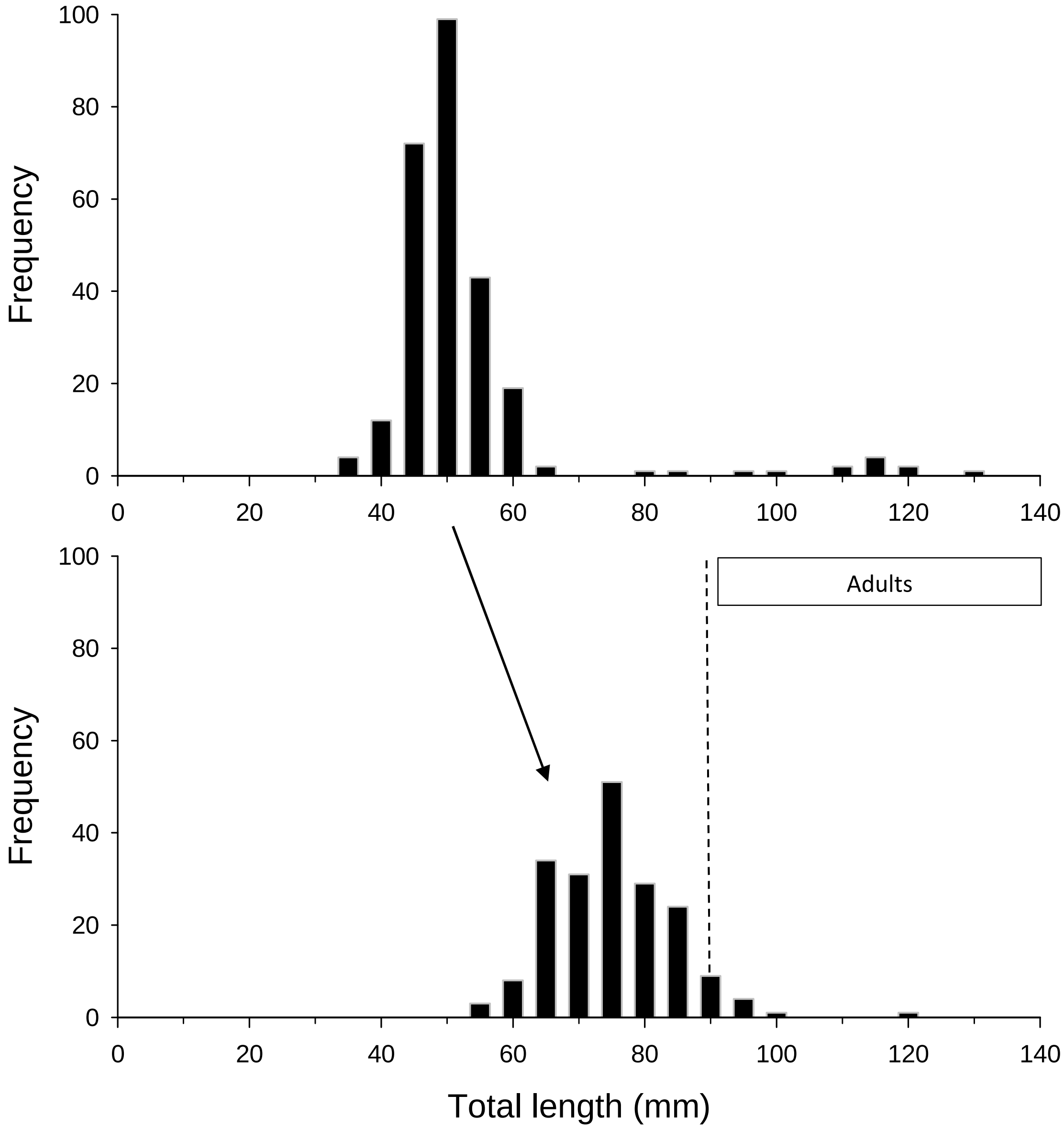

Figure 3. Population structure of common galaxias in the lower Torrens River in (a) spring 2014 and (b) autumn 2015. Black arrow transition of juvenile fish into the sub-adult and adult population.

