

Ecology, Monitoring, Conservation

River Torrens Water Quality Improvement Trial 2013–14: Fish Monitoring, autumn 2014

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Executive summary

River Torrens is a highly modified and regulated system flowing through THE heart of Adelaide, South Australia. A long history of urban development since European settlement has dramatically impacted the catchment and resulted in reduced aquatic biodiversity, with only seven of the 28 indigenous freshwater fish species occurring presently. Concerted efforts to improve biodiversity, such as the installation of three fish ladders (to improve connectivity), enhancement of localised aquatic habitat and provision of environmental and dilution flows through Torrens Lake to ameliorate the risk of cyanobacteria blooms, have recently attempted to redress these impacts. The monitoring of fish communities over recent years has provided a useful assessment of the effectiveness of these restoration efforts.

The present study continues this ongoing assessment. Overall, native fish communities are gradually improving with broad recruitment of native species, expansion of the range of diadromous species, and the limited abundance of alien species (the absence of large cohorts of cyprinids) observed. The two newly installed fish ladders appear to be affording some fish passage with diadromous species recorded upstream and no downstream aggregations of fish observed. The dilution flows over the 2013–14 summer did not appear to have any negative impact on downstream native fish populations, but rather possibly contributed to increased native fish abundance and diversity – although it is difficult to define causal links. Finally, the recent fish kill has clearly impacted the resident fish community, and anticipated medium- to long-term consequences will need to be monitored and resolved. Monitoring that will be conducted in spring 2014 will provide further insight into the Torrens fish community.

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1 Introduction

1.1 Background

Waterways flowing through urban centres – accounting for half of the world’s rivers – represent some of the most degraded (Gurnell *et al.* 2007; UNFPA 2007; Walsh *et al.* 2005). River Torrens is a highly modified and regulated system in the Western Mount Lofty Ranges (WMLR). The river flows through the heart of Adelaide - a major city populated by over one million people in South Australia (Daniels and Hodgson 2010). The river once maintained a complexity of connected aquatic habitat, transitioning from a small flowing upland stream interspersed with many deep and permanent pools to an expansive estuary wetland (Holmes and Iversen 1976). However, activities following European settlement, (e.g. the alteration of flow regimes, draining and bypassing of the estuary wetland, construction of weirs and reservoirs, clearance of riparian vegetation 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; McNeil and Hammer 2007).

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

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

Period	Reach	Action	Assessed
2005	Breakout Creek outlet weir	Installation of fish ladder	McNeil <i>et al.</i> (2010)
2005–2007	Above Henley Beach Rd weir (stage 1)	Habitat restoration	McNeil <i>et al.</i> (2012); Schmarr <i>et al.</i> (2013); 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	Present study
2011–2014	Upper catchment, but with downstream influence	Implementation of environmental flows trial	SARDI, <i>unpublished data</i>
2011–2014	Torrens Lake with downstream influence	Dilution flows for cyanobacteria management	McNeil <i>et al.</i> (2012); Schmarr <i>et al.</i> (2013); present study

Freshwater fish are considered useful indicators of environmental change (Fausch *et al.* 1990) and monitoring their demographics and patterns in distribution and abundance have therefore been used to assess the effectiveness of these restoration efforts (Hammer 2011; McNeil and Hammer 2007). Assessment of the Breakout Creek outlet weir fish ladder, for instance, highlighted the successful ascent of nine species (McNeil *et al.* 2010), but the effectiveness of the two newly installed fish ladders (on Tapleys Hill Road and Stage 2 weirs) remains unclear. Similarly, annual monitoring is presently undertaken to assess the benefits of environmental flows through the catchment (SARDI, *unpublished data*). Concurrent 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). Furthermore, this monitoring provided an ongoing assessment of fish passage through the study region, with the expansion in the range and abundance of diadromous species – those species having both freshwater and marine phases of their life cycle – noted (McNeil *et al.* 2012; Schmarr *et al.* 2013).

The present study, which involves monitoring across autumn and spring 2014, will provide an updated assessment of the dilution flows and fish passage. This report details the outcomes of the autumn 2014 monitoring. Additionally, the impact of a recent fish kill upstream of Henley Beach Road weir will be assessed.

