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Aquatic Ecology Assessment and Analysis of the Diamantina River Catchment: Lake Eyre Basin, South Australia

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Report to the South Australian Arid Lands Natural Resources Management Board

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Cover images:

Barcoo Grunter; Fyke nets drying Koonchera waterhole May 2015

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Contents

1 Acronyms

BCG – The Biological Condition Gradient (Davies and Jackson, 2006). A conceptual approach used to score biotic data to inform ecosystem condition.

CPUE – Catch Per Unit of Effort. A standardisation for raw catch data which allows sites with different fishing effort (number of nets or number of hours set) to be compared.

DISTLM – Distance based linear models. A multivariate statistical test which examines how changes in a data matrix relate to concurrent change in predictor variables.

DO – Dissolved oxygen. A measure of the oxygen content in water.

ENSO – El Niño–Southern Oscillation. An irregularly timed warming of the Pacific Ocean which alters wind patterns and rainfall. In the Lake Eyre Basin ENSO drives large scale flooding events.

LEB – Lake Eyre Basin.

LEBRA – Lake Eyre Basin Rivers Assessment. A Commonwealth project in which fish, hydrology and water quality data are collected biannually throughout the Lake Eyre Basin.

ppt – Parts per thousand. A measure of chemical concentration most often applied to aquatic salinity.

SAALNRMB - South Australian Arid Lands Natural Resources Management Board.

SARDI – South Australian Research and Development Institute.

SIMPER – Similarity percentages analysis. A multivariate statistical test which identifies which species changes are driving the statistical divisions in th fish community.

TL – Total length. A measure of fish length from the tip of the snout to the top of the caudal fin (tail), when the caudal fin is extended along the midline.

TPC – Thresholds of Potential Concern. An observation below which ecosystem function may be responding along a negative trajectory.

YOY – Young of the Year. The fish within a population aged less than one year old.

2 Acknowledgements

We acknowledge the traditional custodians of the lands at all of the sites surveyed for this project and pay our respects to the elders both past, present and future.

Our authors would like to thank Henry Mancini and the South Australian Arid Lands Natural Resources Management Board (SAALNRMB) for directing the Australian Government Project "Managing the high ecological value aquatic ecosystems of the Diamantina River catchment (SA)". The project follows on from the previous successful Neales Catchment Critical Refugia Project (McNeil et al., 2011), and Cooper Creek Critical Refugia project (Schmarr et al., 2013).

Our colleagues and collaborators on this project were Rod Ward and Neil Wellman (SARDI); Justin Costelloe (University of Melbourne) and Graham Tomlinson; Henry Mancini (SAALNRMB); Alex Osti (Department of Environment, Water and Natural Resources); Gresley Wakelin-King (Wakelin Associates Pty Ltd); Nerissa Haby (Wild R&D); Jake Gillen, and Julian Reid, (Australian National University), Jon Lewis and Richard Reilly. These people have made this project both a success and a pleasure. Various people provided comments on this manuscript and Qifeng Ye provided overall staff and project management.

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3 Executive Summary

This study is part of a collaborative Australian Government research project aimed at improving habitat condition and connectivity in South Australia's Channel Country. This project component addresses the aquatic ecology analysis and assessment of the catchment. The report aims to assess the distribution and habitat use of native and introduced fish species, and provide site-specific community composition and productivity data for a range of aquatic biota. The report aims to further our understanding of how fish communities respond to changes in the hydroclimatic regime, assess aquatic health based on the hydroecological context, identify threats to aquatic health, and recommend management actions to reduce the impact of those threats.

Three annual fish surveys were conducted in the Diamantina/Warburton River using a standard sampling protocol developed for the Lake Eyre Basin region. This protocol provided data on the distribution, abundance, size, reproduction and disease of fish in the survey area. Distribution and abundance data were assessed using a condition assessment method called the Biological Condition Gradient (BCG). This method was modified and calibrated specifically for Lake Eyre Basin conditions and provided standardised, repeatable and comparable condition assessments for each site. Size frequency and reproductive data provided information about the relative importance of different habitats for different stages of fish life history.

The period of the survey started with a drought at the end of a long drought period, followed by two years of increasing rainfall and flow. In the three years of sampling, 139,671 fish were caught from 54 sampling events. Out of the 13 species expected for this region, there were 12 fish species captured (11 native and one exotic). Besides fish, Emmott's short-necked turtle (*Emydura macquarii emmotti*) was captured at three sites, greatly expanding its known distribution in the Diamantina.

The region was considered in terms of four geographic management units: Diamantina, Eyre Creek, Goyder Lagoon and Warburton-Kallakoopah. The Diamantina unit was characterised by large deep permanent waterholes that receive annual flow regardless of flood or drought years. The fish community in this unit was diverse, comprising most of the species present in the catchment with most species displaying a broad range of sizes. The Diamantina management unit is a key aquatic refuge and source population for several fish species in the Georgina-Diamantina catchment. The Eyre Creek management unit was represented by a single site which was artificially permanent due to a free flowing artesian bore and wasn't representative of the Eyre Creek management unit. The Goyder Lagoon management unit was characterised by braided channels on broad floodplains and few semi-permanent waterholes within the floodplain. This management unit functions predominantly as a corridor to migrating fish species. The Warburton-Kallakoopah management unit was characterised by permanent and semipermanent saline and hypersaline waterholes in years of drought transforming to freshwater during periods of flood. The fish community in this unit was dominated by highly abundant salt tolerant species in drought periods followed by increases in diversity with increases in the magnitude, duration and frequency of freshwater flow.

Condition assessment using the BCG showed that management units were responding along ecologically healthy trajectories. Only a single site scored poorly enough to raise concern and this normalised on subsequent sampling. The BCG highlighted the proliferation of exotic gambusia (*Gambusia holbrooki*) in artesian bores was the primary ecological concern for fish communities in the study area.

The timing of the study allowed the importance of different habitats at different phases of the hydroclimatic cycle to be revealed. However, we were not able to observe three key aspects of habitats in the system. First, the contribution of the Georgina River via Eyre creek to fish populations was not able to be quantified due to the absence of flow from this system. Second, the timing of this study did not encompass a period of large magnitude flooding, therefore the relative importance of floodplain inundation was not able to be observed. Finally, due to constraints on time and access, sampling in Goyder Lagoon was underrepresented in comparison to other parts of the catchment that were more accessible.

The findings from this study have highlighted a range of management recommendations:

- adopt the proposed management units to frame future management in the region,
- manage artesian bores to control or eliminate source populations of gambusia,
- recognise the importance of low magnitude flows and work to limit upstream and cross-border water development,
- continue to educate the public about the risk of translocating fish species,
- consider a further survey to examine the Goyder Lagoon management unit.

4 Introduction

The Lake Eyre Basin is one of the most variable river systems on earth (Puckridge et al., 1999). The Georgina-Diamantina catchment is the largest in the Lake Eyre Basin (LEB) making up 32% of the total LEB catchment area (Kotwicki and Isdale, 1991). The upper reaches of the Georgina and Diamantina catchments receive rhythmic monsoonal rainfall (Roshier et al., 2001) while the lower reaches of these same catchments may go several years without sufficient rainfall to support aquatic life. Large flood events, driven by the El Niña phase of the ENSO phenomenon, occur every few decades which fill, and connect catchments, driving booms in productivity (Kotwicki and Isdale, 1991). On average flow from the Georgina-Diamantina catchment enters the lake every two years (Kotwicki, 1986), contributing an average of 2,400 GL/y to Kati Thanda-Lake Eyre, 65% of the total flow into the lake (Nanson et al., 1988).

As the name suggests, this large catchment is composed of two sub-catchments; the Georgina and Diamantina Rivers. In the west, the Georgina River headwaters begin in Harts Range and the Barkly Tablelands in the Northern Territory. East of this, the Diamantina headwaters begin in Kirby's Nob east of Selwyn in Queensland. The two catchments enter the South Australian border separately and converge at Goyder Lagoon. The catchment within South Australia is a series of complex flow paths, channels and floodouts and is comprised of four main channels; Eyre Creek (fed from the Georgina catchment), the Diamantina River, Kallakoopah Creek and the Warburton River.

The majority of flow in this catchment enters South Australia from the Diamantina River. Within South Australia, the Diamantina River follows a single channel south until the Diamantina Split about 55 km south of Birdsville. Two flow paths diverge here, one to the south west - which feeds Andrewilla Waterhole, and one to the south east which feeds Yammakira Waterhole. These Waterholes are both large, deep and permanent, receiving flow every year. Both branches then feed into Goyder Lagoon where they converge with the Georgina catchment (via Eyre Creek).

The Georgina River becomes Eyre Creek about 100 km north of the South Australian border. This reach is a wide, diffused flow path with only two waterholes in South Australia; Tepamimi and Tepaminkannie. Both are naturally shallow and lack permanence, although Tepamimi waterhole is fed by an uncapped artesian bore which has created artificial permanence. Connecting flows down Eyre Creek are infrequent, and flow from the Georgina River reaches Goyder Lagoon only once or twice each decade. At the time of writing the last known connectivity occurred in 2012. Eyre Creek converges with the Diamantina River at Goyder Lagoon.

Goyder Lagoon is a large, complex floodout several hundred kilometres north of Kati Thanda-Lake Eyre (Figure 1). Flow paths here are convoluted with a single defined flow path replaced by thousands of small braided channels which diverge and converge, creating a large but ephemeral swamp. Transmission losses in Goyder Lagoon are high and smaller flows do not exit the region.

South of Goyder Lagoon, Eyre Creek and the Diamantina River become the Warburton River which flows for about 70 km before Kallakoopah Creek diverges from the Warburton River. Kallakoopah Creek skirts the edge of the Simpson Desert before meeting the Macumba River (one of the LEB's western catchments) about 15 km north of Kati Thanda-Lake Eyre. The Warburton River and Kallakoopah Creek reconverge on the edge of the Lake filling into the Warburton Groove, a shallow trench which flows south through Kati Thanda-Lake Eyre. This is the primary flow path for water entering the lake. About 30 km upstream on the Warburton River a secondary flow path (Kalaweerina Creek) enters the lake under high flow conditions.

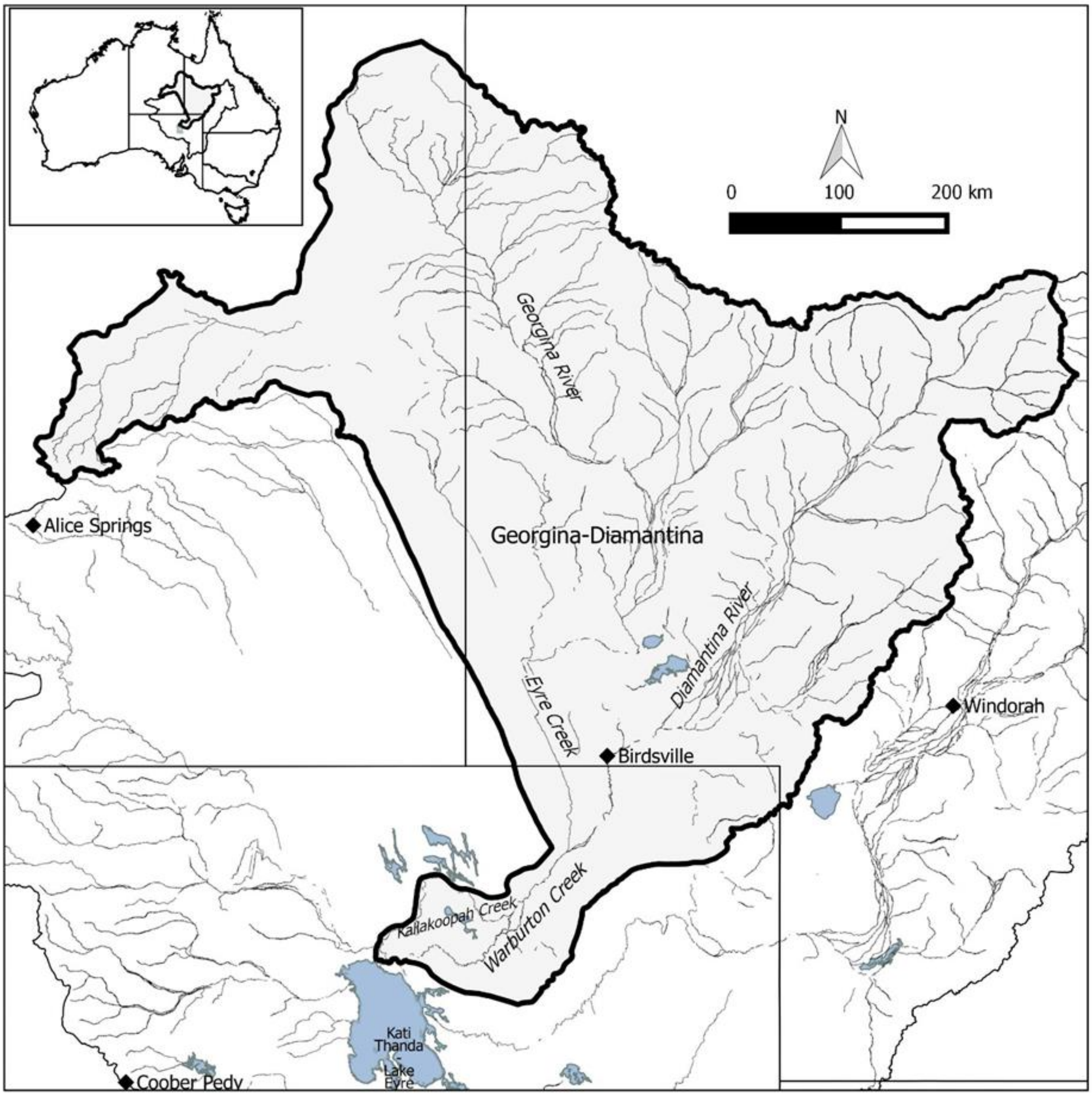


Figure 1. The Georgina-Diamantina catchment includes the Northern Territory, Queensland and South Australia and is the largest catchment in the Lake Eyre Basin (inset).

4.1 Spatial Management Units

This fish ecology project stems from the larger Australian Government funded project "Improving habitat condition and connectivity in South Australia's Channel Country". The project set several broad objectives which included; investigating aquatic ecosystem health and function in South Australian portion of the Georgina-Diamantina catchment and highlighting threats and impacts to the system with associated management recommendations. This information will provide SAALNRMB with a baseline to guide informed decisions and considered recommendations for water affecting activities, environmental water requirements and on ground conservation works.

This project proposes, and evaluates, the South Australian Georgina-Diamantina catchment as five distinct spatial management units. Management units are delineated based on geomorphology and hydrology with the expectation that these are the key drivers of riverine ecosystems in the arid South Australian catchment. If true, then community composition and ecosystem processes will differ spatially between management units as will management priorities. The proposed management units are; the Diamantina management unit, Goyder Lagoon management unit, Eyre Creek management unit and Warburton-Kallakoopah management unit (Figure 3). To evaluate the suitability of this framework, trends in fish ecology will be considered at the management unit scale.

4.2 Condition Assessment and the BCG

In addition to examining key trends in fish ecology, this report utilises the Biological Condition Gradient (BCG) methodology to assess environmental condition. The BCG was developed in the United States as a method to translate expert opinion and biological monitoring data into a common currency to report on environmental health (Davies and Jackson, 2006). The conceptual framework of the BCG is underpinned by observations of biotic response to increasing stressor intensity (Figure 2). That is, with increasing stressors and stressor intensity, functional groups within the taxa will respond along a predictable gradient.

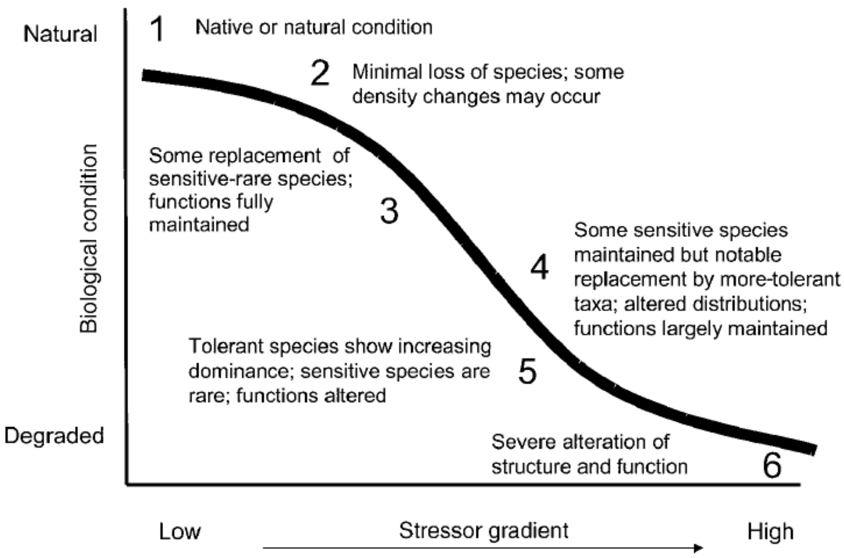


Figure 2 The Biological Condition Gradient (BCG) rates environmental condition against a conceptual scale of degradation, ranging from 1 (native or natural condition) to 6 (severe alteration of structure and function) (Davies and Jackson, 2006).

The BCG methodology scores 10 attributes of aquatic ecosystems, these are; attributes I – V are functional groups into which the target native taxa are divided, attribute VI considers exotic species from the target taxa, attribute VII considers health of the target native taxa, attribute VIII considers ecosystem function (limnology), attribute IX considers the spatial and temporal extent of stressors, and attribute X ecosystem connectance. Outputs from monitoring are then scored for each attribute as it relates to the conceptual model of ecological condition. This approach has been adapted for use in the Lake Eyre Basin (Schmarr et al., 2015) and developed for specific application in the Georgina-Diamantina catchment (Schmarr et al., in Prep.). The current approach contains several key developments from the original approach.

The BCG (per Davies and Jackson 2006) uses expert opinion to score monitoring data against a series of descriptive conceptual responses. To improve the consistency of scoring over time and by different operators, the current approach replaces expert opinion with species-specific numerical thresholds. These thresholds are catchment specific and account for spatial and temporal variability (Schmarr et al., 2015).

Within large catchments (like the Georgina-Diamantina) which have good, consistent spatiotemporal datasets, region-specific trajectories in fish community dynamics are apparent. Previous work has defined six statistically grouped regions (ecoregions) in the Georgina-Diamantina catchment (Schmarr et al., in Prep.). Two of which are represented in South Australia. These are the; Goyder ecoregion (incorporating the Diamantina, Eyre Creek and Goyder Lagoon management units) and the Warburton ecoregion (the Warburton-Kallakoopah management unit). By creating distinct BCG scoring criteria for each ecoregion different fish community trajectories can be accounted for. In this way fish community shifts associated with drying and salinisation are considered normal in one ecoregion but are an issue of concern in another.

The current BCG approach also considers trajectories of fish ecology in the LEB to follow ENSO driven trends which relate to landscape level flooding. Three phases are considered: dispersal, boom and bust, which relate to the time since landscape flooding occurred (Schmarr et al., 2015). Differing rules for each climatic phase are nested inside ecoregion BCG tools to create a regionally specific, temporally sensitive scoring technique.

Several attributes have been excluded from scoring under the current approach. The original BCG included attribute VIII (ecosystem function) as a placeholder for limnological metrics which had not been developed. It was prioritised for future inclusion, once satisfactory metrics were developed. At the current time there is insufficient data and analysis to inform this attribute and it has been excluded. Two further attributes have been excluded from scoring due to a lack of robust analysis; attribute IX (spatial and temporal extent of detrimental effects) and attribute X (ecosystem connectance). It is hoped that these may be incorporated in future iterations of the LEB BCG, once appropriate metrics have been determined and sufficient analysis has been carried out. By adapting the BCG tool in these ways, expert opinion has been removed, and is replaced by an unambiguous algorithm which consistently allocates a numerical representation of ecosystem condition as expressed by fish community dynamics.

4.3 Fish Fauna of the Georgina-Diamantina Catchment

In total 16 species of fish are known from the river channels of the Georgina-Diamantina catchment (Table 1). Thirteen fish species occur naturally within the South Australian catchment. One native species, the golden goby (*Glossogobius aureus*), is only found in the Queensland portion of the Georgina catchment. Two Australian native species have been historically translocated to the catchment, but are no longer considered extant (Murray-Darling golden perch, *Macquaria ambigua* and silver perch, *Bidyanus bidyanus*). Only a single exotic fish species is known in the Georgina-Diamantina catchment, eastern gambusia (*Gambusia holbrooki*).

4.4 Objectives

The specific objectives of this report are:

- assess the suitability of the proposed management units as an ecologically relevant framework to guide management,
- use the BCG to assess the ecological health of the fish fauna at three scales: management units, sites and functional community groups,
- examine the role of flow and aquatic salinity in driving fish community dynamics in the South Australian Georgina-Diamantina catchment,

- investigate the status and possible control strategies for exotic riverine species, gambusia and redclaw crayfish, and
- recommend on-ground management actions to address key issues identified in this study.

Table 1 All fish species known in the Georgina-Diamantina Catchment (excluding the Macumba River which joins the Kallakoopah River 20 km north of Kati Thanda-Lake Eyre). ^ endemic to the Lake Eyre Basin; † exotic to the Lake Eyre Basin; ◊ translocated to the Lake Eyre Basin and not extant; ● known. distribution.

				Whole Catchment	**South Australian Reaches**			
Family	**Genus**	**Species**	**Common name**	**Georgina-Diamantina**	**Eyre Creek**	**Diamantina River**	**Kallakoopah Creek**	**Warburton River**
Clupeidae	*Nematalosa*	*erebi*	Bony herring / bony bream		●	●		
Plotosidae	*Neosilurus*	*hyrtlii*	Hyrtl's catfish		●	●		
	Porochilus	*argenteus*	Silver tandan		●	●		
	Craterocephalus	*eyresii*	Lake Eyre hardyhead ^			●		
Melanotaeniidae	*Melanotaenia*	*splendida tatei*	Desert rainbowfish ^		●	●		
Ambassidae	*Ambassis*	sp.	Desert glassfish ^			●		
Percichthyidae	*Macquaria*	*ambigua*	Murray-Darling golden perch ◊			-		
	Macquaria	sp.	Lake Eyre golden perch ^		●	●		
Terapontidae	*Amniataba*	*percoides*	Barred grunter			●		
	Bidyanus	*bidyanus*	Silver perch ◊			-		
	Bidyanus	*welchi*	Welch's grunter ^		●	●		
	Leiopotherapon	*unicolor*	Spangled grunter / spangled perch		●	●		
	Scortum	*barcoo*	Barcoo grunter			●		
Gobiidae	*Chlamydogobius*	*eremius*	Desert goby ^			●		
	Glossogobius	*aureus*	Golden goby					
Poeciliidae	*Gambusia*	*holbrooki*	Eastern gambusia †		●	●		

5 Methods

5.1 Site Selection

Site selection criteria was designed to encompass a broad range of waterhole characteristics. Considerations were;

- broad spatial distribution along the South Australian reach of the Georgina-Diamantina catchment,
- representing a gradient of identified disturbance (where possible) with sites ranging from pristine to extremely degraded,
- representing a gradient of permanence with sites ranging from ephemeral to permanent,
- adequately represents the range of habitat types present in the catchment,
- includes socially significant and high conservation value sites,
- includes legacy sites where historic data is available.

The final round of sampling, in autumn 2016, represented an exceptionally wet climatic period with high rainfall and inundation patterns. During 2016 site selection became more opportunistic with the principals upheld where possible. This allowed sampling during transient episodes which are typically inaccessible e.g. inundated floodplains and flowing ephemeral creeks.

In total 58 sampling events are included in this report from 30 sites (Table 2). This includes two sites which were initially visited and found to be dry but were sampled in subsequent years (Wadlarkaninna and Mona Downs). It also includes six sampling events carried out under the Lake Eyre Basin Rivers Assessment (LEBRA). These LEBRA samples had identical methodologies and were included where any site within the South Australian Georgina-Diamantina catchment was sampled during the autumn 2014 – 16 period, providing additional spatial and temporal context to the existing data.

The 30 sites sampled were on the Diamantina River, Eyre Creek and Warburton Creek main channels and three sites were sampled on smaller tributaries (Derwent Creek and Tippipilla Creek). This combination of sites achieved broad spatial coverage in most reaches with the exception of Eyre, Gumborie and Kallakoopah Creeks. In addition to being difficult to access these reaches were dry for much of the study.

Table 2. Thirty sites from six reaches are included in this report. This includes four sites which are fed by artesian bores (site name underlined).

Reach	Site	GPS	Management Unit
Diamantina River	Dickeree	54 J 332479 7115984	Diamantina
	Pandie Pandie HS	54 J 338656 7109572	Diamantina
	Double Bluff WH	54 J 340079 7094217	Diamantina
	Diamantina Split	54 J 340074 7078411	Diamantina
	Yammakira	54 J 344707 7064892	Diamantina
	Andrewilla	54 J 330043 7066867	Diamantina
	Pelican WH	54 J 322544 7062659	Goyder Lagoon
	Burts WH	54 J 315535 7057971	Goyder Lagoon
	Peraka Lakes Junction	54 J 352036 7061807	Goyder Lagoon
	Koonchera	54 J 351168 7047454	Goyder Lagoon
	Koonchera West	54 J 351343 7046488	Goyder Lagoon
	Pandiburra Bore	55 J 343275 7040040	Goyder Lagoon
	Goyders Lagoon WH	54 J 297365 7024234	Goyder Lagoon
Tippipilla Creek	Tippipilla Creek Campsite	54 J 7012479 302988	Goyder Lagoon
Eyre Creek	Tepamimi	54 J 300404 7048522	Eyre Creek
Warburton River	Yelpawaralinna	54 J 271874 6997236	Goyder Lagoon
	Ultoomurra	54 J 274432 6994438	Warburton-Kallakoopah
	Kalamunkinna	54 J 257500 6979319	Warburton-Kallakoopah
	Stony Point	54 J 255196 6960864	Warburton-Kallakoopah
Kallakoopah Creek	Mona Downs	54 J 247956 6966514	Warburton-Kallakoopah
Derwent Creek	Mungerannie Wetland	54 J 270410 6898376	Warburton-Kallakoopah
	Cowarie HS	54 J 237310 6932839	Warburton-Kallakoopah
Warburton River	Cowarie Crossing	54 J 234076 6942656	Warburton-Kallakoopah
	Yellow WH	54 J 229583 6931892	Warburton-Kallakoopah
	Mia Mia	54 J 222794 6919717	Warburton-Kallakoopah
	Channel near Wadlarkaninna	55 J 219522 6915214	Warburton-Kallakoopah
	Wadlarkaninna	54 J 218822 6913981	Warburton-Kallakoopah
	Tinnie landing	54 J 206705 6911287	Warburton-Kallakoopah
	Cliff Camp WH	53 J 789769 6912140	Warburton-Kallakoopah
	Poonarunna Bore	53 J 786393 6912610	Warburton-Kallakoopah

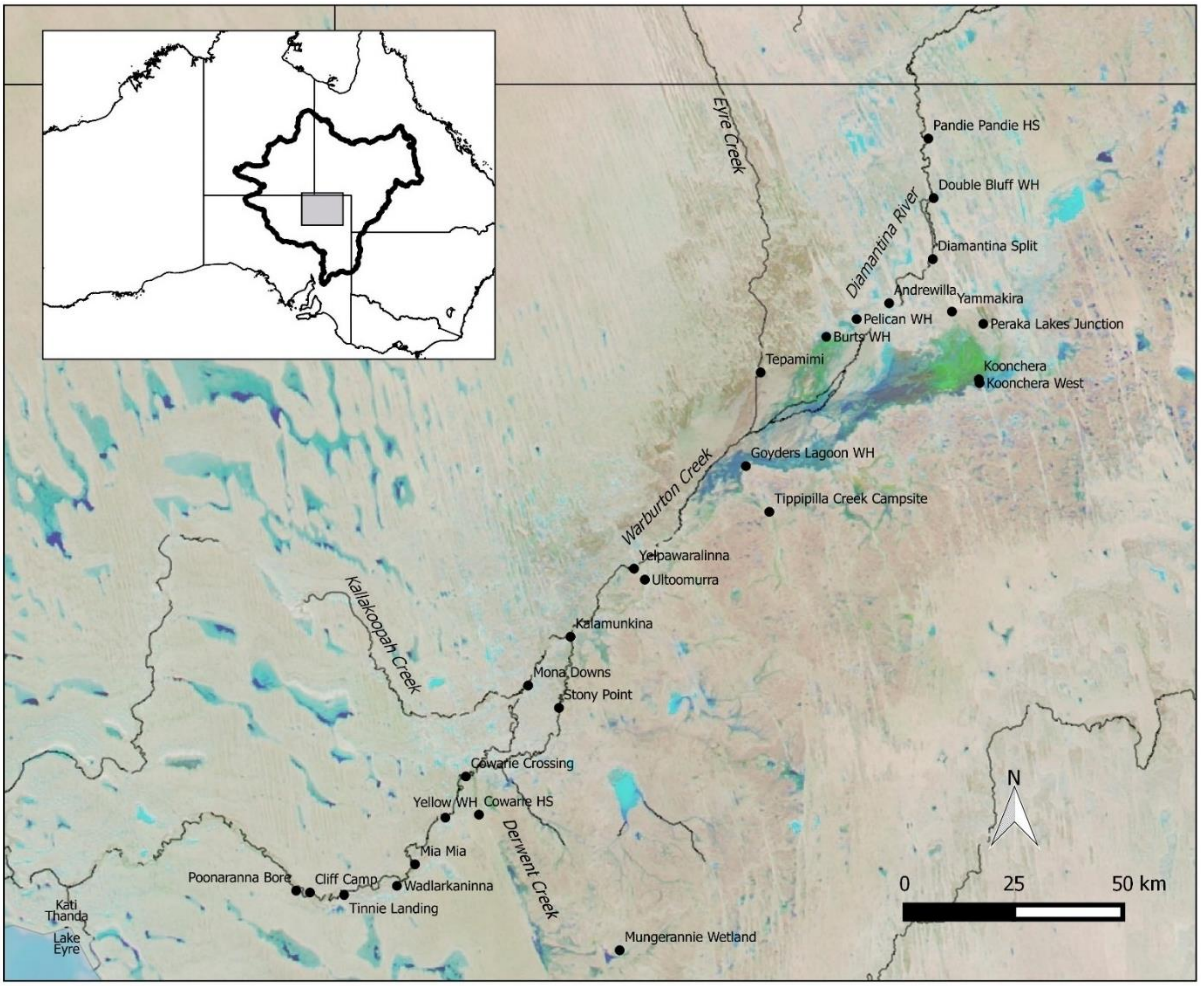


Figure 3. In total 30 sites were sampled on the Diamantina River and Eyre, Warburton, Tippipilla and Derwent Creeks.