Comparison between autumn 2014 and the present monitoring reveals consolidation of the range expansion of common galaxias detected during spring 2014 when improved connectivity benefited the species. In autumn 2014, the species was recorded at five sites but increased their range to eight sites in autumn 2015. The species was again detected downstream of the Second Creek outlet – reflecting recruitment of individuals first observed in spring 2014.

Diadromous species: congolli (left) and common galaxias (right)

The number and location of congolli observed in autumn 2015 was similar to a comparable period last year (e.g. 10 in autumn 2015 compared to seven in autumn 2014) indicating that, whilst the species consolidated its range expansion, it remains patchily distributed across the lower River Torrens. Previously recorded rarer species (e.g. shortfinned eel or pouched lamprey) were again not detected during autumn 2015 sampling.

3.1.3 Freshwater generalist (and wetland specialist) species

Freshwater generalists continued to represent the dominant functional group – accounting for almost 70% of fish sampled - across the study region. The translocated carp gudgeon and flathead gudgeon (3991 fish) remained prevalent across all sites, with the exception of the fast flowing site downstream of the Second Creek outlet weir. New recruits and mature individuals (carp gudgoen, 18−50mm; flathead gudgeon, 18−94mm) were noted, again highlighting robust population structures across both species. Murray rainbowfish were observed at all sites, and in numbers (3656 fish) not seen across the study region over recent years (previously 2931 fish observed in summer 2011). The other translocated MDB species, freshwater catfish, remains a common component of the fish community of the study region with numbers (198 fish) comparable to those of autumn 2014 (183 fish). In the area of the recent fish kill, the numbers of freshwater catfish were low, and adults again absent (size range, 65−104mm), suggesting recovery has not fully occurred.

A single dwarf flathead gudgeon, first recorded in the study region during spring 2014, was observed in present monitoring whereas mountain galaxias where not detected suggesting their presence in the study region is irregular.


Translocated and established: Murray rainbowfish (left) and freshwater catfish (right)

3.1.4 Estuarine species

The expectation of gradual expansion of the diversity and range of estuarine species is yet to occur. The only estuarine species present, western bluespot goby was recorded in low numbers at the upper end of the study region (downstream of Second Creek outlet). It is worth noting that no estuarine species were recorded in the lower Breakout Creek despite the recent presence of western bluespot goby and the ability of other species to ascend the outlet weir.

3.1.5 Alien species

Three alien species – goldfish, common carp and eastern gambusia – are well established across the study region. The present monitoring will be noted for the explosion of eastern gambusia (5736 fish) across the study region (previous high of 1205 fish), with 60% of individuals recorded in the degraded section downstream of Tapleys Hill Road (in fact 92% of individuals were recorded at sites below Henley Beach Road). The large spring 2014 spawning event of common carp (e.g. 5660 fish) corresponded to only modest numbers of juveniles being detected during the most recent sampling. Large adults remain absent in the vicinity of the May 2014 fish kill but the presence of advanced juveniles suggests recovery will occur in the immediate future.

A rare 'mirror' common carp (left) and a catch of eastern gambusia (right), which were abundant across the study region

3.2 Opportunistic catch

Opportunistic catch included common yabby *Cherax destructor* (7 sites), freshwater prawns *Macrobrachium* sp. (5 sites) and freshwater shrimp *Paratya* sp. (4 sites), as well as long and short-necked turtles (5 sites and 4 sites, respectively) and one water rat *Hydromys chryogaster* along the lower section of the study region (Table 5).

Table 5. Summary of opportunistic catch.

		Opportunistic catch						
Site code	Location	Common yabby	Freshwater shrimp	Freshwater prawn	Long-necked turtle	Short-necked turtle	Tadpoles	Other fauna
SAG15-01	Tapleys Hill Rd weir (downstream)	x						
SAG15-02	Tapleys Hill Rd weir (upstream)	x		x	x			
SAG15-03	Stage 2 weir (downstream)	x		x	x	x		
SAG15-04	Stage 2 weir (upstream)	x	x	x	x			Water rat
SAG15-05	Henley Beach Rd weir (upstream)	x		x	x			
SAG15-06	Holbrooks Rd weir (downstream)		x	x	x	x		
SAG15-07	Holbrooks Rd weir (upstream)	x	x					
SAG15-08	City weir (downstream)		x	x		x		
SAG15-09	Torrens Lake							
SAG15-10	Second Creek outlet (downstream)							
SAG15-11	Second Creek outlet (upstream)	x						