1.2 Fish species of study region

The Torrens catchment historically supported 28 indigenous fish species, only seven of which occur upstream of the outlet weir presently (Hicks and Hammer 2004; McNeil *et al.* 2011; McNeil *et al.* 2010). The contemporary fish fauna of 29 fish species (recorded between 1999 and 2013) now includes six species translocated from the Murray-Darling Basin (MDB) and six alien species. Across the study region of Tapleys Hill Road weir to Second Creek outlet weir, 11 endemic, River Murray translocations and alien species have been recorded, representing freshwater generalist, freshwater wetland and diadromous (those migrating between freshwater, estuarine and marine environments to complete their life cycle) and estuarine functional groups as well as alien species (Table 2). Additionally, two threatened diadromous species (climbing galaxias *Galaxias brevipinnis* and pouched lamprey *Geotria australis*) and three estuarine species have been detected downstream in the vicinity of the Breakout Creek outlet weir (McNeil *et al.* 2010).

Table 2. Fish species recorded in the study region (Tapleys Hill Road weir to Second Creek outlet weir) of the Torrens catchment. Conservation status abbreviated as EN=Endangered, VU=Vulnerable, and RA=Rare (Hammer *et al.* 2009).

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

*translocated native species

1.3 Project hypotheses

The overarching aims of the project are to assess (a) the effectiveness of newly completed fish ladders in Breakout Creek, (b) the impact of the dilution flows over the 2013–14 summer, and (c) the impact of a recent fish kill upstream of Henley Beach Road. In doing so, the following hypotheses will be addressed:

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 measurable in fish population structure; and
- 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.

Relating to aim (c):

- Changes in the abundance, distribution and structure of fish populations in the area affected by the fish kill will be detected.

2 Methods

2.1 Study region

River Torrens catchment is a prominent and relatively large system ($\approx 620\text{km}^2$) originating in the WMLR before flowing westward across the Adelaide plains 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).

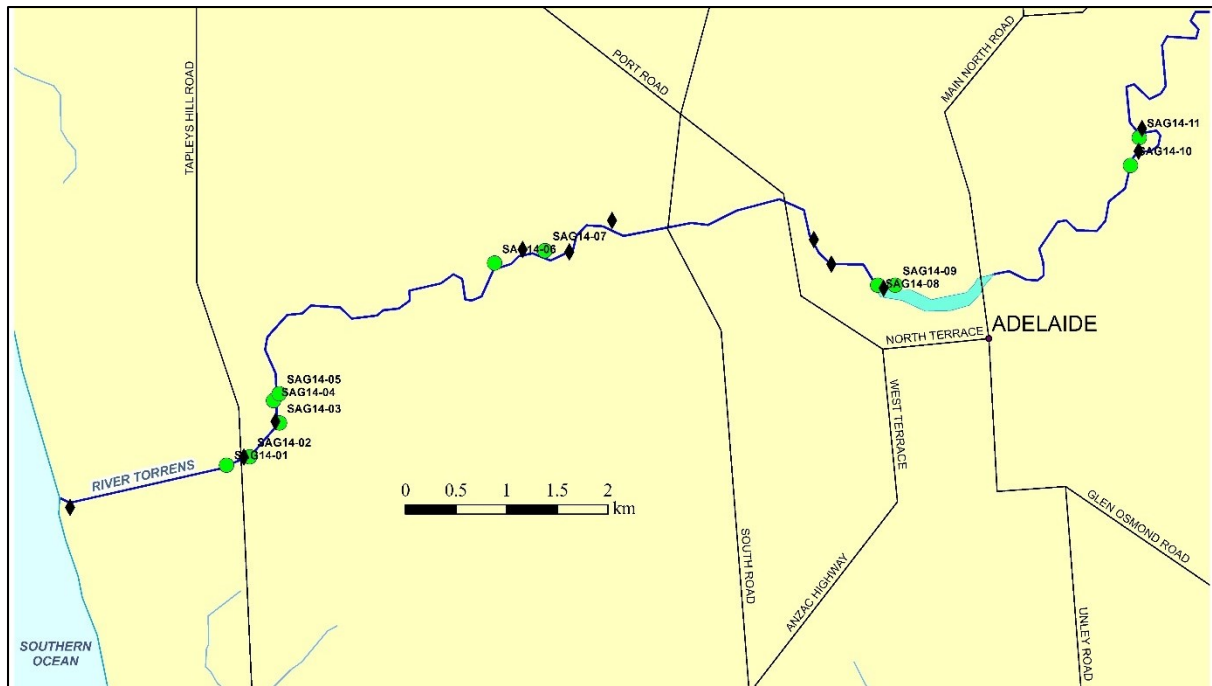


Figure 1. Study region of the Torrens catchment, highlighting sampling sites (green dots) and weirs (black diamonds).