5.2 Water Quality & Habitat

A point of maximum depth was identified within each site where water quality was recorded. Water quality parameters - dissolved oxygen (DO), water temperature, pH and salinity - were collected using an Horriba U50 multisensor water quality checker. Measurements were taken at the water's surface and then at 50 cm depth intervals concluding at the riverbed. These data are used to create a vertical profile of water quality revealing mixing trends (e.g. stratification) within the water column.

Table 3. 58 sampling events are included in this study. This includes sites which were dry when visited (marked with ○*) and sites sampled under an allied project (the Lake Eyre Basin Rivers Assessment marked with ö). All sites were sampled during autumn.*

Management Unit	**Site**	**2014**	**2015**	**2016**
Diamantina	Dickeree	○	○	
Diamantina	Pandie Pandie HS	•ö	ö	ö
Diamantina	Double Bluff WH		•	•
Diamantina	Diamantina Split	•	•	•
Diamantina	Yammakira	•	•	
Diamantina	Andrewilla	•	•	••
Goyder Lagoon	Pelican WH			•
Goyder Lagoon	Burts WH		•	
Goyder Lagoon	Peraka Lakes Junction			•
Goyder Lagoon	Koonchera	••	•	
Goyder Lagoon	Koonchera West			•
Goyder Lagoon	Pandiburra Bore	•		
Goyder Lagoon	Goyders Lagoon WH	•	•	
Goyder Lagoon	Tippipilla Creek Campsite			•
Goyder Lagoon	Yelpawaralinna		•	
Eyre Creek	Tepamimi	•	•	
Warburton-Kallakoopah	Ultoomurra	•	•	•
Warburton-Kallakoopah	Kalamunkinna	•		
Warburton-Kallakoopah	Mona Downs	○	•	•
Warburton-Kallakoopah	Stony Point	•	•	
Warburton-Kallakoopah	Mungerannie Wetland	ö		
Warburton-Kallakoopah	Cowarie HS		ö	
Warburton-Kallakoopah	Cowarie Crossing	•	•ö	••
Warburton-Kallakoopah	Yellow WH	•		•
Warburton-Kallakoopah	Mia Mia		•	•
Warburton-Kallakoopah	Channel near Wadlarkaninna	•		
Warburton-Kallakoopah	Wadlarkaninna	○		•
Warburton-Kallakoopah	Tinnie landing		•	•
Warburton-Kallakoopah	Cliff Camp WH		•	
Warburton-Kallakoopah	Poonarunna Bore	•		

5.3 Fish Sampling Protocols

Each site was sampled using a standard set of fyke nets, this consisted of six small single-winged fyke nets and two large double winged fyke nets. This protocol maintains consistency with the fish survey methodology of the Lake Eyre Basin Rivers Assessment (McNeil and Cockayne 2010).

The dimensions of the net types were:

Large double-wing fyke: meshed double-wing design (2 x 10 m wing, 12 mm mesh, 5 m funnels, 1.2 m high) (Figure 4A),

Small single-wing fyke net: meshed single-winged design (3 m wing, 4 mm mesh, 3 m funnel, 0.6 m high (Figure 4B).

Figure 4. Net types used in this study. A) two large double-wing fyke nets set in opposition, B) small single wing fyke nets.

All nets were set within 250 m of an access point (usually the site of GPS waypoint), with each net type deployed to sample a subsection of the waterhole. Small single-wing fykes were set in shallow locations targeting distinct microhabitats within the waterhole (e.g. complex snags or dense stands of submerged vegetation) (Figure 4B). Large double-wing fykes were deployed paired and in opposition in deeper water, targeting open water habitats and larger bodied fishes (Figure 4A). Fyke nets were anchored using heavy gauge chain clipped to the cod and wing ends. Wing tips were tied off on natural structures or, if unavailable, onto stakes. Two polystyrene buoys were placed in each net's cod end to force a pocket of net above the water's surface. This created a space where by-catch (birds, water rats and turtles) could take refuge until the net was processed. Fykes were set overnight, before dusk and collected after dawn, ensuring that each site was set for a minimum of 14 hours. This allowed capture of diurnal, nocturnal and crepuscular activity and allowed adequate deployment time for effective sampling.

The following outlines the fish processing procedures adapted from McNeil and Cockayne (2010):

All fish were identified using well-known keys (Wager and Unmack, 2000, Allen et al., 2003); J. Pritchard unpublished data).

The lengths of the first 50 individuals of each species were measured (total length in mm). To eliminate within net selection bias, when the 50th measure was taken, this species' measurements continued until the completion of that net. Due to limited size variation and the potential for continuous breeding, no length measurements were recorded for eastern gambusia (*Gambusia holbrooki,* hereafter referred to as gambusia). Measured fish were visually inspected for spawning condition, or external indications of disease (e.g. parasites, lesions or spinal malformation).

Fish that were not measured were counted. All fish were returned to the water at the point of capture however, voucher specimens were kept for any fishes where identification was uncertain.

Records of aquatic bycatch were also recorded, namely: Emmott's short-necked turtle (*Emydura macquarii emmotti*), yabby (*Cherax destructor*) shrimp (*Macrobrachium australiense*, *Paratya australiensis*), and freshwater crab (*Austrothelphusa transversa*).

5.4 Data Analysis

Fish catch data

To standardise catches within the project to a common currency for comparison (independent of gear effort) catch per unit effort (CPUE) was calculated. To do this, the total catch for each sampling event was divided by the number of hours that nets were set, to produce a catch per hour value for each site. A small single-wing fyke net was used as the base gear effort. In this way a small single-wing fyke was worth one unit of effort. Using previously calculated values, the gear effort for a large double-wing fyke was equivalent to 2.02 small fykes (a more detailed description may be found in Schmarr et al., 2013). Catch per hour figures were divided by the sum of the gear effort deployed at the site to generate a CPUE figure for each species for each sampling event.

Water Quality as a Driver of Fish Community Dynamics

A subset of data were generated from fish CPUE where water quality was available. Using PRIMER 7 with (Permanova+ 1.0.2 add-on) CPUE data were Log X+1 transformed and normalised. A BEST analysis was used to explore the relationship between the fish data and the water quality data. A RELATE analysis was used to examine which of the water quality parameters (or which combination of parameters) related to the changes in the fish data. All WQ data and fish data were visualised using distance based linear model to plot the relationship in three dimensional space.

To further explore the relationship between salinity and fish community dynamics, a dataset was generated which combined the current study with salinity and fish presence data from all available fish studies in the LEB. These were;

- ARIDFLO (Costelloe et al., 2004),
- LEBRA (Cockayne et al., 2012b, Cockayne et al., 2013a, Sternberg et al., 2014, Mathwin et al., 2015b, Duguid et al., 2016, Mathwin et al., In Prep.),
- Climatic variability, fish and the role of refuge waterholes in the Neales River Catchment (McNeil et al., 2011),
- Aquatic ecology assessment and analysis of the Cooper Creek, South Australia (Schmarr et al., 2013),
- and several smaller studies (McNeil et al., 2008a, McNeil and Schmarr, 2009, Thwaites et al., 2013, Schmarr et al., 2014, McNeil et al., (in prep)).

From this, a graph was generated which presents the observed field salinity tolerances for Georgina-Diamantina fish species observed throughout the Lake Eyre Basin.

State and Transition Analyses

A dataset comprising every fish sampling event in the Georgina-Diamantina catchment (using comparable methodology) was compiled and converted to CPUE. This included data from the current study, the Lake Eyre Basin Rivers Assessment (Cockayne et al., 2012b, Cockayne et al., 2013b, Sternberg et al., 2014, Mathwin et al., 2015b, Duguid et al., In Prep., Mathwin et al., In Prep.) and three sites from the preliminary LEBRA scoping study (McNeil et al., 2008b). Log 10 (x+1) transformation was applied to the data.

Hierarchical Cluster analyses (Clarke, 1993, Clarke and Gorley, 2001) were used to group fish samples into multivariate factor groups (herein factor groups) via the use of a SimProf test (significance level: 5%). Factor groups were then inserted into state/transition matrices which visually represent samples from upstream to downstream (vertical axis) and over time (horizontal axis). SIMPER analyses (Clarke, 1993, Clarke and Gorley, 2001), were performed using the factor groups, the outputs of which were used to describe fish patterns and trends across ecoregions and hydroclimatic phases. BCG analyses were then used to highlight any potential warning signs within the data, in the form of 'triggering' default thresholds of potential concern. Hierarchical Cluster Analysis and Similarity Percentages (SIMPER) analysis were carried out. All multivariate analyses were conducted using PRIMER 7 with (Permanova+ 1.0.2 add-on).

Definition of ecoregions.

Spatial segregations called 'ecoregions' were defined using *a priori* classification of the state/transition matrix. This process sought to delineate particular sections of the catchment which displayed consistent differences in fish community trajectory. Ecoregions were defined where a distinct geographic area displayed similar factor groups (more detail may be found in Schmarr *et al.*, 2015).

Adapting the BCG for the Study Area

A BCG tool was developed for each ecoregion identified within the study area. Based on a previously determined definition of hydroclimatic phase in the Georgina-Diamantina catchment (Schmarr et al., in Prep.), sampling for this study took place during a bust phase. Within each ecoregion fish abundances (standardised to CPUE) were pooled for each species. From this, the first and third quartiles were calculated and used to classify species abundance; low (below the first quartile), moderate (between the first and third quartiles) and high (above the third quartile).

Based on the observed trends during each ecoregion, descriptors were developed which scored each of seven tiers (representing functional groups within the fish biota) along a conceptual gradient of degradation (Figure 2). In this way sites were allocated up to seven scores which ranged between 1 (pristine) and 6 (highly degraded). These seven scores were averaged to obtain a single score representative of site condition. In keeping with previous BCG work carried out in the LEB, site BCG scores were considered to be of concern (having triggered a Threshold of Potential Concern - TPC) when they scored higher than 2.9. In additional to monitoring overall site condition this approach identifies TPCs within specific functional aspects of the fish biota (tier). A tier TPC was triggered when an individual tier scored above a predefined threshold (typically five).

A more complete description of the methodology used to develop an ecoregion BCG tool may be found in (Schmarr et al., 2015).

6 Results

6.1 Hydrology Summary

Hydrological patterns of rainfall affect the Georgina-Diamantina catchment at several scales. In the northern catchment (above the tropic of Capricorn) annual rainfall patterns follow a seasonal wet-dry cycle which is of sufficient magnitude to provide annual flow to the Diamantina management unit (Figure 5 3). Further south, the system becomes more unpredictable with rainfall driven by ENSO fluctuations. These supraseasonal patterns move the southern catchment unevenly through long dry bust phases and into high volume floods that cause a period of dispersal, followed by a boom in productivity. The Diamantina catchment experienced a boom phase during 2012 and was in a bust phase for the duration of this project. Sites entered this project on a drying trajectory, with 2013 displaying a truncated, low intensity hydrograph. This increased in duration and volume in 2014 and 2015 before larger, more prolonged seasonal flows occurred in 2016 (Figure 5). Flows in 2016 were sufficient to connect much of the greater catchment but the prolonged flow reflects offset rainfall events which produced localised, but not synchronous, connectivity. This pattern of connectivity doesn't not constitute a boom phase for fish populations using the definitions considered in (Schmarr et al., in Prep.).

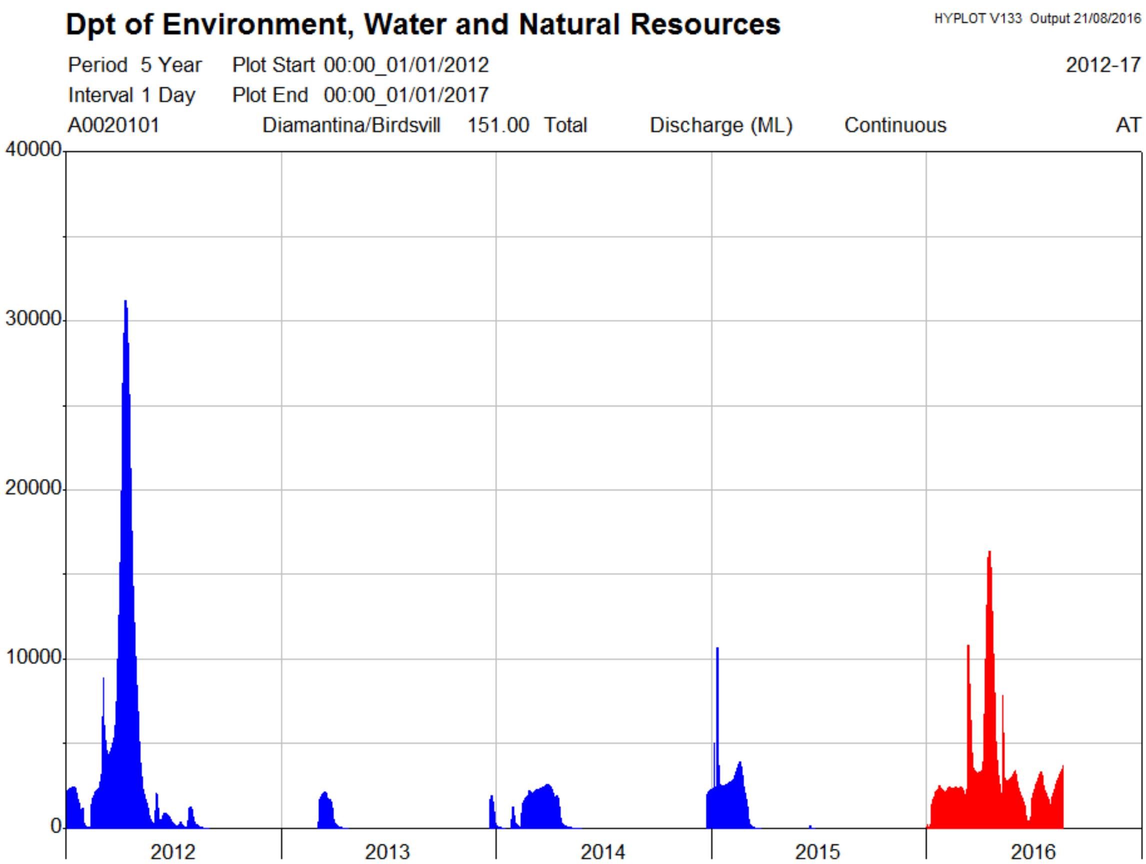


Figure 5. Daily flow Volume in megalitres/day recorded at the gauging station in Birdsville (Gauge No. A0020101). Rhythmic annual flow patterns are overlaid by large supraseasonal flood events. Red indicates unverified data.

6.2 Water Quality

In 2015, water quality from 11 sites was lost due to equipment failure. These data were predominantly from sites in the Warburton-Kallakoopah management unit. Salinity results are presented here and a complete set of water quality measurements are presented in Appendix A.

The Diamantina management unit receives annual channel flow to all of its reaches. These freshwater flows contain low levels of dissolved salts and, in combination with minimal infiltration from saline groundwater, results in the Diamantina management unit remaining fresh throughout the hydroclimatic cycle (Table 4).

Table 4. The Diamantina management unit remained fresh throughout three years of measurement due to annual freshwater inputs from the upper catchment. .

	Salinity (ppt)		
Site	**2014**	**2015**	**2016**
Pandie Pandie HS	**0.1**	**0.1**	
Double Bluff WH		**0.1**	**0.1**
Diamantina Split	**0.1**	**0.1**	**0.1**
Andrewilla	**0.1**	**0.1**	**0.1**
Yammakira	**0.1**		

In 2014 the Warburton-Kallakoopah management unit had received very little channel flow for several years. During this period, the infiltration of saline groundwater and *in situ* concentration of salts through evaporation drove this reach along a trajectory of increasing salinity. In 2014 aquatic salinity measurements throughout the management unit were hypersaline (Table 5). At Cowarie Crossing salinity was 150 ppt and was too saline to support fish. Fresh channel flows entered the management unit in 2015 reducing the aquatic salinity. Due to loss of data this is only observable from a single measurement at Cowarie Crossing. Strong flow was observed during early 2016 resulting in lowered salinity at all sites in the Warburton-Kallakoopah management unit. Two sites (Ultoomurra and Cowarie Crossing on the 19/5/2016) were sampled while channel flows were present resulting in aquatic salinity below 0.1 ppt.

Table 5. In 2014 the Warburton-Kallakoopah management unit was hypersaline. Fresh channel flows entered the management unit in 2015 and 2016 which lowered aquatic salinity.

	Salinity (ppt)		
Site	**2014**	**2015**	**2016**
Ultoomurra	**64**		**0.1**
Kalamunkinna	**111**		
Stony Point	**99.5**		
Cowarie Crossing	**150**	**7.8**	**7 / 0.1**
Yellow WH	**108**		**5.1**
Mia Mia			**4.5**
Wadlarkaninna			**0.3**
Tinnie landing			**3.8**

Sites fed by artesian bores did not follow the flow-driven trends in salinity observed elsewhere in their management unit. These habitats instead represent stable environments where the water quality parameters of influent artesian water is the strongest influence. Due to data loss in 2015 and restricted site access during 2016, this is poorly represented in the available data (Table 6).

Table 6. Bore drain aquatic refuges were stable and low in salinity.

	Salinity (ppt)	
Site	**2014**	**2015**
Tepamimi	**0.9**	**0.9**
Mungerannie Wetland	**0.9**	
Poonarunna Bore	**1.9**	

6.3 Fish Monitoring

In the three years of sampling 139,671 fish were caught from 54 sampling events (Tables 4-6). This incorporated 12 fish species - 11 native and one exotic. The most abundant fish species were Lake Eyre hardyhead (*Craterocephalus eyresii*, 61,787 fish), bony herring (*Nematalosa erebi*) (24,475 fish) and Lake Eyre golden perch (*Macquaria* sp., 17,185 fish). The least abundant species were desert glassfish (which were not detected in this study), desert rainbowfish (*Melanotaenia splendida tatei*, 54 fish) and barred grunter (*Amniataba percoides*) (161 fish). The most frequently encountered species were bony herring (36 sampling events), silver tandan (*Porochilus argenteus*, 35 sampling events) and Lake Eyre golden perch (31 sampling events). The least commonly encountered species were desert glassfish (not detected in this study), desert rainbowfish and barred grunter (each caught on seven sampling events).

In autumn 2014, 18 sampling events took place at 17 sites (Table 7). The Mona Downs site was dry at this time and no fish were captured at Cowarie Crossing. In 2014 the overall fish catches were the highest in the study with 70,886 fish caught. This was due to large catches of Lake Eyre hardyhead in saline sites in the Warburton management unit (Ultoomurra, Kalamunkinna and Stony Point) which constituted 67.4% of the total 2014 catch. Lake Eyre golden perch numbers were also high (7,428 fish) predominantly in the Diamantina management unit. The 2014 sampling round contained the highest numbers of gambusia (6,721 fish) which dominated fish populations at Tepamimi and Poonarunna Bore. These sites are fed by artesian bores which maintain a stable, permanent refuge for gambusia at sites that would have otherwise dried completely.

In autumn 2015, 19 sampling events took place at 18 sites (Table 8). The total fish catch was lower than the previous year (32,526 fish). Halophilic fishes (desert goby, *Chlamydogobius eremius* and Lake Eyre hardyhead) caught in the Warburton-Kallakoopah management unit dominated the total catch (65%). The overall abundance of Lake Eyre golden perch was reduced to 3,681 fish in 2015. No desert rainbowfish or barred grunter were caught in 2015. The overall abundance of gambusia remained high, predominantly due to their abundance at Tepamimi (4,606 fish). Mona Downs contained water but no fish were captured.

In autumn 2016, 17 sampling events took place at 15 sites (Table 9). Due to recent channel flows, salinity in the Warburton River was low and the numbers of halophilic fish (desert goby and Lake Eyre hardyhead) were greatly reduced (1,656 fish). Flows into Mona Downs resulted in fish being detected for the first time since 2014. Barred grunter were caught for the first time in the current study (161 fish). Bony herring were the most abundant species in 2016 (23,875 fish). Catches of this species in 2016 were much higher than in previous years and comprised 65.9% of the total fish catch. Gambusia abundances at this time were the lowest in the study (70 fish) as bore-fed sites were inaccessible due to flooding.

Table 7. Total fish catch from sampling in autumn 2014. W-Kallakoopah refers to the Warburton-Kallakoopah management unit.

Date	Management Unit	Site	**Barcoo grunter** *Scortum barcoo*	**Barred grunter** *Amniataba percoides*	**Bony herring** *Nematalosa erebi*	**Desert goby** *Chlamydogobius eremius*	**Desert rainbowfish** *Melanotanea splendida tatei*	**Eastern gambusia** *Gambusia holbrooki*	**Hyrtl's tandan** *Neosilurus hyrtlii*	**Lake Eyre golden perch** *Macquaria sp.*	**Lake Eyre hardyhead** *Craterocephalus eyresii*	**Silver tandan** *Porochilus argenteus*	**Spangled grunter** *Leiopotherapon unicolor*	**Welch's grunter** *Bidyanus welchi*	Total Catch
6/04/2014	Diamantina	Pandie Pandie HS	1		9				38	670		75		138	931
8/05/2014	Diamantina	Pandie Pandie HS							3	113		5		11	132
9/05/2014	Diamantina	Diamantina Split	2		3				23	390		36		10	464
7/05/2014	Diamantina	Andrewilla	3		2				1,745	220		144		13	2,127
4/05/2014	Diamantina	Yammakira			24				576	156		101		17	874
2/05/2014	Goyder Lagoon	Koonchera			11				136	774		32		7	960
3/05/2014	Goyder Lagoon	Koonchera			5				270	1,594		173		71	2,113
1/05/2014	Goyder Lagoon	Goyders Lagoon WH			78				253	3,502		177		1	4,011
6/05/2014	Eyre Creek	Tepamimi			48		1	2,002	1	9			9		2,070
11/05/2014	W-Kallakoopah	Mona Downs													Dry
4/04/2014	W-Kallakoopah	Mungerannie Wetland			7			6			2		4		19
29/04/2014	W-Kallakoopah	Ultoomurra									5,966				5,966
10/05/2014	W-Kallakoopah	Kalamunkinna				1,716		3			10,992				12,711
12/05/2014	W-Kallakoopah	Stony Point				2,556					30,845				33,401
13/05/2014	W-Kallakoopah	Cowarie Crossing													No Fish
16/05/2014	W-Kallakoopah	Yellow WH				28					42				70
14/05/2014	W-Kallakoopah	Wadlarkaninna													Dry
14/05/2014	W-Kallakoopah	Poonarunna Bore				24		4,710			303				5,037
		Species Total	6	0	187	4,324	1	6,721	3,045	7,428	48,150	743	13	268	70,886

Table 8. Total fish catch from sampling in autumn 2015. W-Kallakoopah refers to the Warburton-Kallakoopah management unit.

Date	Management Unit	Site	**Barcoo grunter** *Scortum barcoo*	**Barred grunter** *Amniataba percoides*	**Bony herring** *Nematalosa erebi*	**Desert goby** *Chlamydogobius eremius*	**Desert rainbowfish** *Melanotanea splendida tatei*	**Eastern gambusia** *Gambusia holbrooki*	**Hyrtl's tandan** *Neosilurus hyrtlii*	**Lake Eyre golden perch** *Macquaria* sp.	**Lake Eyre hardyhead** *Craterocephalus eyresii*	**Silver tandan** *Porochilus argenteus*	**Spangled grunter** *Leiopotherapon unicolor*	**Welch's grunter** *Bidyanus welchi*	Total Catch
8/04/2015	Diamantina	Pandie Pandie HS			8				7	45		75		5	140
12/05/2015	Diamantina	Double Bluff WH	1		66				458	150		139		4	818
13/05/2015	Diamantina	Diamantina Split	1		3				541	14		12		14	585
13/05/2015	Diamantina	Andrewilla	7		9				25	250		42		2	335
10/05/2015	Diamantina	Yammakira			10				7	21		1		11	50
15/05/2015	Goyder Lagoon	Burts WH	12		45				7	506		267			837
8/06/2015	Goyder Lagoon	Koonchera	19		17				40	1,594		175	1	13	1,859
9/05/2015	Goyder Lagoon	Goyders Lagoon WH	2		44				34	543		270	1	8	902
14/05/2015	Eyre Creek	Tepamimi			146			4,555	18	8		2	8	1	4,738
4/05/2015	W-Kallakoopah	Mona Downs													No Fish
7/05/2015	W-Kallakoopah	Cowarie HS										1	11		12
7/05/2015	W-Kallakoopah	Yelpawaralinna				1					2	2			5
5/05/2015	W-Kallakoopah	Ultoomurra	3		46	3			65	546	5	79	7	11	765
2/05/2015	W-Kallakoopah	Stony Point			16	141		5	2	4	243	23	12		446
8/04/2015	W-Kallakoopah	Cowarie Crossing				14		5			413		16		448
29/04/2015	W-Kallakoopah	Cowarie Crossing				38		24			2,682	1	66		2,811
2/05/2015	W-Kallakoopah	Mia Mia				286					3,295	147	1		3,729
30/04/2015	W-Kallakoopah	Tinnie landing			3	348		1			3,033	12	2		3,399
30/04/2015	W-Kallakoopah	Cliff Camp				7,211		16			3,420				10,647
		Species Total	45	0	413	8,042	0	4,606	1,204	3,681	13,093	1,248	125	69	32,526

Table 9. Total fish catch from sampling in autumn 2016. W-Kallakoopah refers to the Warburton-Kallakoopah management unit.