3.3 Environmental descriptors

At the time of sampling, river flows were low (with the exception of downstream of the Second Creek outlet weir site where flows were medium) and water levels across the sampling sites were either low or bank level (see Appendix 2. Environmental data). Consistent with observations during 2014 monitoring, all sites had low levels of physical habitat, predominately snags and rock (ranging from 0 to 10% of water column) and emergent habitat, often *Typha* and *Phragmites* (ranging from 1−30% of water column) and with reduced submerged aquatic vegetation (e.g. only up to 10%) as compared to spring 2014 monitoring. Edge vegetation (within 2m of water's edge) was highly variable amongst sites (1−60%) reflecting levels of riparian clearance, and canopy cover (0−30%) was typically low. Water quality remained relatively consistent across sampling sites, with moderate electrical conductivity (972−2125 µS/cm); pH ranging between 7.29 and 8.17, water temperature between 17.9 and 25.3 °C and dissolved oxygen concentrations (4.10−7.41 mg/L). At all sites, the water was generally clear or slightly brown (transparency ranging from 0.5−1.1 m). A cyanobacteria bloom was detected (peaking at 1,440,000 cells/mL in late March 2015) in the Torrens Lake over the second half of March 2015, with the bloom visually evident at the sampling site downstream of the weir, before dropping rapidly by early April 2015 following a flow pulse through the lake.

Downstream evidence of Torrens Lake cyanoabacteria bloom [Jo-Anne Robinson, *photojo*]

4 Discussion

The Torrens catchment has undergone substantial environmental alteration, leading to habitat degradation and irrevocably changing its fish fauna (Hicks and Hammer 2004). However, despite this backdrop, the catchment continues to maintain moderate species richness, and retains significant populations across multiple functional groups (McNeil and Hammer 2007; Hammer 2011). Furthermore, restoration efforts have occurred including habitat restoration (Breakout Creek Wetland stages 1 and 2), provision of fish ladders to enhance connectivity and passage, algal bloom control (via dilution flows), and environmental flows (which are being specifically assessed as part of another project – see Table 1). Fish monitoring has been undertaken at least annually over the past four years (bi-annually over 2014 and 2015) across the study region, to assess specific hypotheses relating to the status of fish communities to assess the efficiency of these restoration efforts. An updated assessment is provided below.

4.1 Status of fish species

The overall number of fish sampled has changed considerably over the past four years (Table 6). Indeed, only 761 fish were recorded in winter 2013, in contrast with 22,654 fish in summer 2011. Over the last three rounds of sampling, catches of 4135 fish (autumn 2014) and 18,615 fish (spring 2014) and most recently 19,324 fish (this autumn 2015 monitoring) have been recorded. These differences may reflect different effort in terms of sites and nets over time and seasonal biases associated with the timing of fish monitoring (e.g. fish potentially less active during cooler winter months and more concentrated during warmer summer months). Most recently, autumn and spring monitoring has been conducted (e.g. autumn 2014, spring 2014 and now autumn 2015), which should be repeated into the future to enable longer-term trends in population dynamics to be robustly assessed (see McNeil and Hammer 2007). Regardless, an insight into the response of fish species across the study region can be achieved.

Table 6. Status of fish species present in the lower River Torrens (based on autumn 2015, with the most recent increases in range denoted by ●).