Across the study region, separate upstream and downstream sites distinguished the five sites detailed in the project brief, and an additional site (upstream Henley Beach Road weir) was sampled to investigate the recent fish kill. In total, 11 sites were sampled between 26 and 29 May 2014 in accordance with PIRSA Fisheries permit no. 9902631 (Table 3).

Table 3. Summary of sampling sites and methodology

Site Code	Date	Waterway	Location	Easting	Northing	Small fykes	Double wing fykes
SAG14-01	26-May-14	Breakout Creek	Tapleys Hill Rd weir (downstream)	273104	6131680	3	1
SAG14-02	26-May-14	Breakout Creek	Tapleys Hill Rd weir (upstream)	273332	6131762	3	1
SAG14-03	26-May-14	Breakout Creek	Stage 2 weir (downstream)	273627	6132096	3	1
SAG14-04	26-May-14	Breakout Creek	Stage 2 weir (upstream)	273568	6132317	3	1
SAG14-05	27-May-14	Breakout Creek	Henley Bridge Rd weir (upstream)	273624	6132386	6	2
SAG14-06	27-May-14	River Torrens	Holbrooks Rd weir (downstream)	275751	6133674	3	1
SAG14-07	27-May-14	River Torrens	Holbrooks Rd weir (upstream)	276248	6133797	3	1
SAG14-08	28-May-14	River Torrens	City weir (downstream)	279533	6133457	3	1
SAG14-09	28-May-14	River Torrens	Torrens Lake	279705	6133456	3	
SAG14-10	28-May-14	River Torrens	Second Creek outlet (downstream)	282029	6134636	3	
SAG14-11	28-May-14	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) over 2013 to 2014 is presented in Figure 2. Over the summer months, three short (5–7 days) dilution flow pulses (up to 165 ML/day) were achieved through the Torrens Lake (represented as flow peaks of 125 ML/day at the downstream gauging station). There was also an atypical high flow event in late February 2014, small peaks in flow over March–April and high flows during late May and early June (before and during fish monitoring) due to rainfall events.

