Inland Waters & Catchment Ecology

Preliminary Fish Surveys for the Lake Eyre Basin Rivers Assessment: Testing the Fish Trajectory Model in South Australia.

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Dale McNeil, David Reid, David Schmarr and Simon Westergaard.

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Government of South Australia

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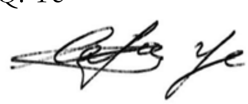

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Executive summary

In general, the South Australian Pilot Monitoring survey revealed that the arid reaches of the Neales/Peake, Lower Diamantina/Warburton and Lower Cooper catchments were far more variable ecologically than the more stable upper reaches of the Basin in Queensland. This variability was related to differences in climate and hydrology, and was expressed in the population structure of waterholes in these reaches. In general, three types of habitats were found:

1: Permanent deep refuge waterholes: These possessed higher species richness (relating to habitat diversity), more large bodied species and fewer micro carnivores (where habitat availability was low). The two principal refugia were Algebuckina (Neales) and Cullyamurra (Cooper) and possibly Clifton Hills outstation although this requires more exhaustive sampling. These habitats act more like the upstream pools in Queensland, but are incredibly important, as they are the most downstream refugia for the entire fish assemblage. These habitats fit the fish trajectory model (FTM) best and biomass, species richness, recruitment, presence of disease and abundance are most important as indicators in these habitats.

2: Ephemeral Large Pools: These pools possessed fewer species but often-larger bodied fish such as spangled perch and bony herring (Neales) or Golden perch and Hyrtl's Tandan (Warburton). These habitats are important for native fish, but due to their transient nature they will go through periods of local extinction, low species diversity (migratory species) and during wetter periods serve as important habitats for a wide range of species (this must be verified by monitoring in wetter periods but is suggested by the ARIDFLO data). Impacts on hydrology (such as water abstraction or climatic drying) are likely to impact these sites heavily. If these transient habitats are continuously moving between no fish and low fish diversity, then populations will come under increasing pressure, especially for slow-recolonising species (almost all small bodied fish) that may require either large floods or successive in stream flows to recolonise following local extinction. Alternatively, a decline in the number or regularity of years in which these habitats serve as high diversity habitats will also signal a decrease in catchment scale population health and may threaten total catchment wide extinction for some species. These transient habitats are difficult to relate to the FTM due to their incredible variability, but make up the majority of fish habitats in the arid section of the LEB. Species richness, presence/abundance of micro-carnivores and recruitment are likely to be the most important FTM indicators in these habitats.

3: Small saline refugia: These are shallow pools, often at the downstream extreme of regular flow (Peake, Ultoomurra). They possess a few highly tolerant species, commonly hardyhead and desert gobies, but may intermittently possess transient tolerant species such as spangled

perch or bony herring. These pools were almost always as salty as sea-water, yet they represent a saline refuge where hardyhead and gobies can largely escape the predation pressure present in permanent refugia. Although in harsh climatic periods such as 06/07/08, these pools may become saltier than sea-water and may be reduced to only a single species, they still possess the highest abundances of these tolerant species and serve as key refugia from which they can recolonise catchments upon resumption of flows. These habitats fit poorly into the FTM, and abundance/biomass, abundance of alien species and recruitment are likely to be the best FTM indicators for these pools. The persistence and recolonisation of these habitats through time are likely to be the best indicators of river health for these habitats. Although these pools may dry up completely, they should be present and inhabited most years. Species richness should not regularly be lower than two.

Overall, efforts to find generalisable indicators for the FTM are thwarted by the high climatic and hydrological variability, patchiness and dynamic nature of fish assemblage structure and species distribution. This does not however, oppose the validity of using the FTM, rather the project has highlighted the need to create more detailed, species and potentially site (or at least regional/catchment) specific FTMs that can be combined to inform the overall river health trajectory using monitoring data outputs.

The monitoring strategy developed in the FTM workshop (Humphries et al. 2007) and trialled over 07/08 is an effective approach in collecting good quality long-term data on the ecological health of LEB rivers. It is suggested that significant resources be directed towards this monitoring program to ensure that it captures a wide range of sites over a wide range of catchments/reaches. Without good coverage, the monitoring program risks missing key impacts to river health before they become irreversible. The arid catchments and reaches of the LEB are especially useful as indicators of declines in river health as they form the harsh edge of the LEB ecosystem where climate and flow are variable and intermittent and pressures on aquatic biota are highest. Basin-wide impacts will become evident at these sites before they are likely to be detectable upstream. As such, the monitoring outputs from these sites will serve as a comparative target for a trajectory of decline in river health. As demonstrated through multivariate techniques, more stable and species rich refuge pools (Type 1 above) may begin to produce data more similar to type 2 or 3 habitats and movement along this trajectory will represent a decline in the integrity and health of these systems. This trajectory may also be useful to detect decline in condition of Queensland sites but this will require more comprehensive assessment.

It is suggested that comprehensive monitoring be initiated as soon as possible during the present drought (in the SA section) to capture the harshest extremes of natural climatic variability and ensure we can capture the widest range of data from within the natural climatic range. Furthermore it is suggested that monitoring programs be linked where possible to biological, ecological and hydrological research projects to maximise the value of monitoring outputs and to improve and develop species FTMs into the future.

1 Introduction

The Lake Eyre basin Rivers Assessment (LEBRA) has been developed to review the condition of catchments and watercourses within the Basin under the Lake Eyre Basin Agreement between the Commonwealth, Queensland and South Australian Governments (LEBSAP 2008). Whilst much of the area currently covered by the LEBRA agreement exists within the eastern drainages of Western Queensland, the lower sections of the Cooper Creek and Diamantina River systems and the entire Warburton Creek system fall within South Australia's boundaries. On the arid, western side of Lake Eyre, the Neales River, Peake Creek and Macumba River systems are important but highly variable waterways (Costelloe 2008) that drain into western side of the Lake during high flows.

In late 2006, a workshop was held in Brisbane to develop a conceptual model for native fish of the Lake Eyre Basin that could be used to inform the ongoing assessment of native fish health under the LEBRA program. The conceptual model was developed using expert opinion and data emanating from past native fish programs, principally the ARIDFLO and Dryland Refugia projects. The model was designed to capture the natural patterns in native fish ecology in the Lake Eyre Basin and especially to determine how fish populations respond to the highly variable environmental conditions present in the Basin (Humphries *et al.* 2007).

The model was used to develop a monitoring strategy where useful information regarding the status and health of native fish populations in the Basin could be collected efficiently in the long term (Humphries *et al.* 2007). This report outlines a pilot monitoring program that was intended to A: trial the monitoring program design at a number of sites across the Basin and B: to test and inform the conceptual model developed at the LEBRA workshop.

The pilot monitoring was conducted in two sections. The first surveyed sites in the Georgina, Diamantina and Cooper Creek Catchments along the semi-arid lowland sections of those waterways in Queensland. The second component surveyed the arid reaches of the Neales River, Peake Ck, Diamantina/Warburton and Cooper Ck within South Australia. This report presents the results of the South Australian survey and addresses the validity of the monitoring strategy and the conceptual model for those arid-zone waterways located within the most extremely variable and harsh sections of the Lake Eyre Basin.

The South Australian portion of the Lake Eyre Basin (LEB) has received little attention from the Natural Resource Management sector due to its remoteness and the low level of industry and development in the region. However, the riverine environments exist in largely natural condition, albeit with impacts of grazing by domestic stock, which impacts most strongly on waterholes during the dry season.

Little is known of the general biology and ecology of most fish species present within the basin (Wager and Unmack 2000). What is known, largely stems from Glover who described many of the species during the mid-twentieth century (Glover and Sim, 1978; Glover, 1982). An Adelaide University post Graduate study by Jim Puckridge led to the development of the Wet/Dry model and a basic understanding of the high variability and role of the climate influencing the ecology of the Basin's rivers.

The subsequent AridFlo program was a joint effort by Universities and state government to improve understanding of the basin's river systems, including the ecology of native fish populations (Costelloe *et al*., 2004). Since the completion of AridFlo, a short and limited survey of some waterways was conducted as part of the South Australian Department of Environment and Heritage Biological survey program (Michael Hammer *pers. comm.*). Smaller studies have investigated the ecology of endemic mound spring communities (Glover 1989, Kodric-Brown and Brown 1993), but these species are often confined to those unique habitats and their ecology is very different to that of arid zone rivers. Despite these studies, there is very little published data on the ecology of the South Australian section of the LEB.

Under the LEBRA program, a workshop was held to develop conceptual models that sought to demonstrate the relationship between hydrological regimes and responses of native fish in LEB waterholes. The subsequent report contained a table summarising the expected responses of fish to various hydrological states, mostly focussed around the occurrence and regularity of flooding events (Table 1).