Date	Management Unit	Site	**Barcoo grunter** *Scortum barcoo*	**Barred grunter** *Amniataba percoides*	**Bony herring** *Nematalosa erebi*	**Desert goby** *Chlamydogobius eremius*	**Desert rainbowfish** *Melanotanea splendida tatei*	**Eastern gambusia** *Gambusia holbrooki*	**Hyrtl's tandan** *Neosilurus hyrtlii*	**Lake Eyre golden perch** *Macquaria sp.*	**Lake Eyre hardyhead** *Craterocephalus eyresii*	**Silver tandan** *Porochilus argenteus*	**Spangled grunter** *Leiopotherapon unicolor*	**Welch's grunter** *Bidyanus welchi*	Total Catch
9/04/2016	Diamantina	Pandie Pandie HS	2		8			1	47	1,237		350	3	34	1,682
6/05/2016	Diamantina	Double Bluff WH	6		57		2		27	546		774	2	36	1,450
7/05/2016	Diamantina	Diamantina Split	13	1	74				21	713		273	1	195	1,291
8/05/2016	Diamantina	Andrewilla	6		12				79	259		18		41	415
11/05/2016	Diamantina	Andrewilla	5		227				82	325		41	1	93	774
13/05/2016	Diamantina	Pelican WH	11		79				6	125		33	69	8	331
5/05/2016	Goyder Lagoon	Koonchera West	7		90		1			214		22	3	1	338
16/05/2016	Goyder Lagoon	Peraka Lakes Junction	36		893				58	716		62	27	89	1,881
4/05/2016	W-Kallakoopah	Mona Downs			1	2					4	1	120		128
17/05/2016	Goyder Lagoon	Tippipilla Creek Campsite								11			21		32
18/05/2016	W-Kallakoopah	Ultoomurra	67	71	1,469				3	1,922		16	284	119	3,951
3/05/2016	W-Kallakoopah	Cowarie Crossing		31	4,328	100	19	15			122		109		4,724
19/05/2016	W-Kallakoopah	Cowarie Crossing	5	38	2,821		3	6		8	29	13	742		3,665
2/05/2016	W-Kallakoopah	Yellow WH		1	1,975	1,002	17	47			265		76		3,383
1/05/2016	W-Kallakoopah	Mia Mia		9	9,416			1			26		27		9,479
30/04/2016	W-Kallakoopah	Wadlarkaninna				8					3		167		178
29/04/2016	W-Kallakoopah	Tinnie landing		10	2,425		11				95		16		2,557
		Species Total	158	161	23,875	1,112	53	70	323	6,076	544	1,603	1,668	616	36,259

6.4 Multivariate Analysis of Fish Community Dynamics

Multivariate fish community dynamics (Figure 6) in the Diamantina management unit displayed a clustered distribution with Lake Eyre golden perch, Hyrtl's tandan (*Neosilurus hyrtlii*) and Barcoo Grunter (*Scortum barcoo*) exerting the strongest influence on the Diamantina fish community in all years of sampling. The Eyre Creek management unit was represented by only two samples (one in 2014 and one in 2015), both at Tepamimi. Fish communities on these two occasions were quite similar and were characterised by high abundances of gambusia. The Goyder Lagoon management unit fish community during 2014 and 2015 corresponded closely with the Diamantina management unit cluster indicating similar fish communities. In 2016 the Goyder Lagoon unit displayed a more complex fish community than previous years with a stronger influence of spangled grunter (*Leiopotherapon unicolor*) and barred grunter, bony herring and desert rainbowfish. The Warburton-Kallakoopah management unit was the most dynamic unit in the study. Fish communities in this region were characterised by gambusia and Lake Eyre hardyhead during drier periods but, when flows were observed, the fish communities were characterised by mobile fish species (spangled and barred grunter, bony herring and desert rainbowfish).

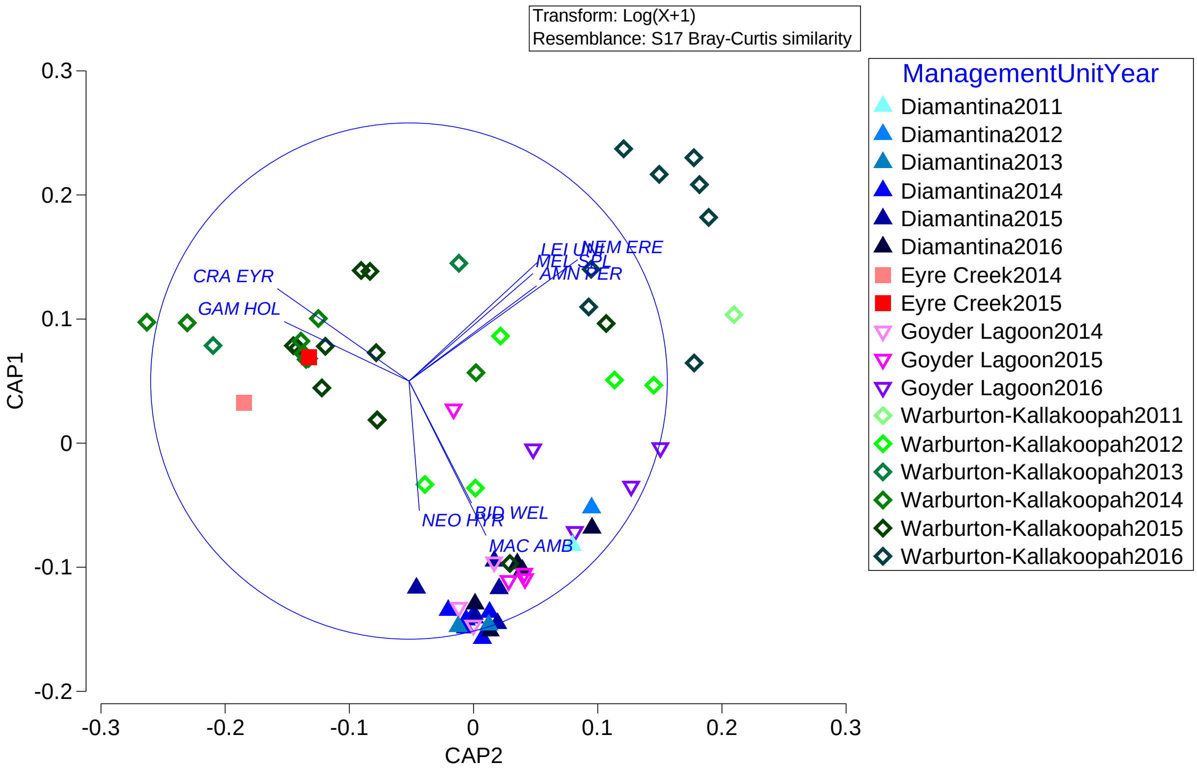


Figure 6. Canonical Analysis of Principal Coordinates (Primer 7) was used to examine how fish populations at each site varied in multivariate space. This was visualised to highlight how management units changed through time. Vector labels are; GAM HOL (eastern gambusia), CRA EYR (Lake Eyre hardyhead), LEI UNI (spangled grunter), AMN PER (barred grunter), NEM ERE (bony herring), MEL SPL (desert rainbowfish), BID WEL (Welch's grunter), MAC AMB (Lake Eyre golden perch).

Large-bodied species with consistent catches throughout the study were selected for length frequency comparison. These species provide the best data for comparison due to typically longer lifespans and broader variability in size at capture which allows observation of distinct cohorts to be tracked through time. The species chosen were Welch's grunter (*Bidyanus welchi*) and Barcoo grunter, Lake Eyre golden perch, bony herring, Hyrtl's tandan and silver tandan. Length frequencies were separated based on management unit and comparison made between each of the three years of the study (Figures 7 and 8).

Welch's grunter population structures varied between management units. In the Diamantina management unit, the population was spread across a broad range of size classes during all years (Figure 7). In the Goyder Lagoon management unit Welch's grunter populations began the study displaying a unimodal population with only very small individuals observed (in the 61–100 mm TL size range). These fish represent a young of the year (YOY) cohort. The following year, in 2015, the population was again dominated by fish in the 60–100 mm size class and a very small proportion was in the 151–160 mm TL size range. In 2016 the Welch's grunter population displays three distinct modes which probably represents three distinct cohorts, the larger two may have survived *in situ* or immigrated via novel flows from the Diamantina management unit. The Warburton-Kallakoopah management unit supported no Welch's grunter in 2014. A YOY cohort is apparent in both subsequent years however no aging has taken place in 2016 as the largest individuals were YOY in the 61–70 mm size class.

Lake Eyre golden perch in the Diamantina management unit were present in a broad range of size classes in all years (Figure 7). A YOY cohort in the 31–70 mm size range was apparent in 2015 and 2016. In the Goyder Lagoon management unit YOY golden perch were apparent in all years but larger size classes were only observed in 2015 and 2016. These individuals represented a small proportion of the overall population and were not observed above 191–200 mm size class. In 2014 in the Warburton-Kallakoopah management unit no Lake Eyre golden perch were observed. The following year small numbers of this species were observed in four distinct size classes which ranged up to 341–350 mm TL.

Barcoo grunter were observed in the Diamantina management unit across a narrow range of size classes in 2014 and 2015, from 120–160 mm TL (Figure 7). In 2016, when sampling took place on the front of novel flows Barcoo grunter were observed across a broad range of size classes up to 330 mm TL. In the Goyder Lagoon management unit no Barcoo grunter were observed in 2014. In 2015 a single YOY cohort was observed in the 71-110 mm size range and in 2016 this size range had expanded to include individuals up to 250 mm TL.

Bony Herring were present in a broad range of size classes in all management units during all years (Figure 8).

Hyrtl's tandan were observed across a broad size range in the Diamantina management unit in all years of sampling. In 2014 and 2015 the population structure was dominated by a YOY cohort in the 81–130 mm size class but in 2016 this single cohort dominance was less apparent. In the Goyder Lagoon management unit the Hyrtl's tandan population was similarly dominated by a juvenile cohort however no larger individuals were observed until 2016 when several larger individuals were also present. No Hyrtl's tandan were present in the Warburton-Kallakoopah management unit in 2014. In 2015 this species reappeared in the management unit in 2015 with a population dominated by YOY in the 71–110 mm TL size class and several larger individuals were also observed. In 2016 only three fish were observed, all in the 101–110 mm TL size class.

In 2014 silver tandan were present in the Diamantina ecoregion across a broad range of lengths from 60–210 mm TL (Figure 8). In 2015 a simple population structure was apparent dominated by a YOY size class around 110 mm TL. In 2016 a more complex population structure had returned which more closely resembled that of 2014. In the Goyder Lagoon management unit in 2014 the silver tandan population was dominated by the same juvenile mode observed in the Diamantina management unit with several larger individuals observed also. This trend continued in 2015 and 2016, however the juvenile cohort was spread across a broader size range in 2016 which matches the changes in juvenile cohort trends observed in the Diamantina management unit at the same time.

No silver tandan were observed in the Warburton-Kallakoopah management unit in 2014. This species re-entered this management unit in 2015 and population structures displayed two modes (81–110 mm TL and 131–150 mm TL), one very large individual (220 mm TL) was also observed at this time. In 2016 this region displayed a single broad mode of size classes from 91–140 mm TL.

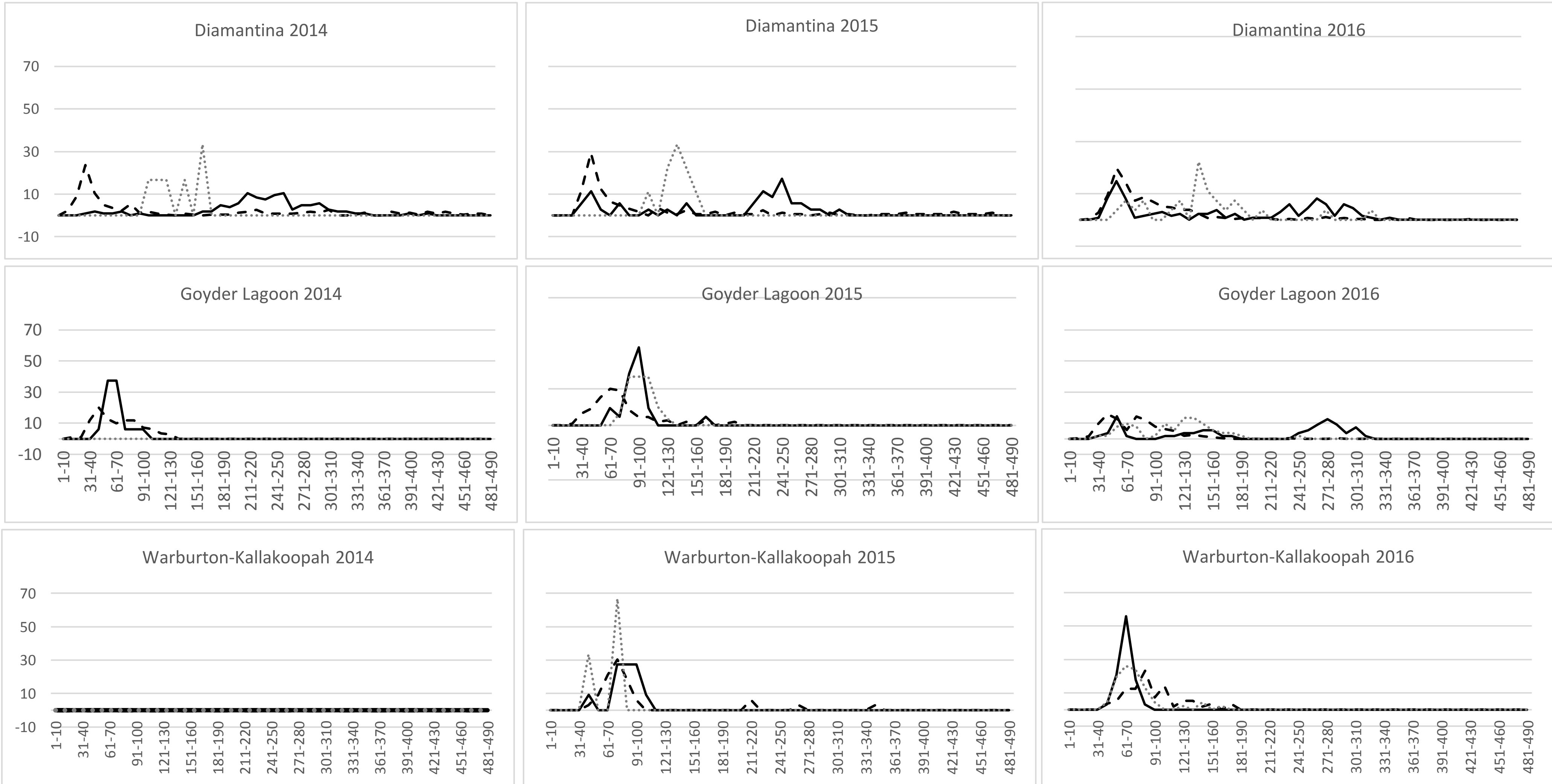


Figure 7. The frequency of different fish lengths observed in each management unit during each year of sampling, presented as a proportion. The solid black line represents Welch's grunter, the dashed line represents Lake Eyre golden perch and the dotted line represents Barcoo grunter.

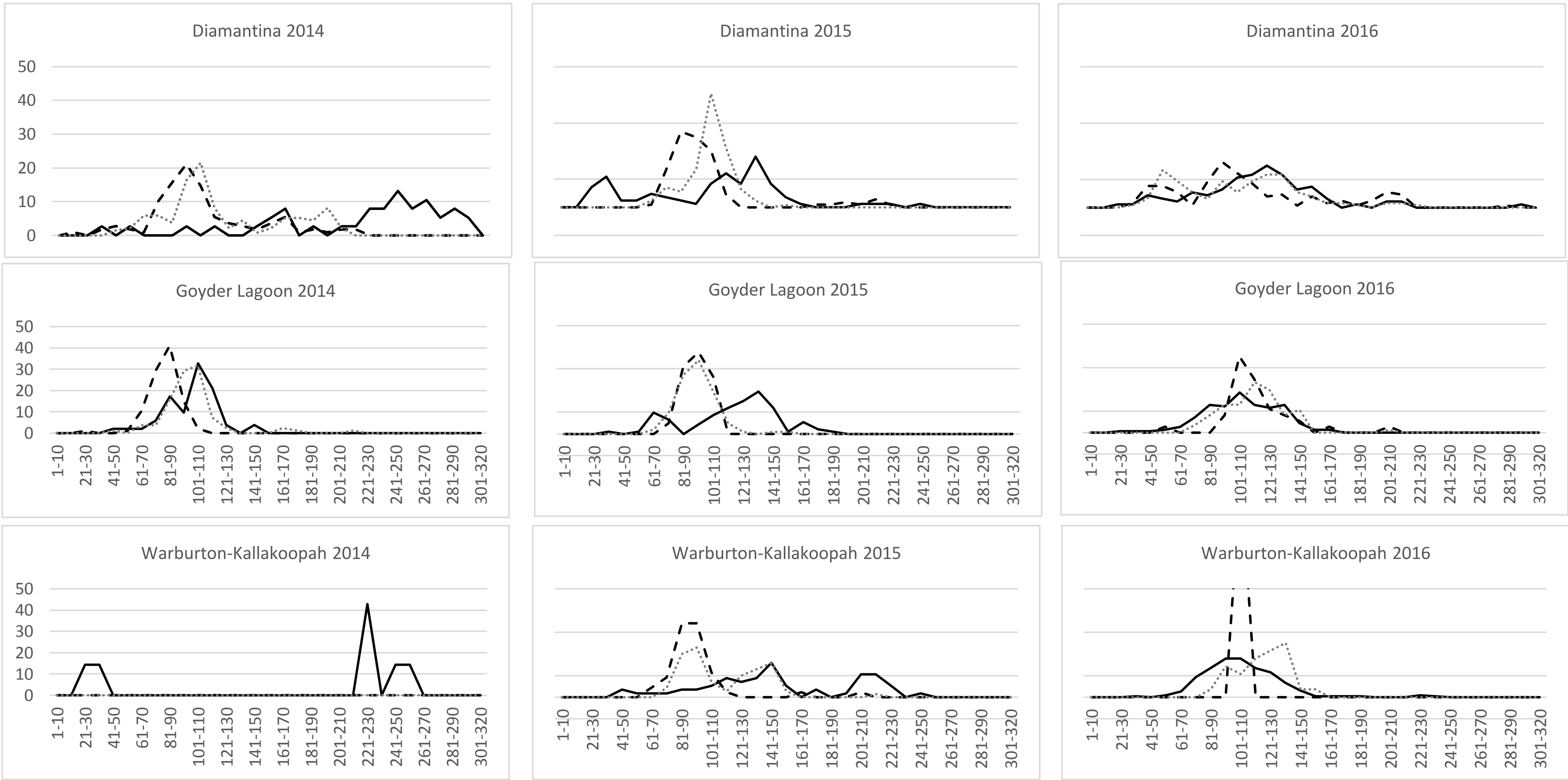


Figure 8. The frequency of different fish lengths observed in each management unit during each year of sampling, presented as a proportion. The solid black line represents bony herring, the dashed line represents Hyrtl's tandan and the dotted line represents silver tandan.

6.5 Water Quality as a Driver of Fish Community Dynamics

BEST analyses indicated that salinity was driving the majority of trends displayed within the data (Rho = 0.65). RELATE analysis of salinity data indicated that 32% of the total variation within the abundance data can be attributed to salinity/conductivity, with a significance level of > 1%. DistLM analysis (Figure 9) was used to display the relationship of salinity against fish vectors and management units within the South Australian portion of the Georgina-Diamantina catchment. Although other water quality parameters were included in this analysis (DO, pH and temperature), salinity was the only water quality parameter of significance (p = 0.001), with fish vectors indicating a strong correlation between Lake Eyre hardyhead (R = 0.67) and desert goby (R = 0.91). This relationship was most apparent in the Warburton Kallakoopah management unit. The salinity trajectory (displayed on the horizontal axis, dbRDA1) shows that 13.7% of the total variation observed in fish community data is driven by salinity.

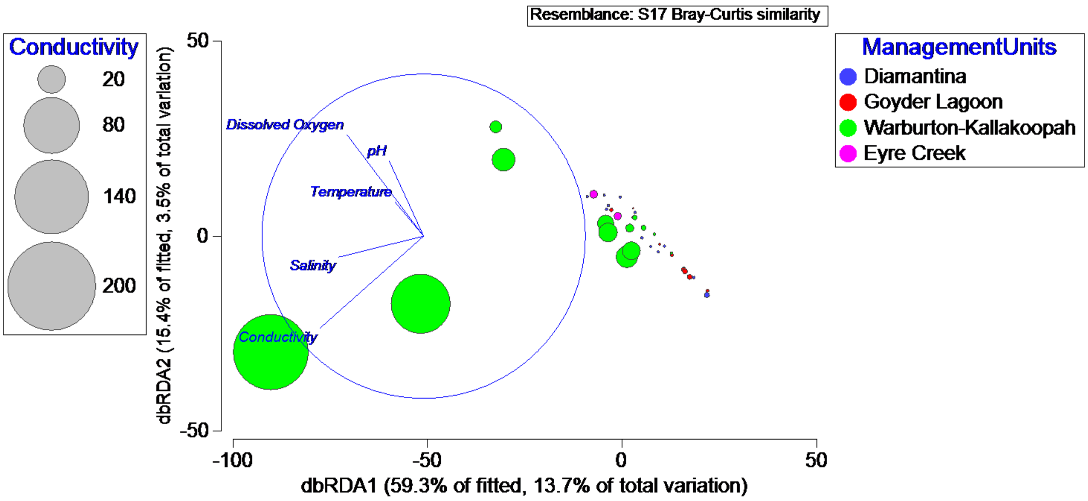


Figure 9. Diamantina dbRDA plot of abundance data analysed against water quality parameters (Salinity, temperature, pH and DO)

6.6 Observed Salinity Tolerance of Fish in the Lake Eyre Basin

Most LEB fish species on most occasions were observed in salinities of 0–3 ppt (Figure 10Figure 10). Exceptions to this were barred grunter, Lake Eyre hardyhead and desert goby. Barred grunter were commonly found in salinities of up to 7 ppt, Lake Eyre hardyhead were commonly observed in salinities up to 19 ppt and desert goby were commonly observed is salinities up to 36 ppt (the same salinity as seawater). Silver tandan were the least tolerant species and displayed a very low maximum tolerance but most other species displayed maximum field tolerance above 10 ppt. Eight species displayed maximum salinity tolerances in excess of sea water (> 36 ppt) and two species (desert goby and Lake Eyre hardyhead) were observed in salinity greater than three times sea water (> 108 ppt).

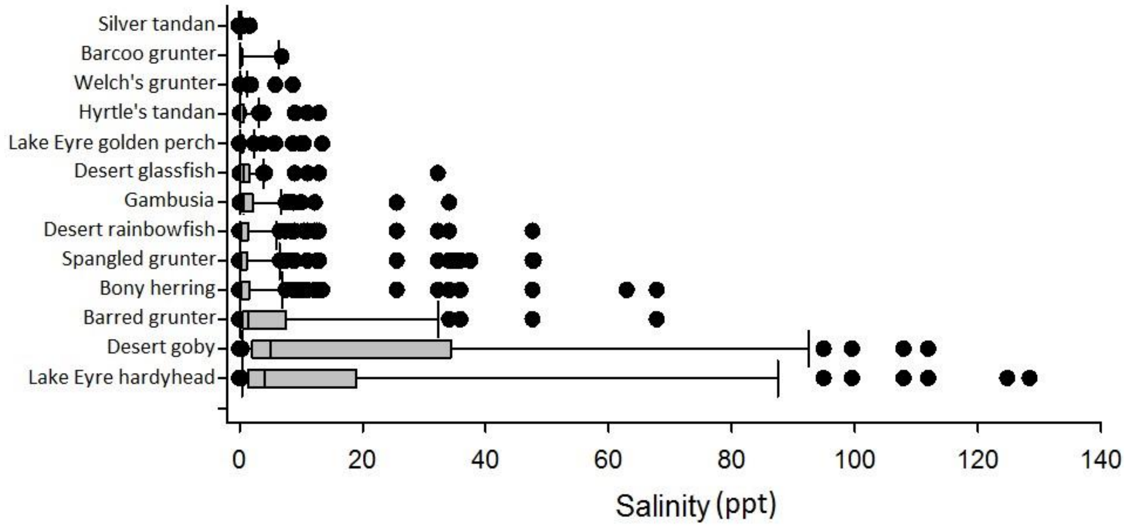


Figure 10. A box plot of observed field salinity tolerance of Lake Eyre Basin fishes from all sampling since 2008. Grey boxes range from the first to the third quartile and contain a vertical line representing the mean. Outliers are presented as black dots and present some of the highest salinity tolerances reported for these species.

6.7 Disease Results

Externally visible diseases (e.g. epizootic ulcerative syndrome, external parasites or spinal malformation) were only observed in large bodied fish species and rates were low in all years. Disease was most commonly observed in Welch's grunter (43% of all disease observed), Barcoo grunter (33%) and Lake Eyre golden perch (11%) (Figure 11). No diseased fish were detected in 2014. In 2015 0.5% of fish were diseased while in 2016 2.5% of fish were diseased. In 2016, when disease rates were the highest, 17.6% of Barcoo grunter, 15.4% of Welch's grunter and 1.1% of Lake Eyre golden perch carried visible exoparasites. Parasites were typically on the ventral body surface between the base of the pectoral fins (Figure 12) with up to 28 parasites per fish observed. Parasites were identified as true leeches of the infraorder Euhirudinea but are awaiting formal identification from fish parasite specialists.

During 2016 sampling at Mona Downs all spangled grunter (n = 120) exhibited signs of spinal malformation (Figure 13).

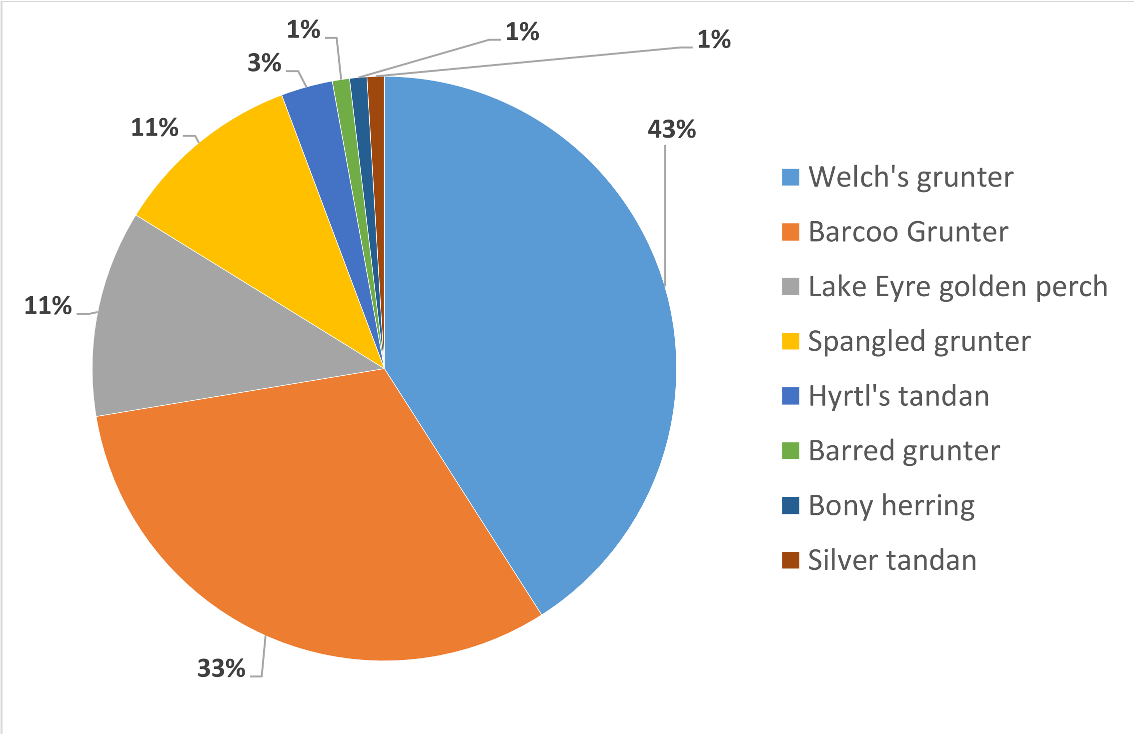


Figure 11. Proportion of observed fish disease by species over the three years of sampling.