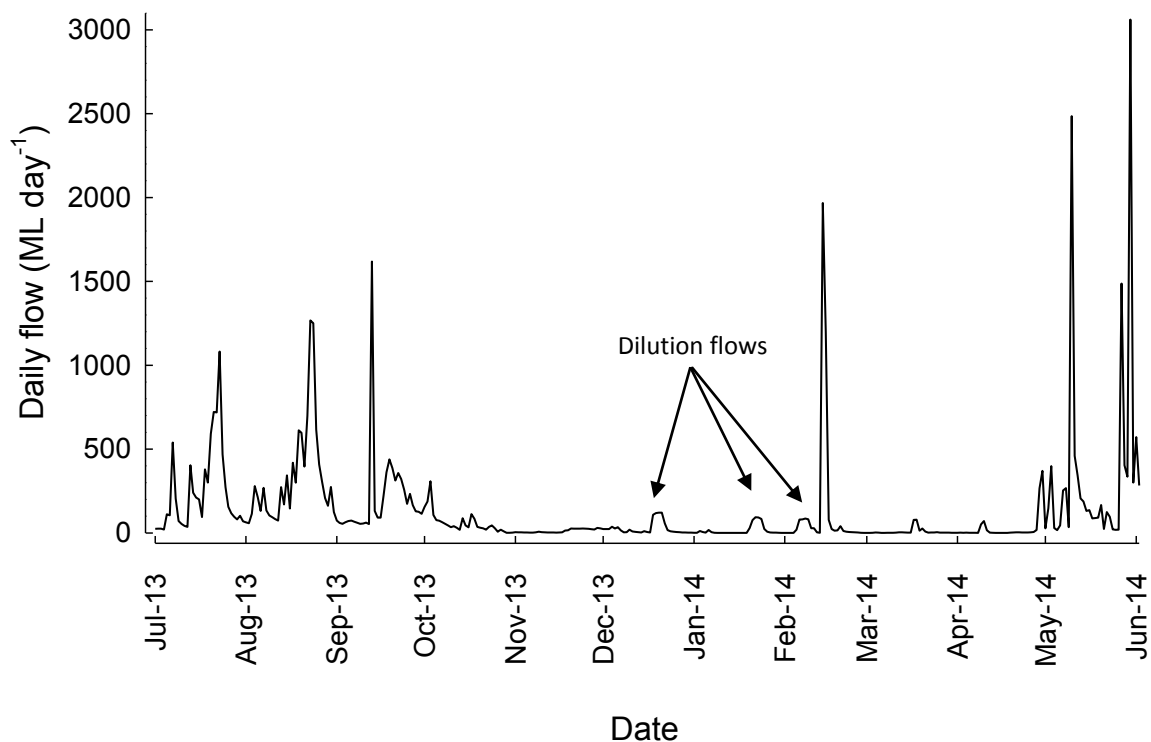


Figure 2. Mean daily flow (ML day⁻¹) for the Torrens River @ Holbrooks Road (A5040529) between July 2013 and June 2014 (source: Water Data Services).

2.3 Field sampling

Fish monitoring followed previously utilised flow dilution methodology (McNeil *et al.* 2012; Schmarr *et al.* 2013) 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, greater effort was employed, i.e. six small fyke nets and two double-winged fyke nets. 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).

3 Results

3.1 Fish community

3.1.1 Summary

Some 4135 individuals across nine fish species (seven native, two alien) were recorded across the 11 sites in the River Torrens between Second Creek outlet and the Tapleys Hill Road weir (Table 4).

Table 4. Summary of fish and opportunistic catch.

Site Code	Location	Fish species									Other fauna					
		Carp gudgeons	Flathead gudgeon	Murray rainbowfish	Freshwater catfish	Common galaxias	Congolli	Western bluespot goby	Common carp	Gambusia	Common yabby	Freshwater shrimp	Freshwater prawn	Long-necked turtle	Short-necked turtle	Water rat
SAG14-01	Tapleys Hill Rd weir (ds)	112	16	3		1		1	1	6	x	x	x	x		
SAG14-02	Tapleys Hill Rd weir (us)	416	10	18	24*	4	4		*	2	x	x	x			
SAG14-03	Stage 2 weir (ds)	456	6	1	18*				3*		x	x	x	x		
SAG14-04	Stage 2 weir (us)	733	12	32	9*	12	1		*	3	x	x	x	x		
SAG14-05	Henley Bridge Rd weir (us)	411	7	96	26*	6			*	39	x	x	x		x	
SAG14-06	Holbrooks Rd weir (ds)	224	32	103	16		2			48		x	x			
SAG14-07	Holbrooks Rd weir (us)	22	8	38	35					13	x	x	x			
SAG14-08	City weir (ds)	43	149	56	17	1				11		x	x	x	x	
SAG14-09	Torrens Lake	199	86	1	4					5	x	x	x			
SAG14-10	Second Creek outlet (ds)	65	279	23	3			10		9		x				
SAG14-11	Second Creek outlet (us)	18	90		31					5		x	x			x

*additional large dead individuals were removed during fish kill

The catch included four species native to River Torrens (flathead gudgeon *Philypnodon grandiceps*, congolli *Pseudaphritis urvillii*, common galaxias *Galaxias maculatus* and western bluespot goby *Pseudogobius olorum*); three native species translocated Murray-Darling Basin (carp gudgeon *Hypseleotris* spp., Murray rainbowfish *Melanotaenia fluviatilis* and freshwater catfish *Tandanus tandanus*); and two alien species (eastern gambusia *Gambusia holbrooki* and common carp *Cyprinus carpio*). The fish catch was numerically dominated by carp gudgeon *Hypseleotris* spp. (2699 fish) and to a lesser extent flathead gudgeon (695 fish), which were the only two species recorded at all eleven sampling sites. All species recorded had previously been observed in the study region.

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 those species that are local native and translocated.

3.1.2 Diadromous species

A key focus of the present monitoring was to assess the status of diadromous species, two of which were recorded. Common galaxias were patchily distributed from below Tapleys Hill Road weir to below city weir, indicating that the species has expanded its range further

upstream – it was recorded above Bonython Park barriers in 2012 and 2013 (but not directly below city weir). Congolli were collected in similar numbers as in December 2012 and July 2013, with small juveniles (75–180mm) observed upstream of both Tapleys Hill Road and Stage 2 weirs, and the most upstream records just below Holbrooks Road weir. Previously recorded rarer species (e.g. shortfinned eel or pouched lamprey) were not detected during the present sampling.