The Conceptual Model and review of current knowledge was then used to develop a monitoring strategy to provide information regarding the ecological condition of the Basin's waterways and to provide a mechanism for identifying key threats and possible trajectories for change that may indicate a deterioration of conditions in the future.

As a result the current pilot surveys were conducted to provide a basic assessment of the Conceptual Model and to inform the process for monitoring and evaluation. The current pilot survey was conducted between December 2007 and May 2008. Whilst the initial sampling trip was focussed on the western drainages, the May survey included sites in the Warburton, Lower Diamantina and Lower

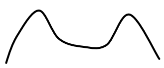
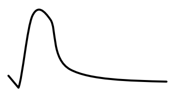
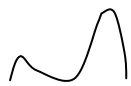
Cooper Creek in order to more effectively integrate findings from the western drainages to the reaches within the LEBA area.

The specific aims of the survey were to:

- Trial the monitoring approach outlined in the LEBRA workshop
- Provide recommendations and direction for improving the monitoring program
- Assess the current status of native fish at key sites within the basin
- Inform and test the Conceptual Model developed in the LEBRA workshop
- Provide further information regarding the relationship between climatic and hydrological variability and the health of the Basin's aquatic biota and ecosystems.
- Identify key knowledge gaps and outline research priorities to maximise the future effectiveness of the Rivers Assessment Program.

o

Table 1. Conceptual Model for the response of fish to hydrological regime in LEB waterholes

	Late flood (March/April)			Pre-flood (November)		
Antecedent condition	No recent flood	'Average' recent flood	Recent 'super' flood	No flood in last 12 months	'Average' flood in last 12 months	'Super' flood in last 12 months
Species richness	N		N	D+		N
Abundance	I		I++	D		I+++
Biomass	D		I+	D		I+++
Abundance of alien species	N		D	N		D-
Recruitment	I		I++	I		I+++
Population size structures						
Abundance of herbivores	D-		I++	N		I++
Abundance of macro-carnivores	D		I++	D-		I++
Abundance of micro-carnivores	D-		I++	D		I++
Prevalence of disease	I relative to degree of disturbance		I	I		N because absent by then

N = no change relative to 'average' scenario
I = small increase, I+ = moderate increase, I++ = large increase, I+++ = enormous increase relative to 'average' scenario
D = small decrease, D- = moderate decrease relative to 'average' scenario

2 Methods

2.1 Sites

The freshwater fish communities of sites across the South Australian portion of the Lake Eyre Basin (Figures 1) were surveyed in December 2007 and May 2008. The Neales River sites (Algebuckina, Stewarts Waterhole, South Stewarts Waterhole and Hookies Waterhole, Figure 2) and Peake Creek (Figure 3) were surveyed during both trips, whilst Lower Coopers Creek (Cullyamurra Waterhole) and Lower Diamantina River sites (Clifton Hill, Goyders Lagoon Waterhole and Ultoomurra, Figure 4) were only surveyed in May 2008. Mathieson Waterhole, on the Neales River, was surveyed in December 2007, but no fish were captured on this occasion and this site was not resurveyed in May. The sites ranged from large reaches (>5km) to small pools (<20m) at the time of the surveys.

Figure 1. Location of sites in the South Australian portion of the Lake Eyre Basin.

2.2 Surveys

Fishing effort varied amongst sites depending on the amount of surface water and time constraints at each site (Table 2). Fyke nets were used in most reaches and pools greater than 50m long, except in Goyders Lagoon Waterhole, where a seine net was used in the littoral zone in May 2008, due to time constraints. Three types of fyke nets were used; two single-winged designs [small fykes (3m leader, two funnel) and large fykes (5m leader, three funnel)] and a double-wing design (2x 5m leaders, three funnels). All types consisted of 4mm mesh fabric with an inlet arch of 650mm in diameter. These fyke nets have been found effective in catching large numbers of both large and small-bodied fish (D. McNeil, pers. obs.). Seine netting (5m x 1.5m; 2mm mesh) and 500µm dip nets were used in small pools (<50m). Spotlighting and daytime observations of fish were noted to supplement data from nets, as certain taxa, such as Desert Goby, may be under represented in fyke nets. All fyke nets were set overnight for approximately fifteen hours. All fish were identified using taxonomic keys (Allen, Midgley and Allen, 2002; Wager & Unmack, 2000; J. Pritchard, unpublished data) and the total number of each taxon counted. When time allowed, the lengths of at least 50 individuals of each taxon were also measured. Once 50 individuals were measured, the remainder of the particular fish taxon from that net was also measured to reduce the potential for any sub-sampling bias. Measured fish were visually inspected for signs of disease and all were returned to the water at the point of capture.

Water quality parameters, including temperature, dissolved oxygen, pH, conductivity and turbidity (FTU or mm) were measured at each site during each survey using a TPS multistation water quality meter and a Secchi disk. This data could not be collected in pools with depths less than 10cm. When the depth was >2m, water quality was measured at multiple depths to account for possible stratification. Observations of the dominant substrate, in-stream macrophytes and riparian vegetation were also recorded at each site.

Figure 2. Photos of sites in the Neales River catchment at (a and b) Stewarts Waterhole, (c) and (d) South Stewarts Waterhole, and (e and f) Algebuckina.

Figure 3. (a) Pools in Peakes Creek, under the Ghan Bridge. The white material on the surface of the dry river bed is salt. (b) There were Desert Goby living in the very shallow pool next to the bridge pylon. Large numbers of Lake Eyre Hardyhead were also present in the larger pools, but only the dried bodies of these taxa (c) were found around the small pool next to the pylon.

Figure 4. Photos of (a) Cullyamurra in the Lower Coopers Creek catchment, (b) Goyders Lagoon, (c) main channel and (d) anabranch at Clifton Hills in the Lower Diamantina catchment, and (e and f) pools at Ultoomurra in the Warburton Creek catchment.

Table 2: Site descriptions, survey times and the types and number of nets used at each site in the South Australian portion of the Lake Eyre Basin.

Catchment	Site Name	Description	Surveyed	Netting Effort
Coopers Creek	Cullyamurra Waterhole	Reach	May 2008	5x small fykes 2x large fykes 4x doublewing fykes
Diamantina River	Clifton Hills	Reach	May 2008	8x small fykes 2x large fykes 4x doublewing fykes
	Goyders Lagoon	Reach	May 2008	4 sweeps w/ seine net
Warburton Creek	Ultoomurra	Small Pools	May 2008	1 sweep w/ seine net dipnet
Neales River	Algebuckina	Reach	December 2007 May 2008	3x small fykes 3x large fykes 2x doublewing fykes 1 sweep w/ seine net 8x small fykes 3x large fykes 4x doublewing fykes
	South Stewarts Waterhole	Large Pool	December 2007 May 2008	2x small fykes 2x large fykes 2x doublewing fykes 3x small fykes 1x large fykes 1x doublewing fykes
	Stewarts Waterhole	Large Pool	December 2007 & May 2008	2x small fykes 2x large fykes 2x doublewing fykes +3x sm. fykes in May
	Mathieson Waterhole	Large Pool	December 2007	2x small fykes 2x large fykes 2x doublewing fykes
	Hookies	Large Pool	December 2007 May 2008	2x small fykes 2x large fykes 2x doublewing fykes 5 sweeps w/ seine net 8x small fykes 3x large fykes 4x doublewing fykes
Peake Creek	Peake Waterhole	Small Pools	December 2007 & May 2008	2 sweeps w/ seine net dipnet

2.3 Data Analyses

The proportions of each taxon in the fish communities captured from each site during each of the two surveys were calculated. The size distributions of the most commonly captured fish taxa were also plotted for each site and survey.

The data from sites within each catchment were combined and catchment-scale species richness, length frequencies and trophic structure were determined for comparison to the Conceptual Model developed by the participants at the LEBRA Workshop held on November 20 and 21, 2006 at Griffith University, Queensland (Table 1). For calculations of proportions of different trophic groups (i.e. macro-carnivores, micro-carnivores and detritivores), the fish taxa were assigned to specific trophic groups as for the Lake Eyre Basin sites in Queensland (Balcombe and Kerezsy, 2008: p. 27). In addition Lake Eyre Hardyhead, Desert Goby and Mosquitofish (which were not captured in Queensland surveys, but were captured in South Australia) were all defined as micro-carnivores. The proportions of different trophic groups within each catchment were then calculated. The catchment-scale data from the Lower Coopers Creek and Lower Diamantina were also used for comparison to those sites surveyed in the upper reaches in Queensland in November 2007 and March/April 2008 (Balcombe and Kerezsy, 2008).