Figure 12. In high flow conditions during 2016 Welch's and Barcoo grunter and Lake Eyre golden perch were frequently observed with external parasites.

Figure 13. The top spangled grunter (Leiopotherapon unicolor) displays scoliosis, a warping of the spine. The bottom fish is a normal specimen for comparison.

6.8 State and Transition Analysis and Ecoregion Definition

State and transition modelling of fish communities (

Table 10) delineates two distinct ecoregions within the South Australian portion of the Georgina-Diamantina catchment. These are hereafter referred to as the Goyder and Warburton ecoregions

The Goyder ecoregion is defined predominantly by multivariate group "m" (19 of 33 samples) and is characterised by high abundances of Lake Eyre golden perch (SIMPER contribution of 54%), as well as moderate abundances of silver tandan (17%) and bony herring (10%) (Appendix B). Group "i" is the second most prevalent group (6 of 33 samples) and is characterised by lower abundances of Lake Eyre golden perch (SIMPER contribution of 44%), silver tandan (21%) and bony herring (11%). Group "j" is the third most prevalent factor group within the Goyder ecoregion (4 of 33 samples) and is characterised by high abundances of Hyrtl's tandan (SIMPER contribution of 61%) and moderate abundances of Lake Eyre golden perch (15%).

The three dominant multivariate groups within the Goyder ecoregion (29 out of the 33 samples) indicate that this ecoregion is defined by varying abundances of Lake Eyre golden perch, both species of tandan and bony herring. Lake Eyre golden perch appear within each of the three dominant factor groups, and appear to drive most of the observed variation within the ecoregion. Silver tandan and bony herring contribute to two of the three factor groups, with Hyrtl's tandan the final species driving similarity in the Goyder ecoregion.

Temporal analyses of the state matrix indicates variability within the Goyder ecoregion over time which appears to correspond with streamflow. Variation was observed during 2014 and 2015, with waterhole assemblages becoming largely homogenous in 2016, dominated by multivariate group "m" communities. Pandie Pandie HS has the most comprehensive dataset within the Goyder Ecoregion, and displays a pattern of transition between wetter periods in 2011 and 2012 (where "m" communities dominate) to dryer periods in 2013, 2014 and 2015 (where "i" communities dominate) and returning to "m" communities with increased flow in 2016.

The Warburton ecoregion is defined predominantly by multivariate group "c" (11 of 36 samples), and is characterised by very high abundances of Lake Eyre hardyhead (SIMPER contribution of 72%), as well as moderate abundances of desert goby (25%). Group "r" is the second most prevalent group (9 of 36 samples) and is characterised by low abundances of spangled grunter (SIMPER contribution of 60%) and very low abundances of Lake Eyre hardyhead (13%) and Lake Eyre golden perch (7%). Group "p" is the next most prevalent factor group within the Goyder ecoregion (5 of 33 samples) and is characterised by high abundances of bony herring (SIMPER contribution of 72%) and moderate abundances of spangled grunter (13%).

The three dominant multivariate groups within the Warburton ecoregion, (25 out of the 36 samples) indicates that this ecoregion is defined by varying abundances of Lake Eyre hardyhead and spangled grunter, with smaller contributions from desert goby and bony herring. Spangled grunter and Lake Eyre hardyhead contribute to two of the three dominant factor groups, and appear to drive most of the observed variation within the ecoregion. Desert goby and bony herring are lesser drivers of community variation.

Table 10. Georgina-Diamantina state/transition matrix displaying multivariate factor groups (generated by cluster analyses) from upstream to downstream through time. Ecoregions were generated based on spatial groupings of similar community assemblages. Shaded ecoregions occur interstate.

		Boom				**Bust**						
		2011		**2012**		**2013**		**2014**		**2015**		**2016**
Ecoregion	**Site**	1	2	1	2	1	2	1	2	1	2	1
Upper Georgina (n dominated)	Junction waterhole									n		n
	Arapunya (roadcrossing)	e										
	Ooratippra waterhole	n		n		n		n		n		n
	Umberumbera									n		n
	Tobermorey Station							p				
	Lake Mary					n		n		n		n
	Camooweal			n								
Upper-Mid Georgina (q/k dominated)	BigRanken Waterhole	n		k		k		q		q		f
	Lake Nash			q		g		q		q		k
Upper Diamantina-Georgina channel country (g/q dominated)	Oondooroo	g		q	q	q	q	g		q		p
	ConnHole			g							q	
	OldCorkWH							g		g		g
	BullaBulla									g	g	n
	WintonJundahRd	f		f		d						
Lower Diamantina-Georgina channel country (l dominated)	DavenportDowns		l	l	i	i	k	i	q	q	q	i
	BedourieFnarh		l	k	g	g		k	q	l	l	o
	Glengyle		l	k		g	k	h		l		
Goyder (m dominated)	Brumby waterhole		i	m		i		m		m		m
	Pandie Pandie HS	m		m		i	i	k	i	i		m
	Double Bluff WH									j		m
	Diamantina Split							m		j		m
	Andrewilla							j		m		k
	Pelican WH											m
	Yammakira							j		g		
	Peraka Lakes Junction											m
	Burts WH									m		
	Koonchera							m		m		
	Koonchera West											m
	Tepamimi							b		b		
	Goyders Lagoon WH							m		m		
Warburton (c/r dominated)	Tippipilla Creek Campsite											r
	Yelpawaralinna									r		
	Ultoomurra							c		m		o
	Kalamunkinna									c		
	Mona Downs									a		r
	Stony Point							c	c	c		
	Cowarie Crossing	p			q		c	x		c		p
	Cowarie Homestead									r		
	Mungerannie Wetland				r	r	b	r	b			
	Yellow WH							c				p
	Stony Crossing			q								
	Mia Mia									c		p
	Wadlarkaninna			r								r
	Tinnie Landing									c		p
	Cliff Camp WH									c		
	Poonarunna Bore			r				b				

6.9 Condition Assessment

To account for differences in regional trajectories a separate BCG tool was developed for each ecoregion in South Australia (Diamantina ecoregion and Warburton ecoregion, not to be confused with the Diamantina and Warburton-Kallakoopah management units) and are presented in Appendices C and D. Using these tools, each sampling event (excluding dry sites) was assessed to generate seven tier scores (reflecting condition of different functional aspects of the fish biota) (Appendix E) and averaged to generate a site BCG score reflecting overall site condition (Table 11, Figure 14).

Average BCG scores for each management unit were lower than the TPC threshold of 2.9 indicating that all management units were in good or acceptable condition throughout this study (Figure 15) (Schmarr et al., 2015). Average management unit BCG scores ranged from 1.3 (Diamantina management unit in 2016) to 2.6 (a single site which represented the Eyre Creek management unit in 2014).

Table 11. BCG scores were calculated for each sampling event. Sites which were dry when visited are marked ○. One site level TPC (number marked in red) and five attribute TPCs (black numbers shaded in red) were triggered.

Management Unit	Site	2014	2015	2016
Diamantina	Dickeree	○	○	
Diamantina	Pandie Pandie HS	1.25 / 3	2	2
Diamantina	Double Bluff WH		1.25	1
Diamantina	Diamantina Split	1.5	1.5	1
Diamantina	Yammakira	1.5	1.75	
Diamantina	Andrewilla	1.25	1.25	1.5 / 1
Goyder Lagoon	Pelican WH			1.25
Goyder Lagoon	Burts WH		1.5	
Goyder Lagoon	Peraka Lakes Junction			1
Goyder Lagoon	Koonchera	1.5 / 1.75	1	
Goyder Lagoon	Koonchera West			1.5
Goyder Lagoon	Pandiburra Bore			
Goyder Lagoon	Goyder Lagoon WH	1.5	1	
Goyder Lagoon	Tippipilla Creek Campsite			2
Goyder Lagoon	Yelpawaralinna		2.2	
Eyre Creek	Tepamimi	2.6	2.4	
Warburton-Kallakoopah	Ultoomurra	2.2	1.2	1.33
Warburton-Kallakoopah	Kalamunkinna	2.67		
Warburton-Kallakoopah	Mona Downs	○	2.6	1.8

Management Unit	**Site**	**2014**	**2015**	**2016**
Warburton-Kallakoopah	Stony Point	2.2	1.67	
Warburton-Kallakoopah	Mungerannie Wetland	2.5		
Warburton-Kallakoopah	Cowarie HS		2.2	
Warburton-Kallakoopah	Cowarie Crossing	2.6	2.5 / 2.3	2.1 / 1.7
Warburton-Kallakoopah	Yellow WH	2.2		2.14
Warburton-Kallakoopah	Mia Mia		1.8	2.14
Warburton-Kallakoopah	Channel near Wadlarkaninna			
Warburton-Kallakoopah	Wadlarkaninna	2.6		2.2
Warburton-Kallakoopah	Tinnie landing		2	1.67
Warburton-Kallakoopah	Cliff Camp WH		2.67	
Warburton-Kallakoopah	Poonarunna Bore	2.83		

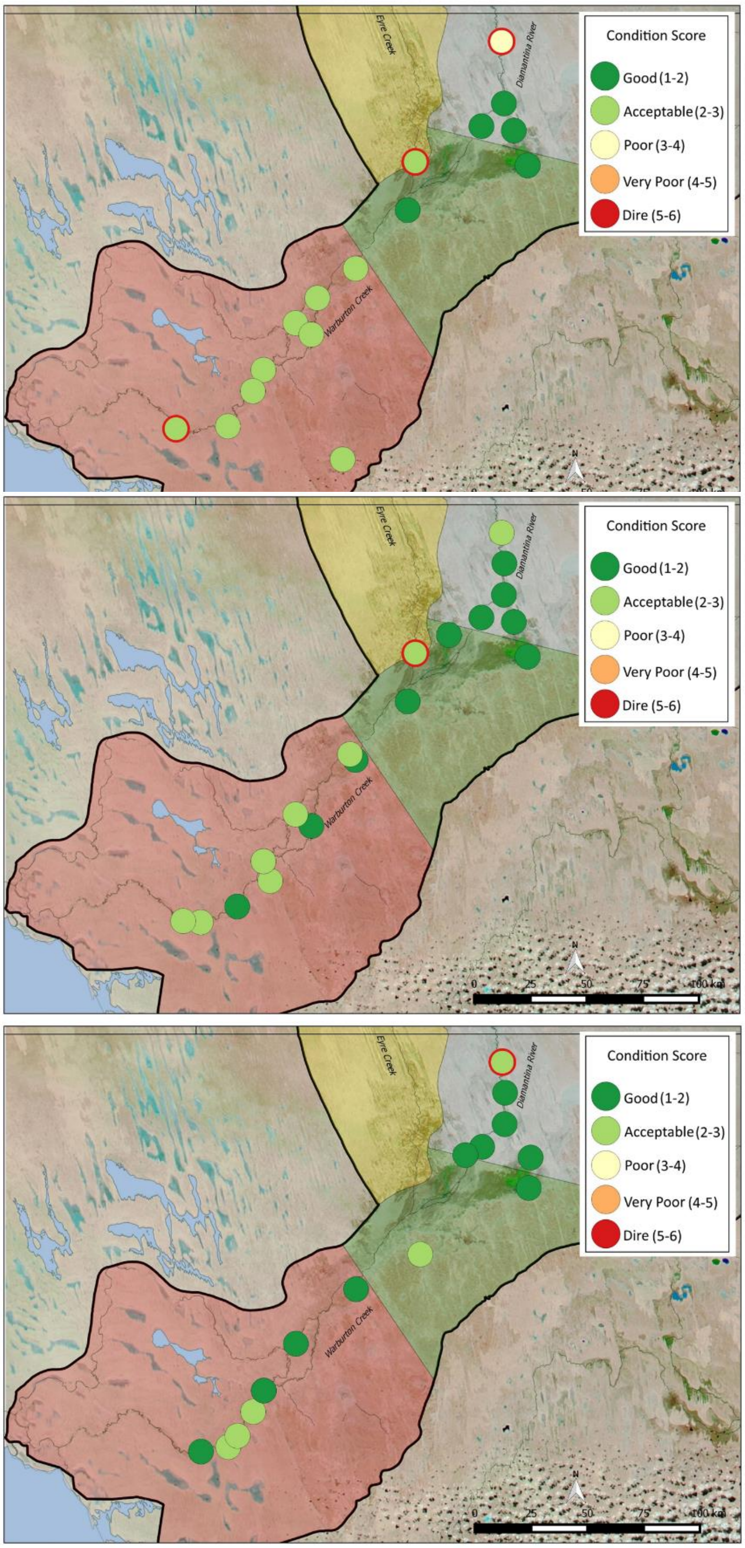


Figure 14. Map of BCG scores for each site for 2014 (a), 2015 (b) and 2016 (c).

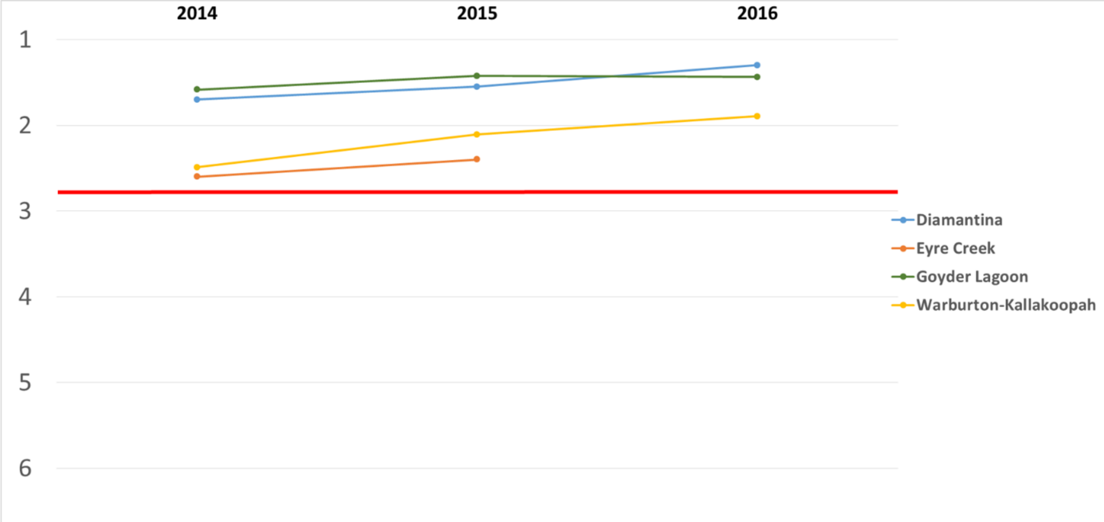


Figure 15. Average BCG scores for each management unit through the three years of the study. The red line indicates the Threshold of Potential Concern (TPC), below which site health appears to have degraded, requiring further consideration.

A total of six TPCs were triggered in the current study (Table 11): one site TPC and five attribute TPCs. Pandie Pandie HS in May 2014 triggered a site TPC with a BCG score of 3. This scored poorly due to a depauperate fish community which lacked the typically ubiquitous bony herring. Five attribute TPCs were triggered in the study, one for attribute IV (Resilient and Resistant taxa) and four for attribute VI (Non-native taxa). The attribute IV (Resilient and Resistant taxa) TPC occurred at Pandie Pandie HS in May 2014 due to the absence of bony herring. Attribute VI (Non-native taxa) TPCs reflect very high abundances of gambusia. Three of these TPCs occurred in artesian bore samples (Tepamimi in 2014 and 2015, and Poonarunna Bore in 2014) while the fourth occurred at Pandie Pandie in 2016.

6.10 Other Taxa

Emmott's Short-Necked Turtle (*Emydura macquarii emmotti*)

Figure 16. Emmott's short-necked turtle (Emydura macquarii emmotti) were caught at three sites which represents a localised range extension for this species.

The current study detected Emmott's short-necked turtles at three sites (Table 12); Diamantina Split, Yammakira and Andrewilla. These sites are in close proximity (both Andrewilla and Yammakira are less than 20 km downstream of the Diamantina Split).

Table 12. Seventeen Emmott's short-necked turtles were caught in this study.

Year	Site	Abundance
2014	**Yammakira**	**4**
2015	**Diamantina Split**	**8**
2016	**Diamantina Split**	**4**
	Andrewilla	**1**

Crustaceans

A high degree of variability was observed between the seasonal distribution and abundance of crustaceans (Table 13). Freshwater shrimps (*Macrobrachium, Paratya* and *Caradina* species) (Table

13**Error! Reference source not found.**) were commonly recorded and widely distributed, possessing the highest abundance of the macroinvertebrates, with populations widespread throughout the system, with the exception of the Warburton-Kallakoopah management unit in 2014-15. Freshwater crabs (*Parathelphusa transversa*) (Table 13) were equally as common though not as prevalent as the shrimp, with a notable increase in numbers within the lower reaches of the system during the 2015-16 period. Yabbies (*Cherax* destructor) (Table 13) were recorded in low numbers and patchy distributions throughout most management units, this species remains relatively unpredictable in its prevalence and distribution throughout the LEB. Redclaw (*Cherax quadricarinatus*) were not detected at any site during the study. The midstream reaches of Diamantina River contained the most consistent richness of crustacean species, with the Goyder Lagoon management unit containing all three groups throughout the study.

Figure 17 Native crustacean fauna of the Georgina-Diamantina catchment include shrimp (Macrobrachium australiense *and Paratya australiensis) (Top Left), Yabbies (Cherax destructor) (Top Right) and freshwater crabs (Parathelphusa transversa) (Bottom).*

Table 13. List of crustacean abundance figures by year, management unit and site.

	Crab	Shrimp	Yabby
2014			
Diamantina			

Pandie Pandie HS		211	
Diamantina Split		179	
Yammakira		79	
Andrewilla		62	1
Eyre Creek			
Tepamimi		2	
Goyder Lagoon			
Koonchera	28	4	2
Warburton-Kallakoopah			
Kalamunkinna	1		
Mungerannie Wetland			22
2015			
Diamantina			
Double Bluff WH		1	
Yammakira		26	
Andrewilla		23	
Goyder Lagoon			
Burts WH	1	4	
Koonchera	3	11	2
Goyders Lagoon WH	8	105	
Yelpawaralinna	9	2	
Warburton-Kallakoopah			
Ultoomurra	22		
Mona Downs	27		
Stony Point	17		
Cowarie Crossing	57		
Cowarie HS	8		3
Mia Mia	1		
2016			
Diamantina			
Pandie Pandie HS	1	25	
Diamantina Split		202	1
Double Bluff WH		460	1
Andrewilla	1	515	
Goyder Lagoon			
Pelican WH	7	64	1
Peraka Lakes Junction	18	56	
Koonchera West	3		
Tippipilla Creek	6	19	
Warburton-Kallakoopah			
Ultoomurra	7	146	
Mona Downs	7		
Cowarie Crossing	16	4	
Yellow WH	3	3	
Mia Mia	2	7	
Wadlarkaninna	301		
Tinnie landing	1	4	
Total	555	2214	33

7 Discussion

7.1 The Biological Condition Gradient

All management units were assessed to be in good overall ecological condition and no units scored below the TPC threshold of 2.8 (Figure 15). The highest scoring management units were Diamantina and Goyder Lagoon where the fish fauna within the expected range of ecological responses for the region within the hydroclimatic cycle were present. This result suggests a system where riverine ecological services remain intact. The Eyre Creek management unit scored consistently lower than other regions. There are no naturally occurring aquatic refuges in the Eyre Creek management unit and the management unit score was comprised of a single site (Tepamimi) which is fed from an artesian bore. Although this management unit did not trigger a TPC, the ecological services observed are anthropogenic rather than pristine.

Only a single site TPC was triggered during the three years of monitoring, Pandie Pandie HS in 2014 (Table 11). The fish assemblage at this time contained few resilient species and no bony herring. Low abundances were recorded for all but one species, Welch's grunter, which were in moderate abundance. Although the species richness was largely within the expected range for this ecoregion during the bust period, the absence of bony herring was anomalous and sufficient to flag a site TPC. The absence of bony herring on this occasion was also sufficient to trigger an attribute TPC (Attribute IV, Resistant and Resilient taxa). Bony herring were identified at Pandie Pandie HS one month earlier (Table 7) and this TPC is probably an artefact of sampling rather than a reflection of declining condition or ecosystem function.

Stochasticity is inherent in ecological surveys and failure to detect a species is common where population sizes are small, where sampling is difficult and where sampling efforts are limited (Gu and Swihart, 2004). While population size and sampling conditions cannot typically be controlled, a robust approach to sampling effort (including a broad spatial and temporal spread) minimises the chance of misrepresentation. One-off sampling may occasionally produce artificially inflated site BCG scores which trigger a TPC (i.e. false negatives). The inclusion of false negatives in the TPC threshold is deliberate and ensures sufficient sensitivity to function as an early warning system. This approach allows discussion to occur before site condition is allowed to decline along unacceptable trajectories.

Five Attribute TPCs were triggered and these are discussed within the context of their management unit.

7.2 The Diamantina Management Unit

The Diamantina management unit incorporates the Diamantina River main channel from the South Australian border downstream to the bottom of two major waterholes; Andrewilla and Yammakira (which occur in parallel on two channels which bifurcate at the Diamantina Split). This unit is characterised by deep, well defined channels and on-channel waterholes. Annual flows provide permanence to all waterholes in this reach and prevent salinization (Table 4). Andrewilla and Yammakira (which define the downstream border of this management unit) receive channel flows at least annually.

The fish community in this reach is characterised by the presence of long lived, large bodied fishes which prefer stable freshwater environments; Lake Eyre golden perch, Welch's grunter and Hyrtl's tandan (Figure 6). Silver tandan, bony herring and (to a lesser extent) Barcoo grunter were also observed regularly in this reach (Table 7, 8 and 9). This management unit was the only one to consistently contain large size classes of these species (Figures 7 and 8). This included fish of the maximum reported length of Welch's and Barcoo grunter, Hyrtl's tandan and bony herring (Allen et al., 2003). Catch results also included silver tandan which were below the maximum reported size (Allen et al., 2003) but were within 10 mm of the ten largest individual TLs collected from 10 years of tristate LEB sampling (which ranged from 230 – 273 mm TL). The capacity for each of these species to reach their maximum size reflects the permanent, freshwater nature of the waterholes in this unit which are not only suitable for the long term survival of large bodied fish but provide consistent access to high quality food resources. Within the South Australian Georgina-Diamantina catchment the Diamantina management unit is a critical refugia for large bodied and long-lived fish species.

The Diamantina management unit was also the only region to contain Emmott's short-necked turtle displays. Populations were limited to Andrewilla, Diamantina Split and Yammakira. This is the only known population in the Georgina-Diamantina catchment and it is unclear what habitat qualities in this region support this species.

The Diamantina management unit plays an important role in connecting populations of Lake Eyre golden perch in the LEB. Gene flow in Lake Eyre golden perch was examined in 2010 and considered populations from Koonchera waterhole (Goyder Lagoon management unit), Algebuckina waterhole (in the Neales River to the west of Lake Eyre) and an upper catchment site in each of the Georgina and Diamantina catchments. Gene flow radiated out from the Koonchera population, achieving genetic transfer to populations in each of the upper Georgina, upper Diamantina and Neales catchments (the Neales requiring traversal of Kati Thanda-Lake Eyre) (Faulks et al., 2010). Although samples were not included from the Diamantina management unit, the greater size of individuals and populations therein suggests that the directional genetic transfer is probably emanating from within the Diamantina management unit rather than from the Koonchera population (which was probably selected due to ease of access from the Birdsville Track).

The persistence of Lake Eyre golden perch in the Lake Eyre Basin hinges on a disproportionate contribution from a small number of reproductive individuals from key populations (Beheregaray and Attard, 2015). Populations of Lake Eyre golden perch in the Diamantina management unit appear to be one of these genetically important populations in the Georgina-Diamantina catchment and also for populations in the Neales Catchment. It is anticipated that this may also be true for other long-lived, large bodied species, although sufficient genetic evidence does not exist to support this hypothesis.

Sampling in 2014 and 2016 took place during periods of flow. Fish abundances during these years were higher than those observed during 2015 when the channel was not flowing (4,528 fish in 2014 and 5,612 fish in 2016, compared to 1,928 fish in 2015) (Table 7, 8 and 9). Increased abundance during 2014 and 2016 highlights the tendency of LEB fish to move on flow. Throughout the study, several species were absent from downstream management units and reappeared following connecting flow (Figures 7 and 8). It is suggested that failure to detect these species reflects localised extirpation and that subsequent detection reflects immigration on channel flow. Increases in catch numbers during channel flows in the

Diamantina management unit and the appearance of fish in the lower reaches following flow, highlight the importance of this management unit as the key immigration pathway for fish in the South Australian Georgina-Diamantina catchment.

Flow in 2014 and 2016 resulted in higher overall catches with only minor differences in community composition.

Detection of gambusia is anomalous in the Diamantina management unit and a single gambusia at Pandie Pandie HS in 2016 was sufficient to trigger an attribute TPC (attribute IV non-native taxa). Sampling in 2016 occurred during a period of flow and this individual appears to have been flushed into South Australia from a Queensland population. The detection of this fish is unlikely to reflect a decline in environmental condition at the site and this TPC may be discounted at the current time.

Summary

Aquatic habitats in the Diamantina management unit are characterised by fresh, annual flows and permanent waterholes. These characteristics support large populations of reproductively mature, large-bodied fish, particularly; Welch's and Barcoo grunter, Hyrtl's and silver tandan, Lake Eyre golden perch and bony herring. This region supports critical reproductive populations of Lake Eyre golden perch, which deliver emigrants to the upper Diamantina and Georgina catchments and also the Neales River, west of Kati Thanda-Lake Eyre. This is probably also true for other species. The Diamantina management unit is also the primary immigration pathway for fish to repopulate the lower catchment.

Management of this unit should focus on maintenance of annual flows, prioritising a natural hydrograph and limiting upstream water extraction and impoundment.

7.3 The Goyder Lagoon Management Unit

The Goyder Lagoon management unit is characterised by dispersed flow paths and braided channels. Although flow may enter this management unit most years Flow entering Goyder Lagoon is dispersed over a broad area and undergoes large transmission losses as the channelized Diamantina River transitions into thousands of braided channels. As a result, although flow enters Goyder Lagoon most years it exits to the Warburton-Kallakoopah management unit only under very wet conditions. Waterholes in this region lack permanence due to the infrequent nature of filling flows and, due to limited influence of saline groundwater, waterholes in this region do not typically dry along a saline trajectory.

Fish communities in the Goyder Lagoon management unit during 2014 and 2015 were similar to those in the Diamantina management unit and were characterised by strong representation of Lake Eyre golden perch, Welch's grunter and Hyrtl's tandan (Table 7 and 8). In 2016 the fish community varied from previous years and displayed an intermediate state between the upstream (Diamantina) and downstream (Warburton-Kallakoopah) states. At this time the fish community was also influenced by the presence of barred and spangled grunter, bony herring and desert rainbowfish (Table 9).

Catch composition and population structure in the Goyder Lagoon management unit varied between years. In 2014, when the system was generally dry and channel flows were absent, five species were detected and the total catch was dominated by Lake Eyre golden perch (Table 7). All species observed in 2014 were large-bodied species (bony herring, Hyrtl's tandan, Lake Eyre golden perch, silver tandan and Welch's grunter) but populations at this time were juvenile, measuring less than 150 mm TL (Figures 7 and 8). Silver tandan were an exception to this displaying individual total lengths of up to 220 mm TL.

Sampling in 2015 and 2016 occurred during wetter periods, 2015 representing a period of recent flow and 2016 sampling occurred during strong flow. Species richness during these years was higher than in 2014 (seven species in 2015 and eight in 2016). This was predominantly due to the presence of Barcoo and spangled grunter which immigrated on flow (Table 8 and 9).