	Previous monitoring					Present monitoring										
Common name	Summer 2011	Summer 2012	Winter 2013	Autumn 2014	Spring 2014	Autumn 2015	Below Tapleys Hill Rd	Tapleys Hill Rd weir to stage 2 weir	Stage 2 weir to Henley Bch Rd weir	Henley Bch Rd weir to Holbrooks Rd weir	Holbrooks Rd weir to city weir	Torrens Lake (to Second Creek outlet weir)	Above Second Creek outlet weir	Recruits (0+ fish)	Mature adults	Size range (TL, mm)
Carp gudgeon	5360	2347	336	2699	3890	3991								x	x	18–50
Common galaxias	32	756	1	24	6838	269								x	x	51–120
Congolli	1	9	8	7	39	10	●		●					x	x	89–250
Dwarf flathead gudgeon	0	0	0	0	5	1				●		●	●		x	42
Flathead gudgeon	7712	9157	370	695	1281	5729								x	x	18–94
Freshwater catfish	64	193	32	183	81	198	●							x	x	31–450
Mountain galaxias	0	0	0	0	2	0						●		-	-	-
Murray rainbowfish	2931	2410	11	371	433	3656							●	x	x	21–100
Short-finned eel	0	1	0	0	0	0								-	-	-
Western bluespot goby	1	3	0	11	17	8	●	●		●				x	x	31–58
Eastern gambusia	1205	702	2	141	351	5436								x	x	14–49
Common carp	4	1710	0	4	5660	22			●		●		●	x	x	36–605
Goldfish	5344	278	1	0	15	4		●	●						x	85–140
	22,654	17,576	761	4135	18,612	19,324										

The fish community of the study region has changed considerably over the past year most noticeably with very high numbers (>5000 individuals) of juvenile common galaxias found during the spring 2014 sampling. Whilst information on seasonal differences (e.g. spring to autumn) is useful, comparison of sampling at comparable times of the year is important. In the case of common galaxias, comparison of autumn 2014 and 2015 monitoring – where a ten-fold increase in numbers (24 to 269 fish) occurred - clearly demonstrated that large numbers of juveniles have persisted through the summer months and will soon enter the adult breeding population. It is anticipated that future monitoring will reveal continued growth in the numbers of common galaxias (i.e. larger peaks of juveniles in spring, and enhanced consolidation of sub-adults and adults in autumn) due to the increasing breeding population present across the study region. Comparison of autumn monitoring across the years also reveals a gradual increase in the number of individuals of other prominent diadromous species (congolli) present in the study region. The species was however, absent from a number of sites where it was recorded in spring and is yet to expand its range to city weir.

Freshwater generalists continue to represent the dominant functional group, with high abundances across broad distributions and the presence of new recruits, mature individuals and survivors. Interestingly in autumn 2015, Murray rainbowfish were recorded in numbers comparable with other freshwater generalists (e.g. carp gudgeon), which are often more prevalent. Of concern, alien species accounted for almost one third of the fish community (28% of total numbers), and largely reflects the explosion of introduced eastern gambusia across Breakout Creek. The majority of eastern gambusia recorded (60%) were observed in the degraded section downstream of Tapleys Hill Rd suggesting that restoration of this section of the creek may lessen the impact of this highly invasive species. However, the species was still recorded in moderate numbers across recently restored sections (e.g. Tapleys Hill Rd to upstream of Henley Beach Rd), and therefore the ability of this still-water specialist species to dominate shallow and stable habitats, as it has across much of the waterways of the Mt Lofty Ranges (McNeil *et al.* 2011; Whiterod and Hammer 2014), has to be acknowledged (and mitigated) as part of management of the lower River Torrens.

4.2 Assessing fish passage

The Torrens estuary was once a large and diverse habitat that supported at least 12 diadromous and estuarine species as well as marine vagrants (Hicks and Hammer 2004). Historically the lower River Torrens was extensively utilised by diadromous species (Hicks and Hammer 2004), but this functional group has been largely absent following channel alteration and construction of weir structures such as the 2.65m Breakout Creek outlet weir (constructed in the 1930s) which acted to disrupt connectivity (McNeil *et al.* 2011). Indeed, common galaxias was last recorded upstream of the outlet weir in 1928 (Hammer 2005) before the species' recent return to the catchment following construction of a fish ladder on Breakout Creek outlet weir in 2005 (McNeil *et al.* 2010). Following this improved connectivity, diadromous species such as common galaxias and congolli have slowly expanded their distribution further upstream. In December 2012, for instance, congolli were observed below Holbrooks Road weir and common galaxias were recorded above the two barriers in Bonython Park (Schmarr *et al.* 2013). However, upstream migration of these species continued to be impeded (except during high flows) by Tapleys Hill Road and Breakout Creek Stage 2 weirs (McNeil *et al.* 2011; Schmarr *et al.* 2011) until fish ladders, which aimed to promote fish passage for more months of the year, were fitted and completed in 2013.