3 Results

3.1 Sites

3.1.1 Cullyamurra Waterhole (Coopers Creek)

Water Quality & Structural Habitat

The dissolved oxygen concentration was relatively low at Cullyamurra Waterhole, compared to other sites, but all the values for the other water quality parameters were similar to the averages across all sites (Table 3). This large reach had predominantly intact riparian vegetation cover, muddy substrate and dense patches of *Polygonum*, a submerged macrophyte, growing adjacent to banks. There was a wide range of habitats at this site and nets were set around snags, amongst macrophytes and submerged grasses, near overhanging tree roots, adjacent to bare banks, and at both the top and the bottom of a riffle with cobble substrate.

Fish Community

The fish community at Cullyamurra Waterhole was the most diverse of any of those at the sites surveyed in May 2008, with a total capture of over 3200 fish, comprising 13 taxa (Table 4, Figure 5). Fish caught comprised of Hyrtl's Tandan (74%), Australian Smelt (11%), Golden Perch (5%) and Bony Bream (3%). In addition, this was the only site surveyed during the present study where Carp Gudgeons (71 fish), Barcoo Grunter (31 fish), Silver Tandan (13 fish), Cooper Creek Catfish (11 fish) and Glassfish (1 fish) were captured.

Population Structures

Welch's Grunter

A wide range of sizes of Welch's Grunter were captured at Cullyamurra Waterhole in May 2008 (Figure 6).

Carp Gudgeon Species

The Carp Gudgeons captured at Cullyamurra Waterhole in May 2008 were mainly medium-sized individuals (Figure 6).

Spangled Perch

The Spangled Perch captured at Cullyamurra Waterhole in May 2008 were mainly medium-sized, but there were some large individuals present (Figure 6).

Golden Perch

A large number of small Golden Perch were captured at Cullyamurra Waterhole in May 2008 (Figure 6). There were also some medium and large individuals of this taxon sampled at the site.

Eastern Rainbowfish

The majority of Eastern Rainbowfish captured at Cullyamurra Waterhole in May 2008 were small, and there were also a number of medium-sized individuals of this taxon captured at the site (Figure 6).

Bony Bream

A wide range of sizes of Bony Bream were captured at Cullyamurra Waterhole in May 2008 (Figure 6).

Australian Smelt

The Australian Smelt captured at Cullyamurra Waterhole in May 2008 were medium- to large-sized individuals, and there were no small individuals of this taxon captured at the site (Figure 7).

Hyrtl's Tandan

Most of the Hyrtl's Tandan captured at Cullyamurra Waterhole in May 2008 were medium-sized individuals, but some large individuals were also captured (Figure 7).

Cooper Creek Catfish

The small numbers of Cooper Creek Catfish captured at Cullyamurra Waterhole in May 2008 were medium-sized fish (Figure 7).

Silver Tandan

There was a small number of Silver Tandan, of a wide range of sizes, captured at Cullyamurra Waterhole in May 2008 (Figure 7).

Barcoo Grunter

Medium- and large-sized Barcoo Grunter were captured at Cullyamurra Waterhole in May 2008 (Figure 7).

Mosquitofish

The Mosquitofish captured at Cullyamurra Waterhole in May 2008 were predominantly small fish, and there were also a number of medium-sized individuals captured (Figure 7).

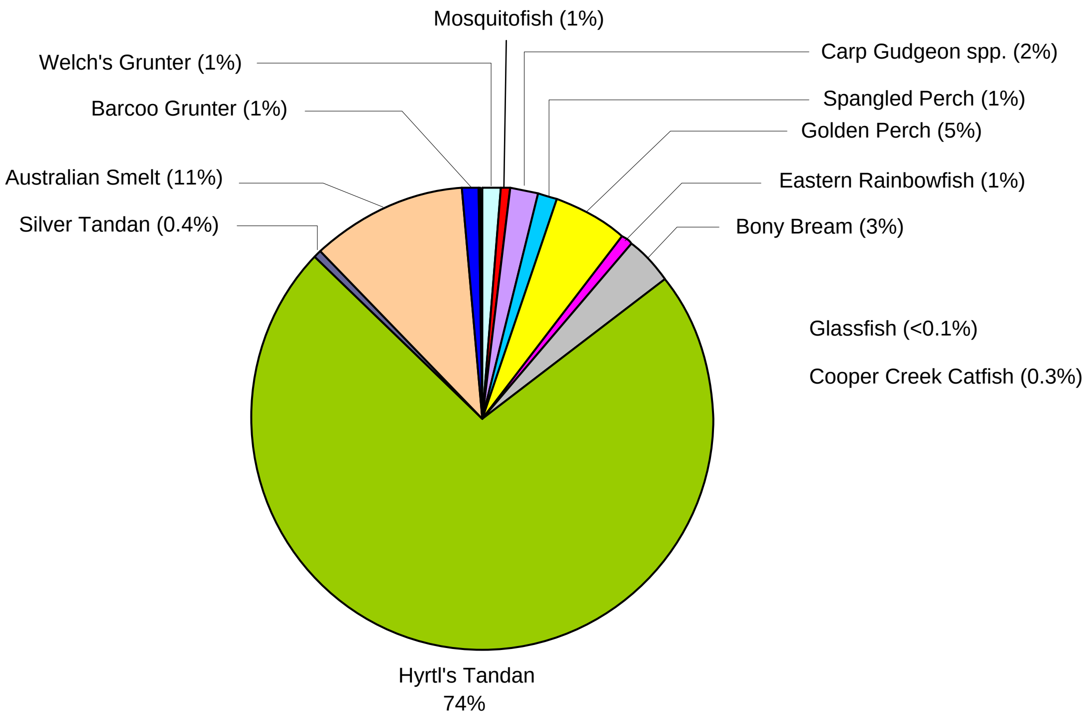


Figure 5. Proportion of each fish taxa (%) captured at Cullyamurra Waterhole in May 2008 (total number of fish = 3296, catch per fyke net = 299).

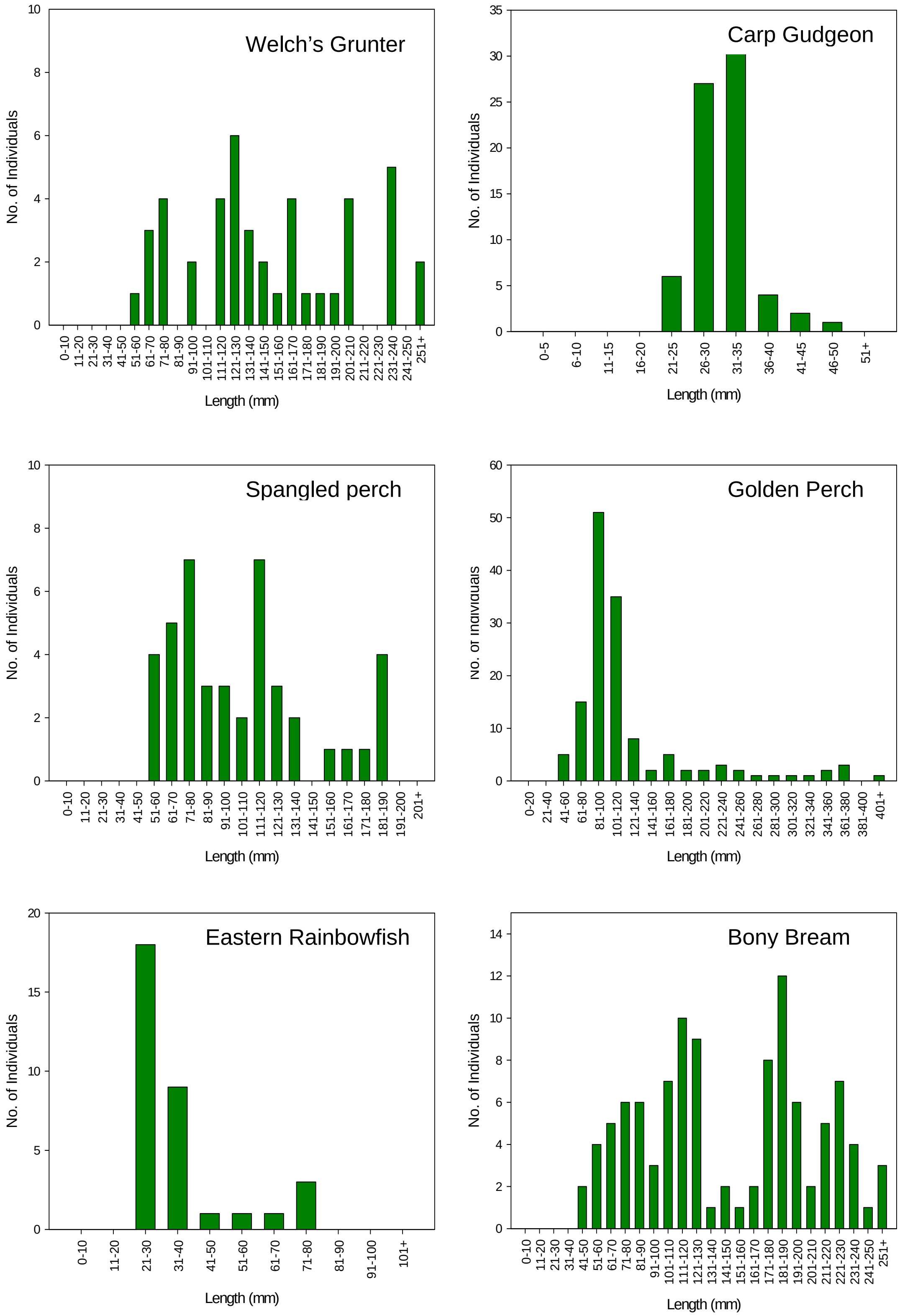


Figure 6. Lengths of fish species captured at Cullyamurra Waterhole in May 2008.