Downstream, in the Warburton-Kallakoopah management unit, three species were present during 2014. In 2015 and 2016 a further nine species previously absent in the Warburton-Kallakoopah management unit were detected having entered via connecting flows through the Goyder Lagoon management unit. This immigration event included Barcoo grunter and large size classes of Lake Eyre golden perch neither of which were present in the Goyder Lagoon management unit in 2014 (Table 8 and 9). These fish must have commenced their movement from upstream of Goyder Lagoon however it is unclear whether this was from the Diamantina management unit or from reaches in Queensland. This highlights the role of the Goyder Lagoon management unit as an immigration pathway for the lower catchment.

It is unclear what role the Goyder Lagoon management unit plays as a source of immigrants to the lower catchment. This region contains few refuge waterholes, none of which have sufficient depth to persist for longer than two years without fresh inputs (there are several dams which have been constructed within Goyder Lagoon which may outlast waterholes in this region, however they do not appear to last substantially longer). This is reflected in length frequency distributions in 2014 which were typically unimodal and comprised of juvenile fish. This is in contrast to length frequency distributions in the Diamantina management unit at the same time which were multimodal and included fish up to the maximum known length for most species. During wetter periods (*ie* 2015 and more so in 2016) length frequency distributions were more complex in Goyder Lagoon reflecting immigration, and subsequent survival of larger, older fish. Although it is possible to infer the direction and success of immigration into this management unit, it is not possible to determine the direction or success of emigration. Although it is clear that some species are migrating through Goyder Lagoon (from the Diamantina to the Warburton-Kallakoopah management unit) it is unclear if these examples reflect all species or all size classes.

Summary

The Goyder Lagoon management unit is characterised by thousands of periodically wetted braided channels with few shallow waterholes present. Long lived anthropogenic refuges within Goyder Lagoon may extend the persistence of fish in this management unit, however it is unclear how long these refuges persist and which species they support. Without this it is difficult to determine the importance of these structures to landscape processes. The Goyder Lagoon management unit is a key migratory pathway for fish to repopulate the Warburton-Kallakoopah management unit and to migrate between the Georgina-Diamantina catchment and the western catchments of the LEB (Macumba and Neales catchments).

7.4 The Eyre Creek Management Unit

The Eyre Creek management unit incorporates Eyre Creek from the South Australian border downstream to its convergence with Goyder Lagoon. Eyre Creek is fed by the Georgina River but flows to its terminus infrequently due to high transmission losses. At the time of writing, the Georgina catchment is thought to have reached Goyder Lagoon seven times since 1990 (Osti, 2014). The Eyre Creek management unit does not appears to contain any permanent refuges for fish. Only two sampling events were undertaken in the Eyre Creek management unit, both at Tepamimi. This is an ephemeral waterhole which is fed by an uncapped artesian bore, creating a permanent, anthropogenic refuge.

Free flowing artesian bores exert both positive and negative effects on the surrounding ecosystem (James et al., 1999). For fish in the Lake Eyre Basin, free flowing artesian bores vary in their biodiversity implications, dependant on site characteristics like location and migrational pathways. Paddy's Bore in the Finke catchment and Junction Bore in the Macumba catchment each support a community of native fish species with no exotic fish species present (SARDI unpublished data, 2014). These bores create refugia and source populations for native fish in regions where natural refugia do not exist. In the Neales catchment, One Mile Bore and the now capped Big Blyth Bore were found to support large populations of gambusia with few other species present (McNeil et al., 2011). These latter refugia extend the range of exotic fish which act as source populations, seeding the system during periods of connectivity.

Tepamimi acts as a refuge for native fish species. In 2014 this site supported low numbers of bony herring, desert rainbowfish, Hyrtl's tandan, Lake Eyre golden perch and spangled grunter (Table 7). In 2015 this site supported bony herring, Hyrtl's tandan, Lake Eyre golden perch, silver tandan, spangled grunter and Welch's grunter (Table 8). Although species diversity was high at Tepamimi in 2014 and 2015, gambusia dominated the total fish catch on both occasions (96.7% of total catch in 2014 and 96.1% of total catch in 2015). Tepamimi expands the range of several native species into the Eyre Creek management unit but the range expansion is modest being only 35 km downstream of the Diamantina management unit which receives annual channel flows and contains large permanent waterholes. The positive influence that Tepamimi exerts on native fish ecology in the catchment is minimal.

The proliferation and persistence of gambusia in artesian bore drains occurs throughout the LEB (Wager and Unmack, 2000, McNeil et al., 2011, McNeil et al., (in prep)) and is reflected in the common name "the bore-drain fish". Gambusia are a hardy fish which are tolerant to a range of water quality parameters which would prove fatal to most LEB fish, this includes elevated salinity (Chervinski, 1983) and low dissolved oxygen (McKinsey and Chapman, 1998). Gambusia have very high fecundity (Milton and Arthington, 1983) and the habitat stability (Table 6) and shallow warm water present in bore drains enable gambusia to maximise their fecundity. As a result they rapidly achieve very high densities and dominate bore drain assemblages, which is reflected in another common name, "the millions fish".

In 2015 and 2016 channel flows reconnected Tepamimi to the lower catchment. At this time one other large population of gambusia was present and gambusia reappeared at sites throughout the Warburton-Kallakoopah management unit. There were two major source populations of gambusia present in the state prior to 2015 flow: Tepamimi and Poonarunna Bore (the most downstream site in the study). Gambusia have limited swimming ability and are unlikely to have moved upstream from

Poonarunna Bore during strong flow. The migration of fish from Queensland cannot be discounted however Tepamimi is the closest population and may be the most likely source of these fish.

It is recommended that Tepamimi be considered for management intervention. Capping the artesian bore completely would remove a key refuge for this species with minimal impact on native fish ecology. Alternatively capping and replacement with a valved bore would allow periodic drying to eliminate gambusia whilst maintaining the refuge for other ecological services.

Summary

The Eyre Creek management unit flows infrequently and contains no permanent natural refuges. Near the edge of Goyder Lagoon, an uncapped artesian bore drains into Tepamimi waterhole creating an anthropogenic aquatic refuge. This waterhole supports a range of native species however the fish community is dominated by gambusia which seed the downstream catchment during periods of flow. It is recommended that Tepamimi be considered for management action to turn off flow from the bore or divert bore flow to storage in dams or tanks.

7.5 The Warburton-Kallakoopah Management Unit

Fish communities in the Warburton-Kallakoopah management unit were variable, being characterised by Lake Eyre hardyhead and gambusia in 2014 and by spangled and barred grunter, bony herring and desert rainbowfish in subsequent years (Figure 6). This reflects the changeability inherent in this management unit which varies between a dry reach with few hypersaline refuges, to a strongly flowing, freshwater river. These transitions may occur rapidly and the system will experience both states several times each decade.

Sampling in 2014 took place during a dry period and the Warburton-Kallakoopah management unit does not appear to have received channel flows since 2012. In the absence of flow, the reach was on a drying trajectory with a corresponding increase in aquatic salinity (Table 5). Increases in salinity occur through a concentration of salts as evaporation reduces pool volume and also through interaction with shallow saline groundwater (Tweed et al., 2011). Ultoomurra, Kalamunkinna and Stony Point each retained small pools, fresh enough to support halophilic fish species (desert goby and Lake Eyre hardyhead) and Cowarie Crossing retained water, however after approximately 2 years without fresh inputs, this site was too saline to support fish (Table 5). It is likely that Ultoomurra, Kalamunkinna and Stony Point were the only three natural refuges in the management unit which supported fish during this dry period. The capacity of these refuges to support fish during extended droughts is unclear, however the continued presence of desert goby and Lake Eyre hardyhead in the system suggests that inputs from localised rainfall and small, periodic channel flows maintain favourable conditions for halophilic fish species even during extended drought periods.

Low level flow events are critically important to the long term survival of halophilic fish species in the South Australian catchment. Compared to most Australian catchments, the LEB is largely unregulated and current flow regimes reflect near-natural patterns. The improvement of technology and infrastructure in the basin (particularly roads and petroleum industry exploration) has resulted in an increase in proposed water affecting activities in the Georgina-Diamantina catchment. Many anthropogenic activities have the potential to alter the magnitude and frequency of flow patterns (Smakhtin, 2001) and include groundwater abstraction (including agricultural bores and non-conventional petroleum industries), river abstraction, an accumulation of smaller flow control mechanisms like farm dams (Warner, 1984) and large damming structures (Benn and Erskine, 1994). The impacts of water extraction and flow regulation are well documented and may include a reduction in the number and frequency of low level flow events (Walker and Thoms, 1993, Thoms and Cullen, 1998). Given the rates of salinization observed in this management unit, even subtle increases in the number of consecutive zero flow days may have a strong impact on the persistence of halophilic fish refugium in South Australia. Water affecting activities which reduce the periodicity of small flow pulses entering the Warburton-Kallakoopah management unit will have a large impact on the capacity for desert goby and Lake Eyre hardyhead to persist in the South Australian Georgina-Diamantina catchment.

This management unit includes several confluences through which intercatchment dispersal is possible (Figure 18). The Warburton River flows into Kati Thanda-Lake Eyre at two points. The primary flow path enters the Lake downstream of the Warburton-Kallakoopah confluence and flows into the Warburton Groove, a shallow channel which runs southwards across the Lake travelling within 20 km of the Neales River catchment. This is believed to be the migratory pathway that enables gene flow and recolonization of Lake Eyre golden perch into the Neales catchment (Beheregaray and Attard, 2015). A smaller flow path (Kalaweerina Creek) meets Kati Thanda-Lake Eyre about 30 km upstream of the Warburton-Kallakoopah confluence and only connects under high flow. The Georgina-Diamantina catchment also converges with the Macumba catchment on Kallakoopah Creek 10 km upstream of the Warburton-Kallakoopah confluence. Critical aspects of the hydrograph which enable dispersal and gene flow between the Georgina-Diamantina catchment and the eastern drainages of the LEB relate to the magnitude and duration of large flow events. It is anticipated that connectivity with the Macumba and Neales catchments occurs rarely and only when suitable flow is present simultaneously in both connecting catchments. Although infrequent, this connectivity is critical to fish ecology in the LEB and consideration should be given when considering water affecting activities in the Georgina-Diamantina, Macumba and Neales catchments. It must be noted that, given the magnitude of flood events required to enable interbasin connectivity only very large scale activities are likely to affect this process.

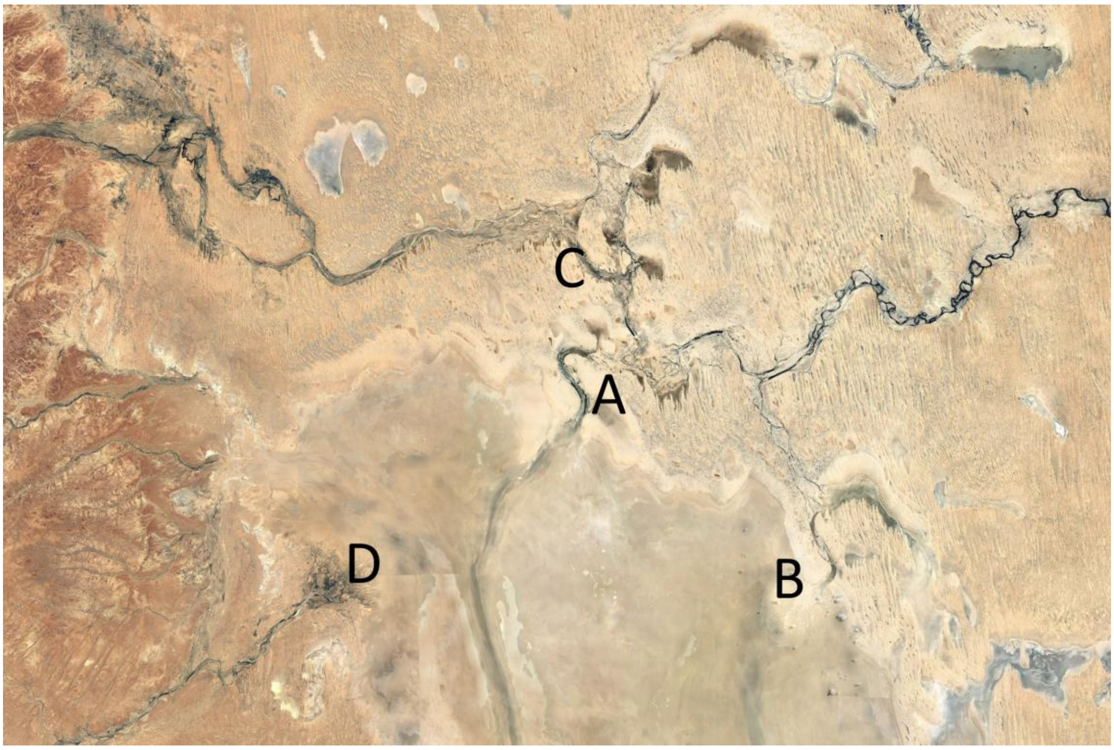


Figure 18. The Georgina-Diamantina catchment enters Kati Thanda-Lake Eyre at two points (A and B). During periods of favourable flow fish may also move between the Macumba River (C) and the Neales River (D) via the Warburton Groove.

Strong channel flows entered the management unit in 2015 and 2016, enabling the return of eight species (Barcoo, spangled and Welch's grunter, silver and Hyrtl's tandan and Lake Eyre golden perch in 2015, and barred grunter and desert rainbowfish in 2016). Seven of these species were present in the management unit in 2011 but were unable to survive the salinisation that followed. In 2015 and 2016 flows refilled, and freshened the reach, opening new favourable habitat to LEB fish taxa which were able to immigrate on strong flow. The extent of range expansions into the reach varied between species and provide insight into migratory strategies in these species. Large scale movements of LEB fish with flows are well documented (Puckridge, 1999, Schmarr et al., 2013). Bony herring, silver tandan and spangled grunter were able to penetrate downstream to the extent of 2015 flows (Tinnie Landing). These species are all considered extreme dispersers in the Georgina catchment (Kerezsy et al., 2013b).

In the Warburton-Kallakoopah management unit, gambusia were abundant in 2014, being detected at three sites: Poonarunna Bore, Mungerannie Wetland and Kalamunkinna. Poonarunna Bore and Mungerannie Wetland are anthropogenic refuges fed by artesian bores, habitats which are known to favour gambusia. This species is adept at rapidly proliferating in stable environments, like those present in bore fed wetlands, where it reaches very high abundance (e.g. Poonarunna Bore with 4,710 gambusia in 2014). Following the reintroduction of flow in 2015 and 2016, gambusia were found throughout the Warburton-Kallakoopah management unit (at five of ten sites in 2015 and four of seven sites in 2016). Gambusia have poor swimming ability (Ward et al., 2003) and are disadvantaged by strong flow (Costelloe et al., 2010). Where displacement occurs due to strong flows they are believed to suffer high rates of mortality. Given their limited swimming ability, it is unlikely that gambusia from Poonarunna bore were able to establish upstream populations at in 2015 and 2016 and it is more plausible that these populations were sourced from populations upstream such as Tepamimi in the Eyre Creek management unit.

This species was unable to persist in the natural saline refugia which characterised the management unit in 2014 with the exception of four fish at Kalamunkinna. It is unclear how this small population was able to persist in salinity of 111 ppt. This is the highest salinity this species has been observed to tolerate and is over 60 ppt higher than the previous highest field observation (REF TO TABLE) and 50 ppt higher than the highest reported laboratory tolerance (Chervinski, 1983). The most likely explanation is that these individuals were subsisting in a less saline lens suspended on top of the hypersaline waters of the pool. The equipment used to measure salinity requires a minimum depth in order to function effectively and would have measured the hypersaline waters below the halocline rather than the thin surficial lens. It is recommended that this observed salinity tolerance be considered an artefact of sampling rather than an expansion in the range of observed tolerance for this species.

Summary

Aquatic environments in the Warburton-Kallakoopah management unit are highly variable. Large but infrequent flows freshen the reach and introduce immigrant fish from many species. This enables emigration and gene flow between the Georgina-Diamantina catchment and western catchments of the LEB (Macumba and Neales catchments). After a year without fresh flow, the management unit dries until very few refugia persist. Those that remain are highly saline (beyond the physiological thresholds for most fish species) and provide a specialised niche for halophilic fish species: Lake Eyre Hardyhead and desert goby (which in South Australia are only know from this management unit).

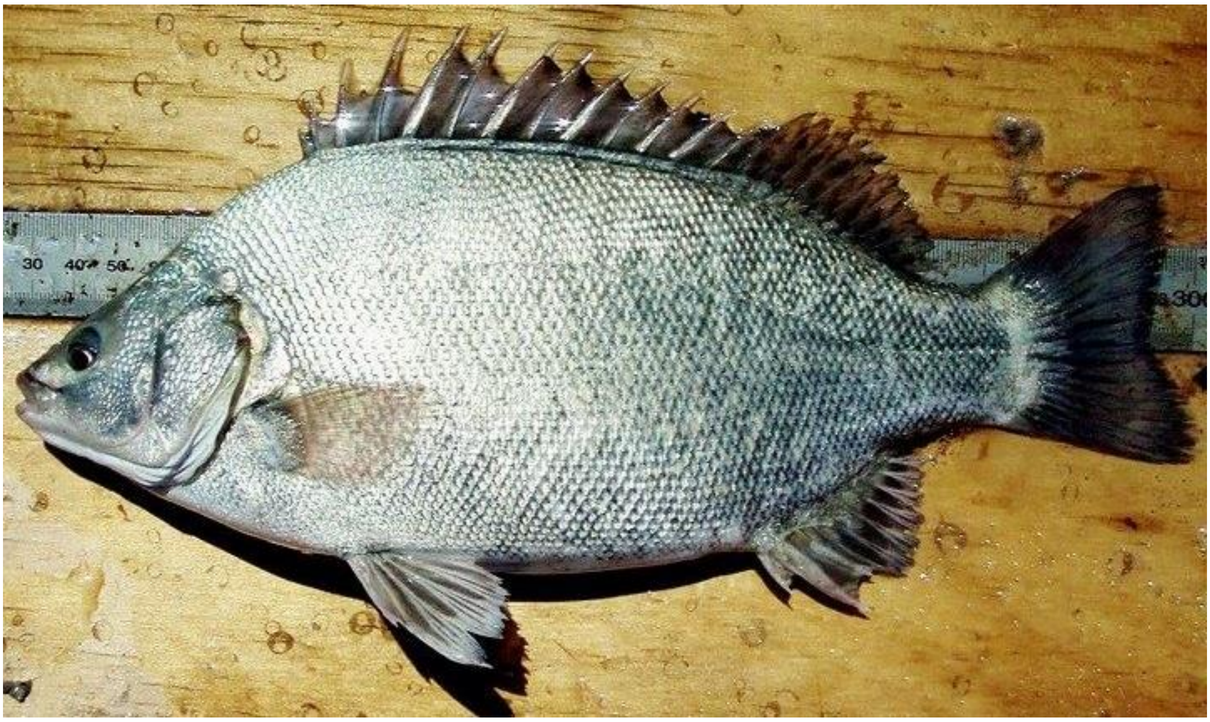
Management in this unit should focus on limiting water affecting activities throughout the catchment to ensure that near-natural patterns of flow are maintained. It is hypothesised that two aspects of the hydrograph are of particular note. The magnitude of infrequent, high-flow events (which enables movement between catchments) and the frequency of low flow events (which maintain saline refugia within the physiological limits of halophilic fish species).

Poonarunna Bore and Mungerannie Wetland are anthropogenic bore drains and should be considered for active management to control the presence of gambusia. This may include periodic drying.

7.6 Fish species

Native species

Barcoo grunter (Scortum barcoo)



Barcoo grunter numbers increased through the study from six fish in 2014 to 158 fish in 2016. This species was most frequently observed in the Diamantina River and was less frequent in subsequent reaches. In 2014 and 2015 Barcoo grunter in the Diamantina management unit were less than 160 mm TL however, in 2016 individuals were observed up to 320 mm TL (the maximum length for this species). Although the Diamantina management unit supports this species throughout the hydroclimatic cycle, key breeding populations for this species (reflected in fish of the maximum size class) are probably upstream of the South Australian border.

The furthest downstream this species was observed was at Cowarie Crossing (on the Warburton River), in 2016 when sampling took place during strong channel flows. The highest abundances were also observed at this time, suggesting Barcoo grunter move during large flows but are slower to move than other species.

Bony herring (Nematolosa erebi)

Bony herring is an algivore and detritivore capable of shifting dietary preference depending on hydrological conditions (Sternberg et al., 2008). In 2014 bony herring was present in the Diamantina and Goyder Lagoon management unit as well as both borefed anthropogenic refuges: Tepamimi (Eyre Creek management unit) and Mungerannie Wetland (Warburton-Kallakoopah management unit). In the Diamantina management unit this included fish of the maximum size class for this species suggesting that even in dry times (*eg* 2014) this management unit is a high quality refuge for the long term survival of this species.

Bony herring move quickly on commencement of flow and display strong migratory capacity. Following flows in 2015, abundance of bony herring increased from 187 (2014) to 413 fish and during 2016, when sampling took place during a period of high flow, bony herring abundance increased to 23,875 fish. During 2015, bony herring were one of three species to penetrate downstream to Tinnie Landing. The following year bony herring were present at fifteen of the seventeen sites sampled and dominated the fish assemblage at most Warburton-Kallakoopah sites. High mobility with a broad salinity tolerance (Figure 10) and limited dietary overlap with other fish species makes bony herring one of the most abundant and commonly encountered fish in the LEB.

Desert glassfish (Ambassis sp.)

Desert glassfish are a common species throughout the Lake Eyre Basin. Within the Georgina-Diamantina catchment, this species is regularly observed in Queensland but infrequently in South Australia. This species does not appear to have permanent populations within South Australia instead relying on flow driven dispersal and subsequent *in situ* population growth (as seen in (Costelloe et al., 2004)). No desert glassfish were detected during this study. Desert glassfish appear to be a late-mid successional species that is intolerant of declining water quality and their poor detection reflects unsuitable antecedent flow conditions rather than ecological decline.

Desert Goby (Chlamydogobius eremius)

Desert goby are an extremophile fish which are adapted to thrive in conditions too harsh to support most other species in the catchment (Figure 10). This includes pools with elevated salinity and low oxygen (Thompson and Withers, 2002). Abundances are highest in the Warburton-Kallakoopah management unit, where drier conditions and the influence of saline ground water result in poorer water quality and elevated salinities. During 2014 and 2015, where flow did little to refresh the lower catchment desert goby displayed large and widespread populations in the Warburton River. Channel flows in 2016 flowed through the Warburton-Kallakoopah management unit, lowering salinity and dispersing large numbers of immigrants into this reach. A combination of increased competition and a reduction in aquatic salinity resulted in decreased desert goby abundance.

Desert rainbowfish (Melanotaenia splendida tatei)

Desert rainbowfish are a common and widespread species throughout the Lake Eyre Basin. Despite this, abundances were low throughout the study with only one fish caught in the first two years of the study. This suggests that key source populations for this species are within the Queensland portion of the catchment. During 2016 interstate populations dispersed downstream to Tinnie Landing (Table 9), highlighting the capacity of rainbowfish to move early on the arrival of flow and to penetrate deeply into newly wetted habitats. Desert rainbowfish disperse on flow but populations do not boom immediately, and will typically require a delay of several months before spawning takes place. As such, the low abundances observed in this study, reflect unsuitable flow conditions rather than a decline in ecosystem condition.

Hyrtl's tandan (Neosilurus hyrtlii)

Hyrtl’s tandan were present during all sampling events in the Diamantina and Goyder Lagoon management units and at Tepamimi (Eyre Creek management unit) with the exception of Koonchera West in 2016. In the Diamantina management unit, this included fish of the maximum size class for this species suggesting this region is a key refuge for Hyrtl’s tandan. During 2015 and 2016, after connectivity was re-established with the lower catchment, this species displayed modest downstream range expansion when compared to other species, entering Ultoomurra and Stony Point in low abundances. In tropical, coastal catchments Hyrtl’s tandan are a flow cued spawner which move upstream at the commencement of monsoonal flow (Orr and Milward, 1984). A preference for upstream movement on flow may explain why Hyrtl’s tandan numbers decreased with increases in flow and why downstream range extensions were modest.

Lake Eyre golden perch (Macquaria sp.)

Lake Eyre golden perch is a large-bodied angling species with strong migratory capacity. This species was detected during all sampling events in the Diamantina management unit and Tepamimi (Eyre Creek management unit). This distribution highlights a preference for permanent habitats with low salinity where it is capable of reaching large sizes.

In 2015 moderate channel flows reconnected the Diamantina management unit to the upper reaches of the Warburton-Kallakoopah management unit. This enabled Lake Eyre golden perch to migrate downstream to Ultoomurra and Stony Point (Figure 7). This migration included a broad range of size classes indicating that downstream migratory behaviour is not limited to juvenile life stages. In 2016 juvenile Lake Eyre golden perch and spangled grunter were the only species to penetrate the previously dry, Tippipilla Creek. This species moves during periods of flow. This movement occurs throughout the life span of the fish.

Lake Eyre hardyhead (Craterocephalus eyresii)

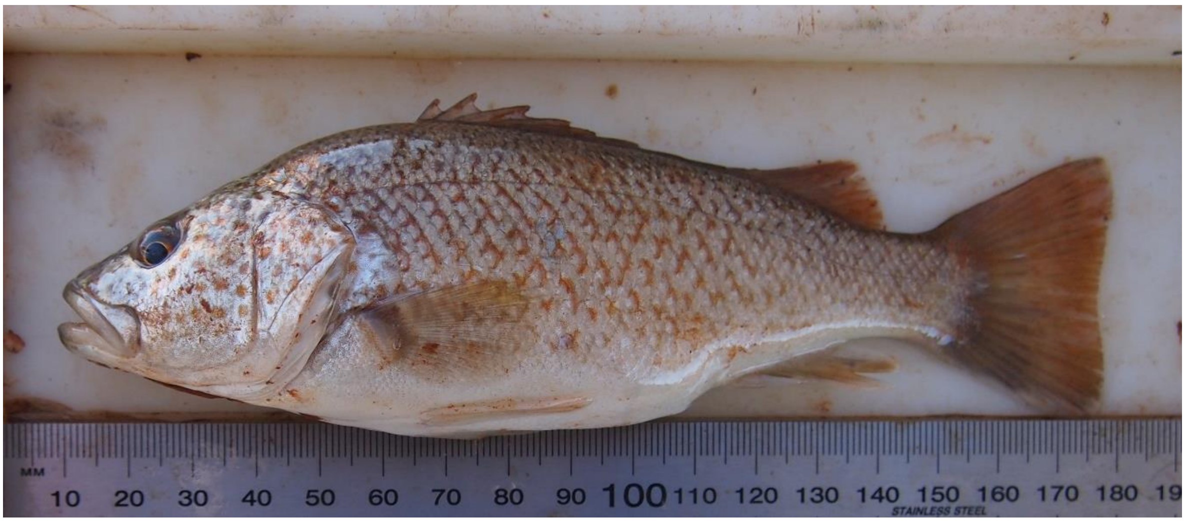
Lake Eyre hardyhead are an extremophile fish which specialise in water conditions too saline to support most other species in the catchment (Figure 10). For this reason their populations are highest in the lowest reaches of the catchment where lower rainfall and saline groundwater influences result in waterholes with elevated salinity. They appear to have limited capacity to persist in freshwater and during the current study were only detected in the Warburton-Kallakoopah management unit, although they are known historically from the Goyder Lagoon management unit (Costelloe et al., 2004) and the ephemeral Mulligan River in the Queensland catchment (Kerezsy et al., 2013a).

During 2014 and 2015, where flow did little to refresh the lower catchment, Lake Eyre hardyhead were the most abundant fish and constituted the majority of fish caught in both years. Channel flows in 2016 flowed through the management unit lowering salinity and introducing large numbers of immigrants. Lake Eyre hardyhead populations were greatly decreased at this time, however, this is a seemingly normal phenomena that has been observed on several occasions during other LEB studies (McNeil and Schmarr, 2009, Schmarr et al., 2013, Schmarr et al., 2015, Duguid et al., 2016).