Diadromous species: congolli (left) and most upstream recorded common galaxias (right)

3.1.3 Freshwater generalist (and wetland specialist) species

The four previously documented freshwater generalist (and wetland specialist) species continue to be present across the study region. Unlike previous monitoring (2011–2013), the translocated carp gudgeon was the most abundant species of these functional groups. At all sites, new recruits and mature individuals (15–55mm) were observed, highlighting robust population structures of this species. The local native flathead gudgeon was increasingly abundant with distance upstream (i.e. typically more abundant than carp gudgeon upstream of below city weir). Again, broad size ranges (15–98mm) were recorded, indicating both recent recruitment and ongoing survivorship.

The other two freshwater, translocated MDB species were recorded across the majority of sites (10 sites each). The abundance of Murray rainbowfish was variable (perhaps representing schooling nature), with highest catches recorded along the stretch upstream of Henley Beach Road weir to Holbrooks Road weir, and below city weir. Freshwater catfish formed a common component of the fish community at all sites (except upstream of Tapleys Hill Road weir), with new recruits commonly observed (except downstream of Second Creek

outlet). Interestingly, adults were only observed from below Holbrooks Road weir upwards, highlighting the impact of the recent fish kill (see discussion).



Freshwater catfish: large individual (left) and large catch of juveniles (right)

3.1.4 Estuarine species

Whilst passage of estuarine species through the fish ladder associated with the Breakout Creek outlet weir has been documented (McNeil *et al.* 2010), there was no observed increase in the range of this functional group (e.g. to the site below Tapleys Hill Road weir). This is perhaps not surprising, given the low numbers of individuals likely to be ascending the fish ladder and prevailing habitat (limited aquatic vegetation and low salinities). Interestingly, western bluespot goby were observed at both ends of the study region; below Tapleys Hill Road weir (where they have previously been recorded) and below Second Creek weir. The species has previously been recorded above city weir (e.g. in 2004: Rowntree and Hammer 2004) but not over recent (2006–2013) monitoring.

3.1.5 Alien species

Three alien species – goldfish, common carp and eastern gambusia – are well established across the study region. Over 2011–2013, large recruitment events of goldfish and common carp were evident in the reach below Henley Beach Road (e.g. 5344 juvenile goldfish were recorded in December 2011). During the present monitoring, however, goldfish were not recorded and only four large juvenile or adult common carp sampled. Adult common carp were particularly impacted by the fish kill – accounting for over half of the approximately 800–1000kg of dead fish removed in the affected area (contractor, *personal communication*). Eastern gambusia remained common; occurring in low numbers at all but one site.

3.2 Opportunistic catch

Opportunistic catch included freshwater shrimp *Paratya* sp. (12 sites), freshwater prawns *Macrobrachium* sp. (11 sites), common yabby *Cherax destructor* (7 sites) as well as long-necked (4 sites) and short-necked turtles (2 sites) and one water rat *Hydromys chryogaster*.



Opportunistic catch: short-necked turtle (left) and long-necked turtle (right).

3.3 Environmental descriptors

At the time of sampling, localised flooding was experienced as all sites maintained bank to high level with medium to high flow (except for Torrens Lake, where flow was low) (see Appendix 2. Environmental data). 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 minimal submerged aquatic habitat (e.g. only up to 2% of water column). Edge vegetation (within 2m of water's edge) was highly variable amongst sites (1–80%) reflecting levels of riparian clearance, and canopy cover (0–30%) was typically low. Water quality relatively consistent across sampling sites, with electrical conductivity indicating low salinity ($609\text{--}932\mu\text{Scm}^{-1}$); pH ranging from 7.46 to 7.88; water temperature between 13.5 and 17.4°C; dissolved oxygen always above concerning levels ($4.40\text{--}8.95\text{mgL}^{-1}$), and transparency relatively low (0.4–0.95m). Adverse water quality that contributed to the fish kill (namely low dissolved oxygen concentrations) was no longer evident, due to the flushing and mixing by the rainfall event.

