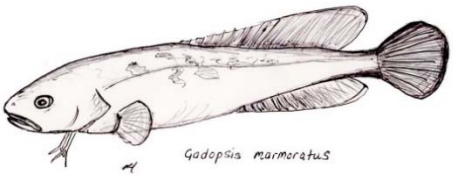
AQUASAVE - Nature Glenelg Trust



Ecology, Monitoring, Conservation

An update on the status of fish communities in the Barossa Valley Prescribed Water Resource Area

Nick Whiterod, Lauren Veale and Ruan Gannon

A report for the South Australian Department for Environment and Water



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1. Background

The extensive network of waterways across the western Mount Lofty Ranges (those that flow west to St Vincent Gulf) provide diverse water-dependent ecosystems (WDEs) (AMLRNRM Board 2013b). These WDEs naturally support a range of endemic aquatic species, including freshwater fish, which represent an important component of the aquatic biodiversity of the area (McNeil and Hammer 2007). Historical and current pressures including habitat degradation, water resource development, sedimentation (from run-off) and incursion of non-native species threaten the resilience of WDEs and their native fish populations, resulting in reduced ecosystem function. In response, the Adelaide and Mount Lofty Ranges Natural Resources Management Board (AMLRNRM Board) has developed a regional NRM plan with a range of objectives aimed at management and protection of natural resources within the region (AMLRNRM Board 2013a). A key consideration has been the development of water allocation plans (WAPs), which specifically seek to balance the water requirements of WDEs (referred to as Environmental Water Requirements) with the needs of consumptive water users. WAPs have been developed for prescribed water resources across the region, including the Barossa (AMLRNRM Board 2009; 2014) and Western Mount Lofty Ranges Prescribed Water Resource Areas (PWRAs) (AMLRNRM Board 2013b).

Freshwater fish are considered useful indicators of environmental condition (Fausch et al. 1990), and knowledge of fish communities provides a means to assess changes over time (McNeil and Hammer 2007; Green et al. 2014). The present project, drawing on baseline fish monitoring from 2013 (Schmarr et al. 2014), allows an opportunity to provide medium-term (five-years) assessment of changes to fish communities across the Barossa PWRA.

1.1 Barossa Prescribed Water Resources Area (PWRA)

Background

The Barossa PWRA, covering approximately 520 km^2, is located in the northern extent of the western Mount Lofty Ranges, ~60-km north-east of Adelaide (AMLRNRM Board 2009). The PWRA is topographically characterised by hills and valleys, extending into localised flat plains in the north-west. The climate of the PWRA is characterised Mediterranean; summers are typically hot and dry with mild, wet winters (Green et al. 2014). The Barossa PWRA supports

major towns of Nuriootpa, Tanunda, Angaston, Lyndoch and Greenock. The surrounding landscape is dominated by primary production including vineyards as well as broad acre cropping and dairy farming (AMLRNRM Board 2009). The long-term average annual rainfall for the Barossa PWRA is 548.7 mm (based on water-use years – July to June – over the 1896−97 to 2016−2017 period, using the Tanunda station, M023318), and substantial inter-annual variation is evident; ranging from 306.4 mm (1896−97) to 862.4 mm (2010−11) (Figure 2-1). Over the past five-year period (2013−14 to 2017−18), the average annual rainfall for the water-use year is 527.6 mm, with evidence of a declining trend over time, although above average rainfall was recorded in the 2013−14 (634.3 mm) and 2016−17 (617.1 mm) water-use years. The declining trend is consistent with previous annual surface water status reports (DEWNR 2015; 2017).

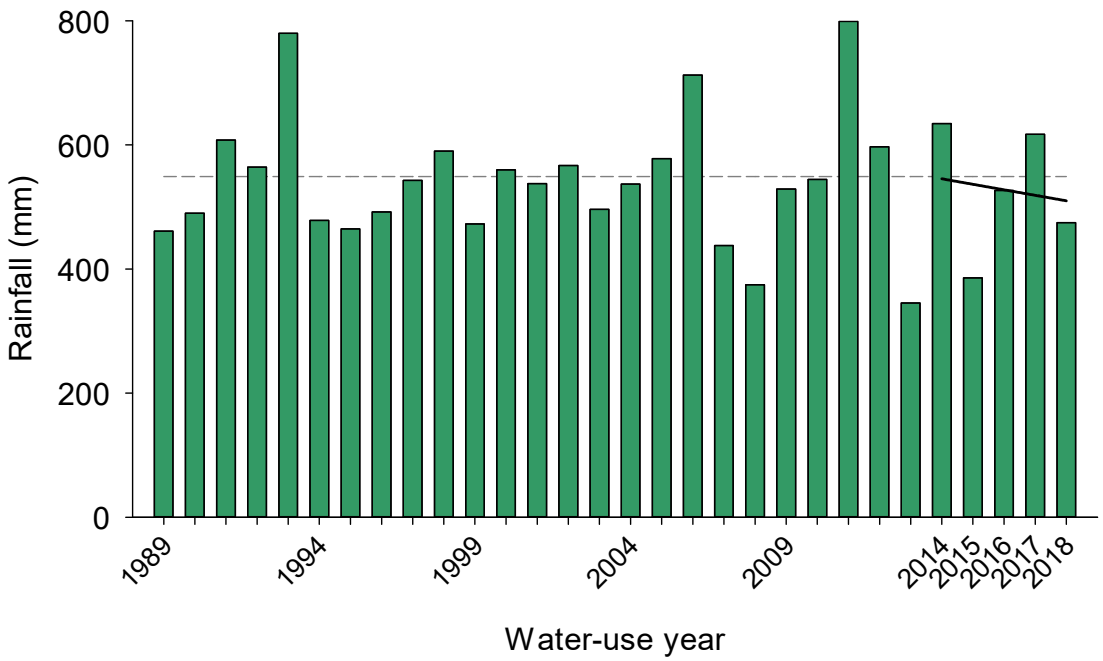


Figure 2-1. Representative annual rainfall (mm) across water-use year (1988−89 to 2017−18) for the Barossa PWRA (using Tanunda Rainfall Station 023318). Also shown is the long-term average (dotted line) and the trend over the past 5-years (black bold).

Surface water resources

The Barossa PWRA (with the exception of Stockwell Creek, which is part of the Light River catchment) is largely contained in a sub-catchment of the Gawler River. The main waterway is the North Para River, which has a number of tributaries, including Tanunda and Jacob creeks. The surface water resources across the Barossa PWRA are highly dependent on

rainfall, with the high variability in streamflow and salinity primarily being climate driven (DEWNR 2017). Recorded annual streamflow in the North Para River at the Yaldara gauging station, which is the drainage location for most of the Barossa PWRA has varied from 900 ML (1994) to 64,500 ML (1992) with the long-term (1943–2014) average annual streamflow being 12,898 ML (Jones-Gill and Savadamuthu 2014). The surface water resources are also influenced by extensive surface and groundwater resource development, in the form of farm dams (rather than large reservoirs) and bores, primarily for viticulture. In fact, an estimated 1790 farm dams that occur in the area, have a total water capacity of approximately 8100 ML, which is capable of holding approximately 60% of the long-term average annual discharge of the Barossa PWRA (Jones-Gill and Savadamuthu 2014).

Streamflow regimes also vary spatially in response to rainfall and water resource development (Jones-Gill and Savadamuthu 2014). For example some sections of Jacob Creek exhibit perennial flows, whereas other waterways flow for only 30% of the time (Jones-Gill and Savadamuthu 2014). Generally, most waterways in the Barossa PWRA (with the exception of the aforementioned sections of Jacob Creek) have become ephemeral and contract to a series of permanent pools over summer months that are fed predominantly by groundwater (Jones 2004; DEWNR 2017). These permanent pools provide important refuges for a range of native fish and macroinvertebrate taxa, as the permanent supply of water provides temporally stable aquatic habitat and food resources.

Generally, the status of streamflow in the Barossa PWRA is considered poor (DEWNR 2015; 2017). Furthermore, there has been a declining trend in recent years, with streamflow in the North Para River at the Yaldara gauging station over the water-use year declining from the 25–50th percentile of the medium-term recorded in 2014–15, to the <25th percentile in 2015–16 (DEWNR 2015; 2017). Correspondingly, water extractions, as a proportion of the total estimated resource capacity, have risen from 21% in 2014–15 to 62% in 2015–16 (DEWNR 2015; 2017). Yet, emphasising the variability, streamflow during the 2016–17 water-use year were considerably greater (29,973 ML) than the long-term average annual streamflow, but lower most recently (e.g. over the 2017–18 water-use year) (www.waterconnect.sa.gov.au).