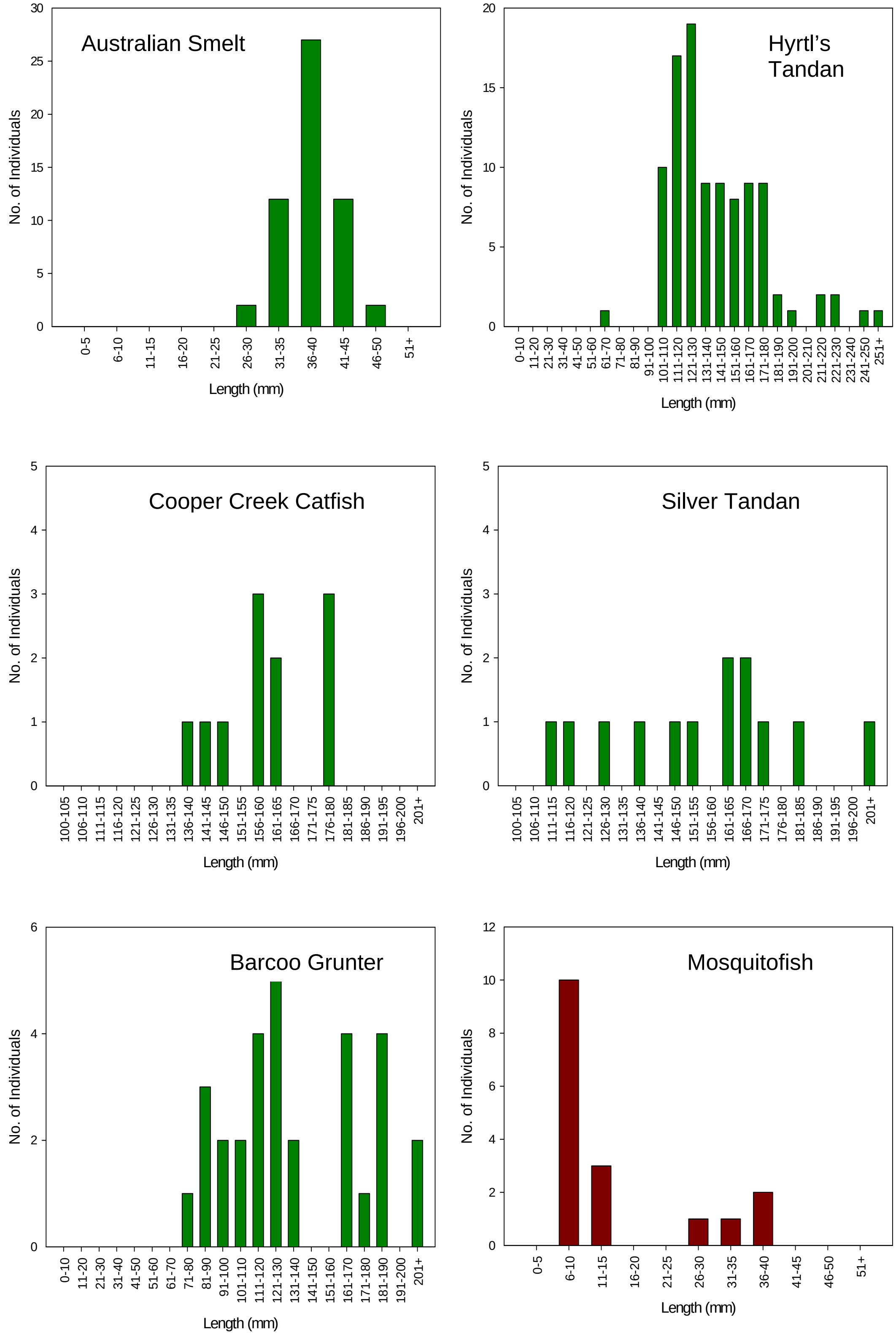


Figure 7. Lengths of fish species captured at Cullyamurra Waterhole in May 2008.

3.1.2 Clifton Hills (Diamantina River)

Water Quality & Structural Habitat

In May 2008 the reach at Clifton Hills had very steep banks, and was very deep as well as highly turbid in May 2008 (Table 1). There was an intact corridor of overstorey riparian vegetation along both banks, but only small patches of the macrophyte (*Persicaria* sp.) in-stream. Nets were set along banks in a range of habitats in the main channel, including macrophyte beds, snags and backwaters, and also in an anabranch creek with knee-deep surface water.

Fish Community

Only a relatively small number of fish (139 individuals) were captured at Clifton Hills during the survey conducted in May 2008. Half of these fish were Golden Perch, a further 43% were Hyrtl's Tandan and the remainder were Welch's Grunter (Figure 9).

Population Structures

Welch's Grunter

Only ten Welch's Grunter were captured at Clifton Hills in May 2008, and the majority of these were large fish (Figure 8).

Golden Perch

There was a wide range of sizes of Golden Perch captured at Clifton Hills in May 2008 (Figure 8).

Hyrtl's Tandan

Most of the Hyrtl's Tandan captured at Clifton Hills in May 2008 were medium-sized, and there were also two large individuals (Figure 8).

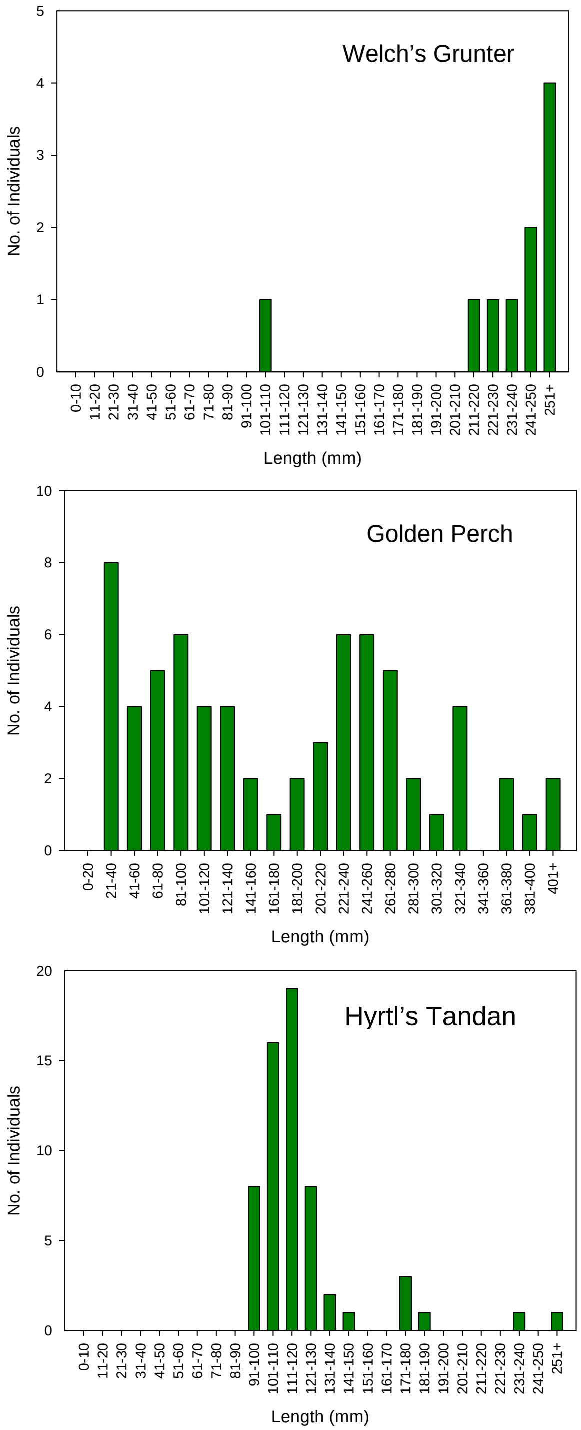


Figure 8. Lengths of fish captured at Clifton Hills in May 2008.