Whilst the present monitoring did not coincide with the movement season, our monitoring over the past two years, provides strong evidence that the fish ladders are largely allowing the passage of fish species and that prevailing habitats and conditions are suitable for large numbers of diadromous species to persist through summer months (and enter the adult breeding population). As emphasised by Whiterod (2014b), the re-colonisation of the lower River Torrens by common galaxias and congolli is an overwhelmingly positive observation, but a number of questions remain regarding the movement of fish species across the study region. It is unclear, for instance, if Stage 2 weir allows complete fish passage over extended periods and there are similar unknowns for structures further upstream (e.g. Holbrooks Road weir). Again it is necessary to recommend a dedicated fish movement study, with regular sampling events over the migration period (July to December), to more comprehensive assess the presence and timing of movements of a broader range of species, as well as resolve questions about the longer-term effectiveness of the fish ladders (see Hammer *et al.* 2012 for example).

4.3 The influence of dilution flows

Dilution flows trialled over the past four summers (2011−12 to 2014−15) have aimed to maintain sufficient water movement so as to limit conditions that contribute to cyanobactiera (blue green algae) growth, as well as diluting algal concentrations in an attempt to suppress algal bloom formation in Torrens Lake. Over 2011−12 and 2012−13 summers, flows of up to 40 ML/d (or 10% of the total lake volume) were provided over extended periods (Brookes 2012; 2013) whereas short (4−5 day duration) dilution flow pulses (up to 185 ML/d) occurred over 2013−14 and 2014−15 summers. These dilution flows are unseasonal (i.e. peak flows naturally occur over late winter/early spring not summer months) and it is necessary to assess whether they cause adverse impacts on native fish species or benefit alien fish species, before they can form part of the long-term management of cyanobacteria in the Torrens Lake.

The frequency of monitoring makes it difficult to explicitly separate the influence of specific dilution flows from other, potentially confounding, factors such as atypical natural flows (which have occurred over the past two summers), improved habitat connectivity and abrupt disturbance events (Whiterod 2014a). With these particular constraints in mind, the outcomes of the present round of monitoring are consistent with those of recent years (McNeil *et al.* 2012; Schmarr *et al.* 2013; Whiterod 2014b; a) which indicate that the dilution flows are not negatively impacting native fish populations across the study region. Indeed, there was broad recruitment of native species, consolidation of the range of diadromous species and no significant recruitment of common carp (despite large spawning event observed in spring 2014) over the period coinciding with 2014−15 dilution flow trialling. Comparison of autumn 2014 and autumn 2015 data revealed comparable fish numbers at both sites (between the two sampling times) suggesting that the the cyanobacteria bloom occurring in the Torrens Lake (and also impacting downstream of the structure) in March 2015 did not impact fish communities.

4.4 Medium-term impacts of the May 2014 fish kill

Rainfall and subsequent stormwater runoff, which input a large organic load to the river, and unseasonal warm air temperatures contributed to the deterioration of water quality in May 2014. This deterioration of water quality resulted in hypoxic conditions (i.e. dissolved oxygen concentrations below <2mg/L) and the growth of algae in the area upstream of Henley Beach Road weir over a short period in May 2014. A substantial fish kill resulted and a large biomass of dead fish where removed over a three day period. Targeted sampling by Whiterod (2014a) confirmed an immediate impact, with freshwater catfish not detected and common carp in low numbers, as well as comparatively lower numbers of small-bodied species than found in nearby sites. Monitoring over spring 2014 and autumn 2015 has revealed partial recovery of the fish community at the affected site is occurring. Numbers of freshwater generalists were consistent with those prior to the fish kill. Although adult freshwater catfish were again absent, the presence of juveniles suggests population recovery is progressing. Similarly, for the alien common carp, the increasing size range of sampled individuals indicates numbers will soon recover completely. Perhaps reflecting the absence of large fish, common galaxias numbers were highest at the affected site compared to all other sites sampled in autumn 2015 – this also indicates there are no lasting impacts to habitat suitability at the site.