Water resource management

There has been a staggered prescription of water resources within the Barossa PWRA, including underground water (i.e. groundwater, prescribed in 1989), watercourses (prescribed in 1992) and surface water (prescribed in 1998) (note that surface water and watercourses of the Greenock Creek Catchment were prescribed in 2005). In addition to prescribed water resources, the Barossa PWRA is supported by imported water delivered via the Barossa Infrastructure Limited (BIL) scheme (River Murray water and community wastewater) and SA Water Mains off-peak supply. In addition, some water users also hold River Murray Water Licences, for which water allocations are delivered through SA Water infrastructure. A number of irrigators in the Barossa PWRA use one or more of these various water sources on their properties (AMLRNRM Board 2009; 2014).

The current WAP for the Barossa PWRA was adopted in 2009 (AMLRNRM Board 2009). It was reviewed in 2014, which led to a recommendation to amend the WAP which was endorsed by both the AMLR NRM Board and the then Minister for Sustainability, Environment and Conservation.

1.2 Fish of the Barossa PWRA

The contemporary fish fauna of the western Mount Lofty Ranges includes 34 freshwater fish species, (representing native, translocated native and alien species: McNeil and Hammer 2007; McNeil et al. 2011a). In the Barossa PWRA, knowledge on the fish communities has resulted from irregular sampling between 2000 and 2012, baseline monitoring (37 sites) in 2013 and more recent surveys at selected sites in 2015–2017 (Hicks and Sheldon 1999; McNeil et al. 2011b; Schmarr et al. 2014). In total, 12 freshwater fish species, including six native, one translocated native and five alien (non-native) species, have been recorded in the Barossa PWRA (Table 1-1).

Flathead Gudgeon (*Philypnodon grandiceps*) are abundant and widespread throughout the catchment, occurring in the North Para River and Jacob Creek, while Western Bluespot Goby (*Pseudogobius olorum*) show a patchy distribution in the North Para River. Mountain Galaxias (*Galaxias olidus*) occurs in high numbers across Jacob Creek, where it represents a critical source population for the Barossa PWRA (Schmarr et al. 2014). Common Galaxias (*Galaxias maculatus*) and Congolli (*Pseudaphritis urvillii*), diadromous species that require connection

with the sea to complete its life cycle, have previously been recorded below Yaldara Weir on the North Para River (McNeil et al. 2011b; SARDI, unpublished data). A further diadromous species, Climbing Galaxias (*Galaxias brevipinnis*), is present in the Gawler River Catchment (and is presumed to have historically occurred in the Barossa PWRA), but is not reflected in the contemporary fish community (Green et al. 2014; Schmarr et al. 2014). A single translocated native, Silver Perch (*Bidyanus bidyanus*) was detected in the lower North Para River during the 2013 monitoring.

Table 1-1. Contemporary fish species recorded in the Barossa PWRA prior to the present study. Functional groups (FG) are: Diadromous (DI), freshwater generalist (FG); freshwater specialist (FS) and estuarine species (ES).

Status	FG	Common name	Scientific name	Comments
Native	DI	Common Galaxias	*Galaxias maculatus*	Occasionally detected at Yaldara Weir
	DI	Congolli	*Pseudaphritis urvillii*	Recently detected at Yaldara Weir
	FS	Mountain Galaxias	*Galaxias olidus*	Strong population in Jacob Creek; temporally present in Tanunda Creek
	FG	Flathead Gudgeon	*Philypnodon grandiceps*	Abundant in North Para River and Jacob Creek
	EG	Dwarf Flathead Gudgeon	*Philypnodon macrostomus*	Recently recorded from several sites across lower North Para River
	ES	Western Bluespot Goby	*Pseudogobius olorum*	Patchy in North Para River
Translocated native	FG	Silver Perch	*Bidyanus bidyanus*	Single record from lower North Para River
Alien (non-native)	FG	Common Carp	*Cyprinus carpio*	Several records from North Para River
	FG	Goldfish	*Carassius auratus*	Uncommon in North Para River
	FG	Redfin Perch	*Perca fluviatilis*	Widespread and abundant in North Para River; rare in Jacob Creek
	FG	Eastern Gambusia	*Gambusia holbrooki*	Widespread and abundant
	FG	Tench	*Tinca tinca*	Rare, restricted to North Para River

The most abundant alien species is the Eastern Gambusia (*Gambusia holbrooki*) which occurs broadly across the region, whereas Redfin Perch (*Perca fluviatilis*) is dominant in the North Para River. Tench (*Tinca tinca*), Goldfish (*Carassius auratus*) and Common Carp (*Cyprinus carpio*) are all detected infrequently.

1.3 Project objectives

This project aimed to re-assess the status of fish communities across the Barossa PWRA. The specific objectives were to:

- Undertake fish monitoring at a subset (16) of the Barossa PWRA sites sampled in 2013;
- Provide a summary report detailing outcomes of fish monitoring, with specific comparison with 2013 data to provide an updated status of fish communities, including any shifts; and
- Draw on regional fish monitoring data to summarise trends across the western Mount Lofty Ranges (see Appendix 1).

The outcomes of this project will provide updated knowledge of the status of fish communities across the Barossa PWRA, as well as any change over the preceding 5 years, which will help guide development of the next WAP.

2. Methods

2.1 Barossa PWRA sampling sites

In autumn 2018, sampling occured at 16 sites to allow comparison with 2013 monitoring (Figure 2-1 and 2-2, Table 2-1). The 16 sites represented a subset of the 37 sampled in 2013, and were selected to provide broader spatial coverage as well as allow re-sampling of key ecological assets. The sites encompassed the upper, mid and lower reaches of the North Para River, as well as Jacob Creek. The North Para River initially flows north from 'North Para Gauge' to 'Penrice Quarry', before flowing south from 'DS (downstream) Mathos' to 'Yaldara Weir'. Jacob Creek flows west to east from 'Jacob Creek old gauge' to 'Jacob Creek crossing', where after it converges with the North Para River.

Table 2-1. Summary of sites sampled across Barossa PWRA in autumn 2018.

Site code	River reach	Location	Easting	Northing	Date sampled
SAG18-12	upper North Para River	North Para Gauge	323841	6172730	20-March-2018
SAG18-11		Cornerstone Stud	324015	6177070	20-March-2018
SAG18-09		DS Evans Weir [Lindsay Park]	323664	6177070	19-March-2018
SAG18-10		Thorne-Clarke ford	323602	3180599	19-March-2018
SAG18-08		Old Moculta bridge	323077	6184299	19-March-2018
SAG18-07		Penrice Quarry	321912	6184861	19-March-2018
SAG18-04	mid-North Para River	DS (downstream) Matchos	313801	6180917	18-March-2018
SAG18-03		Smythe Road crossing	312702	6178875	18-March-2018
SAG18-13	lower North Para River	St Hallets crossing [Pool 138]	311326	6174943	20-March-2018
SAG18-15		St Hallets bike path	310804	6174300	21-March-2018
SAG18-14		Barossa Novotel [Pwnp 17]	310092	6173479	20-March-2018
SAG18-17		US Landcare Reserve [PWNP 18]	309093	6171107	21-March-2018
SAG18-16		DS Landcare Reserve [PWNP019]	308654	6172059	21-March-2018
SAG18-05		Yaldara Weir [BAR0306]	305050	6172113	18-March-2018
SAG18-06	Jacob Creek	Jacob Creek crossing	311077	6173263	18-March-2018
SAG18-18		Jacob Creek old gauge	313250	6171426	21-March-2018



Figure 2-2. Selection of sites sampled in autumn 2018 monitoring (clockwise from top left): North Para River – DS Evans Weir (SAG18-09); North Para River – Smythe Road crossing (SAG18-03); North Para River – Barossa Novotel (SAG18-14); and Jacob Creek – old gauge (SAG18-18).