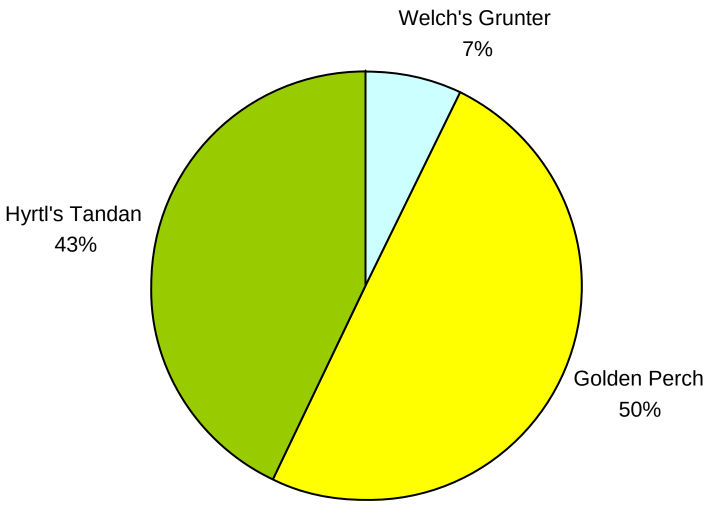


Figure 9. Proportion of each fish taxa (%) captured in reach at Clifton Hills in May 2008 (total number of fish = 139, catch per fyke net = 10).

3.1.3 Goyders Lagoon Waterhole (Diamantina River)

Water Quality & Structural Habitat

The large reach at Goyders Lagoon Waterhole had both high turbidity and conductivity in May 2008 (Table 1). Unfortunately, there was inadequate time allowed to set fyke nets at this large reach, and the littoral zone at this site was surveyed only using a seine net.

Fish Community

There were only a small number of fish captured in four sweeps with a seine net at Goyder's Lagoon Waterhole in May 2008. The total catch of 13 fish consisted of seven Golden Perch and six Hyrtl's Tandan (Figure 11).

Population Structures

Golden Perch

All of the Golden Perch captured in Goyders Lagoon Waterhole in May 2008 were small individuals (Figure 10).

Hyrtl's Tandan

The Hyrtl's Tandan captured in Goyders Lagoon Waterhole in May 2008 were all small individuals (Figure 10).

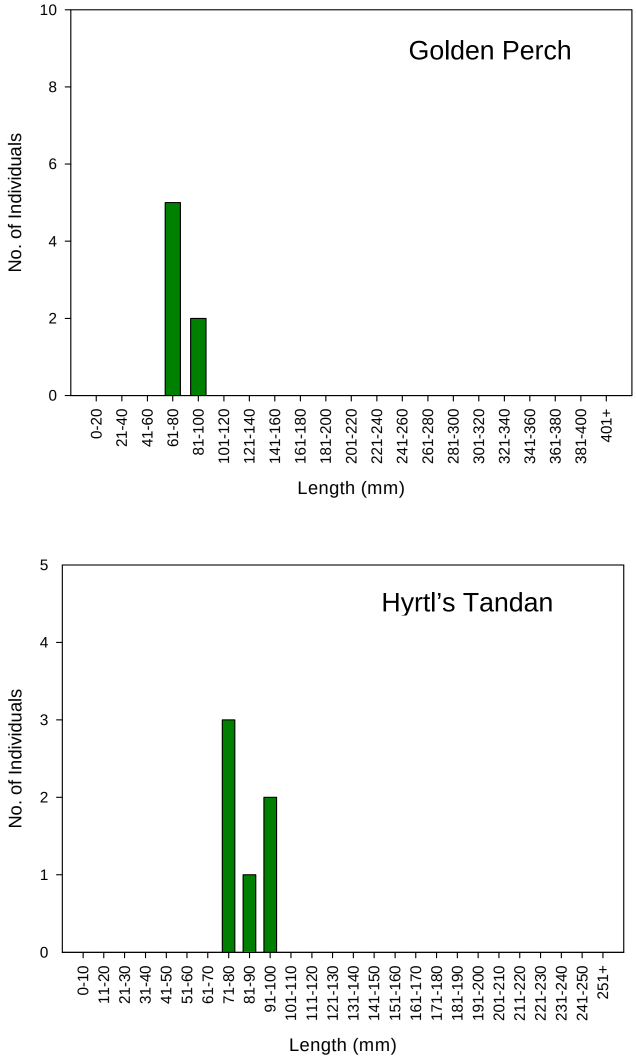


Figure 10. Lengths of fish captured at Goyders Waterhole in May 2008.

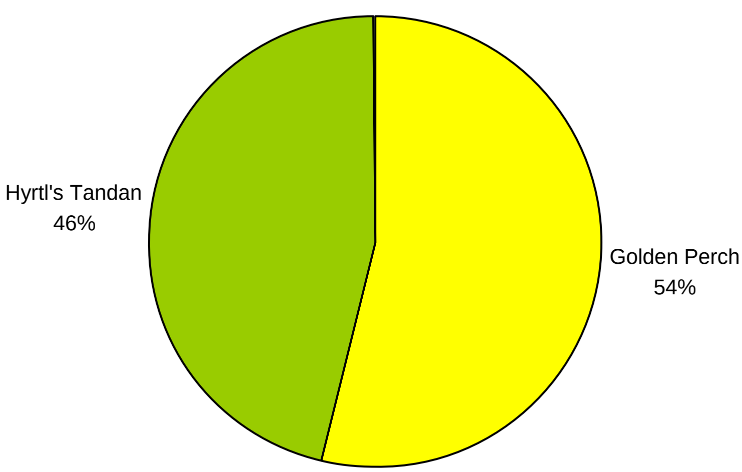


Figure 11. Proportion of each fish taxa (%) captured at Goyders Lagoon Waterhole pools in May 2008 (total number of fish = 13, catch per seine net = 3).

3.1.4 Ultoomurra (Warburton Creek)

Water Quality & Structural Habitat

The small pools in the middle of the Warburton Creek channel at Ultoomurra had very high conductivities and high concentrations of dissolved oxygen in May 2008 (Table 3). A seine net and dip net were used to survey these pools. The largest pool at this site was c.8m long and 3m wide (Figure 2e).

Fish Community

A large number of fish, mainly Lake Eyre Hardyhead, were present in both the small pools at Ultoomurra (Figure 12). A low number of Desert Goby were also collected in the larger pool along with a single, small Bony Bream (Figure 13).

Population Structures

Lake Eyre Hardyhead

The Lake Eyre Hardyhead captured at Ultoomurra in May 2008 were all small- to medium-sized individuals (Figure 12).

Desert Goby

The Desert Goby captured at Ultoomurra were mainly medium sized (20-40mm, 5 individuals), with two large individuals (41mm+).

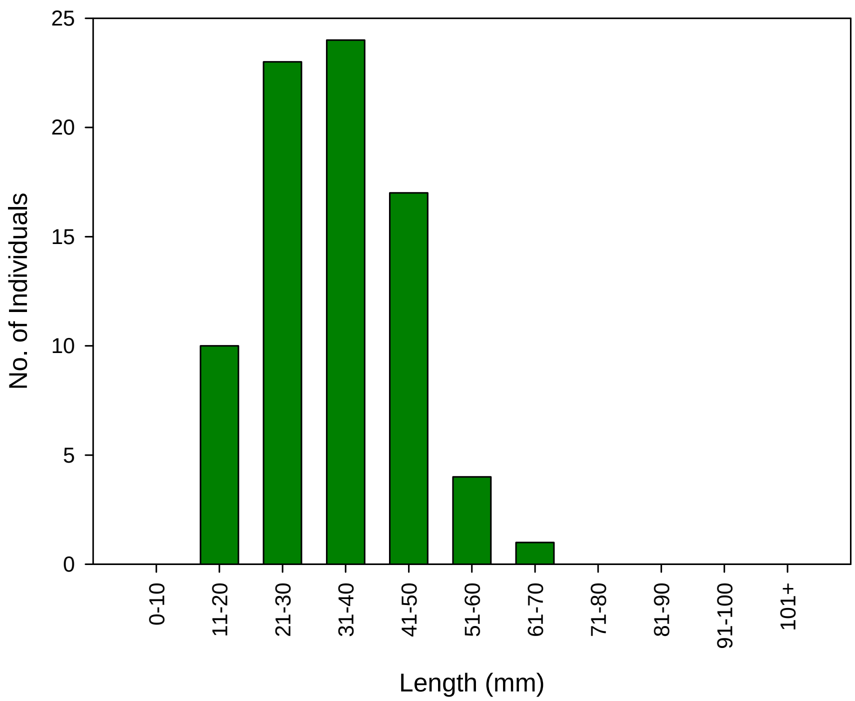


Figure 12. Lengths of Lake Eyre Hardyhead (*Craterocephalus eyresii*) captured in Ultoomurra waterhole in May 2008.