4.5 Evaluation of hypotheses

4.5.1 **Hypothesis 1:** *Diadromous fishes would be facilitated in moving upstream of the Breakout Creek fish ladder towards the city weir*.

This hypothesis is strongly supported with the consolidation of juveniles of diadromous species, observed in spring 2014, into the sub-adult and adult population as revealed by the present monitoring.

4.5.2 **Hypothesis 2:** *In-channel barriers between Breakout Creek and the city weir may serve as barriers to upstream fish movements resulting in aggregations below barriers.*

Hypothesis partially supported as greater fish movement (and consolidation into sub-adult and adult population in the recent monitoring) has been evident but so has downstream aggregations (below stage 2 weir) and the navigability of weir structures identified in the vicinity of Bonython Park (see Schmarr *et al.* 2011) remains unclear.

4.5.3 **Hypothesis 3:** *Flows may induce spawning and/or recruitment responses that are measurable by assessing fish population structure.*

This hypothesis is supported as new recruits were detected across all functional groups, including freshwater generalists (carp gudgeon, flathead gudgeon, Murray rainbowfish), diadromous species (common galaxias) but also aliens (common carp and eastern gambusia).

4.5.4 **Hypothesis 4:** *Freshwater inflows into the relatively poorer water quality environment of the Torrens Lake will result in aggregations of spawning common carp and lead to increases in common carp abundance, biomass and distribution.*

This hypothesis is not supported as common carp were not recorded in the Torrens Lake and only a small increase in abundance and distribution of the species was evident downstream, despite a large spawning event observed in spring 2014.

4.5.5 **Hypothesis 5:** *The abundance, distribution and structure of fish populations in the area affected by the May 2014 fish kill will be impacted.*

This hypothesis was partially supported as numbers of freshwater generalist have fully recovered and common galaxias are establishing, but adult freshwater catfish remain absent from the affected site.

5 Conclusions

The present study provided ongoing assessment of the influence of restoration efforts on fish communities of the River Torrens.

- Overall, native fish communities continued to improve, with broad recruitment of native species and consolidation of the range of diadromous species; although numbers of the introduced eastern gambusia have rapidly increased across Breakout Creek and management of this highly invasive species will be paramount.
- Diadromous species, whose movement into the Lower River Torrens en masse was detected during spring 2014 monitoring, have consolidated this range expansion and even greater movement is anticipated during 2015.
- The dilution flows over the 2014−15 summer (along with other recent summers) did not appear to have any negative impact on downstream native fish populations, even possibly contributing to increased native fish abundance and diversity – although the sampling regime is insufficient to prove causation with certainty.
- Finally, the impact of the recent fish kill continues to diminish and the fish species (with the exception of adult freshwater catfish) have recovered to comparable levels to those observed prior to the event. The affected areas has also been colonised by diadromous species (e.g. common galaxias) highlighting habitat suitability.

The continuation of monitoring (e.g. repeat autumn and spring sampling, as well as a targeted fish movement study to track the expansion of diadromous species) will be necessary to document changes in the fish community in response to catchment management efforts. Also, a considerable engagement opportunity exists (e.g. schools, general public, interested groups) to showcase the positive changes documented by recent monitoring and garner community support for further restoration efforts.

6 References

Allen GR, Midgley SH, Allen M (2002). 'Field Guide to the Freshwater Fishes of Australia.' Western Australian Museum: Perth.

Brookes JD (Ed.) (2012). 'River Torrens Water Quality Improvement Trial - Summer 2011/2012.' Technical Report Series No. 12/4. Goyder Institute for Water Research: Adelaide.

Brookes JD (Ed.) (2013). 'River Torrens Water Quality Improvement Trial - Summer 2012/13.' Technical Resport No. 13/16. Goyder Institute for Water Research: Adelaide.

Daniels CB, Hodgson J (2010). 'Adelaide: Water of a City.' Wakefield Press: Adelaide.

Fausch KD, Lyon J, Karr JR, Angermeier PL (1990). Fish communities as indicators of environmental degradation. *American Fisheries Society Symposium* **8**, 123–144.

Feminella JW, Walsh CJ (2005). Urbanization and stream ecology: an introduction to the series. *Journal of the North American Benthological Society* **24**, 585–587.