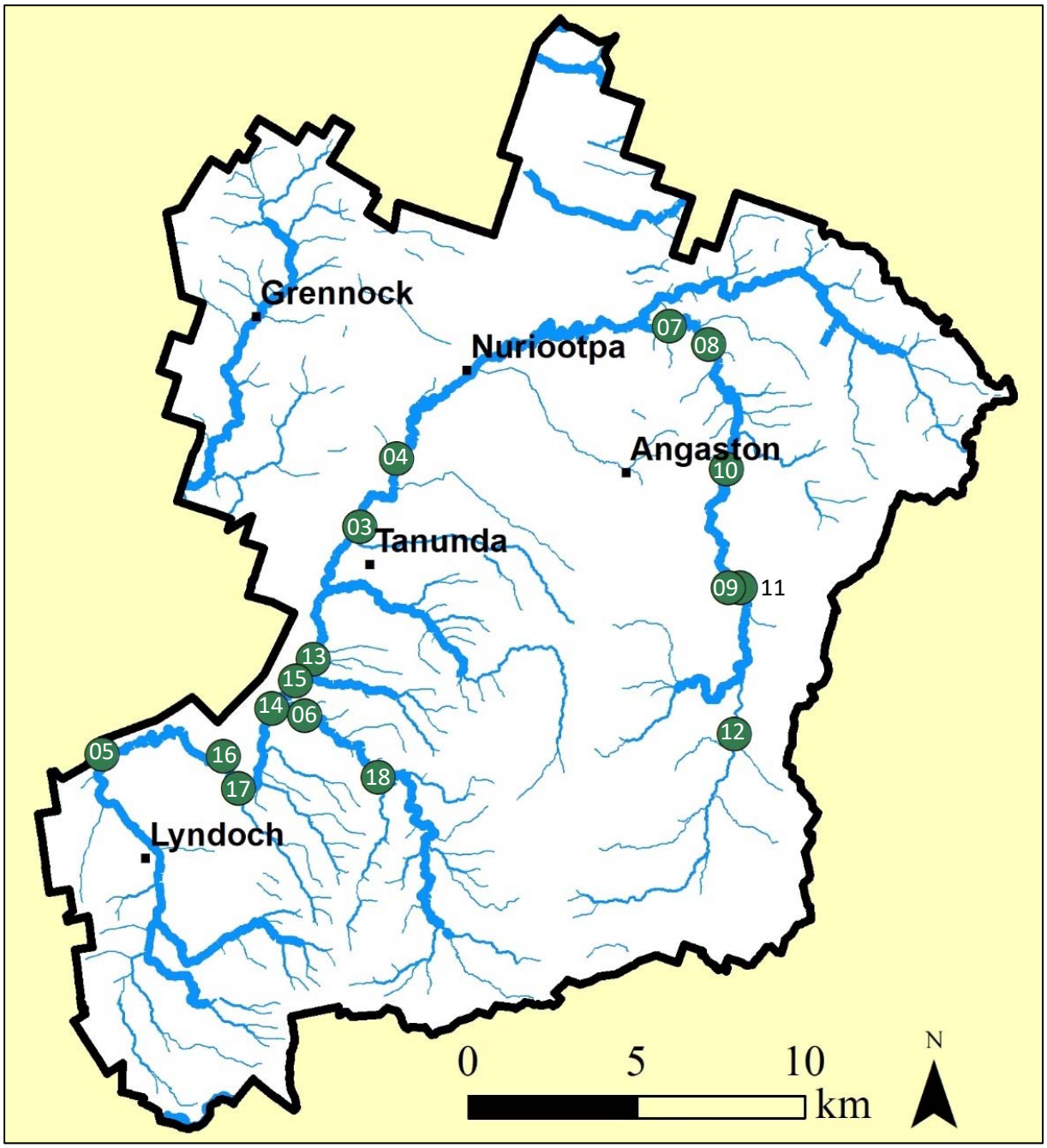


Figure 2-1. Location of sites (●) sampled across waterways (–) of the Barossa Prescribed Water Resources Area (–; shaded white) in autumn 2018. Number for each site denotes last number of site code, detailed in Table 2-1.

2.2 Sampling protocol

Baseline fish monitoring in 2013 used a variety of sampling equipment to estimate fish population structure and abundance (e.g. single- and double-winged fyke nets, backpack electrofishing and bait traps) across the Barossa PWRA (Schmarr et al. 2014). In autumn 2018, sampling methods were consistent with those utilised in baseline monitoring although the number of nets deployed overnight, across available habitat at each site, was reduced (in

2018: 4 single-wing fyke nets; in 2013: 4 single-wing and 2 double-wing fyke nets were typically deployed).

Fish captured at each site were taxonomically identified to species (McDowall 1996), except for the Carp Gudgeon complex owing to taxonomic uncertainty (Bertozzi et al. 2000), and enumerated. At each site, the total length (TL, mm) was recorded for at least 50 individuals of each species to determine length structure to provide a measure of recruitment (as evidenced by juvenile fish) and survivorship (as evidenced by larger, older fish) based on known length-age structure for each species (cf. Whiterod and Hammer 2014; Whiterod et al. 2017). Additionally, for each species, biological information was also recorded (reproductive condition and presence of external disease or parasites). Other aquatic fauna captured opportunistically were also recorded at each site.

Environmental descriptors, such as extent of habitat cover (measured visually as the percentage of total water volume at the site occupied by combination of submerged physical structure (e.g. rocks, woody structure); submerged and emergent aquatic vegetation: Whiterod et al. 2017), flow and pool condition, as well as water quality parameters (electrical conductivity, dissolved oxygen concentration, pH, water temperature and transparency) were also recorded to assist the interpretation of findings. All sampling was undertaken in accordance with relevant permits (PIRSA Fisheries Exemption, ME9902959).

2.3 Statistical analysis

The PRIMER 7 statistical package (with PERMANOVA add-on) was used to perform all multivariate analyses (Anderson et al. 2008; Clarke et al. 2014; Clarke and Gorley 2015), using only data from the four single-wing fyke nets at each of the 16 sites sampled in each year (2013 and 2018). Given this consistency, total abundance of each fish species (recorded in each replicate single-wing fyke net) were transformed using the Log(x+1) function to down-weight the contributions of species with consistently high abundance. The resultant data were then used to construct a Bray-Curtis similarity matrix, which was subjected to a two-way PERMANOVA design for year and site. A two-way Analysis of Similarities (ANOSIM) test was used to assess the relative magnitudes of overall year and site factors, via the universally scaled ANOSIM *R* statistic which ranges from ~0 (not significant) to 1.

Separate Bray-Curtis similarity matrices were then constructed for each site and subjected to one-way ANOSIM tests to depict which sites significantly differed between years. When there was a significant difference between fish community compositions of *a priori* groups, similarity percentages analysis (SIMPER) was used to identify the species that typified the fish composition of each *a priori* group, and those that were responsible for distinguishing between the fish compositions in each pair of groups.

Non-metric Multidimensional Scaling (nMDS) ordination, using averaged data for each site, were constructed to visualise the extents to which fish composition differed across years and sites. Fish sites were presented based on the cluster groupings that separated at 5% similarity. Segmented bubbles of proportional sizes, representing the transformed mean abundances of selected species, were overlaid on the corresponding nMDS plot. This illustrates the abundance trends exhibited by some of the species, which varied between years and/or sites.

Environmental data (pH, temperature, salinity and dissolved oxygen concentration) recorded at each site in 2013 and 2018 were related to fish community structure using distance based linear model (DistLM) to assess the significance of each parameter.

3. Results

3.1 Autumn 2018 monitoring

Summary

In autumn 2018, a total of 7349 fish were caught, including three native, one translocated native and three alien species (Figure 3-1 and Table 3-1). The catch was dominated by the alien Eastern Gambusia (*n*=4331), which accounted for 58.9% of the total catch, and the native Flathead Gudgeon (*n*=2091; 28.5% of the total catch). These two species were widely distributed, occurring at most of the 16 monitoring sites (i.e. Eastern Gambusia: 12 sites; Flathead Gudgeon: 11 sites). Mountain Galaxias were also moderately abundant (*n*=304, 4.1%), but remained restricted to Jacob Creek sites, while Western Bluespot Goby (*n*=79, 1.1%) were recorded at two of the lower North Para River sites. Finally, the alien Redfin Perch (*n*=35, 0.5%) and Tench (*n*=7, 0.1%) occurred in low numbers throughout all reaches of the North Para River. A new record for the Barossa PWRA was the translocated native species

Carp Gudgeon (*Hypseleotris* spp.) (*n*=502, 6.8%), which was recorded at three sites in the upper North Para River.



Figure 3-1. Selection of fish species sampled in autumn 2018 monitoring (clockwise from top left): translocated native Carp Gudgeon; juvenile Redfin Perch; net full of Flathead Gudgeon; Western Bluespot Goby; juvenile Mountain Galaxias, and juvenile Tench.

Table 3-1. Summary of the fish catch in 2013 and 2018 fish monitoring of the Barossa PWRA.