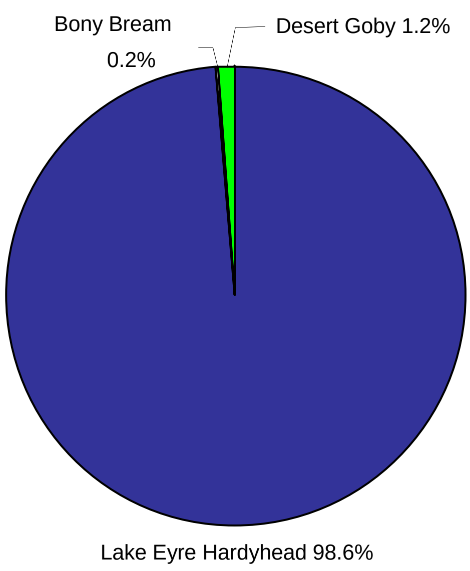


Figure 13. Proportion of each fish taxa (%) captured at Ultoomurra waterhole in May 2008 (total number of fish = 567, catch per seine net = 535).

3.1.5 Peake Waterhole (Peake Creek – d/s of Oodnadatta under Ghan bridge)

Water Quality & Structural Habitat

The conductivity and dissolved oxygen in the small pools in Peake Creek were very high, whilst turbidity was very low (Table 1). The temperature in these pools in December 2007 was much higher than that in May 2008. These small pools were in the middle of a large channel, with salt crystals precipitated on the dry river bed (Figure 3).

Fish Community

A seine net was used to sample the isolated pools at Peake Waterhole during both of the surveys conducted for the present study. In December 2007 fish were counted but not measured, whereas in May 2008 fish were both counted and measured. Two fish taxa, 280 fish in total, were captured at Peake Waterhole during the survey conducted in December 2007 (Table 4). During this survey, Lake Eyre Hardyhead were the most commonly caught taxa, but there were also relatively high numbers of Desert Goby (Figure 15).

In May 2008 there were 3540 fish captured at the site. Lake Eyre Hardyhead was again the most predominantly captured fish taxon as well as a small number of Desert Goby. Over 150 Spangled Perch were also captured in May, after being absent from the site in December.

Population Structures

Desert Goby

A small number of medium- to large-sized Desert Goby were captured in Peake Waterhole in May 2008 (Figure 14). Some gobies were found living in extremely small and shallow pools next to the pylons for the Ghan bridge (Figure 4b). Notes from the December 2007 survey indicate mostly smaller individuals were present, approximating 30mm in length, at that time.

Lake Eyre Hardyhead

Most of the Lake Eyre Hardyhead captured in Peake Creek in May 2008 were medium-sized individuals but some smaller fish (<30mm and a few very large fish (70mm+) were also captured (Figure 14). Notes from the December 2007 survey indicate a range between 30mm and 100mm, indicating a similar size range as for the May data.

Spangled Perch

The majority of Spangled Perch captured at Peake Waterhole in May 2008 were small individuals, but there were also a number of larger individuals captured at the site during this survey (Figure 14). Three of these fish were ripe males.

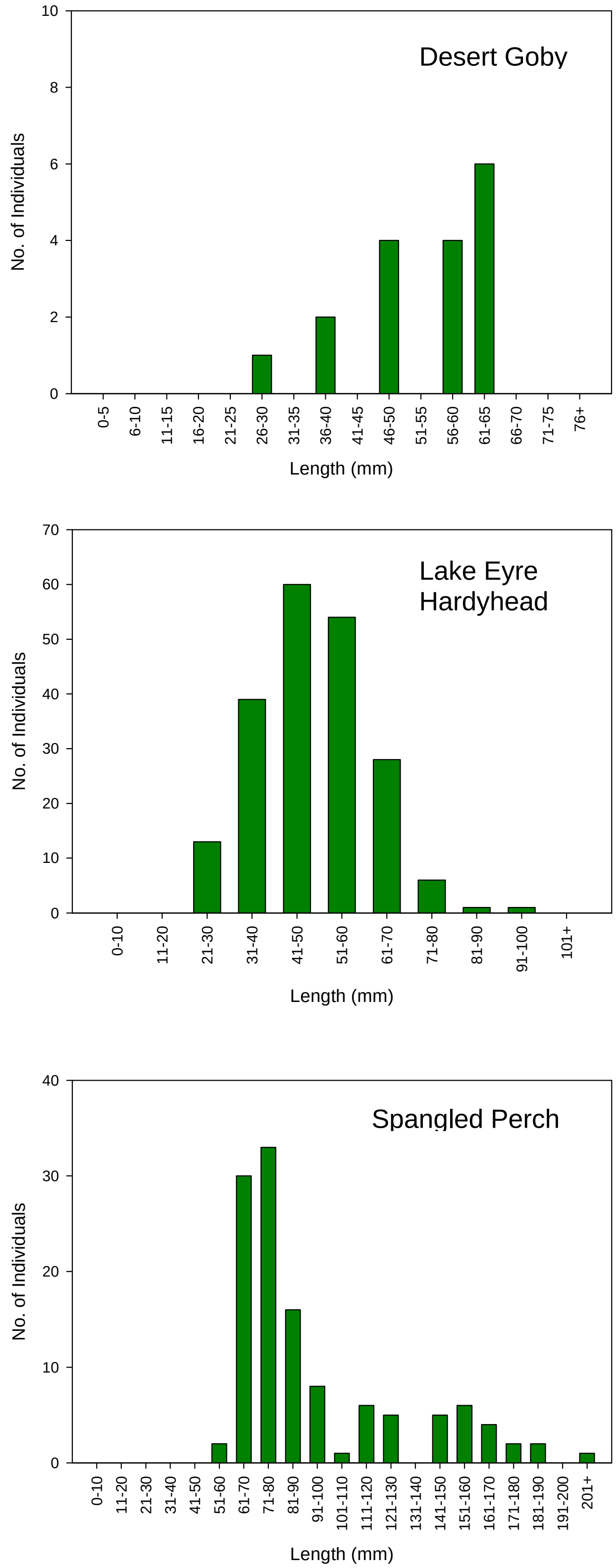
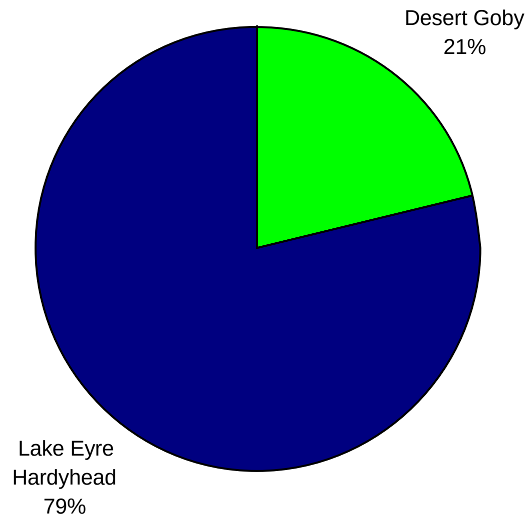


Figure 14. Lengths of fish captured at Peakes Waterhole in May 2008.

a) December 2007



b) May 2008

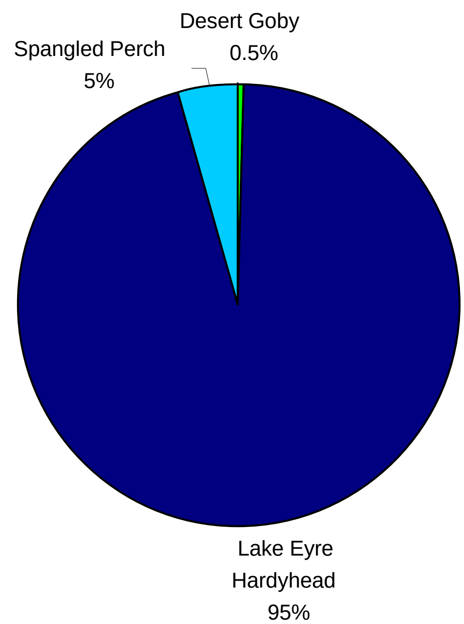


Figure 15. Proportion of each fish taxa (%) captured in Peakes in a) December 2007 (total number of fish = 280, catch per seine net = 140), and b) May 2008 (total number of fish = 3540, catch per seine net = 1770).