Silver tandan (Porochilus argenteus)

The silver tandan is a species of catfish that are typically found throughout the Diamantina and Cooper Creek systems within the LEB. They can grow up to 300mm and are known to migrate in large numbers. This species was present at every sampling event in the Diamantina management unit and at Tepamimi (Eyre Creek management unit) during 2015. The Diamantina population included very large silver tandan most years, indicating that the Diamantina management unit is a key refuge for this species as the species is known to maintain populations in permanent waterholes and moves on large flow events. During 2015 this species dispersed throughout the system and was detected at 16 of the 18 sites which contained fish and was observed as far downstream as Tinnie landing. In 2016 this species was only observed in the upper Warburton River, with lower abundance and distribution than that of 2015. The largest size classes for this species were present within the Diamantina management unit.

Spangled grunter (Leiopotherapon unicolor)



Spangled grunter (also known as spangled perch) tend to move immediately at the commencement of flow and through prolonged swimming are adept at penetrating deep into newly wetted habitats.

Spangled grunter have a very large heart and gill surface area when compared to other fishes (Gehrke, 1987) which facilitates oxygen uptake and promotes improved endurance. In 2016 spangled grunter and Lake Eyre golden perch were the only species to penetrate the newly wetted Tippipilla Creek. Rapid movement was also observed in 2015 when spangled grunter (along with bony herring and silver tandan) used novel flow to reach Tinnie Landing. Strong flows present during 2016 resulted in increased spangled grunter numbers in the catchment. This included spangled grunter in the Diamantina management unit for the first time during this study. The Georgina-Diamantina source populations for this species appears to be upstream, in Queensland.

Despite their capacity for strong, long-distance swimming, they appear to be poor competitors and tend not to feature strongly in stable communities in South Australia (Mathwin et al., 2015a, Schmarr et al., 2015, Duguid et al., 2016).

Welch's grunter (Bidyanus welchi)

Welch's grunter displayed similar distributions to the closely related Barcoo grunter but were in higher abundances on most sampling events. Welch's grunter were detected on every sampling occasion in the Diamantina management unit and included fish of the maximum reported size class for this species. This indicates that even in dry times (e.g. 2014) this management unit is a high quality refuge for the long term survival of this species and is likely acting as a source population for this species.

During 2015 and 2016 downstream range expansions in this species were modest (to Ultoomurra) suggesting limited capacity for migration. This species moves during large flows but is slower to move than other species.

Invasive species

Eastern gambusia (Gambusia holbrooki)

Gambusia had a restricted distribution, typically centred on anthropogenic habitats fed by artesian bores (Tepamimi, Poonarunna, Mungerannie Wetland). Gambusia are a hardy fish, tolerant of the harsh water chemistry typical in artesian bores. In these stable habitats, this species often dominated the fish assemblage and reached very high densities (up to 4,710 fish). During periods of connectivity this species appeared to move out of anthropogenic refuges and entered the main channel waterholes.

In this study three sampling events were carried out in anthropogenic refuges created by uncapped artesian bores feeding into waterholes. Twice at Tepamimi (Eyre Creek management unit) in autumn 2014 and 2015 and at Poonarunna bore (Warburton-Kallakoopah management unit) in 2014. Each of these three samples triggered an attribute VI TPC (non-native taxa) due to large populations of gambusia dominating the fish population. It is anticipated that further sampling in bore-fed anthropogenic refuges in the Georgina-Diamantina management unit would result in further TPCs being triggered. The presence of low numbers of gambusia in main channel waterholes following flow events should trigger management action to control anthropogenic refugia.

In contrast to Cooper Creek where there are three invasive species present (Schmarr et al., 2016), the Diamantina only has one invasive species. The threat posed by invasive species in Cooper Creek was recently increased through the emergence of a new invasive species in sleepy cod (*Oxyeleotris linealata*). The cumulative impact of multiple invasive species and other threats has impacted the overall condition score of Cooper Creek in comparison to the Diamantina (Lake Eyre Basin Ministerial Forum, 2017). Genetic studies indicate that dispersal and migration between Cooper Creek and the Diamantina Catchment appear to be very limited (Beheregaray and Attard, 2015), which leaves transport over land as the most likely mode of dispersal for sleepy cod. Whilst the threat from invasive species in the Diamantina appears to be limited to Gambusia at the moment, the introduction of additional invasive species through human intervention should be avoided through increased education and awareness.

7.7 Salinity

Salt is a dominant feature of the Lake Eyre Basin and has been a defining characteristic of the aquatic landscape of the Basin since the earliest European explorers described the region (Eyre, 1845). Salinisation is a key characteristic of endorheic river basins like Kati Thanda-Lake Eyre, Lake Chad in Africa and the Great Salt Lake in North America (Bailey et al., 2006). This is particularly prevalent in the downstream extremes of rivers entering the sub-sea level Kati Thanda-Lake Eyre where permanent waterbodies become saline during bust periods, a trend which may either relate to saline groundwater influence or salt concentration through drying.

Early ecological and biological accounts of the Lake Eyre Basin focused heavily on the extreme environmental harshness of the system and in particular, the seemingly ubiquitous pressure from salinisation on riverine and wetland habitats (Glover, 1973, Glover and Sim, 1978b). It was also acknowledged that salinity in both groundwater and surface water systems was likely to be in a state of permanent flux (Glover, 1973) and that adaptations of fish would need to cover a broader range of tolerance to both freshwater and saline conditions.

Salinity tolerance trials have established that all fish species tested were tolerant of freshwater and that a wide range of tolerances to high salinity was observed (Glover and Sim, 1978a). Whilst lab estimates undertaken in McNeil et al. (2011) provide excellent comparative data across species, field observations detailed within the results of this report revealed that in the wild species tolerances were far higher than those recorded in the laboratory.

Salinity profiles presented within the results for the South Australian section of the Georgina-Diamantina catchment describe a typical trend of increased salinity of waterholes towards the downstream sections of the catchment. Hypersaline environments, usually only encountered during the bust phase, typically start near the downstream (southern) end of Goyders Lagoon, where the Eyre Creek and Diamantina Rivers converge to become the Warburton. Most on channel sites from Ultoomurra onwards (downstream) typically present as hyper saline during the bust period. Thus, these sites are predominantly characterised by both extremophile fish species, Lake Eyre hardyhead and desert gobies, which are capable of living in environments that reach saline levels several times that of sea water (>100 ppt).

Some sites within the study area, such as Stony Point, were observed to have supported both extremophile fish species throughout the entirety of the bust phase; whilst others, such as Cowarie Crossing, were observed to have gradually increased salinity concentrations beyond that which could support any fish life (>130 ppt). Similar trends such as these have been observed previously in several LEB rivers, including the Neales River, Finke River and Cooper Creek (Schmarr et al., 2016) and appear to be a naturally occurring process; however, increases in the distribution, prevalence and duration of saline waterholes may indicate degradation of the abiotic environment, which will ultimately effect the viability of biological assets within these aquatic systems in future.

7.8 Fish Disease

Spinal Malformation

Incidence of disease in fish was generally very low over the course of this study. However, at Mona Downs in 2016 (fish community consisting of five species dominated by spangled grunter) spinal malformation was present in all spangled grunter on this occasion (Figure 13). Scoliosis, lordosis and kyphosis are descriptive terms referring to directional malformation of the spine all of which impact a fish's ability to disperse, compete for food resources and escape predation. All three forms of spinal malformation were present in the population, but kyphosis and lordosis were most commonly observed. The underlying causes of spinal malformation are varied and may include; temperature dependant genetic development (Grimes et al., 2016), may be seen as a symptom of disease or parasite infection (Yokoyama et al., 2004), as a response to pesticide exposure (Couch et al., 1977), amino acid deficiency (Kloppel and Post, 1975) or vitamin deficiency (Halver et al., 1975). Although it is unclear what the causative agent was in this population, pesticide exposure may be ruled out (as Cowarie is a certified organic station) and population wide deficiency in a vitamin or amino acid seems unlikely. Given the geographic isolation of this population and the penetrance of the malformation, the etiology appears to be genetic.

7.9 Other Taxa

Emmott's Short-Necked Turtle (*Emydura macquarii*)

Emmott's short-necked turtle (*Emydura macquarii emmotti*) (Figure 14) is a subspecies of the southern clade of southern river turtles *Emydura macquarii* (Gray, 1830) which includes *E. macquarii macquarii*, *E. m. krefftii* and *E. m. nigra*. Electrophoretic tests of genetic diversity within *E. macquarii* distinguished no distinct taxons within southern river turtles which share even rare genes (Georges and Adams, 1996). However, subsequent mitochondrial sequence data recognised distinct haplotypes within the clade and Emmott's short-necked turtle is a currently recognised subspecies (Georges and Thomson, 2010).

This species is known predominantly from the Cooper Creek catchment where they are commonly observed in deep permanent waterholes or in proximate waterholes during dispersal and boom phases. This has led to their other common name, the Cooper Creek Turtle. Prior to this study only a single definitive record of turtles in the Georgina-Diamantina catchment existed. This was from 2003 when two individuals were caught at Clifton Hills Outstation (a sub-site within Yammakira Waterhole) during sampling for the Aridflo project (Costelloe et al., 2004). Turtle fossils are also observed at Cowarie Crossing, however these date back to a much wetter climatic period about 100,000 – 200,000 years ago (G. Prideaux pers comm.) and do not necessarily reflect the persistence of turtle populations in the catchment.

Although this species is widespread and abundant in the Cooper Creek catchment only 17 turtles were detected in the current study (Table 12). These were restricted to three sites within a localised area in the Diamantina management unit (Diamantina Split, Yammakira and Andrewilla). Both Andrewilla and Yammakira are large, deep permanent waterholes of a similar typology to the habitats associated with this species in the Cooper catchment (Schmarr et al., 2013). Turtles in the Diamantina were encountered less frequently and abundances were lower despite superficial similarities in refuge typology. This suggests that the Georgina-Diamantina turtle population is much smaller than that of the Cooper (with both fewer individuals and a smaller range). It is unclear why the Diamantina turtle population is smaller than that of the Cooper but may relate to: the population only being recently translocated to the catchment, unsuitable habitat characteristics or interspecies competition or predation.

The history of turtles in the Georgina-Diamantina is unclear. Communication with Don Rowlands (Wangkangurru Traditional Owner) and Dr Luise Hercus (Australian National University linguistics researcher) indicate that there is no evidence in Aboriginal language or song of freshwater turtles in the Diamantina River.

The distance for a turtle to migrate across land, beginning its journey near the Coongie Lakes system (Cooper Creek) and ending its journey in Koonchera (Georgina-Diamantina catchment) is about 45 km. During very wet periods (like those seen in 1974 flooding) much of the intervening land is inundated with interdune pools and small endorheic lakes and through a circuitous route it would be possible for a turtle to make much of the journey within ephemeral waterbodies (Figure 19). Ephemeral waterbodies in the LEB contain abundant food resources for turtles including tadpoles (e.g. *Cyclorana platycephala*) and fairy shrimp (*Branchinella* sp.) (Mathwin et al., 2015b). It is not beyond reckoning that during a protracted flood period, one or more Emmott's short-necked turtles could complete a cross-country migration between the two catchments. Despite this possibility, the most plausible explanation for the presence of Emmott's short-necked turtle in this catchment is an anthropogenic translocation between the two catchments within the last 200 years.

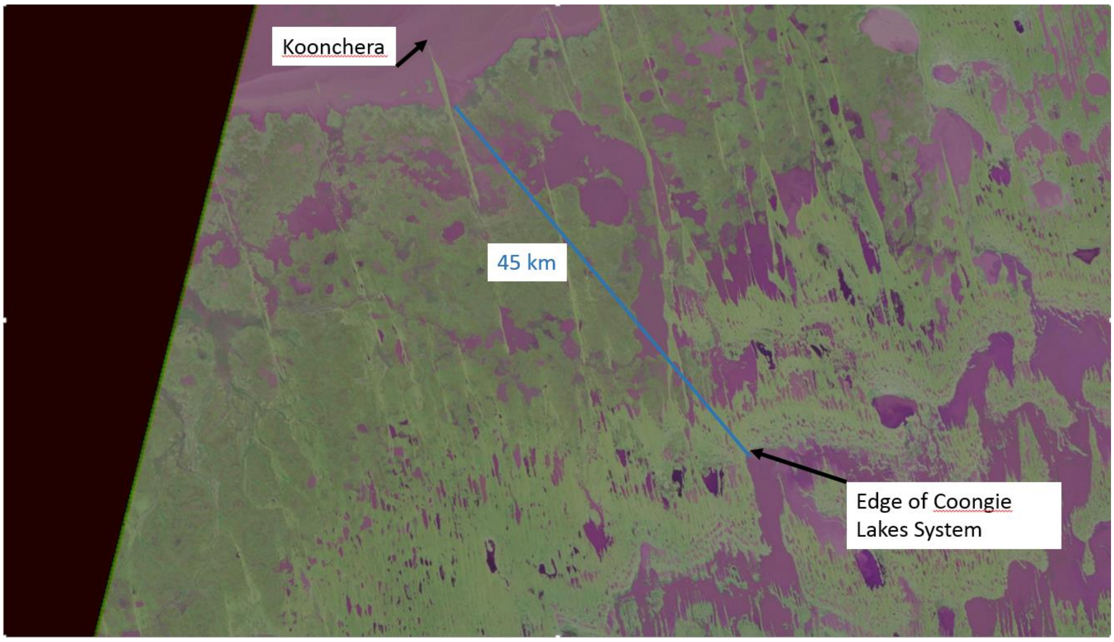


Figure 19. Landsat satellite imagery from February 1974 was taken during landscape level flooding which filled Lake Eyre. Purple indicates water

Crustaceans

Catches of yabbies in this study were insufficient to show definitive patterns in distribution and abundance, but they appear to be restricted to Goyder Lagoon and upstream. This is most likely due to the shallow saline aquifer in the lower reaches producing surface water too salty for them to tolerate (Mills and Geddes, 1980) and preventing burrowing. Habitats in the Warburton/Kallakoopah region where saline groundwater is absent were subject to drying periods too long for yabbies to survive in burrows. Further study into the drivers of yabby population dynamics is required to properly ascertain their status in this system.

Shrimp species were restricted to the Goyder Lagoon and Diamantina management units in 2014 and 2015. They were absent from the Warburton/Kallakoopah at this time due to lack of freshwater flows large enough to decrease salinity in the region. The shrimp species present in the Diamantina tolerate salinity up to 30-40 mS/cm (Dunlop et al., 2008). Salinity values in the Warburton/Kallakoopah region were well in excess of these values in 2014 and 2015. As large flows in 2016 provided connectivity throughout the catchment and kept salinity low in the lower reaches, these shrimp species which have effective dispersal capabilities (Cook et al., 2002), became more prevalent. The timing of this dispersal is important as they are an important prey item for many fish species that also became more prevalent in this area in 2016.

Freshwater crabs are highly adapted to arid conditions through their adoption of burrowing behaviour (Greenaway and MacMillen, 1978) and physiological dormancy (MacMillen and Greenaway, 1978). Using this strategy, freshwater crabs are able to conserve water by slowly metabolising fat to access water whilst losing very little water to the humid conditions in their burrows. This strategy has enabled them to occupy ephemeral habitats throughout the arid zone. Given that freshwater crabs were present in saline waters when yabbies and shrimp were absent, they appear to have a higher tolerance of salinity than yabbies and shrimp, although their salinity tolerance is not reported in the literature. In 2014, most of the waterholes in the Warburton/Kallakoopah region were extremely hypersaline and crabs were not captured, although they had been present there prior to the survey as evidenced by large numbers of dead crabs at this time. Smaller flows in 2015 decreased salinity in the lower reaches enabling crabs to emerge from burrows and survive in the fresher water. Large flows in 2016 were also favourable for crabs to survive in the lower reaches of the study area.

Redclaw (Cherax quadricarinatus)

Redclaw crayfish (*Cherax quadricarinatus*), are a species of freshwater crayfish endemic to tropical and sub-tropical parts of northern Australia. Considered to be a translocated pest species within the LEB, they have been recorded in the upper to mid reaches of the Georgina, Diamantina and Cooper catchments (Cockayne et al., 2012a). In the Georgina catchment, redclaw have previously been collected at sites as far south as Bedourie, whilst in the Diamantina catchment, redclaw were found as far south as the Diamantina National Park (B. Cockayne pers. obs.). Despite extensive sampling, redclaw were not captured below the South Australian border during this study. Redclaw are a moderately mobile species and it is unclear why they have not dispersed into South Australian waters yet. There are conflicting lower thermal tolerance values for redclaw in the published literature, with some values as high as 22°C and some as low as 4°C (Westhoff and Rosenberger, 2016), however the species has a narrow temperature range for optimal growth (King, 1994). The water temperature range at one site in the Warburton/Kallakoopah management unit was between 8.4°C in winter and 31.8°C in summer (SA Water Gauge A0021005 at Poothapoota Waterhole). These values may be at the limits of redclaw survival and may explain the absence of this species thus far. However, more favourable conditions may exist in waterholes upstream in the Diamantina management unit. It is essential that ongoing monitoring remain in place to detect encroachment of redclaw into South Australian waters.

Exotic crayfish species occupy a similar ecological niche to that of the native yabby (*Cherax destructor*) and are likely to compete for resources, particularly food and residential habitats. Within South Australia, introduced freshwater crayfish such as marron (*Cherax cainii*) have been recorded in high abundance throughout southern Fleurieu rivers, with notable reductions in populations of native yabbies recorded in these areas when compared with nearby catchments (SARDI unpublished data). International studies on introduced freshwater crayfish species also indicate possible impacts upon other aquatic biota such as macrophytes, macroinvertebrates, amphibians and fishes (Ahyong and Yeo, 2007).

7.10 Key Recommendations

The findings from this study have highlighted a range of management recommendations:

1. The fish community composition and ecosystem response in each management unit largely concurred with the hydrological and geomorphological patterns that defined each unit. Therefore it is recommended that the proposed management units are adopted to frame future management in the region.
2. The high abundance of gambusia exclusively in bore-fed wetlands should be used as a trigger for managing artesian bores to control or eliminate source populations of gambusia.
3. Despite relatively low flows into South Australia over the period of this study, fish populations were able to flourish in the available habitat. These low flows need to be protected from water development upstream.
4. The risk of novel invasive fish species being translocated to the Diamantina and other catchments should be minimised through increased public education.
5. Whilst every attempt was made to cover the full range of habitats in the South Australian section of the Diamantina, sampling in Goyder Lagoon was severely restricted in this study. As a consequence, the understanding of fish species' use of this habitat is also limited. Future studies should consider more comprehensive surveys in the Goyder Lagoon management unit.

8 Appendix A

8.1 Water quality Measurements

Date	Site_Name	Depth (m)	DO%	pH	Salinity	Specific Gravity	TDS	Temperature	Turbidity
4/04/2014	Mungerannie Wetland	Surface	58.2	9.4	0.9	0.0	1.2	24.7	38.3
4/04/2014	Mungerannie Wetland	1.0	42.2	9.4	1.0	0.0	1.2	21.6	46.6
6/04/2014	Pandie Pandie HS	1.0	98.1	8.3	0.1	0.0	0.1	24.7	377.0
6/04/2014	Pandie Pandie HS	2.5	83.5	7.9	0.1	0.0	0.1	24.6	380.0
29/04/2014	Ultoomurra	Surface	107.6	9.0	64.0	46.7	54.0	22.1	150.0
29/04/2014	Ultoomurra	0.5	84.1	8.9	63.9	46.7	54.0	22.0	147.0
29/04/2014	Ultoomurra	1.0	40.9	8.8	63.8	46.8	53.9	21.3	121.0
29/04/2014	Ultoomurra	1.5	15.7	8.8	63.9	47.0	54.0	20.6	81.3
29/04/2014	Ultoomurra	1.8	5.8	8.8	63.9	47.1	54.1	20.4	90.5
1/05/2014	Goyder Lagoon WH	Surface	0.0	8.2	0.1	0.0	0.2	15.2	329.0
1/05/2014	Goyder Lagoon WH	0.7	0.4	8.3	0.1	0.0	0.2	15.0	344.0
2/05/2014	Koonchera	Surface	83.9	8.6	0.1	0.0	0.2	17.8	103.0
2/05/2014	Koonchera	0.5	77.4	8.1	0.1	0.0	0.2	17.8	103.0
2/05/2014	Koonchera	1.1	71.5	7.9	0.1	0.0	0.2	17.8	498.0
3/05/2014	Koonchera	Surface	83.9	8.6	0.1	0.0	0.2	17.8	103.0
3/05/2014	Koonchera	0.6	77.4	8.1	0.1	0.0	0.2	17.8	103.0
3/05/2014	Koonchera	1.1	71.5	7.9	0.1	0.0	0.2	17.8	498.0
4/05/2014	Yammakira	Surface	49.5	8.5	0.1	0.0	0.1	18.6	0.0
4/05/2014	Yammakira	0.5	53.7	8.5	0.1	0.0	0.1	18.3	605.0
4/05/2014	Yammakira	1.0	53.2	8.6	0.1	0.0	0.1	18.3	615.0
4/05/2014	Yammakira	1.6	54.3	7.8	0.1	0.0	0.1	18.2	698.0
4/05/2014	Yammakira	2.1	58.7	7.7	0.1	0.0	0.1	18.1	866.0
4/05/2014	Yammakira	2.5	59.3	7.7	0.1	0.0	0.1	18.1	955.0
4/05/2014	Yammakira	2.9	61.5	7.7	0.1	0.0	0.1	18.1	89.7
4/05/2014	Yammakira	3.0	68.0	7.7	0.1	0.0	0.1	18.1	835.0
6/05/2014	Tepamimi	Surface	62.7	9.9	0.9	0.0	1.1	18.0	125.0
6/05/2014	Tepamimi	0.5	57.6	10.0	0.9	0.0	1.1	17.9	126.0
6/05/2014	Tepamimi	1.1	56.4	10.0	0.9	0.0	1.2	18.0	115.0

Date	Site_Name	Depth (m)	DO%	pH	Salinity	Specific Gravity	TDS	Temperature	Turbidity
6/05/2014	Tepamimi	1.5	55.9	10.0	0.9	0.0	1.2	17.9	111.0
6/05/2014	Tepamimi	2.0	55.5	10.0	0.9	0.0	1.2	17.9	160.0
6/05/2014	Tepamimi	3.1	46.8	7.9	0.1	0.0	0.1	17.4	988.0
7/05/2014	Andrewilla	Surface	44.5	7.8	0.1	0.0	0.1	18.0	1000.0
7/05/2014	Andrewilla	0.5	44.6	7.8	0.1	0.0	0.1	17.8	934.0
7/05/2014	Andrewilla	1.0	44.8	7.9	0.1	0.0	0.1	17.6	974.0
7/05/2014	Andrewilla	1.5	45.4	7.9	0.1	0.0	0.1	17.6	994.0
7/05/2014	Andrewilla	2.1	44.8	7.9	0.1	0.0	0.1	17.5	1000.0
7/05/2014	Andrewilla	2.6	47.0	7.9	0.1	0.0	0.1	17.5	1000.0
7/05/2014	Andrewilla	3.1	45.6	7.9	0.1	0.0	0.1	17.5	1000.0
8/05/2014	Pandie Pandie HS	Surface	133.5	7.4	0.1	0.0	0.1	16.5	967.0
8/05/2014	Pandie Pandie HS	0.5	123.8	7.3	0.1	0.0	0.1	16.4	972.0
8/05/2014	Pandie Pandie HS	1.0	119.4	7.2	0.1	0.0	0.1	16.3	967.0
8/05/2014	Pandie Pandie HS	1.6	109.9	7.1	0.1	0.0	0.1	16.2	963.0
8/05/2014	Pandie Pandie HS	2.1	86.9	7.0	0.1	0.0	0.1	16.1	1000.0
9/05/2014	Diamantina Split	Surface	76.5	7.3	0.1	0.0	0.1	16.8	19.0
9/05/2014	Diamantina Split	0.6	53.8	7.9	0.1	0.0	0.1	16.3	0.0
9/05/2014	Diamantina Split	0.9	80.4	6.5	0.1	0.0	0.1	17.2	0.0
9/05/2014	Diamantina Split	1.0	44.8	7.9	0.1	0.0	0.1	16.2	0.0
9/05/2014	Diamantina Split	1.6	48.7	7.8	0.1	0.0	0.1	16.2	0.0
9/05/2014	Diamantina Split	2.0	49.1	7.7	0.1	0.0	0.1	16.2	0.0
9/05/2014	Diamantina Split	2.5	44.8	7.7	0.1	0.0	0.1	16.1	0.0
9/05/2014	Diamantina Split	3.1	48.9	7.6	0.1	0.0	0.1	16.1	0.0
9/05/2014	Diamantina Split	3.6	45.5	7.6	0.1	0.0	0.1	16.0	0.0
9/05/2014	Diamantina Split	3.7	44.8	7.6	0.1	0.0	0.1	16.0	0.0
10/05/2014	Kalamunkinna	Surface	154.6	7.9	111.0	32.7	40.9	23.6	39.1
12/05/2014	Stony Point	Surface	181.2	8.3	99.5	35.1	43.5	23.7	275.0
12/05/2014	Stony Point	0.2	214.2	7.7	99.5	50.0	60.0	19.1	640.0
12/05/2014	Stony Point	0.6	146.4	7.7	99.5	50.0	60.0	18.8	635.0
12/05/2014	Stony Point	0.8	134.6	7.7	99.5	50.0	60.0	18.7	797.0
14/05/2014	Poonarunna Bore	Surface	184.8	8.8	1.9	0.1	2.3	18.7	0.0

Date	Site_Name	Depth (m)	DO%	pH	Salinity	Specific Gravity	TDS	Temperature	Turbidity
14/05/2014	Poonarunna Bore	0.5	186.4	8.8	1.9	0.2	2.3	18.2	0.0
14/05/2014	Poonarunna Bore	0.7	171.5	8.9	1.9	0.1	2.3	18.3	524.0
16/05/2014	Yellow WH (salinity only)	Surface			108.0				
8/04/2015	Cowarie Crossing	Surface	162.6	9.1	7.8	4.3	8.4	19.9	31.2
8/04/2015	Cowarie Crossing	0.5	167.6	10.7	7.8	4.4	8.4	19.4	33.3
8/04/2015	Cowarie Crossing	1.0	144.6	10.5	7.9	4.4	8.5	19.4	69.1
6/05/2015	Pandie Pandie HS	0.3	176.2	9.5	40.6	30.9	37.0	12.4	26.9
10/05/2015	Double Bluff WH	Surface	36.3	8.9	0.1	0.0	0.2	17.9	625.0
10/05/2015	Double Bluff WH	0.5	4.3	8.9	0.1	0.0	0.2	17.4	619.0
10/05/2015	Double Bluff WH	1.1	1.8	8.9	0.1	0.0	0.2	17.2	618.0
10/05/2015	Double Bluff WH	1.4	0.6	8.8	0.1	0.0	0.2	16.5	744.0
12/05/2015	Diamantina Split	Surface	75.3	8.8	0.1	0.0	0.1	20.2	547.0
12/05/2015	Diamantina Split	0.5	26.3	8.8	0.1	0.0	0.1	17.6	550.0
12/05/2015	Diamantina Split	1.0	2.9	8.6	0.1	0.0	0.1	17.2	550.0
12/05/2015	Diamantina Split	1.6	0.1	8.5	0.1	0.0	0.1	17.0	555.0
12/05/2015	Diamantina Split	2.0	0.0	8.4	0.1	0.0	0.1	16.6	570.0
12/05/2015	Diamantina Split	2.5	0.0	8.4	0.1	0.0	0.1	16.4	576.0
12/05/2015	Diamantina Split	3.0	0.0	8.4	0.1	0.0	0.1	16.4	579.0
12/05/2015	Diamantina Split	3.6	0.0	8.2	0.1	0.0	0.1	16.3	579.0
12/05/2015	Diamantina Split	4.1	0.0	8.1	0.1	0.0	0.1	16.3	581.0
12/05/2015	Diamantina Split	4.5	0.0	8.1	0.1	0.0	0.1	16.3	609.0
12/05/2015	Diamantina Split	4.8	2.5	8.3	0.1	0.0	0.1	16.3	648.0
13/05/2015	Andrewilla	Surface	5.8	8.7	0.1	0.0	0.1	16.4	482.0
13/05/2015	Andrewilla	0.6	0.0	8.7	0.1	0.0	0.1	16.4	482.0
13/05/2015	Andrewilla	1.1	0.0	8.7	0.1	0.0	0.1	16.4	484.0
13/05/2015	Andrewilla	1.7	0.0	8.7	0.1	0.0	0.1	16.3	484.0
13/05/2015	Andrewilla	2.5	4.2	8.7	0.1	0.0	0.1	16.3	482.0
13/05/2015	Andrewilla	3.0	2.5	8.7	0.1	0.0	0.1	16.3	483.0
13/05/2015	Andrewilla	4.1	1.9	8.6	0.1	0.0	0.1	16.3	485.0
13/05/2015	Andrewilla	4.2	18.5	8.5	0.1	0.0	0.1	16.2	486.0
13/05/2015	Andrewilla	5.6	11.8	8.4	0.1	0.0	0.1	16.2	1000.0