Site code	River reach	Location	2013								2018							
			Mountain Galaxias	Flathead Gudgeon	Carp Gudgeon	Western Bluespot Goby	Eastern Gambusia	Redfin Perch	Tench	Goldfish	Mountain Galaxias	Flathead Gudgeon	Carp Gudgeon	Western Bluespot Goby	Eastern Gambusia	Redfin Perch	Tench	Goldfish
SAG18-12	upper North Para River	North Para Gauge					585	3							22	8		
SAG18-11		Cornerstone Stud											168		16	4		
SAG18-09		DS Evans Weir [Lindsay Park]					10	231					333		208			
SAG18-10		Thorne-Clarke ford		1				99				1				8	1	
SAG18-08		Old Moculta bridge		362				111				80				1		
SAG18-07		Penrice Quarry		142			105					421	1		9		1	
SAG18-04	mid-North Para River	DS (downstream) Matchos*		225			40			3		97			64		3	
SAG18-03		Smythe Rd crossing		313			98			2		53			3			
SAG18-13		St Hallets crossing [Pool 138]		409			167					424			56			
SAG18-15		St Hallets bike path		197			1215					213			974			
SAG18-14	lower North Para River	Barossa Novotel [Pwnp 17]*		665		286	117	1	1			84		11	518			
SAG18-17		US Landcare Reserve [PWNP 18]		174			138	11	1			154			22	1	2	
SAG18-16		DS Landcare Reserve [PWNP019]		9				24				280			738	12		
SAG18-05		Yaldara Weir [BAR0306]		119		120	716			1		284		68	1701	1		
SAG18-06	Jacob Creek	Jacob Creek crossing	40					1			62							
SAG18-18		Jacob Creek old gauge	83								242							
		Species total	**123**	**2616**	**0**	**406**	**3191**	**481**	**2**	**6**	**304**	**2091**	**502**	**79**	**4331**	**35**	**7**	**0**
		TOTAL				**6825 fish**								**7349 fish**				

**Common Carp (1 fish, North Para River - DS Mathos) and Silver Perch (1 fish, North Para River - Barossa Novotel) were detected by other sampling gear in 2013.*

Length structure

Assessing length structure data provides insight into the recruitment and survivorship of key species recorded in the present study (Figure 3-2). The dominant fish species, Eastern Gambusia (15–56 mm) and Flathead Gudgeon (19–97 mm), were represented by broad length structures, indicating recent recruitment and survivorship over multiple years. Similarly, Western Bluespot Goby exhibited a broad length structure (21–64 mm) inferring a persisting self-sustaining population. For Mountain Galaxias, the population mostly consisted of recent recruits (i.e. <65 mm), with fewer larger individuals compared to 2013, suggesting limited survivorship. The newly detected Carp Gudgeon was observed across a broad length structure (13–52 mm), inferring a persisting self-sustaining population has established in the Barossa PWRA. The length structure of Redfin Perch was better reflected by larger individuals (>200 mm: 60%) compared to 2013 monitoring (<100 mm: 68%; >200 mm: 5%), although individuals less than 100 mm were also common (34% of total numbers).

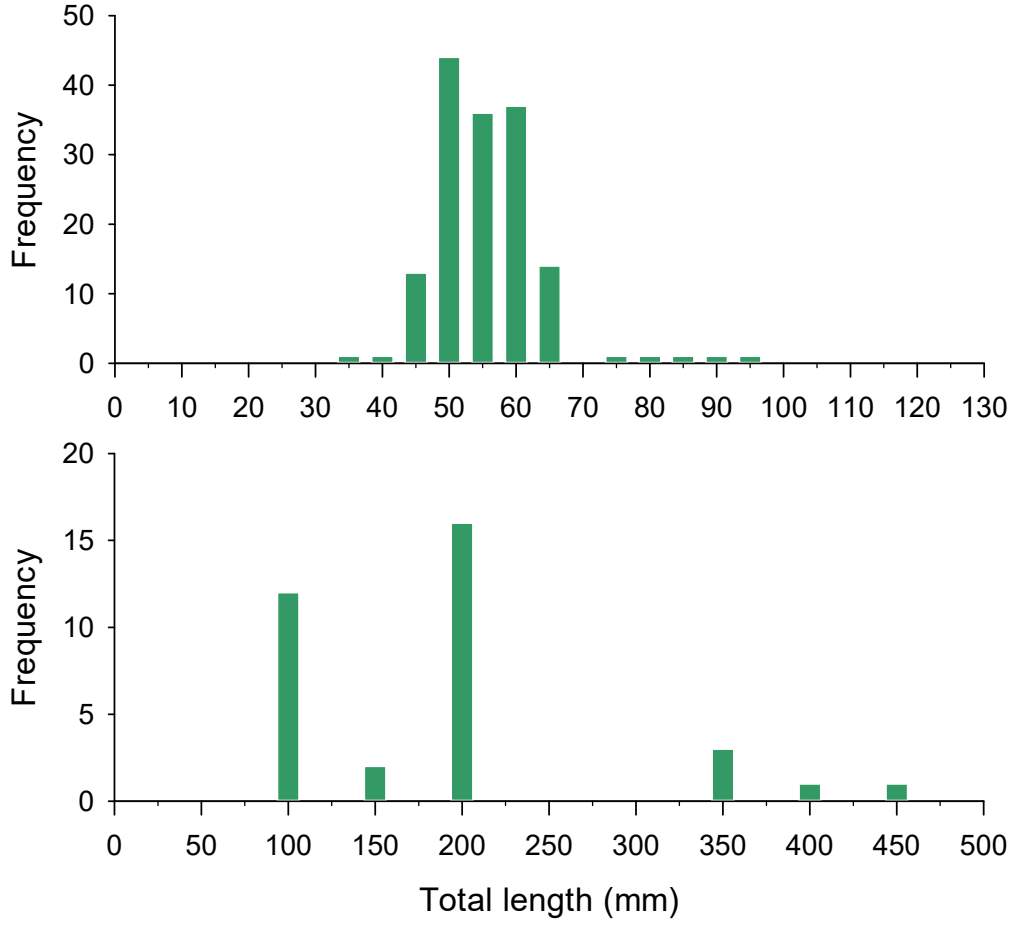


Figure 3-2. Length structure for (top) Mountain Galaxias; and (bottom) Redfin Perch sampled across the Barossa PWRA in autumn 2018 (note: data is pooled across sites).

Environmental descriptors

All sites had low to moderate levels of physical habitat; predominately rock and snags (ranging from 1 to 55% of water column), with limited habitat cover provided by submerged aquatic vegetation (less than 5% of the water column) and emergent vegetation (ranging from 1−30% of water column) (Appendix 2). Across sampling sites, the extent of bank vegetation was variable (15−100% of the 2 m strip by the water's edge was vegetated), as was canopy cover (1−80%). Water quality parameters were also variable, including electrical conductivity (1183−7982 μScm^{-1}, with the highest recording being at the Old Moculta bridge site), and dissolved oxygen concentration (2.2−19.30 mgL^{-1}, with higher concentrations in the mid- and lower-reaches of the North Para River). Also, water temperature ranged between 14.6 to 19.1°C whereas pH ranged from 7.2 to 9.5 (Appendix 2)

3.2 Temporal comparison (2013 and 2018)

Total catches were lower in 2013 (*n*=6825) compared to the present monitoring (*n*=7349). This was explained by greater numbers of Eastern Gambusia and Mountain Galaxias in the current sampling period (Table 3-1). In contrast to 2013, Goldfish and single individuals of Common Carp and Silver Perch were not observed in 2018. On the contrary, although not detected in 2013, Carp Gudgeon was observed in 2018 representing the first record of the species in the Barossa PWRA.

Multivariate analyses revealed only subtle differences in fish composition between years (PERMANOVA, *pseudo-F*=4.3, *P* = 0.04). Rather, the analyses indicated that site was far more significant (PERMANOVA, *pseudo-F*=15.7, *P*=0.01) which was also highlighted in the two-way crossed ANOSIM test (R values, 0.65 for site and 0.21 for year). Cluster analyses of the averaged fish data found three significant groupings considering a 5% similarity (Figure 3-3). These cluster groupings can be seen visually on the nMDS ordination plot (Figure 3-4). Group A contained all sites in the lower and mid-North reaches of the North Para River (except the DS Landcare site in 2013) and, according to SIMPER results, were characterised by consistently higher catches of Eastern Gambusia and Flathead Gudgeon. Group B contained mainly sites in the upper North Para River, and was typified by Redfin Perch, while Group C consisted of the two Jacob Creek sites (both years) and was distinguished by Mountain Galaxias.

Results of the one-way ANOSIM tests for each site showed that fish composition at only four of the 16 sites differed significantly between 2013 and 2018. These sites were all located in the upper North Para River, and included Evans Weir (Global R=1.00), North Para Gauge (Global R=0.625), Cornerstone Stud (Global R=0.458) and Penrice Quarry (Global R=0.406). No significant changes in fish composition were observed between 2013 and 2018 across the lower and mid reaches of North Para River and Jacob Creek.

SIMPER analyses were used to depict which species were responsible for driving these changes between years. These are also presented visually on the nMDS bubble plot (Figure 3-4). In summary, sampling in 2018 recorded:

- Higher numbers of Eastern Gambusia at North Para Gauge;
- Higher numbers of Eastern Gambusia and Redfin Perch, and new detection of Carp Gudgeon, at Cornerstone Stud (noting that no fish were caught in 2013);
- Higher numbers of Eastern Gambusia, new detection of Carp Gudgeon, and absence of Redfin Perch at Evans Weir; and
- Higher numbers of Carp Gudgeon and Flathead Gudgeon, and lower numbers of Eastern Gambusia, at Penrice Quarry.