3.1.6 Algebuckina (Neales River)

Water Quality & Structural Habitat

The large reach at Algebuckina had more surface water in May 2008 than in December 2007. The turbidity in this reach was relatively low, but conductivity was relatively high when measured in the reach in May (Table 1). There was minimal variability in the amount of dissolved oxygen and the pH between the two periods when the surveys were conducted. There was a wide range of habitats available along this reach and fyke nets were set adjacent to snags, within patches of macrophyte, near large boulders, along bare banks and in a shallow anabranch.

Fish Community

At Algebuckina there were eight species of fish, 2379 fish in total, captured during the survey conducted in December 2007 (Table 4). Mosquitofish, an introduced taxon, were the most abundant fish (33% of captures, Figure 14). Bony Bream and Eastern Rainbowfish were also present in high numbers, together representing 50% of the total number of fish captured. There were over 200 Desert Goby, and over 100 Lake Eyre Hardyhead captured. Only relatively small numbers of Spangled Perch, Barred Grunter and Golden Perch were captured at this site in December 2007.

In May 2008, seven species of fish were captured at Algebuckina (Table 4). Spangled Perch, which were present in December 2007, were not sampled during the second survey. In total, 2693 individual fish were captured during the May 2008 survey. Bony Bream were much more commonly sampled than any other fish taxa, representing 84% of the total number of fish captured in May (Figure 18). Whilst Mosquitofish were not as abundant during this survey than they had been in December, there were still over 300 of these fish captured (11% of the total number of fish captures). There were over 50 individuals of both Eastern Rainbowfish and Desert Goby captured, whereas only relatively small numbers of Barred Grunter, Golden Perch and Lake Eyre Hardyhead were sampled at the site in May 2008.

Population Structures

Barred Grunter

A small number of medium to large sized Barred Grunter were captured at Algebuckina in December 2007 (Figure 16). The majority of these fish, both males and females, were ripe (Table 4). A small number of these fish were also captured at this site in May 2008. Most of these were small individuals, with only a few larger individuals captured during this later survey.

Golden Perch

A low number of small sized Golden Perch, including one ripe female, were captured during surveys conducted at Algebuckina in December 2007 (Figure 16). Slightly higher numbers of these taxa, including some large individuals, were captured at this site during the surveys conducted in May 2008.

Desert Goby

In December 2007 Desert Goby, of a range of sizes, were captured using dip nets at Algebuckina (Figure 16). One of these fish was a ripe female (Table 4) and goby nests were observed in interstitial spaces beneath small rocks. Turning over likely rocks revealed that nests were attended by single large males, with 100+ eggs attached to the bottom of the rock. Developing larvae could be clearly seen within egg masses. These taxa were also counted at the site during spotlight surveys conducted in May 2008, but no individuals were captured and measured during these surveys.

Bony Bream

Large numbers of Bony Bream were captured at Algebuckina during surveys conducted in both December 2007 and May 2008. During each survey, most of these fish were small, but there were also some medium and large individuals (Figure 16).

Spangled Perch

There were 32 Spangled Perch captured at Algebuckina during surveys conducted in December 2007. Most of these fish were medium-sized individuals (Figure 16). Some of these fish were spawning males and a ripe female was also captured (Table 4). However, this fish taxon was not present during surveys conducted in May 2008 at this site.

Eastern Rainbowfish

Most of the Eastern Rainbowfish captured at Algebuckina in December 2007 were medium-sized individuals (Figure 17). Many of these fish, both males and females, were ripe (Table 4). In May 2008 there was a higher proportion of small individuals of this taxon captured at the site, in addition to a large number of medium-sized individuals. Again, a number of these fish were ripe.

Lake Eyre Hardyhead

Most of the Lake Eyre Hardyhead captured at Algebuckina were small individuals during both surveys, with higher numbers of these fish captured in December 2007 than in May 2008 (Figure 17). In December both small and large individuals of this taxon were spawning at this site (Table 4).

Mosquitofish

Mosquitofish were the only introduced fish taxon captured during the present surveys conducted in the Lake Eyre Basin. In December 2007, this taxon was one of the most commonly observed fish at Algebuckina, although only a small number of medium sized fish of this taxon were captured and measured (Figure 17). In May 2008, more individuals of this taxon were captured in fyke nets, and most of these fish were medium to large, with a ripe male and female present.

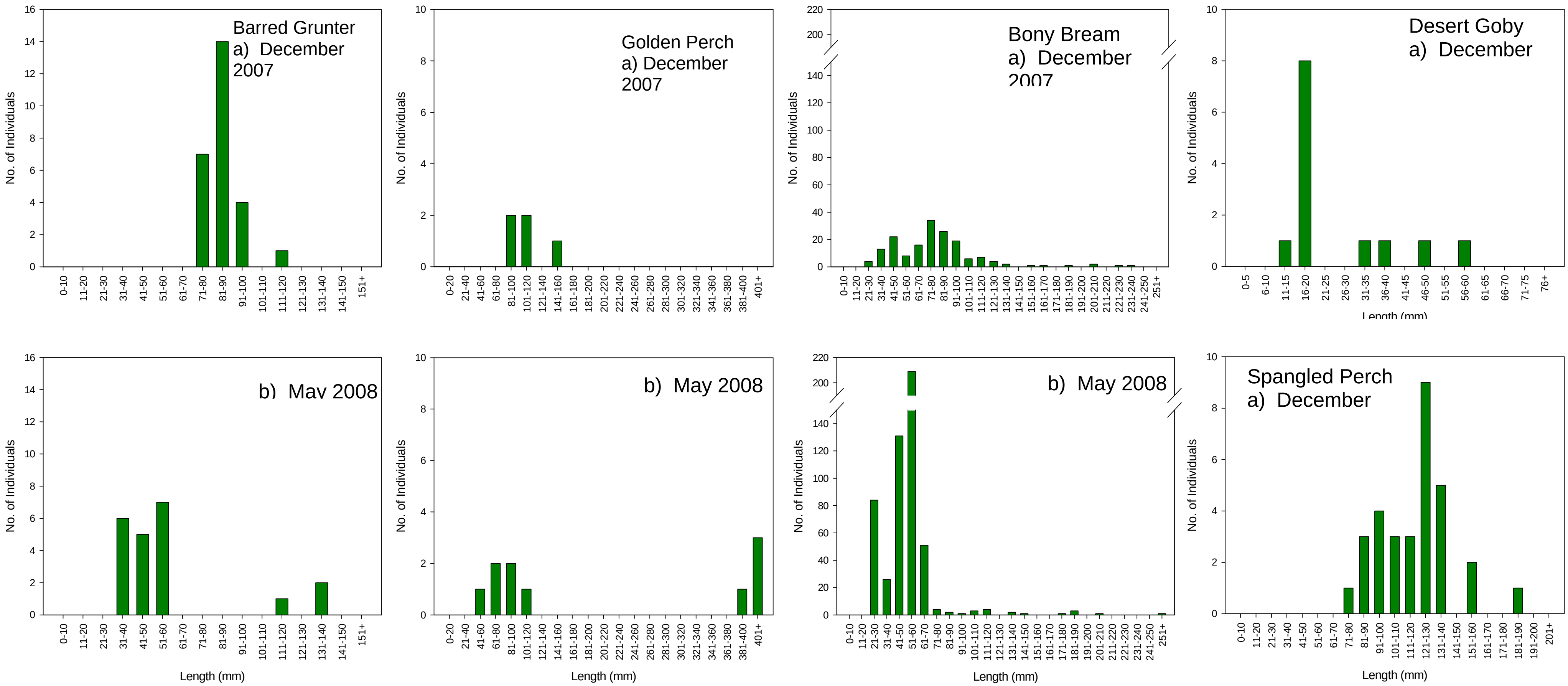


Figure 16. Lengths of fish captured at Algebuckina Waterhole in December 2007 and May 2008.