4 Discussion

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

4.1 Status of fish species

Fish communities across the study region have varied markedly over the past four years (Table 5). Most notably, monitoring has highlighted that overall abundance (and numbers of species) has fluctuated widely from 22,654 fish in December 2011 to 4135 fish in May 2014 and only 761 fish in July 2013. 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) (e.g. summer 2011, 2012; winter 2012, and now autumn 2014). Ideally, the autumn and spring monitoring of the present study, utilising consistent sampling effort, would be continued to allow long-term trends in population dynamics to be robustly assessed (see McNeil and Hammer 2007). To this end, spring monitoring will be conducted as part of the present study.

Table 5. Status of fish species present in the Lower Torrens, autumn 2014.

Common name	Previous			Present monitoring										
	Dec 2011	Dec 2012	July 2013	May 2014	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								x	x	15–55
Flathead gudgeon	7712	9157	370	695								x	x	15–98
Murray rainbowfish	2931	2410	11	371								-	x	28–91
Freshwater catfish	64	193	32	183								x	x	15–570
Common galaxias	32	756	1	24								x	x	75–112
Congolli	1	9	8	7								x	-	75–180
Short-finned eel	0	1	0	0								-	-	-
Western bluespot goby	1	3	0	11								x	x	38–57
Eastern gambusia	1205	702	2	141								x	x	16–41
Common carp	4	1710	0	4								-	x	150–655
Goldfish	5344	278	1	0								-	-	-
	22,654	17,576	761	4135										

Regardless, insight into the status of fish species across the study region can be achieved. 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. There appears to have been a shift in composition, with carp gudgeon – becoming more common relative to the endemic flathead gudgeon – perhaps reflecting the flow regime prevailing over the most recent summer months. Populations of the translocated freshwater catfish remain strong across the study region, with the possible exception of the area affected by the recent fish kill (see below). Estuarine species, with the exception of western bluespot goby, have failed to colonise the lower Torrens. Finally, alien species represented a smaller component of the fish community in 2014 (4%) compared to earlier years, i.e. 2011 (29%) and 2012 (15%), largely due to the absence of large cohorts of juveniles.

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 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 construction of a fish ladder on Breakout Creek outlet weir in 2005 – an absence of almost 80 years (McNeil *et al.* 2010).

This fish ladder on Breakout Creek outlet weir has allowed for the passage of both diadromous and estuarine species into the lower Torrens (below Tapleys Hill Road weir) (McNeil *et al.* 2010). This improved connectivity has seen diadromous species such as common galaxias and congolli slowly expanding 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 were fitted and completed in 2013. It is anticipated that these fish ladders will promote fish passage for more months of the year. Furthermore, preliminary assessment as part of the present study highlighted further dispersal upstream, with common galaxias now being recorded directly below city weir and an increase in numbers of congolli below Holbrooks Road weir.

In terms of specific assessment, it appears that the newly installed fish ladders are allowing fish passage to some extent. Indeed, there was no obvious aggregation of fish below the weirs and both common galaxias and congolli were observed upstream, although this may simply reflect the downstream movement to estuarine and marine spawning areas that adults of both species undertake at the time of sampling (autumn) or movements at higher flows (when weirs are passable without specific fish passage provisions). Further monitoring this spring should shed more information as the timing will coincide with the upstream movement of the juveniles of these diadromous species. It is clear that maintenance of these fish ladders will

be an ongoing consideration so that the most effective passage can be provided. Indeed, the Tapleys Hill Road weir fish ladder was blocked with debris and required clearing prior to sampling during the present study (see below). Presently, it is unclear if higher flows will naturally clear the fish ladders of debris or whether regular inspection (e.g. fortnightly to monthly) and maintenance will be necessary, particularly during the period when most diadromous species are migrating upstream (i.e. June to December). Again, a clearer understanding of the operation of the fish ladder will be achieved during spring monitoring.



Tapleys Hill Road weir fishway efficiency: blocked with debris one day (left) and partially unblocked and flowing the next (right)

In addition to enhancement assessment of the two recently established fish ladders, attention must turn to facilitating fish passage through other barriers that impede connectivity in the lower Torrens (i.e. ‘city to sea’ fish passage: Hammer 2011). The Holbrooks Road weir structure now appears to be the most downstream barrier impeding the upstream movement of fish species. Options must be explored to allow fish passage through this weir and city weir – a barrier that has almost continuously stopped upstream fish movement since its construction in 1881. More broadly, continued habitat restoration and provisioning of environmental flows will be necessary to enhance suitability of habitat for diadromous species across the lower Torrens.