Distance based linear modelling showed that salinity (p = 0.001) was the only environmental factor that significantly explained the differences in fish assemblage structure (Figure 3-5). Salinity produced an R^2 value of 0.16, suggesting that this variable only accounted for 16% of the total variability in fish assemblage structure. The main reason for this presumably relates to the far lower salinities observed at North Para Gauge in 2013 (Figure 3-5). Salinity progressively increased from Group B → Group C → Group A, suggesting that those species typifying Group A (i.e. Eastern Gambusia and Flathead Gudgeon) are resilient to higher salinities, while those typifying Groups B and C (i.e. Mountain Galaxias and Redfin Perch) prefer lower salinities. While pH, dissolved oxygen, and temperature didn't significantly influence the fish assemblage structure, they appear to have been consistently lower in 2018.

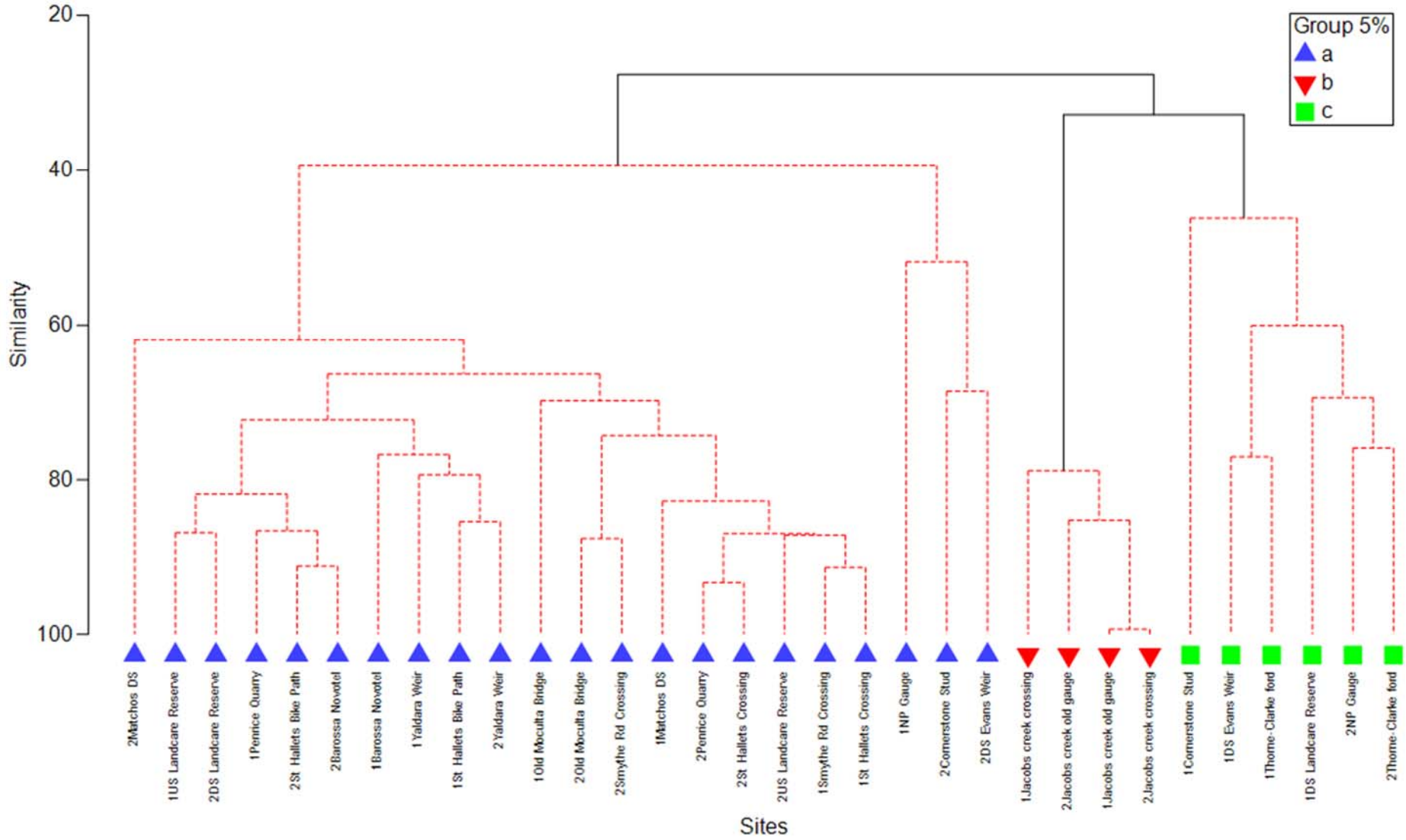


Figure 3-3. Dendogram cluster analysis of the averaged fish data recorded in the Barossa PWRA in 2013 (1) and 2018 (2).

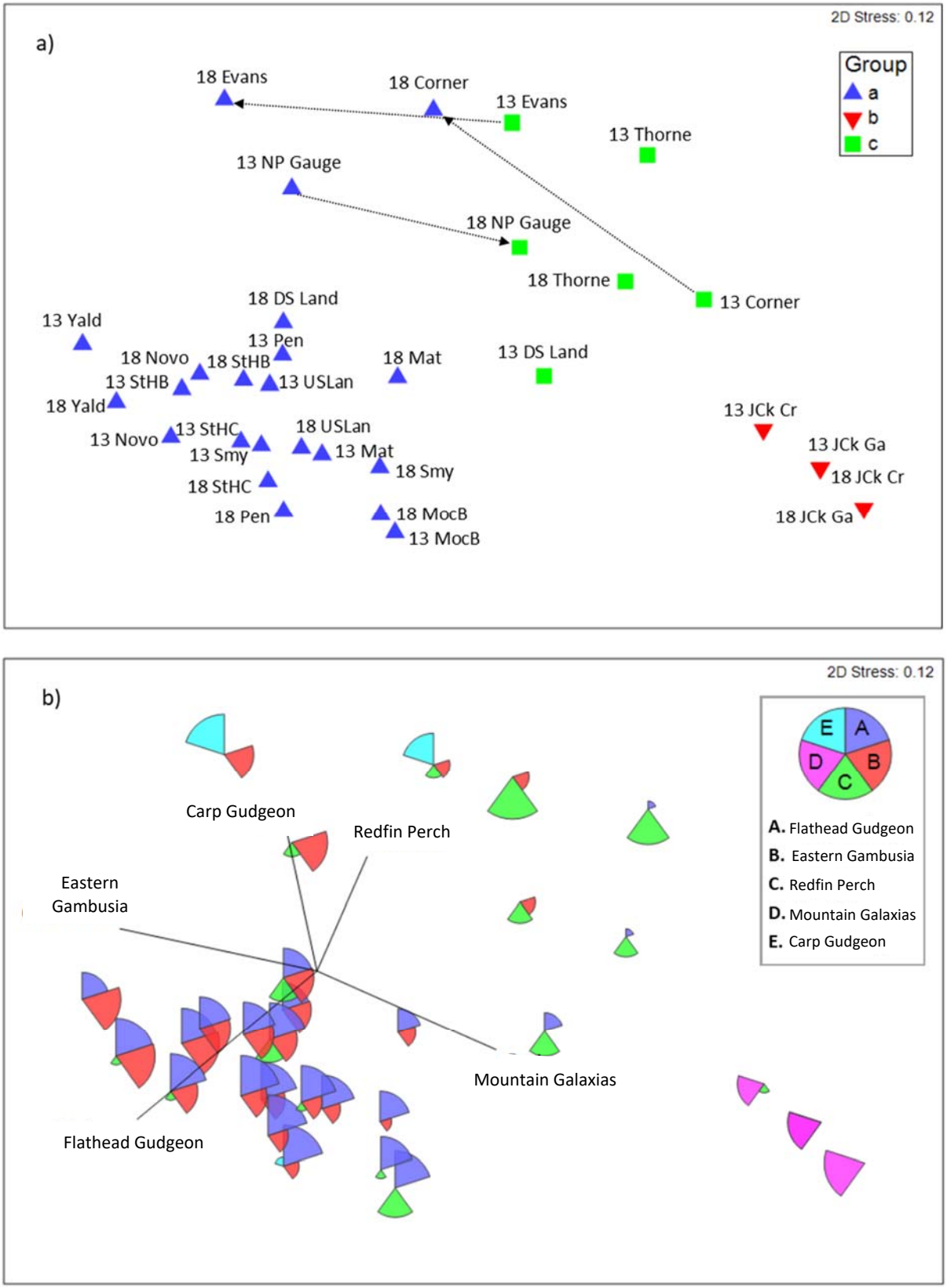


Figure 3-4. (a) site-based representation of 2013 and 2018 monitoring across Barossa PWRA (with larger site-based temporal changes highlighted by directional arrow) achieved by nMDS ordination constructed from Bray-Curtis similarity matrices derived from the mean fish abundance, and (b) with superimposition of segmented bubble plots to highlight the relative abundance (and direction of influence) of key fish species.