Date	Site_Name	Depth (m)	DO%	pH	Salinity	Specific Gravity	TDS	Temperature	Turbidity
13/05/2015	Burts WH	Surface	83.9	8.7	0.2	0.0	0.2	12.3	0.0
13/05/2015	Burts WH	0.5	74.1	8.7	0.2	0.0	0.2	11.9	0.0
13/05/2015	Burts WH	0.8	60.2	8.7	0.2	0.0	0.2	11.7	0.0
14/05/2015	Tepamimi	Surface	98.6	10.1	0.9	0.0	1.1	16.4	113.0
14/05/2015	Tepamimi	0.5	79.3	10.1	0.9	0.0	1.1	16.2	107.0
14/05/2015	Tepamimi	1.0	75.1	10.1	0.9	0.0	1.1	15.5	115.0
14/05/2015	Tepamimi	1.6	72.6	10.2	0.9	0.1	1.1	13.9	115.0
14/05/2015	Tepamimi	1.8	56.6	10.2	0.9	0.1	1.2	13.4	118.0
14/05/2015	Tepamimi	2.0	51.8	10.2	0.9	0.1	1.2	13.4	138.0
15/05/2015	Pandie Pandie HS	Surface	96.2	9.1	0.1	0.0	0.2	14.8	429.0
15/05/2015	Pandie Pandie HS	0.6	74.6	9.2	0.1	0.0	0.2	14.6	409.0
15/05/2015	Pandie Pandie HS	1.0	69.5	9.2	0.1	0.0	0.2	13.2	409.0
15/05/2015	Pandie Pandie HS	1.5	68.4	9.1	0.1	0.0	0.2	13.0	412.0
15/05/2015	Pandie Pandie HS	2.0	63.2	9.1	0.1	0.0	0.2	12.9	484.0
15/05/2015	Pandie Pandie HS	2.9	56.9	9.0	0.1	0.0	0.2	12.6	518.0
9/04/2016	Pandie Pandie HS	0.4	60.9	11.3	0.1	0.0	0.1	24.2	870.0
9/04/2016	Pandie Pandie HS	1.3	56.1	11.1	0.1	0.0	0.1	24.2	868.0
9/04/2016	Pandie Pandie HS	2.0	53.9	11.1	0.1	0.0	0.1	24.2	865.0
9/04/2016	Pandie Pandie HS	2.8	51.3	11.0	0.1	0.0	0.1	24.2	863.0
9/04/2016	Pandie Pandie HS	3.5	50.4	11.0	0.1	0.0	0.1	24.2	0.0
9/04/2016	Pandie Pandie HS	5.1	46.8	9.8	0.1	0.0	0.1	24.2	0.0
9/04/2016	Pandie Pandie HS	5.2	48.3	9.8	0.1	0.0	0.1	24.2	0.0
29/04/2016	Tinnie landing	Surface	87.3	10.0	3.8	0.8	4.4	22.1	72.8
29/04/2016	Tinnie landing	0.5	77.9	9.9	3.8	0.8	4.4	22.0	76.0
29/04/2016	Tinnie landing	1.0	66.6	9.9	3.8	0.9	4.4	21.8	81.4
29/04/2016	Tinnie landing	1.5	41.8	9.8	3.8	1.2	4.4	20.3	78.5
30/04/2016	Wadlarkaninna	0.1	22.8	12.0	0.3	0.0	0.4	20.8	0.0
30/04/2016	Wadlarkaninna	0.5	13.7	11.8	0.3	0.0	0.4	20.4	0.0
30/04/2016	Wadlarkaninna	1.0	9.4	11.6	0.3	0.0	0.4	19.7	0.0
30/04/2016	Wadlarkaninna	1.1	10.3	11.2	0.3	0.0	0.4	19.9	0.0
1/05/2016	Mia Mia	Surface	56.4	9.3	4.5	1.4	5.2	21.7	57.7

Date	Site_Name	Depth (m)	DO%	pH	Salinity	Specific Gravity	TDS	Temperature	Turbidity
1/05/2016	Mia Mia	0.6	53.4	9.3	4.6	1.5	5.2	21.7	59.1
1/05/2016	Mia Mia	1.0	46.5	9.3	4.6	1.5	5.2	21.6	62.7
1/05/2016	Mia Mia	1.4	44.7	9.5	4.6	1.5	5.2	21.6	112.0
2/05/2016	Yellow WH	0.1	70.5	9.7	5.1	2.1	5.7	20.5	98.1
2/05/2016	Yellow WH	0.4	63.0	9.7	5.1	2.1	5.7	20.5	101.0
3/05/2016	Cowarie Crossing	Surface	53.8	10.1	7.0	3.6	7.6	20.1	80.5
3/05/2016	Cowarie Crossing	0.5	45.3	10.2	6.9	3.5	7.6	20.4	60.0
3/05/2016	Cowarie Crossing	1.0	39.4	10.2	6.9	3.5	7.5	20.5	63.2
3/05/2016	Cowarie Crossing	1.5	41.6	10.3	6.9	3.5	7.5	20.6	62.6
3/05/2016	Cowarie Crossing	1.9	42.2	9.0	6.9	3.5	7.5	20.6	123.0
4/05/2016	Mona Downs	Surface	19.1	9.8	0.1	0.0	0.1	18.6	983.0
4/05/2016	Mona Downs	0.5	2.6	10.0	0.1	0.0	0.1	18.3	978.0
4/05/2016	Mona Downs	1.0	0.5	10.0	0.1	0.0	0.1	18.3	981.0
4/05/2016	Mona Downs	1.5	0.0	10.1	0.1	0.0	0.1	18.3	987.0
4/05/2016	Mona Downs	1.8	0.0	10.1	0.1	0.0	0.1	18.3	0.0
5/05/2016	Koonchera West	Surface	6.7	9.7	0.1	0.0	0.1	19.7	189.0
5/05/2016	Koonchera West	0.4	6.3	9.7	0.1	0.0	0.1	20.1	228.0
6/05/2016	Double Bluff WH	Surface	8.7	10.2	0.1	0.0	0.1	20.9	367.0
6/05/2016	Double Bluff WH	0.6	4.2	10.3	0.1	0.0	0.1	21.0	368.0
6/05/2016	Double Bluff WH	1.1	2.6	10.3	0.1	0.0	0.1	21.0	368.0
6/05/2016	Double Bluff WH	1.5	2.1	10.3	0.1	0.0	0.1	21.0	363.0
6/05/2016	Double Bluff WH	2.1	2.0	10.4	0.1	0.0	0.1	21.0	367.0
6/05/2016	Double Bluff WH	2.5	2.6	10.4	0.1	0.0	0.1	21.0	370.0
6/05/2016	Double Bluff WH	2.9	2.8	10.3	0.1	0.0	0.1	21.0	440.0
7/05/2016	Diamantina Split	Surface	8.3	13.1	0.1	0.0	0.1	21.2	357.0
7/05/2016	Diamantina Split	0.6	3.5	13.0	0.1	0.0	0.1	21.2	356.0
7/05/2016	Diamantina Split	1.0	1.6	13.1	0.1	0.0	0.1	21.2	357.0
7/05/2016	Diamantina Split	1.5	1.4	13.2	0.1	0.0	0.1	21.2	358.0
7/05/2016	Diamantina Split	2.0	2.3	13.3	0.1	0.0	0.1	21.2	357.0
7/05/2016	Diamantina Split	2.6	2.2	13.5	0.1	0.0	0.1	21.2	356.0
8/05/2016	Andrewilla	Surface	4.3	12.5	0.1	0.0	0.1	20.9	319.0

Date	Site_Name	Depth (m)	DO%	pH	Salinity	Specific Gravity	TDS	Temperature	Turbidity
8/05/2016	Andrewilla	0.6	0.4	12.6	0.1	0.0	0.1	21.0	313.0
8/05/2016	Andrewilla	1.0	0.0	12.5	0.1	0.0	0.1	21.0	314.0
8/05/2016	Andrewilla	1.5	0.0	12.4	0.1	0.0	0.1	21.0	317.0
8/05/2016	Andrewilla	2.1	0.0	12.3	0.1	0.0	0.1	21.0	317.0
8/05/2016	Andrewilla	2.6	0.0	12.3	0.1	0.0	0.1	21.0	315.0
8/05/2016	Andrewilla	3.1	0.0	12.4	0.1	0.0	0.1	21.0	315.0
8/05/2016	Andrewilla	4.1	0.0	12.5	0.1	0.0	0.1	20.9	318.0
8/05/2016	Andrewilla	4.3	0.0	12.6	0.1	0.0	0.1	21.0	450.0
11/05/2016	Andrewilla	Surface	4.3	12.5	0.1	0.0	0.1	20.9	319.0
11/05/2016	Andrewilla	0.6	0.4	12.6	0.1	0.0	0.1	21.0	313.0
11/05/2016	Andrewilla	1.0	0.0	12.5	0.1	0.0	0.1	21.0	314.0
11/05/2016	Andrewilla	1.5	0.0	12.4	0.1	0.0	0.1	21.0	317.0
11/05/2016	Andrewilla	2.1	0.0	12.3	0.1	0.0	0.1	21.0	317.0
11/05/2016	Andrewilla	2.6	0.0	12.3	0.1	0.0	0.1	21.0	315.0
11/05/2016	Andrewilla	3.1	0.0	12.4	0.1	0.0	0.1	21.0	315.0
11/05/2016	Andrewilla	4.1	0.0	12.5	0.1	0.0	0.1	20.9	318.0
11/05/2016	Andrewilla	4.3	0.0	12.6	0.1	0.0	0.1	21.0	450.0
13/05/2016	Pelican WH	Surface	37.4	9.6	0.1	0.0	0.1	17.7	888.0
13/05/2016	Pelican WH	0.5	13.5	9.7	0.1	0.0	0.1	17.6	894.0
13/05/2016	Pelican WH	1.0	9.3	9.7	0.1	0.0	0.1	17.6	895.0
13/05/2016	Pelican WH	1.6	22.6	9.8	0.1	0.0	0.1	17.5	888.0
13/05/2016	Pelican WH	2.1	11.8	9.8	0.1	0.0	0.1	17.5	885.0
17/05/2016	Tippipilla Creek Campsite	Surface	4.9	12.9	0.0	0.0	0.0	16.5	128.0
17/05/2016	Tippipilla Creek Campsite	0.5	0.0	12.9	0.0	0.0	0.0	16.1	179.0
18/05/2016	Ultoomurra	Surface	1.1	11.2	0.1	0.0	0.1	20.7	224.0
19/05/2016	Cowarie Crossing	Surface	73.1	10.0	0.1	0.0	0.2	20.1	552.0
19/05/2016	Cowarie Crossing	0.5	7.3	11.3	0.1	0.0	0.2	20.2	525.0
19/05/2016	Cowarie Crossing	1.0	4.5	11.4	0.1	0.0	0.2	20.3	499.0
19/05/2016	Cowarie Crossing	1.2	6.2	11.7	0.1	0.0	0.2	20.3	468.0

9 Appendix B

9.1 Georgina-Diamantina catchment Simper Analyses

Group q
Average similarity: 60.27

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Nematalosa erebi	1.01	39.90	5.34	66.21	66.21
Macquaria sp.	0.26	6.90	1.37	11.45	77.66

Group p
Average similarity: 64.19

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Nematalosa erebi	2.35	46.64	3.61	72.66	72.66
Leiopotherapon unicolor	0.66	8.79	1.27	13.70	86.36

Group j
Average similarity: 73.55

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Neosilurus hyrtlii	1.74	45.10	5.56	61.31	61.31
Macquaria sp.	0.55	11.21	1.52	15.24	76.55

Group m
Average similarity: 65.01

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Macquaria sp.	1.47	35.65	3.79	54.83	54.83
Porochilus argenteus	0.58	11.14	2.18	17.13	71.96
Nematalosa erebi	0.39	7.11	1.45	10.94	82.90

Group i
Average similarity: 61.40

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Macquaria sp.	0.42	27.54	2.98	44.85	44.85
Porochilus argenteus	0.29	13.40	1.43	21.82	66.67
Nematalosa erebi	0.14	6.94	1.52	11.31	77.98

Group e
Less than 2 samples in group
Group l
Average similarity: 64.56

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Porochilus argenteus	1.42	27.96	4.48	43.31	43.31
Nematalosa erebi	0.67	9.17	1.25	14.20	57.51
Neosilurus hyrtlii	0.45	7.61	3.90	11.79	69.30
Scortum barcoo	0.58	6.97	1.54	10.79	80.09

Group k
Average similarity: 68.11

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Neosilurus hyrtlii	0.81	27.53	4.17	40.42	40.42
Nematalosa erebi	0.55	14.70	2.18	21.58	62.00
Porochilus argenteus	0.25	7.70	2.27	11.30	73.30
Macquaria sp.	0.15	5.48	6.58	8.05	81.35

Group g
Average similarity: 57.19

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Nematalosa erebi	0.27	21.33	1.93	37.30	37.30
Macquaria sp.	0.12	14.77	2.33	25.82	63.12
Neosilurus hyrtlii	0.15	12.42	1.65	21.71	84.83

Group n
Average similarity: 54.85

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Melanotaenia splendida tatei	1.60	22.01	1.50	40.13	40.13
Ambassis sp.	1.36	13.61	1.16	24.81	64.94
Nematalosa erebi	0.92	8.74	1.28	15.93	80.87

Group c
Average similarity: 59.32

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Craterocephalus eyresii	3.42	42.98	2.84	72.45	72.45
Chlamydogobius eremius	1.84	15.18	1.24	25.60	98.05

Group r

Average similarity: 27.92

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Leiopotherapon unicolor	0.25	16.93	0.84	60.65	60.65
Craterocephalus eyresii	0.05	3.71	0.62	13.30	73.95
Macquaria sp.	0.03	2.16	0.25	7.75	81.71

Group h

Less than 2 samples in group

Group a

Average similarity: 100.00

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
No Fish	0.69	100.00	SD=0!	100.00	100.00

Group b

Average similarity: 62.06

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gambusia holbrooki	2.77	58.40	3.68	94.09	94.09

Group o

Average similarity: 58.08

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Macquaria sp.	2.23	21.22	SD=0!	36.54	36.54
Nematalosa erebi	2.23	19.34	SD=0!	33.30	69.84
Leiopotherapon unicolor	0.90	7.33	SD=0!	12.61	82.45

Group f

Average similarity: 78.47

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Melanotaenia splendida tatei	0.69	43.32	7.06	55.21	55.21
Ambassis sp.	0.15	9.08	5.47	11.58	66.78
Neosilurus hyrtlii	0.16	9.05	16.92	11.53	78.31

Group d

Less than 2 samples in group

10 Appendix C

10.1 Goyder Ecoregion BCG Rules

At the time of sampling had Birdsville received at least an average of 5000 ML/d of flows over the last 12 months? (No-1, Yes - 2)

1 – Flows have receded or have returned to seasonal flow patterns. When calculating BCG tier scores use the bust phase descriptors.

2 –Is this the first flow event to exceed 5000 ML/d within the last two years? (Yes -**3**, No – **4**)

3 – When calculating BCG Tier scores use the dispersal phase descriptors.

4 – This is a subsequent flow comprising a part of a supra-seasonal flood event. When calculating BCG tier scores use the boom phase descriptors.

When considering low, moderate or high abundances in the Goyder ecoregion, refer to this table.

Goyder Abundance Range			
Attribute	**Species**	**Low Abundance (<=)**	**High Abundance (>=)**
I	***Amniataba percoides***	0.06	0.06
	Glossogobius aureus	0.00	0.01
II	***Bidyanus welchi***	0.11	0.27
	***Macquaria* sp.**	0.71	3.32
	Scortum barcoo	0.05	0.16
III	***Neosilurus hyrtlii***	0.11	0.57
	Porochilus argenteus	0.19	0.87
	***Ambassis* sp.**	0.05	0.06
	Melanotaenia splendida tatei	0.06	0.12
IV	***Nematalosa erebi***	0.12	0.52
	Leiopotherapon unicolor	0.06	0.22
V	***Craterocephalus eyresii***	0.00	0.01
	Chlamydogobius eremius	0.00	0.01
VI	***Gambusia holbrooki***	0.00	0.01

BCG Tier	Description
Attribute I	**Rare taxa and species with unpredictable occurrence. (*Amniataba percoides* and *Glossogobius aureus*) Species with unpredictable occurrence are only scored if a historical record exists for locality.**
Tier 1	At least one rare taxa present.
Tier 2	
Tier 3	
Tier 4	
Tier 5	
Tier 6	Rare taxa absent due to catchment extirpation or global extinction. A Tier score of 6 triggers this site as a TPC.
Attribute II	**Large bodied resilient taxa (*Macquaria* sp., *Scortum barcoo* and *Bidyanus welchi*), species are only scored if a historical record exist for locality.**
Tier 1	Three large bodied resilient taxa present.
Tier 2	Two large bodied resilient taxa present, one with high abundance during boom phase, any abundance during dispersal and bust phases.
Tier 3	Two large bodied resilient taxa present in low to moderate abundance during boom phase. OR One large bodied taxa during bust phase.
Tier 4	Large bodied resilient taxa absent at any time with *at least two large bodied resilient taxa captured concurrently elsewhere in the Goyder ecoregion. (* only applies if more than two samples were taken at that time, otherwise score as Tier 3).
Tier 5	Large bodied resilient taxa absent at any time all large bodied resilient taxa present within the Goyder ecoregion within the last 12 months. A Tier score of 5 triggers this site as a TPC.
Tier 6	Large bodied resilient taxa absent at any time and not observed within the Goyder ecoregion in the previous 12 months. A Tier score of 6 triggers this site as a TPC.

Attribute III	**Resilient taxa (*Neosilurus hyrtlii*, *Porochilus argenteus*, *Ambassis* sp., *Melanotaenia splendida tatei*).**
Tier 1	More than two resilient taxa present. OR Two resilient taxa present with at least one species in high abundance during boom phase. OR More than one resilient taxa present, one in high abundance or two in moderate abundance during dispersal or bust phase.
Tier 2	Two resilient taxa present in moderate abundance during boom phase. OR More than one resilient taxa present, one in moderate abundance during bust phase. OR One species in high abundance during dispersal phase.
Tier 3	Two resilient taxa in any abundance during boom phase. OR One resilient taxa present during dispersal or bust phases.
Tier 4	One resilient taxa present during boom phase with *at least two other species captured concurrently within the Goyder ecoregion. OR Resilient taxa absent during dispersal phase with *some resilient taxa captured concurrently within the Goyder ecoregion. (* only applies if more than two samples were taken at that time, otherwise score as Tier 3).
Tier 5	Resilient taxa absent during the boom or dispersal phases with all resilient taxa captured in the Goyder ecoregion within the previous 5 years. A Tier score of 5 triggers this site as a TPC.
Tier 6	Resilient taxa absent due to regional extirpation (not during bust phase). A Tier score of 6 triggers this site as a TPC.

Attribute IV	**Resilient and resistant taxa (*Nematalosa erebi* and *Leiopotherapon unicolor*).**
Tier 1	Both resilient and resistant taxa present with at least one resilient and resistant taxa in high abundance during boom period and low abundance during dispersal and bust phases.
Tier 2	Both resilient and resistant taxa present during boom and dispersal phase. OR *Nematalosa erebi* present in moderate to high abundance during bust phase.
Tier 3	Only *Nematalosa erebi* present with *Leiopotherapon unicolor* captured concurrently within the Goyder ecoregion during boom phase. OR Only *Nematalosa erebi* present in low abundance during bust phase.
Tier 4	Only *Nematalosa erebi* present, no *Leiopotherapon unicolor* captured in the Goyder ecoregion during bust phase.
Tier 5	Only *Nematalosa erebi* present, no *Leiopotherapon unicolor* captured in the Goyder ecoregion during boom phase. A Tier score of 5 triggers this site as a TPC.
Tier 6	No bony herring present. A Tier score of 6 triggers this site as a TPC.

Attribute V	**Specialist taxa (*Craterocephalus eyresii* and *Chlamydogobius eremius*). Attribute is only scored if species are present. *Craterocephalus eyresii* have not been**

	historically documented
Tier 1	
Tier 2	
Tier 3	
Tier 4	
Tier 5	
Tier 6	Specialist taxa present. A Tier score of 6 triggers this site as a TPC.
Attribute VI	**Non-native or intentionally introduced taxa (*Gambusia holbrooki*). This Attribute is scored only where invasive taxa are present**
Tier 1	
Tier 2	
Tier 3	
Tier 4	Non-native taxa present in low abundance.
Tier 5	Non-native species present in moderate to high abundance.
Tier 6	Non-native fish dominate all other fish taxa in abundance. OR Range extension of non-native taxa (e.g. *Gambusia holbrooki* observed for the first time at this site). A Tier score of 6 triggers this site as a TPC.
Attribute VII	**Organism and population condition. This Attribute is scored for long lived native fish only, where historic record exists for locality. (**Disease & congenital abnormalities to be included with improved data.)**
Tier 1	Multiple age classes apparent for two or more long-lived taxa in catchment, evidence of recruitment.
Tier 2	Multiple age classes apparent for two or more long-lived taxa within catchment.
Tier 3	Multiple age classes apparent for at least one long-lived species within catchment.
Tier 4	Multiple age classes apparent for long-lived species within catchment within last 12 months.
Tier 5	No multiple age classes apparent for long-lived species within catchment within last 12 months.
Tier 6	No multiple age classes apparent for long-lived species within catchment over the last 5 years. A Tier score of 6 triggers this site as a TPC.

11 Appendix D

11.1 Warburton Ecoregion BCG Rules

At the time of sampling had Birdsville received at least an average of 5000 ML/d of flows over the last 12 months? (No-1, Yes - 2)

1 – Flows have receded or have returned to seasonal flow patterns. When calculating BCG tier scores use the bust phase descriptors.

2 –Is this the first flow event to exceed 5000 ML/d within the last two years? (Yes -**3**, No – **4**)

3 – When calculating BCG Tier scores use the dispersal phase descriptors.

4 – This is a subsequent flow comprising a part of a supra-seasonal flood event. When calculating BCG tier scores use the boom phase descriptors.

When considering low, moderate or high abundances in the Warburton ecoregion, refer to this table.

Warburton Ecoregion Abundance Range			
Attribute	**Species**	**Low Abundance (<=)**	**High Abundance (>=)**
I	***Amniataba percoides***	0.07	0.20
	Glossogobius aureus	0.00	0.01
II	***Bidyanus welchi***	0.08	0.28
	***Macquaria* sp.**	0.09	1.07
	Scortum barcoo	0.09	0.25
III	***Neosilurus hyrtlii***	0.06	0.31
	Porochilus argenteus	0.06	0.23
	***Ambassis* sp.**	0.00	0.01
	Melanotaenia splendida tatei	0.15	0.25
IV	***Nematalosa erebi***	0.09	8.89
	Leiopotherapon unicolor	0.08	0.59
V	***Craterocephalus eyresii***	0.14	23.86
	Chlamydogobius eremius	0.12	4.36
VI	***Gambusia holbrooki***	0.09	0.43

BCG Tier	Description
Attribute I	**Rare taxa and species with unpredictable occurrence. (*Amniataba percoides* and *Glossogobius aureus*) Species with unpredictable occurrence are only scored if a historical record exists for locality.**
Tier 1	At least one rare taxa present.
Tier 2	
Tier 3	
Tier 4	
Tier 5	
Tier 6	Rare taxa absent due to catchment extirpation or global extinction. A Tier score of 6 triggers this site as a TPC.
Attribute II	**Large bodied resilient taxa (*Macquaria* sp., *Scortum barcoo* and *Bidyanus welchi*), species are only scored if a historical record exist for locality.**
Tier 1	Two or more large bodied resilient taxa present or one large bodied resilient taxa present with high abundance during boom or dispersal phases. OR One or more large bodied resilient taxa present during bust phase.
Tier 2	One large bodied resilient taxa present with moderate abundance during boom, low abundance during dispersal phases.
Tier 3	One large bodied resilient taxa present with a low abundance during boom phase, large bodied resilient taxa absent during dispersal or bust phases.
Tier 4	Large bodied resilient taxa absent during boom phase with *at least one large bodied resilient taxa captured concurrently elsewhere in the Warburton ecoregion. (* only applies if more than two samples were taken at that time, otherwise score as Tier 3).
Tier 5	Large bodied resilient taxa absent during boom phase with all large bodied resilient taxa present within the Warburton ecoregion within the last 12 months. A Tier score of 5 triggers this site as a TPC.
Tier 6	Large bodied resilient taxa absent during boom phase and not observed within the Warburton ecoregion in the previous 12 months. A Tier score of 6 triggers this site as a TPC.

Attribute III	**Resilient taxa (*Neosilurus hyrtlii*, *Porochilus argenteus*, *Ambassis* sp., *Melanotaenia splendida tatei*).**
	***denotes a "concurrent clause"**
Tier 1	Three or more resilient taxa present during boom phase. OR More than one resilient taxa present during dispersal or bust phase.
Tier 2	Two resilient taxa present with one in high abundance during boom phase. OR One resilient taxa present during bust phase. OR One resilient taxa in high abundance during dispersal phase.
Tier 3	Two resilient taxa present. OR One resilient taxa present during dispersal phase OR Absent during bust phase.
Tier 4	One resilient taxa in low to moderate abundance during boom phase with *at least one other resilient taxa captured concurrently within the Warburton ecoregion. OR. Resilient taxa absent during dispersal phase with *some resilient taxa captured concurrently within the Warburton ecoregion. (* only applies if more than two samples were taken at that time, otherwise score as Tier 3).
Tier 5	Resilient taxa absent during the boom or dispersal phases with all resilient taxa captured in the Warburton ecoregion within the previous 5 years. A Tier score of 5 triggers this site as a TPC.
Tier 6	Resilient taxa absent due to regional extirpation (not during bust phase). A Tier score of 6 triggers this site as a TPC.

Attribute IV	**Resilient and resistant taxa (*Nematalosa erebi* and *Leiopotherapon unicolor*).**
	***denotes a "concurrent clause"**
Tier 1	Both resilient and resistant taxa present with at least one resilient and resistant taxa in high abundance during boom period and low abundance during dispersal and bust phases.
Tier 2	Both resilient and resistant taxa present during boom and dispersal phase, one species present during bust phase.
Tier 3	Only *Nematalosa erebi* during dispersal and boom phase. OR Resilient and resistant taxa absent during bust phase.
Tier 4	*Nematalosa erebi* absent during boom and dispersal phase but *captured concurrently at all other sites within the Warburton ecoregion. (* only applies if more than two samples were taken at that time, otherwise score as Tier 3).
Tier 5	Both resilient and resistant taxa absent during boom or dispersal phase, both captured concurrently in the Warburton ecoregion. A Tier score of 5 triggers this site as a TPC.
Tier 6	Both resilient and resistant taxa during boom or dispersal phase, *Leiopotherapon unicolor* not captured concurrently within the Warburton ecoregion. OR *Nematolosa erebi* absent during boom or dispersal phase and not captured concurrently at all sites within the Warburton ecoregion. A Tier score of 6 triggers this site as a TPC.