4.3 The influence of dilution flows

Dilution flows seek to suppress cyanobacteria growth and bloom formation in Torrens Lake over the summer months. Specifically, these flows – which have been trialled over the past three years – attempt to maintain sufficient water movement as to limit conditions that contribute to algal growth as well as diluting algal concentrations. Over 2011–12 and 2012–13

summers, low base flows (of up to 40ML/day or 10% of the total lake volume) were provided (Brookes 2012; Brookes 2013) whereas short (5–7 day) dilution flow pulses (up to 165 ML/day) occurred over the 2013–14 summer. These flows were however unable to prevent cyanobacteria bloom formation over both 2011–2012 and 2012–13 summers, due to extremely high January temperatures (Brookes 2012; Brookes 2013). No cyanobacteria blooms occurred in Torrens Lake during 2013–14 (but see below impacts of May 2014 cyanobacteria bloom in Breakout Creek).

These dilution flows are however 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 additional benefits to alien fish species, before they can form part of the long-term management of cyanobacteria in the Torrens Lake. The assessment over 2011–12 and 2012–13 concluded that dilution flows during summer months had an overall positive influence on native fish communities (McNeil *et al.* 2012; Schmarr *et al.* 2013), given observations of:

- Increased native fish abundance and diversity,
- Decreased abundances of alien and translocated fish,
- No immediate negative effects resulting from changes in water quality due to summer flow releases, and
- Despite simulation of common carp spawning, impacts were restricted to the Torrens Lake with no lasting downstream consequences.

Using a similar approach (i.e. comparison of abundance and demographics of fish species) based on monitoring over the present study, it would be argued that dilution flows again contributed to increased native fish abundance and diversity; although there was greater prevalence of translocated relative to endemic native species. Furthermore, the distribution and abundance of alien species was low and dilution flows did not appear to simulate spawning of common carp or juveniles perished (as may have occurred at a similar time last year: Schmarr *et al.* 2013). However, these comparisons cannot explicitly separate the influence of specific dilution flows from other factors. Over the 2013–14 summer, for instance, atypical high flows (almost up to 2000 ML/day) experienced following rains in February and above-average minimum temperatures are likely to have influenced fish communities. Furthermore, abrupt disturbances such as fish kills are strong regulating

influences on fish communities (see below). Overall, fish communities have improved (i.e. broad recruitment of native species, expansion of the range of diadromous species and limited abundance of alien species) over the period coinciding with dilution flow trialling.

4.4 An unseasonal fish kill

Unseasonal rainfall and subsequent flows in early May 2014 added a large organic load, which coupled with unusually warm air temperatures, caused the deterioration of water quality and the development of an algal bloom in the area upstream of Henley Beach Road weir for a short period by mid May 2014. Over this period, dissolved oxygen concentrations dropped to near zero before cooler air temperatures and a small-scale flood event restored dissolved oxygen concentrations in late May 2014. However, the hypoxic conditions lead to a substantial fish kill with approximately 800–1000kg of dead fish removed over a three day period (21–23 May 2014), comprising almost equal proportions of adult common carp and freshwater catfish (contractor, *personal communication*). The large biomass of dead fish clearly indicates the resident fish community has been substantially impacted. Monitoring during the present study confirmed this, with low numbers of common carp and the absence of large freshwater catfish observed in the affected area. Additionally, small-bodied species sampled from the affected area were generally in poor condition, and fish numbers were comparatively lower than nearby sites. Whilst the abundance of flathead gudgeon was low in the affected area, it is unclear whether this relates to the fish kill or other general factors, since abundance was similarly low across all sites sampled below Holbrooks Road weir.

Whilst immediate impacts of the fish kill are evident, the medium- to long-term consequences remain uncertain. For freshwater catfish, the observation of only young fish (i.e. only 1–2 years old; maturity occurs at 4–5 years) and the mortality of large mature individuals implies that breeding capacity will be limited in the affected area, perhaps for years. Recolonisation from upstream populations may be slow, given the limited movement exhibited by the species (Reynolds 1983). In contrast, adult common carp did persist in the affected area, and downstream transport of juveniles from spawning areas in Torrens Lake (McNeil *et al.* 2012; Schmarr *et al.* 2013) suggests that populations of this species will readily recover to pre-fish kill levels. Populations of carp gudgeon and Murray rainbowfish remained relatively abundant

with broad age structures so will likely be greatly unaffected. Ongoing monitoring will be necessary to investigate these anticipated medium- to long-term patterns.