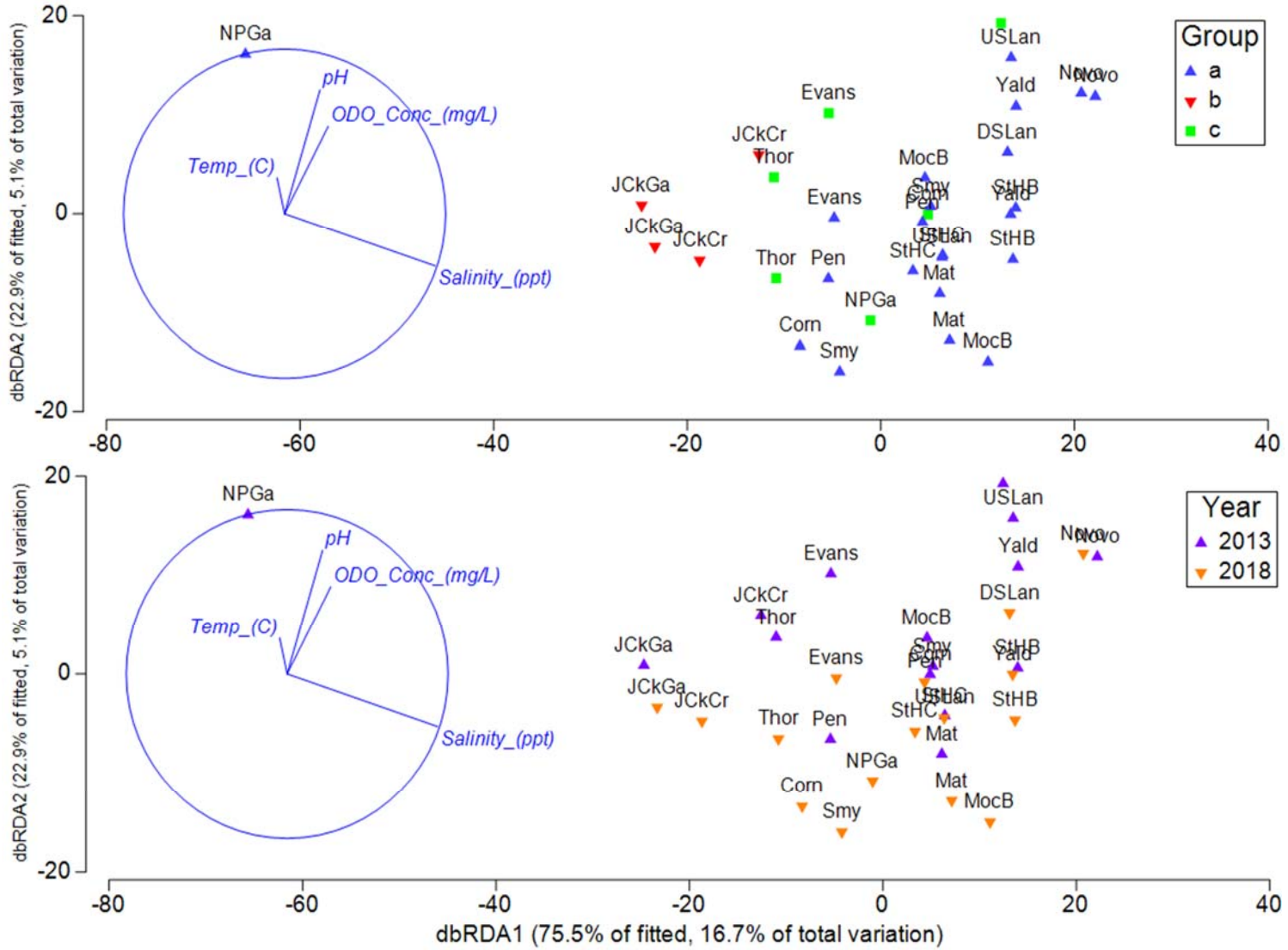


Figure 3-5. Distance based linear model for the Barossa PWRA showing correlation of species group clusters (top) and years (bottom) with environmental variables

4. Discussion

The Barossa PWRA currently supports a degraded fish community, with low species diversity characterised by the dominance of alien species (Eastern Gambusia, Redfin Perch). Native freshwater generalists (Flathead Gudgeon) and instream specialists, Mountain Galaxias, only persist as restricted populations. It is evident that there has been no improvement in diversity or distribution of native fish communities in this region between 2013 and 2018, which reinforces the need for improved streamflow and habitat enhancement to aid the improvement of fish communities (as well as other ecological assets) across the Barossa PWRA.

4.1 Spatial patterns and temporal trends

The present study revealed that fish communities across the Barossa PWRA were strongly structured by spatial differences. The upper North Para River is characterised by Redfin Perch and Carp Gudgeon (new species first detected in 2018), whereas sites in the lower reaches of the river maintain Flathead Gudgeon and Eastern Gambusia – with some evidence of salinity explaining some of this structuring. Regardless, both reaches remain dominated by freshwater generalists, most of which are alien species. Consistent with 2013, Jacob Creek was the only waterway that currently supports a population of locally threatened Mountain Galaxias in the Barossa PWRA. The small of individuals sampled at both sites in the creek was indicative of a population comprising primarily recruits, suggesting possibly limited survivorship of the Mountain Galaxias over multiple years. Alternatively, the life stage separation often observed in the species due to its source-sink population dynamic (e.g. larvae drift with the flow to reside in downstream pools with adults remaining in upstream pools: Dexter et al. 2014), suggests that adults may persist at other pools in the creek that were not sampled during the current period. Nevertheless, restriction of Mountain Galaxias to only Jacob Creek indicates it is the source, albeit, threatened population, for the entire Barossa PWRA. The absence of alien species, namely Redfin Perch, from Jacob Creek is a positive, and a likely result of instream barriers across the lower reaches of the creek impeding dispersal and limiting colonisation. Maintaining, the creek alien species free should be a priority.

We only detected subtle changes in the fish community across the Barossa PWRA when results were compared between 2013 and 2018. Notably, there was an apparent shift resulting from an increase in abundance of the dominant alien species at a number of sites. Redfin Perch, for example, were abundant mostly as juveniles (<100mm) in 2013 across the Barossa PWRA, presumably reflecting a large recruitment event in response to above average streamflow over the 2010–11 water-use year. In 2018, Redfin Perch was represented by fewer, large individuals despite an expectation of a similarly large recruitment event would result from the above average streamflow over 2016–17. The reduced number of Redfin Perch across the Barossa PWRA (particularly the shift from high abundance to absence of redfin perch in North Para sites DS (downstream) Evans Weir, Thorne Clarke ford, and Old Moculta bridge) may have favoured Eastern Gambusia and the observed increase in abundance and dominance (almost two-thirds of the catch) across the Barossa PWRA. This species is dominant across much of the western Mount Lofty Ranges (Appendix 1) as well as the nearby eastern Mount Lofty Ranges (Whiterod et al. 2015) and widespread impacts on native fish species are anticipated (Pyke 2008).

Carp Gudgeon was detected in the Barossa PWRA for the first time during the present study. This species complex occurs in the Murray-Darling Basin, with its translocation to other waterways of the western Mount Lofty Ranges, mostly through inter-basin water transfer (McNeil and Hammer 2007; Schmarr et al. 2014). Given the nature of inter-basin water transfer through the BIL scheme (i.e. underground piping directly to properties), it is unlikely that Carp Gudgeon were translocated into the Barossa PWRA by the mechanism. It is more probable that fish were accidentally released directly into the river, or into farm dams that subsequently overflowed (during 2016–17 high flows), as part of illegal stocking (of angling species) or bait buckets introductions (following angling on the Lower Murray) (cf. Lintermans 2004). The fact that Carp Gudgeon were observed in moderate numbers across a broad length structure infers that self-sustaining populations have established. Whilst its presence at multiple sites (across an approximately 10 km section of the upper North Para River) could have resulted from separate translocations, it is possible that it may have dispersed to colonise these sites. Further expansion of its range across the upper North Para River as well as the lower North Para River is anticipated. Carp Gudgeon has similarly broad flow and

habitat requirements to the endemic freshwater generalist (Flathead Gudgeon) in the Barossa PWRA, so direct competition for resources and habitat is anticipated.