Attribute V	**Specialist taxa (*Craterocephalus eyresii* and *Chlamydogobius eremius*).**
Tier 1	Both specialist taxa absent during dispersal or boom phases. OR Any taxa present with low abundance during dispersal or boom phases. OR Both specialist taxa present in moderate abundance, or one taxa present in high abundance during bust phases
Tier 2	Any specialist taxa present in moderate abundance during boom phase. OR Both specialist taxa present in low abundance, or one specialist taxa in moderate abundance during bust phase.
Tier 3	Any specialist taxa present with high abundance during dispersal or boom phases. OR Specialist taxa absent or one species in low abundance during bust phase, but captured elsewhere in catchment within the previous 12 months.
Tier 4	Specialist taxa absent during bust period, but captured elsewhere in the Warburton ecoregion within the last 5 years.
Tier 5	Specialist taxa absent during bust period, but captured elsewhere in the Warburton ecoregion within the last 10 years. A Tier score of 5 triggers this site as a TPC.
Tier 6	Specialist taxa absent due to regional extirpation. A Tier score of 6 triggers this site as a TPC.

Attribute VI	**Non-native or intentionally introduced taxa (*Gambusia holbrooki*). This Attribute is scored only where invasive taxa are present**
Tier 1	
Tier 2	
Tier 3	
Tier 4	Non-native taxa present in low abundance.
Tier 5	Non-native species present in moderate to high abundance.
Tier 6	Non-native fish dominate all other fish taxa in abundance OR range extension of non-native taxa (e.g. *Gambusia holbrooki* observed for the first time at this site). A Tier score of 6 triggers this site as a TPC.

Attribute VII	**Organism and population condition. This Attribute is scored for long lived native fish only, where historic record exists for locality. (**Disease & congenital abnormalities to be included with improved data.)**
Tier 1	Multiple age classes apparent for two or more long-lived taxa in catchment, with evidence of recruitment.
Tier 2	Multiple age classes apparent for two or more long-lived taxa within catchment.
Tier 3	Multiple age classes apparent for at least one long-lived species within catchment.
Tier 4	Multiple age classes apparent for long-lived species within catchment within last 12 months.
Tier 5	No multiple age classes apparent for long-lived species within catchment within last 12 months
Tier 6	No multiple age classes apparent for long-lived species within catchment over the last 5 years. A Tier score of 6 triggers this site as a TPC.

12 Appendix E

12.1 Detailed Biological Condition Gradient scores for all sampling events.

				Attribute							
Ecoregion	**Site**	**Management Unit**	**Date**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Site BCG**
Goyder	Pandie Pandie HS	Diamantina	6/04/2014	-	1	1	2	-	-	1	1.25
Goyder	Pandie Pandie HS	Diamantina	8/05/2014	-	2	3	6	-	-	1	3
Goyder	Diamantina Split	Diamantina	8/05/2014	-	1	1	3	-	-	1	1.5
Goyder	Andrewilla	Diamantina	7/05/2014	-	1	1	2	-	-	1	1.25
Goyder	Yammakira	Diamantina	4/05/2014	-	2	1	2	-	-	1	1.5
Goyder	Koonchera	Goyder Lagoon	2/05/2014	-	2	1	2	-	-	1	1.5
Goyder	Koonchera	Goyder Lagoon	3/05/2014	-	2	1	3	-	-	1	1.75
Goyder	Goyders Lagoon WH	Goyder Lagoon	1/05/2014	-	2	1	2	-	-	1	1.5
Goyder	Tepamimi	Eyre Creek	6/05/2014	-	3	2	1	-	6	1	2.6
Goyder	Pandie Pandie HS	Diamantina	8/04/2015	-	2	2	3	-	-	1	2
Goyder	Double Bluff WH	Diamantina	10/05/2015	-	1	1	2	-	-	1	1.25
Goyder	Diamantina Split	Diamantina	12/05/2015	-	1	1	3	-	-	1	1.5
Goyder	Andrewilla	Diamantina	13/05/2015	-	1	1	2	-	-	1	1.25
Goyder	Yammakira	Diamantina	9/05/2015	-	2	2	2	-	-	1	1.75
Goyder	Burts WH	Goyder Lagoon	13/05/2015	-	2	1	2	-	-	1	1.5
Goyder	Koonchera	Goyder Lagoon	8/06/2015	-	1	1	1	-	-	1	1
Goyder	Goyders Lagoon WH	Goyder Lagoon	7/05/2015	-	1	1	1	-	-	1	1
Goyder	Tepamimi	Eyre Creek	14/05/2015	-	2	2	1	-	6	1	2.4
Goyder	Pandie Pandie HS	Diamantina	9/04/2016	-	1	1	1	-	6	1	2
Goyder	Double Bluff WH	Diamantina	6/05/2016	-	1	1	1	-	-	1	1
Goyder	Diamantina Split	Diamantina	7/05/2016	1	1	1	1	-	-	1	1
Goyder	Andrewilla	Diamantina	8/05/2016	-	1	2	2	-	-	1	1.5
Goyder	Andrewilla	Diamantina	11/05/2016	-	1	1	1	-	-	1	1
Goyder	Pelican WH	Goyder Lagoon	13/05/2016	-	1	2	1	-	-	1	1.25
Goyder	Koonchera West	Goyder Lagoon	5/05/2016	-	1	3	1	-	-	1	1.5
Goyder	Peraka Lakes Junction	Goyder Lagoon	16/05/2016	-	1	1	1	-	-	1	1
Warburton	Mona Downs	Warburton-Kallakoopah	11/05/2014	-	3	3	3	3	-	1	2.6

				Attribute							
Ecoregion	**Site**	**Management Unit**	**Date**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Site BCG**
Warburton	Mungerannie Wetland	Warburton-Kallakoopah	4/04/2014	-	3	3	1	3	4	1	2.5
Warburton	Ultoomurra	Warburton-Kallakoopah	29/04/2014	-	3	3	3	1	-	1	2.2
Warburton	Kalamunkinna	Warburton-Kallakoopah	4/05/2014	-	3	3	3	1	5	1	2.67
Warburton	Stony Point	Warburton-Kallakoopah	12/05/2014	-	3	3	3	1	-	1	2.2
Warburton	Cowarie Crossing	Warburton-Kallakoopah	13/05/2014	-	3	3	3	3	-	1	2.6
Warburton	Yellow WH	Warburton-Kallakoopah	16/05/2014	-	3	3	3	1	-	1	2.2
Warburton	Wadlarkaninna	Warburton-Kallakoopah	14/05/2014	-	3	3	3	3	-	1	2.6
Warburton	Poonarunna Bore	Warburton-Kallakoopah	14/05/2014	-	3	3	3	1	6	1	2.83
Warburton	Mona Downs	Warburton-Kallakoopah	4/05/2015	-	3	3	3	3	-	1	2.6
Warburton	Cowarie HS	Warburton-Kallakoopah	8/04/2015	-	3	2	2	3	-	1	2.2
Warburton	Yelpawaralinna	Goyder Lagoon	7/05/2015	-	3	2	3	2	-	1	2.2
Warburton	Ultoomurra	Warburton-Kallakoopah	5/05/2015	-	1	1	1	2	-	1	1.2
Warburton	Stony Point	Warburton-Kallakoopah	2/05/2015	-	1	1	1	1	5	1	1.67
Warburton	Cowarie Crossing	Warburton-Kallakoopah	8/04/2015	-	3	3	2	1	5	1	2.5
Warburton	Cowarie Crossing	Warburton-Kallakoopah	29/04/2015	-	3	2	2	1	5	1	2.33
Warburton	Mia Mia	Warburton-Kallakoopah	2/05/2015	-	3	2	2	1	-	1	1.8
Warburton	Tinnie landing	Warburton-Kallakoopah	30/04/2015	-	3	2	1	1	4	1	2
Warburton	Cliff Camp WH	Warburton-Kallakoopah	30/04/2015	-	3	3	3	1	5	1	2.67
Warburton	Mona Downs	Warburton-Kallakoopah	4/05/2016	-	3	2	1	2	-	1	1.8
Warburton	Tippipilla Creek Campsite	Goyder Lagoon	17/05/2016	-	1	3	2	3	-	1	2
Warburton	Ultoomurra	Warburton-Kallakoopah	18/05/2016	1	1	1	1	3	-	1	1.33
Warburton	Cowarie Crossing	Warburton-Kallakoopah	3/05/2016	1	3	2	1	2	5	1	2.14
Warburton	Cowarie Crossing	Warburton-Kallakoopah	19/05/2016	1	1	1	1	2	5	1	1.71
Warburton	Yellow WH	Warburton-Kallakoopah	2/05/2016	1	3	2	1	2	5	1	2.14
Warburton	Mia Mia	Warburton-Kallakoopah	1/05/2016	1	3	3	1	2	4	1	2.14
Warburton	Wadlarkaninna	Warburton-Kallakoopah	30/04/2016	-	3	3	2	2	-	1	2.2
Warburton	Tinnie landing	Warburton-Kallakoopah	29/04/2016	1	3	2	1	2	-	1	1.67

13 References

AHYONG, S. T. & YEO, D. C. J. 2007. Feral populations of the Australian Red-Claw crayfish (Cherax quadricarinatus von Martens) in water supply catchments of Singapore. *Biological Invasions,* 9**,** 943-946.

ALLEN, G. R., MIDGLEY, S. H. & ALLEN, M. 2003. *Field Guide to the Freshwater Fishes of Australia (Revised edition),* Collingwood, Victoria, Australia, CSIRO publishing.

BAILEY, P. C. E., BOON, P. I., BLINN D. W. & WILLIAMS, W. D. 2006. Salinity as an ecological perturbation to rivers, streams and wetlands of the arid and semi-arid zone. *In:* KINGSFORD., R. T. (ed.) *Changeable, Changed, Changing: the Ecology of Rivers from the World's Dry Regions.* Cambridge.: Cambridge University Press.

BEHEREGARAY, L. B. & ATTARD, C. R. M. 2015. Developing a Population Genomic Approach for Indicators of Environmental Condition in the Lake Eyre Basin. *Technical Report Series.* Goyder Institute for Water Research.

BENN, P. C. & ERSKINE, W. D. 1994. Complex channel response to flow regulation: Cudgegong River below Windamere Dam, Australia. *Applied Geography,* 14**,** 153-168.

CHERVINSKI, J. 1983. Salinity tolerance of the mosquito fish, *Gambusia affinis* (Baird and Girard). *Journal of Fish Biology,* 22**,** 9-11.

CLARKE, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology,* 18**,** 117-143.

CLARKE, K. R. & GORLEY, R. N. 2001. *PRIMER v5: user manual/tutorial*, Primer-E Limited.

COCKAYNE, B., SCHMARR, D., DUGUID, A., COLVILLE, S., MATHWIN, R. & MCNEIL, D. G. 2012a. Lake Eyre Basin Rivers Assessment LEBRA 2011/12 *Monitoring Report Report from the LEBRA Operations Group to the Lake Eyre Basin Ministerial Forum* Canberra.

COCKAYNE, B., SCHMARR, D., DUGUID, A. & MATHWIN, R. 2013a. Lake Eyre Basin Rivers Assessment 2012 Monitoring Report. Canberra ACT: A report to the Department of Sustainability Environment Water Population and Communities SEWPaC

COCKAYNE, B., SCHMARR, D. W., DUGUID, A., COLVILLE, S., MATHWIN, R. & D.G., M. 2012b. Lake Eyre Basin Rivers Assessment 2011 Monitoring Report, A report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), Canberra, ACT. Draft ed.

COCKAYNE, B., SCHMARR, D. W., DUGUID, A. W. & MATHWIN, R. 2013b. Lake Eyre Basin Rivers Assessment 2012 Monitoring Report, A report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), Canberra, ACT.

COOK, B. D., BUNN, S. E. & HUGHES, J. M. 2002. Genetic structure and dispersal of Macrobrachium australiense (Decapoda: Palaemonidae) in western Queensland, Australia. *Freshwater Biology,* 47**,** 2098-2112.

COSTELLOE, J. F., HUDSON, P. J., PRITCHARD, J. C., PUCKRIDGE, J. T. & REID, J. R. W. 2004. ARIDFLO Scientific Report: Environmental Flow Requirements of Arid Zone Rivers with Particular Reference to the Lake Eyre Drainage Basin School of Earth and Environmental Sciences University of Adelaide Adelaide Final Report to South Australian Department of Water Land and Biodiversity Conservation and Commonwealth Department of Environment and Heritage.

COSTELLOE, J. F., REID, J. R. W., PRITCHARD, J. C., PUCKRIDGE, J. T., BAILEY, V. E. & HUDSON, P. J. 2010. Are alien fish disadvantaged by extremely variable flow regimes in arid zone rivers? *Marine and Freshwater Research* 61**,** 57-63.

COUCH, J. A., WINSTEAD, J. T. & GOODMAN, L. R. 1977. Kepone-induced scoliosis and its histological consequences in fish. *Science,* 197.

DAVIES, S. P. & JACKSON, S. K. 2006. The Biological Condition Gradient: A Descriptive Model for Interpreting Change in Aquatic Ecosystems. *Ecological Applications,* 16**,** 1251-1266.

DUGUID, A. B., MATHWIN, R., STERNBERG, D., COCKAYNE, B. & SCHMARR, D. W. 2016. Lake Eyre Basin Rivers Assessment (LEBRA) 2014/15. Canberra Report from the LEBRA Operations Group to the Lake Eyre Basin Ministerial Forum Department of the Environment

DUGUID, A. W., MATHWIN, R., STERNBERG, D., CHESHIRE, D. L. M., SCHMARR, D., COCKAYNE, B., ELDRIDGE, S. & MCNEIL, D. In Prep. Lake Eyre Basin Rivers Assessment (LEBRA) 2013/14 Monitoring Report. A report to the Lake Eyre Basin Ministerial Forum, via the Department of Agriculture and Water Resources, Canberra, ACT. .

DUNLOP, J. E., HORRIGAN, N., MCGREGOR, G., KEFFORD, B. J., CHOY, S. & PRASAD, R. 2008. Effect of spatial variation on salinity tolerance of macroinvertebrates in Eastern Australia and implications for ecosystem protection trigger values. *Environmental Pollution,* 151**,** 621-630.

EYRE, E. J. 1845. *Journal of expeditions of discovery in central Australia and overland to King Georges Sound in the years 1840-41* London, TW Boone

FAULKS, L. K., GILLIGAN, D. M. & BEHEREGARAY, L. B. 2010. Islands of water in a sea of dry land: hydrological regime predicts genetic diversity and dispersal in a widespread fish from Australia's arid zone the golden perch Macquaria ambigua *Molecular Ecology,* 1921**,** 4723-4737.

GEHRKE, P. C. 1987. Cardio-respiratory morphometrics of spangled perch, Leiopotherapon unicolor (Günther, 1859), (Percoidei, Teraponidae). *Journal of Fish Biology,* 31**,** 617-23.

GEORGES, A. & ADAMS, M. 1996. Electrophoretic delineation of species boundaries within the short-necked freshwater turtles of Australia (Testudines: Chelidae). *Zoological Journal of the Linnean Society,* 118**,** 241-260.

GEORGES, A. & THOMSON, S. 2010. Diversity of Australasian freshwater turtles, with an annotated synonymy and keys to species. *Zootaxa,* 2496**,** 1-37.

GLOVER, C. J. M. 1973. Adaptations of a central Australian gobiid fish. *Bulletin of the Australian Society for Limnology,* 5**,** 8-10.

GLOVER, C. J. M. & SIM, T. C. 1978a. Studies on central Australian Fishes: a progress report *South Australian Naturalist,* 523**,** 35-44.

GLOVER, C. J. M. & SIM, T. C. 1978b. A survey of central Australian Ichthyology *Australian Zoologist,* 193**,** 245-256.

GREENAWAY, P. & MACMILLEN, R. E. 1978. Salt and Water Balance in the Terrestrial Phase of the Inland Crab Holthuisana (Austrothelphusa) transversa Martens (Parathelphusoidea: Sundathelphusidae). *Physiological Zoology,* 51**,** 217-229.

GRIMES, D. T., BOSWELL, C. W., MORANTE, N. F. C., HENKELMAN, R. M., BURDINE, R. D. & CIRUNA, B. 2016. Zebrafish models of idiopathic scoliosis link cerebrospinal fluid flow defects to spine curvature. *Science,* 352**,** 1341 - 1344.

GU, W. & SWIHART, R. K. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. *Biological Conservation,* 116**,** 195-203.

HALVER, J. E., SMITH, R. R., TOLBERT, B. M. & BAKER, E. M. 1975. Utilization of ascorbic acid in fish. *Annals of the New York Academy of Sciences,* 258**,** 81-102.

JAMES, C. D., LANDSBERG, J. & MORTON, S. R. 1999. Provision of watering points in the Australian arid zone: a review of effects on biota. *Journal of Arid Environments,* 41**,** 87-121.

KEREZSY, A., BALCOMBE, S. J., TISCHLER, M. & ARTHINGTON, A. H. 2013a. Fish movement strategies in an ephemeral river in the Simpson Desert Australia *Austral Ecology,* 38**,** 798–808.

KEREZSY, A., BALCOMBE, S. R., TISCHLER, M. & ARTHINGTON, A. H. 2013b. Fish movement strategies in an ephemeral river in the Simpson Desert, Australia. *Austral Ecology,* 38**,** 798-808.

KING, C. R. 1994. Growth and survival of redclaw crayfish hatchlings (Cherax quadricarinatus von Martens) in relation to temperature, with comments on the relative suitabitity of Cherax quadricarinatus and Cherax destructor for culture in Queensland. *Aquaculture,* 122**,** 75-80.

KLOPPEL, T. M. & POST, G. 1975. Histological alterations in tryptophan-deficient rainbow trout. . *The Journal of Nutrition,* 105**,** 861 - 866.

KOTWICKI, V. 1986. Floods of Lake Eyre. Adelaide: Engineering and Water Supply Department.

KOTWICKI, V. & ISDALE, P. 1991. Hydrology of Lake Eyre, Australia: El Niño link. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 84**,** 87-98.

LAKE EYRE BASIN MINISTERIAL FORUM 2017. Draft Lake Eyre Basin: State of the Basin Condition Assessment 2016 Report (Public Consultation document). Canberra: Department of Agriculture and Water Resources.

MACMILLEN, R. E. & GREENAWAY, P. 1978. Adjustments of Energy and Water Metabolism to Drought in an Australian Arid-Zone Crab. *Physiological Zoology,* 51**,** 230-240.

MATHWIN, R., CHESHIRE, D. L. & SCHMARR, D. In Prep. Lake Eyre Basin Rivers Assessment (LEBRA) 2015/16 Monitoring Report. A report to the Lake Eyre Basin Ministerial Forum, via the Department of Agriculture and Water Resources, Canberra, ACT. .

MATHWIN, R., DUGUID, A. B., STERNBERG, D., COCKAYNE, B., SCHMARR, D. W. & MCNEIL, D. G. 2015a. Lake Eyre Basin Rivers Assessment (LEBRA) 2013/14 Monitoring Report. Canberra: Report from the LEBRA Operations Group to the Lake Eyre Basin Ministerial Forum, Department of the Environment.

MATHWIN, R., DUGUID, A. W., STERNBERG, D., COCKAYNE, B., SCHMARR, D. & MCNEIL, D. 2015b. Lake Eyre Basin Rivers Assessment (LEBRA) 2013/14 Monitoring Report. A report to the Department of the Environment, Canberra, ACT.

MCKINSEY, D. M. & CHAPMAN, L. J. 1998. Dissolved oxygen and fish distribution in a Florida spring *Environmental Biology of Fishes,* 53**,** 211-223.

MCNEIL, D. G., REID, D. J., SCHMARR, D. W. & WESTERGAARD, S. 2008a. Preliminary Fish Surveys for the Lake Eyre Basin Rivers Assessment: Testing the Fish Trajectory Model in South Australia. *SARDI Research Report* Adelaide: South Australian Research and Development Institute (Aquatic Sciences).

MCNEIL, D. G., REID, D. J., SCHMARR, D. W. & WESTERGAARD, S. 2008b. Preliminary Fish Surveys for the Lake Eyre Basin Rivers Assessment: Testing the Fish Trajectory Model in South Australia. SARDI Report Series No. 351. South Australian Reseacrh and Development Institute (Aquatic Sciences), Adelaide, 89pp. .

MCNEIL, D. G. & SCHMARR, D. W. 2009. Recovery of Lake Eyre Basin Fishes Following Drought: 2008/09 Fish Survey Report. *SARDI Publication.* Adelaide: South Australian Research and Development Institute (Aquatic Sciences).

MCNEIL, D. G., SCHMARR, D. W. & ROSENBERGER, A. E. 2011. Climatic variability, fish and the role of refuge waterholes in the Neales River Catchment: Lake Eyre Basin, South Australia. Port Augusta: South Australian Research and Development Institute (Aquatic Sciences) to the South Australian Arid Lands NRM Board.

MCNEIL, D. G., WHITE, D., SCHMARR, D. W., GOTCH, T. & MATHWIN, R. (in prep). Big Blythe Bore closure: Baseline survey and mapping of ecology of adjacent GAB springs, bores and waterholes. Adelaide: Draft report to the South Australian Arid Lands Natural Resources Management Board, South Australian Research Development Institute (Aquatic Sciences).

MILLS, B. & GEDDES, M. 1980. Salinty tolerance and osmoregulation of the Australian freshwater crayfish <I>Cherax destructor</I> Clark (Decapoda : Parastacidae). *Marine and Freshwater Research,* 31**,** 667-676.

MILTON, D. A. & ARTHINGTON, A. H. 1983. Reproductive biology of *Gambusia affinis holbrooki* Baird and Girard, *Xiphophorus helleri* (Gunther) and *X. maculatus* (Heckel) (Pisces; Poeciliidae) in Queensland, Australia. *Journal of Fish Biology,* 23**,** 23-41.

NANSON, G. C., CALLEN, R. A. & PRICE, D. M. 1988. Hydroclimatic interpretation of Quaternary shorelines on South Australian playas. *Paleogeography. Paleoclimatology, Paleoecology,* 144**,** 281-305.

ORR, T. & MILWARD, N. 1984. Reproduction annd development of <I>Neosilurus ater</I> (Perugia) and <I>Neosilurus hyrtlii</I> Steindachner (Teleostei : Plotosidae) in a tropical Queensland stream. *Marine and Freshwater Research,* 35**,** 187-195.

OSTI, A. 2014. Hydrological modelling of the Diamantina-Warburton River System. DEWNR Technical note 2014/15, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide.

PUCKRIDGE, J. T. 1999. *The Role of Hydrology in the Ecology of Cooper Creek Central Australia: Implications for the Flood Pulse Concept* PhD, The University of Adelaide Adelaide.

PUCKRIDGE, J. T., COSTELLOE, J. F. & WALKER, K. F. 1999. DRY/WET: Effects of Changed Water Regimes on the Fauna of Arid Zone Wetlands Canberra, Australia: National Wetlands Research and Development Program Environment Australia, Land and Water Resources Research and Development Corporation.

ROSHIER, D. A., WHETTON, P. H., ALLAN, R. J. & ROBERTSON, A. I. 2001. Distribution and persistence of temporary wetland habitats in arid Australia in relation to climate. *Austral Ecology,* 26**,** 371-384.

SARDI UNPUBLISHED DATA. Arid Catchment Ecology database (ACEbase). Cheshire, D.L.M., McNeil, D.G., Schmarr, D.W., Mathwin, R. and Ward, R., Urban and Regional Ecology, Inland Waters Catchment Ecology, Aquatic Sciences, South Australian Research and Development Institute.

SCHMARR, D., CHESHIRE, D. L. & MATHWIN, R. in Prep. Fish Condition Ananlysis to inform State of the Basin Reporting process.

SCHMARR, D., DUGUID, A., CHESHIRE, D. L. M., MATHWIN, R., STERNBERG, D. & COCKAYNE, B. 2016. Lake Eyre Basin Rivers Assessment (LEBRA) 2015/16 Monitoring Report. A report to the Lake Eyre Basin Ministerial Forum. Canberra, ACT: Department of Agriculture and Water Resources.

SCHMARR, D., MATHWIN, R. & HOOPER, R. 2014. Lake Eyre Basin River Monitoring: Stage 2 Macumba and Neales River Survey.

SCHMARR, D. W., CHESHIRE, D. L. M., MATHWIN, R., MCNEIL, D. G., HOWSON, T., COCKAYNE, B. & DUGUID, A. 2015. Evidence Based Approaches to Condition Assessment of Fish Communities in the Lake Eyre Basin, Central Australia. *Technical Report Series* Adelaide, South Australia.: Goyder Institute for Water Research.

SCHMARR, D. W., MATHWIN, R., CHESHIRE, D. L. & MCNEIL, D. G. 2013. Aquatic ecology assessment and analysis of Cooper Creek: Lake Eyre basin South Australia *SARDI Research Report Series.* West Beach, Adelaide, South Australia: South Australian Research and Development Institute Aquatic Sciences to the South Australian Aridlands Natural Resources Management Board Port Augusta.

SMAKHTIN, V. U. 2001. Low flow hydrology: a review. *Journal of Hydrology,* 240**,** 147-186.

STERNBERG, D., BALCOMBE, S., MARSHALL, J. & LOBEGEIGER, J. 2008. Food resource variability in an Australian dryland river: evidence from the diet of two generalist native fish species. *Marine and Freshwater Research,* 59**,** 137-144.

STERNBERG, D., COCKAYNE, B., SCHMARR, D., DUGUID, A. W., MATHWIN, R. & MCNEIL, D. 2014. Lake Eyre Basin Rivers Assessment (LEBRA) 2012/13 Monitoring Report. A report to the Department of the Environment, Canberra, ACT.

THOMPSON, G. G. & WITHERS, P. 2002. Aerial and aquatic respiration of the Australian desert goby, Chlamydogobius eremius. *Comparative Biochemistry and Physiology - Part A Molecular & Integrative Physiology,* 131**,** 871-879.

THOMS, M. & CULLEN, P. 1998. The Impact of Irrigation Withdrawals on Inland River Systems. *The Rangeland Journal,* 20**,** 226-236.

THWAITES, L. A., FREDBURG, J. F. & MATHWIN, R. 2013. Confirming the presence of common carp (Cyprinus carpio) wihtin the Alinta mine complex and Leigh Creek. A Brief communication to Biosecurity SA. South Australian Research and Development Institute (Aquatic Scinces), (Adelaide). SARDI Publication No. F2013/000533-1. SARDO Research Report Series No. 730. 15 pp.

TWEED, S., LEBLANC, M., CARTWRIGHT, I., FAVREAU, G. & LEDUC, C. 2011. Arid zone groundwater recharge and salinisation processes; an example from the Lake Eyre Basin, Australia. *Journal of Hydrology,* 408**,** 257-275.

WAGER, R. & UNMACK, P. J. 2000. *Fishes of the Lake Eyre catchment of central Australia,* Brisbane, DPI Publications.

WALKER, K. F. & THOMS, M. C. 1993. Environmental effects of flow regulation on the lower river Murray, Australia. *Regulated Rivers: Research & Management,* 8**,** 103-119.

WARD, D. L., SCHULTZ, A. A. & MATSON, P. G. 2003. Differences in Swimming Ability and Behavior in Response to High Water Velocities among Native and Nonnative Fishes. *Environmental Biology of Fishes,* 68**,** 87-92.

WARNER, R. F. 1984. Man's impacts on Australian drainage systems. *Australian Geographer,* 16**,** 133-141.

WESTHOFF, J. T. & ROSENBERGER, A. E. 2016. A global review of freshwater crayfish temperature tolerance, preference, and optimal growth. *Reviews in Fish Biology and Fisheries,* 26**,** 329-349.

YOKOYAMA, H., FREEMAN, M. A., YOSHINAGA, T. & OGAWA, K. 2004. Myxobolus buri, the myxosporean parasite causing scoliosis of yellowtail, is synonymous with Myxobolus acanthogobii infecting the brain of the yellowfin goby. *Fisheries science,* 70**,** 1036 - 1042.