Findlay SJ, Taylor MP (2006). Why rehabilitate urban river systems? *Area* **38**, 312–325.

Gurnell A, Lee M, Souch C (2007). Urban rivers: hydrology, geomorphology, ecology and opportunities for change. *Geography Compass* **1**, 1118-1137.

Hammer M (2005). 'Adelaide Hills Fish Inventory: distribution and conservation of freshwater fishes in the Torrens and Patawalonga catchments, South Australia. Report to Torrens and Patawalonga Catchment Water Management boards.' Native Fish Australia (SA) Inc., Adelaide.

Hammer M (2011). 'Ecological implications for freshwater fishes arising from specific hydrological changes to the lower River Torrens, Adelaide. A technical note to the Adelaide and Mount Lofty Ranges Natural Resources Management Board.' Aquasave Consultants, Adelaide.

Hammer M, Wedderburn S, van Weenan J (2009). 'Action Plan for South Australian Freshwater Fishes.' Native Fish Australia (SA) Inc., Adelaide.

Hammer M, Whiterod N, Barnes T, Tucker M (2012). 'Baseline fish survey and movement study of the Drain L Catchment, South Australia. Report to Department for Water, South Australian Government.' Aquasave Consultants, Adelaide.

Hicks DC, Hammer M (2004). 'Investigation of the impact of barriers on indigenous fish in the River Torrens Catchment: Literature Review. Report to the Torrens Catchment Water Management Board.' Australian Water Quality Centre, Adelaide.

Holmes JW, Iversen MB (1976). Hydrology of the Cowandilla Plains, Adelaide, Before 1836. In 'Natural History of the Adelaide Region'. (Eds C. R. Twidale, M. J. Tyler and B. P. Webb) pp. 91–97. Royal Society of South Australia (Inc.): Adelaide.

McNeil DG, Hammer M (2007). 'Biological review of the freshwater fishes of the Mount Lofty Ranges.' SARDI publication number: F2006/000335. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.
McNeil DG, Schmarr DW, Mathwin R, Thwaites L (2012). Chapter 5: Fish monitoring. In 'River Torrens Water Quality Improvement Trial - Summer 2011/12'. (Ed. J. D. Brookes). Technical Report Series No 12/4. Goyder Institute for Water Research: Adelaide.
McNeil DG, Schmarr DW, Wilson PJ, Reid DJ (2011). 'Fish community and flow ecology in the Western Mount Lofty Ranges. Final report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board and the SA Department for Water.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide.
McNeil DG, Wilson PJ, Fredberg JF, Westergaard S (2010). 'Fish passage at the Breakout Creek Fishway, River Torrens, South Australia. Report to the Adelaide & Mount Lofty Ranges Natural Resources Management Board. .' SARDI Publication No. F2009/000409-1. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.
Schmarr DW, Mathwin R, Cheshire D (2013). Chapter 3: Fish monitoring. In 'River Torrens Water Quality Improvement Trial - Summer 2012/13'. (Ed. J. D. Brookes). Technical Report Series No 13/16. Goyder Institute for Water Research: Adelaide.
Schmarr DW, Mathwin R, McNeil DG (2011). 'Mapping threats to aquatic biota movement and recovery with the provision of environemtnal water in selected reaches of the South Para, Torrens and Onkaparinga Rivers ' SARDI Research Report Series No. 570. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.
UNFPA (2007). 'State of the world population 2007: unleashing the potential of urban growth.' United Nations, New York.
Walsh CJ (2000). Urban impacts on the ecology of receiving waters: a framework for assessment, conservation and restoration. *Hydrobiologia* **431**, 107–114.
Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan II RP (2005). The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society* **24**, 706–723.
Whiterod N (2014a). 'River Torrens Water Quality Improvement Trial 2013−14: Fish Monitoring, autumn 2014. A report for the Adelaide and Mount Lofty Ranges Natural Resources Management Board.' Aquasave - Nature Glenelg Trust, Goolwa Beach.
Whiterod N (2014b). 'River Torrens Water Quality Improvement Trial 2013−14: Fish Monitoring, spring 2014. A report for the Adelaide and Mount Lofty Ranges Natural Resources Management Board.' Aquasave - Nature Glenelg Trust, Goolwa Beach.
Whiterod N, Hammer M (2014). 'Condition reporting for fish communities across the tributary streams of the Eastern Mount Lofty Ranges, 2010 to 2013. Report to the SA Department of Environment, Water and Natural Resources.' Aquasave - Nature Glenelg Trust, Goolwa Beach, South Australia.