Dead common carp – upstream of Stage 2 Weir (SAG14-04)

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 supported as it is evident that diadromous species are slowly expanding their distribution across the study region.

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.*

This hypothesis is partially supported as newly installed fish ladders appear to be working (with no downstream aggregations of fish) but it is evident that the Holbrook Road weir continues to block the passage of fish species such as congolli as well as freshwater generalists (due to observation of downstream aggregations).

4.5.3 Hypothesis 3: *Flows may induce spawning and/or recruitment responses measurable in fish population structure.*

This hypothesis is supported as new recruits were detected across freshwater generalist/specialist (carp gudgeon, flathead gudgeon, Murray rainbowfish and freshwater catfish) and diadromous functional groups (common carp) and aliens (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 carp abundance, biomass and distribution.*

This hypothesis is not supported as common carp were not recorded in the Torrens Lake and no increase in abundance and distribution of the species was evident downstream. Greater clarity will be afforded by spring monitoring that will be able to target spawning individuals.

4.5.5 Hypothesis 5: *The abundance, distribution and structure of fish species populations in the area affected by the algal bloom would be impacted.*

This hypothesis is supported as monitoring data confirmed the low numbers of common carp and absence of large freshwater catfish (as highlighted by anecdotal reports) and general poor condition of sampled fish in the affected area. The long-term impacts of the fish kill remain unclear, and ongoing monitoring will be necessary.

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 are gradually improving with broad recruitment of native species, expansion of the range of diadromous species and limited abundance of alien species (the absence of large cohorts of cyprinids) observed. The two newly installed fish ladders appear to be affording some fish passage with diadromous species recorded upstream and no downstream aggregations of fish observed. The dilution flows over the 2013–14 summer did not appear to have any negative impact on downstream native fish populations, but rather possibly contributed to increased native fish abundance and diversity – although it is difficult to define causal links. Finally, the recent fish kill has clearly impacted the resident fish community, and anticipated medium- to long-term

consequences will need to be monitored and resolved. Monitoring that will be conducted in spring 2014 will provide further insight into the Torrens fish community.

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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), and
- 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) 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 (uS/cm)	Temperature (°C)	Dissolved oxygen @0.2m (mg/L)	Dissolved oxygen @ 1m (mg/L)	Transparency (m)
SAG14-01	26-May-14	Tapleys Hill Rd weir downstream	Large	1.6	High level	Medium	1	2	1	30	0	7.7	626	17.4	6.29	6.2	0.75
SAG14-02	26-May-14	Tapleys Hill Rd weir upstream	Large	1.0	High level	Medium	1	2	55	10	0	7.8	716	17.3	6.50	6	0.55
SAG14-03	26-May-14	Stage 2 weir downstream	Large	1.3	Bank level	Medium	1	0	45	15	0	7.7	609	16.7	4.40	4.8	0.60
SAG14-04	26-May-14	Stage 2 weir upstream	Large	1.2	High level	Medium	2	1	55	10	0	7.6	646	16.9	5.27	5.1	0.40
SAG14-05	27-May-14	Henley Beach Rd weir upstream	Large	1.3	High level	Medium	1	0	25	20	0	7.7	705	13.5	7.86	7.3	0.90
SAG14-06	27-May-14	Holbrooks Rd weir downstream	Large	2.5	High level	Low	5	0	80	10	5	7.9	891	16.7	8.16	7.9	0.75
SAG14-07	27-May-14	Holbrooks Rd weir upstream	Medium	1.5	High level	Medium	2	0	30	5	25	7.8	891	16.7	8.06	8.1	0.65
SAG14-08	28-May-14	City weir downstream	Medium	2.0	High level	Medium	2	0	35	5	5	7.7	926	16.6	8.13	8.1	0.60
SAG14-09	28-May-14	Torrens Lake	Large	10.0	Bank level	Low	0	0	60	1	0	7.5	932	16.6	5.53	5.3	0.80
SAG14-10	28-May-14	Second Creek outlet weir downstream	Medium	0.95	Bank level	Medium	10	0	5	2	30	7.7	682	16.1	8.95	-	0.95
SAG14-11	28-May-14	Second Creek outlet weir upstream	Large	1.5	Bank level	Medium	1	0	55	5	5	7.5	655	16.1	7.28	7.4	0.50