The findings of the present study are reinforced by those obtained from similar analyses on the WMLR PWRA data set over the same period (see Appendix 1). In particular, the composition of fish communities across the PWRA exhibited minimal differences to those identified in 2013, demonstrating a strong spatial structuring according to sub-catchments that reflected similar species being present. In this context, sites in the lower North Para River showed similarities with sites in the WMLR PWRA, each being typified by high numbers of Eastern Gambusia (i.e. Inman Creek, Scott Creek, Brownhill Creek). Mountain Galaxias, found in Jacob Creek were also found in the WMLR PWRA sub-catchments (Central Sturt River, Brownhill Creek, Deep Creek, Lenswood Creek).

4.2 Insight into WAP for Barossa PWRA

The water allocation plan (WAP) must balance the need to maintain ecological assets along with social and economic values of the Barossa PWRA (AMLRNRM Board 2009; 2014). At the time of the 2014 review of the Barossa WAP, '*no adverse hydrological trend, suggesting a stable or improving situation*' was noted. However, since 2014 (i.e. over the study period), annual rainfall (at the Tanunda gauging station) and streamflow appear to be declining and water abstraction is increasing (DEWNR 2015; 2017). The fact that significant change in the fish community was not observed between 2013 and 2018 most likely reflects the already degraded nature and current paucity of habitats suitable to sustain healthy native fish populations. For instance, the broad habitat and flow requirements of the dominant freshwater generalists (both native and alien species) (McNeil and Hammer 2007), suggests that this functional group may be more tolerant (or adaptable) to poor water quality and habitat availability; conditions indicative of degraded or deteriorating systems. Further declines in condition across the PWRA however, could impact PWRA ecosystem integrity. In particular, if the threshold for fish resilience to poorer conditions is reached, it could induce further deterioration and declines in the fish community. The amended Barossa WAP should propose actions that attempt to prevent further declines in in ecosystem condition and fish population structure, aiming to improve conditions and availability of suitable habitats to

promote healthier ecosystems and native fish communities in the PWRA. Some considerations for key functional groups are discussed below.

Mountain Galaxias represent the only freshwater specialist recorded in the present study. This regionally rare species has specific habitat and flow requirements, relating to the maintenance of baseflows, regular bankfull flows as well as freshes (Hammer et al. 2009; Green et al. 2014; Whiterod et al. 2017). The relatively non-impacted flow regime of Jacob Creek, with some sections maintaining perennial flows, clearly provides the necessary conditions for the native species in most years. Furthermore, dispersal and re-colonisation appear necessary to maintain connected populations along the creek, and it is therefore imperative that flows are maintained. Mountain Galaxias have been recorded elsewhere across the Barossa PWRA; occasionally observed in some temporary streams (e.g. Tanunda Creek) (Green et al. 2014; SARDI, unpublished data). Enhancing baseflows should, in time, create permanent refuge pools that allow the species to persist in locations beyond its current permanent range.

Although not recorded in the present study, the diadromous Common Galaxias and Congolli have recently been observed in the lower North Para River (SARDI, unpublished data). Furthermore, despite historical accounts and detection in the broader Gawler Catchment (Green et al. 2014; Schmarr et al. 2014), Climbing Galaxias remain absent from Barossa PWRA. Irregular connectivity between the sea and freshwater habitats, which is required by such diadromous fish, likely explains the periodic occurrence of these species. Equally, the condition of refuge pools is likely to be inadequate (i.e. warm temperature, high salinity, low dissolved oxygen) to support the freshwater residence of these species. Again, the maintenance of baseflows should help to improve connectivity and refuge pool condition, which would act to support the more frequent occurrence of diadromous species in the Barossa PWRA.

The benefit of comparable monitoring to assess spatial patterns and temporal trends in fish communities was emphasised by the present study. As regular monitoring and assessment is central to the effectiveness of the Barossa WAP, the present study is particularly useful to help with the upcoming WAP amendment. It is recommended that regular fish monitoring (i.e. annual or even bi-annual) be undertaken to assess the status of fish communities in response to the implementation of the amended Barossa WAP. This may be important in

detecting more rare species for the region, such as the diadromous Common Galaxias and Congolli, or investigating the source of translocations and the potential expansion of Carp Gudgeon in the Barossa PWRA. Similarly, monitoring lower trophic levels (e.g. macroinvertebrates), which provide food resources for fish species would provide benefit to understand the potential to maintain or improve fish populations into the future.

More broadly, the increased abundance of Eastern Gambusia, and continued presence of Redfin Perch is a concern and future work should aim to explore options to control and/or remove such alien species. The ephemeral nature of surface water flows in the Barossa PWRA, for example, may provide an opportunity to undertake seasonal removal of these species from key refuge pools (and perhaps nearby farm dams in the case of Redfin Perch), which may assist native species to persist over the drier months of the year. Restoration actions that specifically improve habitat and reduce other threats are also warranted.

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Appendix 1. Regional context

A.1 Background

Monitoring of fish communities across the western Mount Lofty Ranges has been a useful approach to assess changes over time. In particular, over 2015–2018, targeted monitoring of the Onkaparinga, South Para and Torrens rivers has occurred in relation to environmental and dilution flows (as well as fish passage) restoration efforts (Whiterod 2015; 2016a; b; 2017a; b; Whiterod and Gannon 2018). Further sites have been broadly sampled as part of ambient condition monitoring across the region (SARDI, unpublished data) (Figure A-1). This appendix provides a summary of multivariate analyses undertaken to explore spatial patterns and temporal trends in fish compositions across the region in recent years. The outcomes will help provide an updated assessment of fish communities of the Barossa PWRA in a regional context.

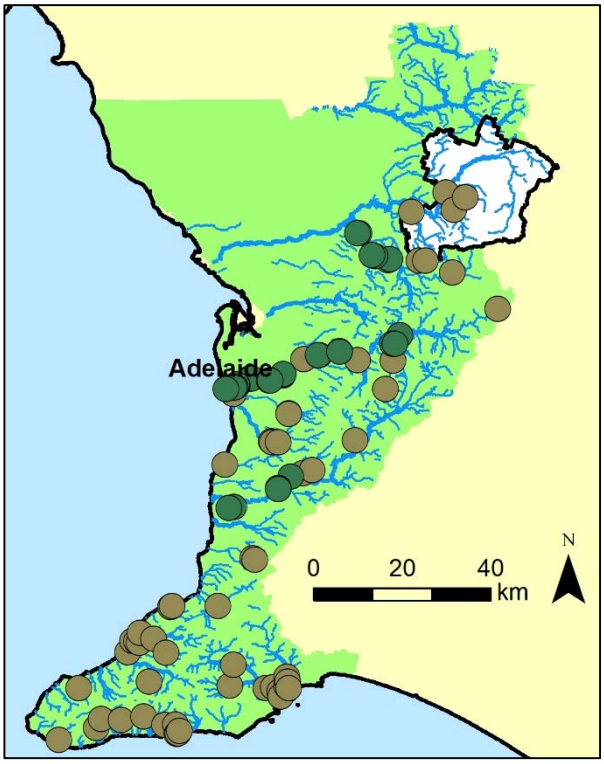


Figure A-1. Location of sites (●, Aquasave–NGT; ●, SARDI) sampled across the Adelaide and Mount Lofty Ranges ( ) between 2015–2018.

A.2 Data summary

In total, 89 sites across 31 waterways in the western Mount Lofty Ranges were sampled, with 30 sites sampled only once whereas others were sampled up to six times (in total, 372 separate site visits) (Figure A-1). All sites were sampled using consistent fyke netting, with standardised fish catch for each species expressed as fish net^{-1} hour^{-1} (i.e. CPUE Abundance). In terms of the fish catch, 43 fish species were recorded, with the diadromous Common Galaxias (200 occasions), Flathead Gudgeon (193) and Eastern Gambusia (147) the most prevalent, whereas 18 species were detected on less than five occasions. The highest CPUE Abundance were observed for Black Bream (Inman River – Inman Estuary, autumn 2015, 129

CPUE Abundance), Common Carp (Torrens River – Henley Beach Road weir upstream, spring 2014, 52 CPUE Abundance) and Common Galaxias (Torrens River–Stage 2 weir downstream, spring 2014, 42 CPUE Abundance).

A.3 Spatial patterns and temporal trends

The dataset was explored using multivariate analyses (PERMANOVA, ANOSIM, nMDS) performed in PRIMER 7 (with PERMANOVA add-on) in a consistent manner to the main report, noting however, that the dataset contained no replicates. A three-way PERMANOVA test revealed that sub-catchment was significant PERMANOVA, *pseudo-F*=7.3, *P*=0.01), but not year (PERMANOVA, *pseudo-F*=1.5, *P*=0.15) or season (PERMANOVA, *pseudo-F*=1.4, *P*=0.09). This is reflected visually on the accompanying nMDS plot, which shows weak grouping of points according to sub-catchment (Figure A-2). Correspondingly, one-way ANOSIM tests for sub-catchment was used to help ascertain the relative degree to which each pair of sub-catchments differed, however some comparisons were unreliable due to inconsistent sampling periods (low permutations).