7 Appendix 1. Habitat descriptors

The following habitat descriptors were recorded at each sampling site:

Site descriptors

- River system, waterway, location
- weather
- Landuse impacts
- Pool size as an estimation of surface area
- Bank slope (e.g. gradual to vertical)
- Depth (maximum and sampling range)
- Substrate type (e.g. sand, gravel, mud)

Flow environment

- A temporal measure of connectivity based on seasonal conditions and local landholder input (e.g. ephemeral, six months flow connection, or permanently connected), plus comments such as whether the area is spring fed.

Pool condition and flow

- A measure of water level in comparison to the normal bank level of a pool (e.g. concentrated, bank level, in flood), and
- Flow category ranked relative to magnitude.

Contributions to cover (% of volume occupied and type):

- Submerged physical (e.g. snags, leaf litter, rock), biological (e.g. aquatic plants, algae) and emergent (e.g. reeds, rushes and sedges) habitat cover,
- Fringing vegetation (within 2 metres of the waters' edge),
- Canopy cover – measure of overhanging vegetation (shade), and
- General surrounding terrestrial vegetation cover.

Water quality

- Recording, taken at 0.2m depth, of (a) temperature (°C), (b) conductivity (µS/cm), (c) pH, and (d) dissolved oxygen (mg/L), and
- Water transparency (m) as the depth to which visibility through the water is no longer possible from the surface measured using Secchi disk.

8 Appendix 2. Environmental data

Site Code	Date	Location	Size	Depth max (m)	Pool condition	Flow	Subsurface physical (%)	Subsurface biological (%)	Emergent (%)	Edge vegetation (%)	Shade (%)	pH	Conductivity (µS/cm)	Temperature (°C)	Dissolved oxygen @0.2 m (mg/L)	Transparency (m)
SAG15-01	30-Mar-15	Tapleys Hill Rd weir downstream	Large	1.3	Low level	Low	5	2	30	0	0	8.01	1091	25.3	7.41	0.50
SAG15-02	30-Mar-15	Tapleys Hill Rd weir upstream	Large	0.9	Bank level	Low	1	2	10	55	0	7.89	1071	21.2	6.32	0.50
SAG15-03	30-Mar-15	Stage 2 weir downstream	Large	1.1	Bank level	Low	1	2	20	45	0	8.17	1001	20.3	5.41	0.75
SAG15-04	30-Mar-15	Stage 2 weir upstream	Large	1.1	Low level	Low	2	1	10	60	0	8.17	1004	20.9	6.90	0.85
SAG15-05	31-Mar-15	Henley Beach Rd weir upstream	Large	1.3	Low level	Low	1	1	20	25	0	7.65	972	20.0	4.10	0.60
SAG15-06	31-Mar-15	Holbrooks Rd weir downstream	Large	1.5	Bank level	Low	2	0	5	30	25	7.29	1204	18.9	4.96	0.65
SAG15-07	31-Mar-15	Holbrooks Rd weir upstream	Medium	0.8	Low level	Low	10	0	5	40	25	7.94	1126	19.2	5.98	0.60
SAG15-08	01-Apr-15	City weir downstream	Medium	2.0	Bank level	Low	2	5	10	35	5	7.77	1137	17.9	4.55	1.00
SAG15-09	01-Apr-15	Torrens Lake	Large	10	Bank level	Low	1	2	1	60	0	8.00	1175	19.1	6.38	0.80
SAG15-10	01-Apr-15	Second Creek outlet weir downstream	Medium	0.9	Low level	Medium	10	0	2	5	30	7.89	2125	18.2	6.77	>0.9
SAG15-11	01-Apr-15	Second Creek outlet weir upstream	Large	1.5	Low level	Low	1	10	5	50	5	7.57	2099	18.8	6.63	1.10