The North Para River (Barossa Valley) sites formed a loose group but also showed similarities with Inman Creek, Scott Creek, Brownhill Creek which was primarily attributed to all sites being typified by high numbers of Eastern Gambusia. The South Para sites were also similar to North Para but were more closely aligned with Mount Pleasant, Gumeracha and Willunga Creek and Patawalonga River sub-catchments, which was attributed to higher numbers of Flathead Gudgeon and infrequent detections of Mountain Galaxias. Finally, the Jacob Creek sub-catchment (represented by one sampling occasion) was most similar to Central Sturt River, Brownhill Creek, Deep Creek, Lenswood Creek, due to consistent high catches of Mountain Galaxias.

The spacing between points for each sub-catchment is seen to reflect the relative seasonal and/or annual variability in fish community structure, bearing in mind that in some cases this is heightened by inconsistent sampling, e.g. not all sub-catchments were sampled in both autumn and spring. This considered, Hindmarsh River, Aldgate Creek, Bungala River and Boat Harbour Creek appear to show less variability among years and/or seasons, in comparison to sub-catchments such as Myponga River, Inman River and South Para River which are more widely dispersed and therefore more varied across years and/or seasons.

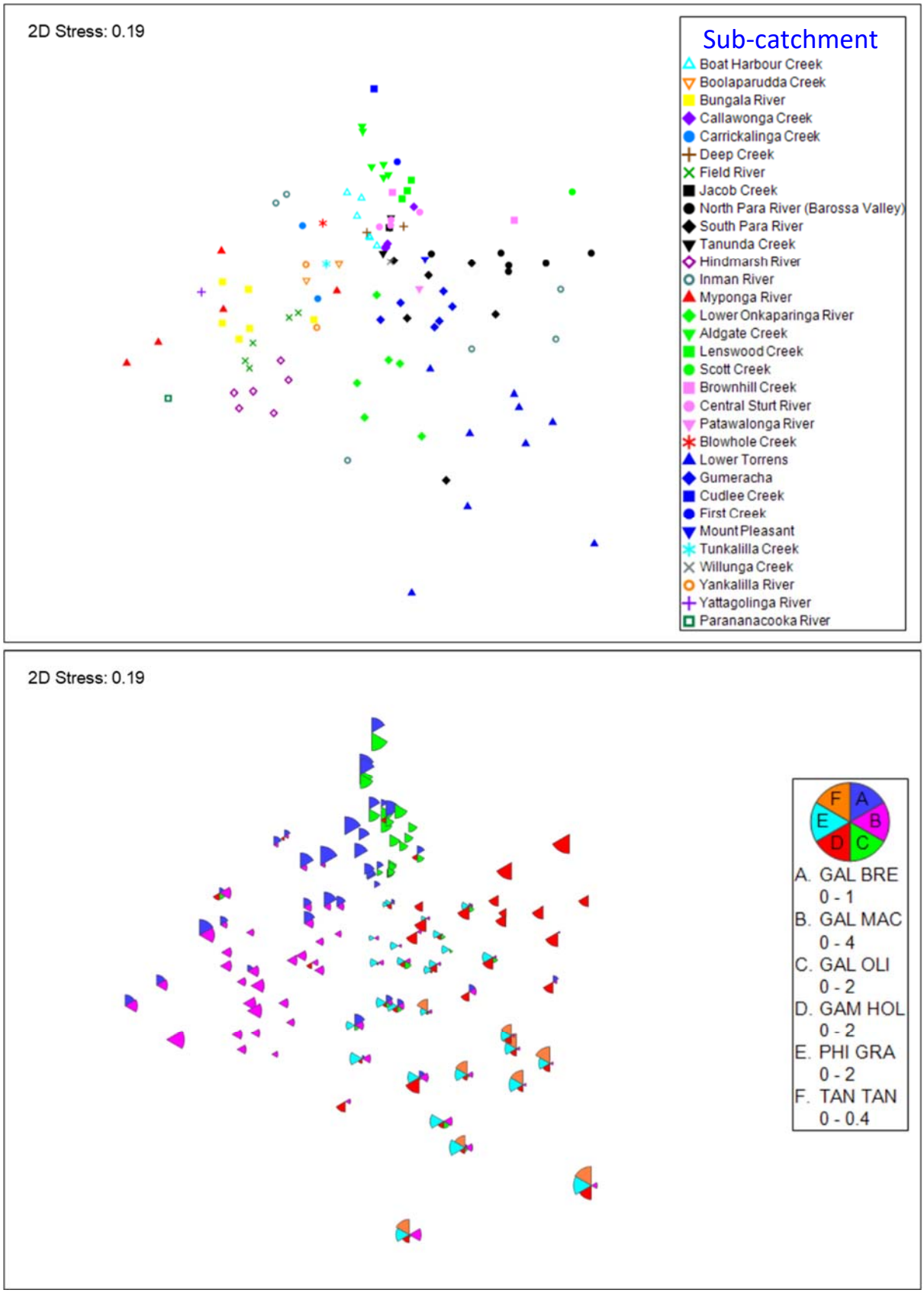


Figure A-2. nMDS ordination plots constructed from Bray-Curtis similarity matrices, derived from the mean fish abundances in the western Mount Lofty Ranges dataset (a). Superimposed are segmented bubble plots where segment size reflects the transformed abundances (b).

A.4 Conclusion

The additional analyses of the western Mount Lofty Ranges dataset show similar trends to those observed in the Barossa PWRA, in that there appears to be minimal temporal change (i.e. annual and/or seasonal) in fish community structure across the region over the study period. In the case of the western Mount Lofty Ranges, this is somewhat influenced by inconsistencies in the dataset (i.e. not all years and seasons were sampled for each sub-catchment). There are, however, moderate spatial patterns across the sub-catchments, which are attributed to discrete species partitioning. In this context, the fish community structure of North Para River (as well as South Para River) sites are being driven by higher numbers of mainly Eastern Gambusia and Flathead Gudgeon, while Jacob Creek is distinguished by the occurrence of Mountain Galaxias.

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Appendix 2. Summary of environmental descriptors

Code	River reach	Location	Water level	Maximum Depth (m)	Subsurface physical %	Subsurface biological %	Emergent %	Edge vegetation %	Canopy cover %	pH	Conductivity (µScm^{-1})	Temperature (°C)	Dissolved oxygen (mgL^{-1})
SAG18-12	upper North Para River	North Para Gauge	Low	1.0	15	0	20	20	10	7.7	3868	14.6	3.9
SAG18-11		Cornerstone Stud	Low	1.8	5	<1	1	30	5	7.7	3118	16.1	2.2
SAG18-09		DS (downstream) Evans Weir [Lindsay Park]	Low	1.8	10	1	1	15	1	8.0	2734	18.3	11.4
SAG18-10		Thorne-Clarke ford	Bank	3.3	1	0	5	80	5	7.9	2460	18.3	4.9
SAG18-08		Old Moculta bridge	Low	1.6	2	0	5	60	80	7.7	7982	16.0	4.0
SAG18-07		Penrice Quarry	Low	1.5	4	4	15	30	20	8.2	4286	17.9	10.3
SAG18-04	mid-North Para River	DS (downstream) Matchos	Bank	1.6	5	0	20	100	10	7.6	6265	16.6	6.0
SAG18-03		Smythe Rd crossing	Bank	2.0	5	0	5	85	75	7.2	4120	19.1	6.9
SAG18-13		St Hallets crossing [Pool 138]	Low	2.8	5	0	10	80	20	8.1	4777	18.7	6.6
SAG18-15		St Hallets bike path	Low	1.4	30	0	15	85	40	8.2	7248	17.3	8.8
SAG18-14	lower North Para River	Barossa Novotel [Pwnp 17]	Low	1.0	20	2	7	70	3	9.5	6880	16.7	12.7
SAG18-17		US (upstream) Landcare Reserve [PWNP 18]	Bank	2.2	10	1	30	60	50	8.1	5168	17.8	8.0
SAG18-16		DS (downstream) Landcare Reserve [PWNP019]	Low	2.0	10	0	5	15	15	8.5	5210	16.7	19.3
SAG18-05		Yaldara Weir [BAR0306]	Concentrated	0.9	55	0	15	20	1	8.9	7050	19.1	6.2
SAG18-06	Jacob Creek	Jacob Creek crossing	Concentrated	1.2	2	0	1	20	45	7.6	1525	17.3	7.3
SAG18-18		Jacob Creek old gauge	Concentrated	1.0	25	0	5	50	50	7.7	1193	17.5	6.9