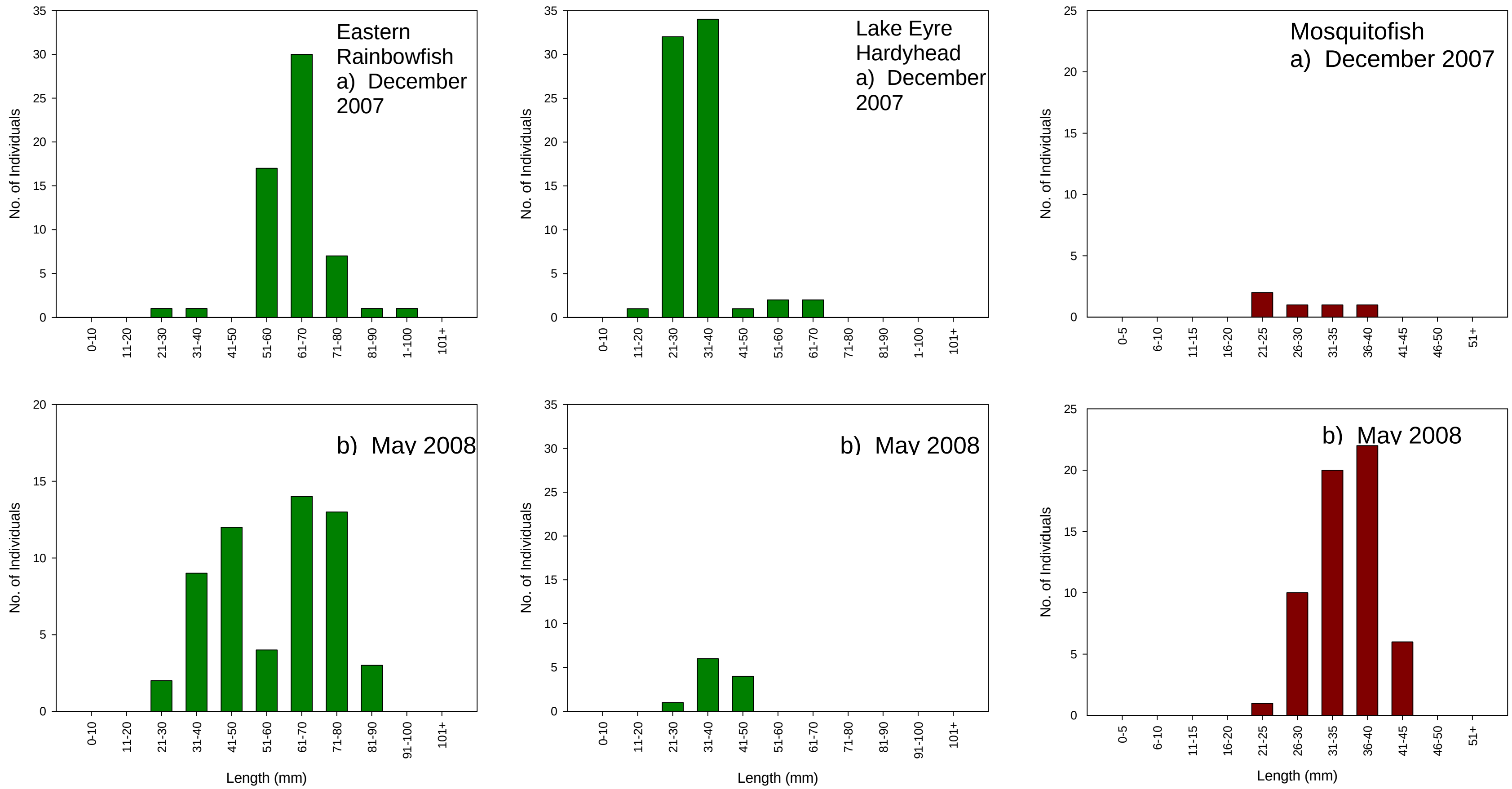


Figure 17. Lengths of fish captured at Algebuckina Waterhole in December 2007 and May 2008.

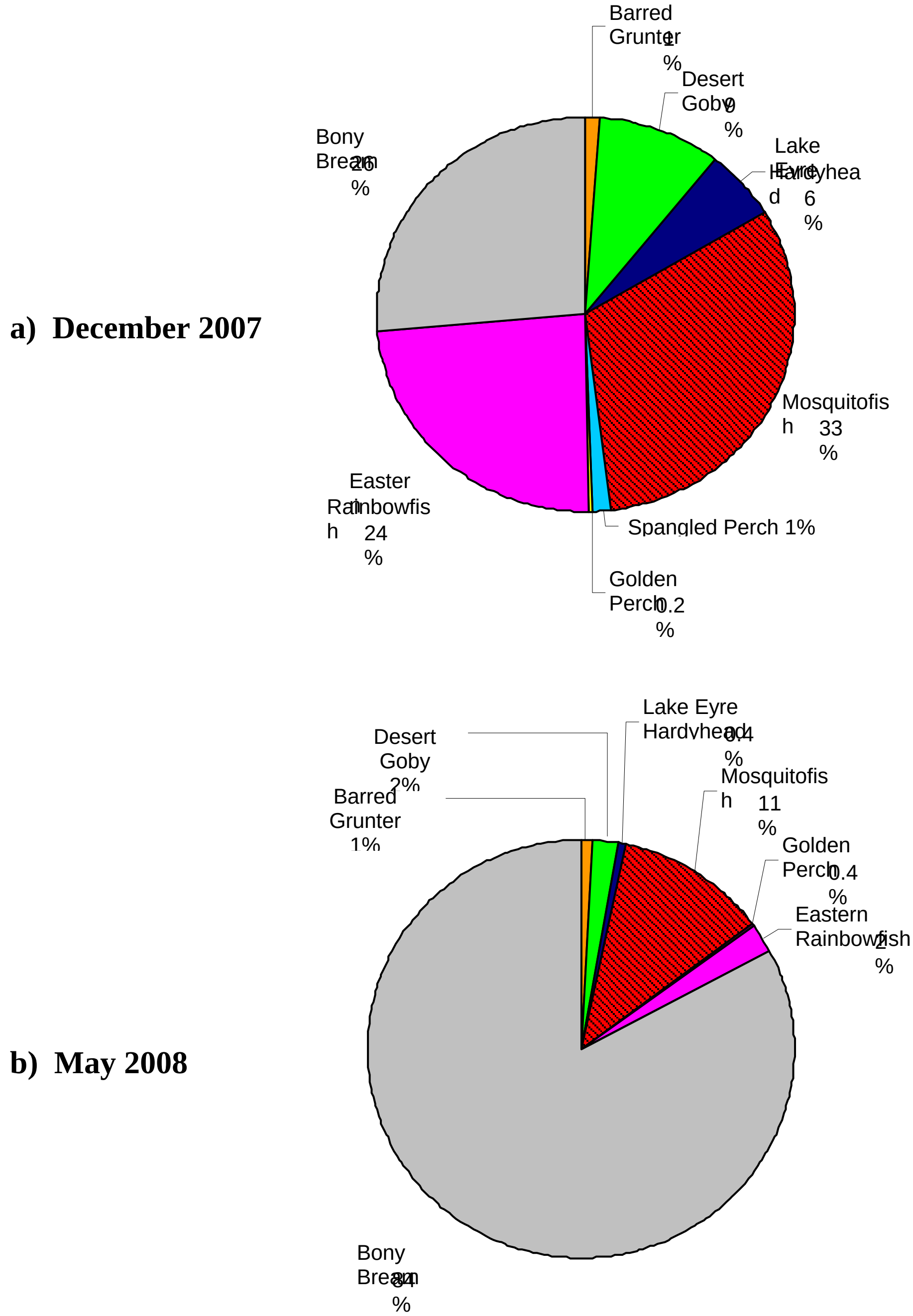


Figure 18. Proportion of each fish taxa (%) captured in Algebuckina in a) December 2007 (total number of fish = 2379, catch per fyke net = 297), and b) May 2008 (total number of fish = 2693, catch per fyke net = 180).

3.1.7 Hookies Waterhole (Neales River)

Water Quality & Structural Habitat

The concentration of dissolved oxygen was low in Hookies Waterhole when surveys were conducted in December 2007, whilst the turbidity at the site was relatively high at this time (Table 3). This site was also highly turbid during the May 2008 survey, but the concentration of dissolved oxygen at this time was over double the amount during the earlier survey.

Fish Community

Spangled Perch (62 individuals) were the only fish taxa captured at Hookies Waterhole during the December 2007 survey (Table 4). Spangled Perch were again captured at this site in May 2008. However, despite being absent in December, Bony Bream were the most common fish taxon captured during the later survey (82% of captures). A total of 724 individual fish were sampled during these surveys conducted in May 2008.

Population Structures

Bony Bream

Although there were no Bony Bream captured at Hookies Waterhole during the initial survey, there were high numbers and a wide range of sizes of this taxon captured during the survey in May 2008 (Figure 19). Most of these fish captured in May were small, with some large individuals sampled.

Spangled Perch

The Spangled Perch captured at Hookies Waterhole in December 2007 were predominantly medium sized individuals (Figure 19). The majority of both male and female individuals of this taxon were spawning at this site at that time (Table 4). A wide range of sizes of this taxon of fish were captured during May 2008. There were more small fish, as well as a number of larger fish, captured during this survey, than there had been during the earlier survey. During the later surveys a number of males of various sizes, were in spawning condition.

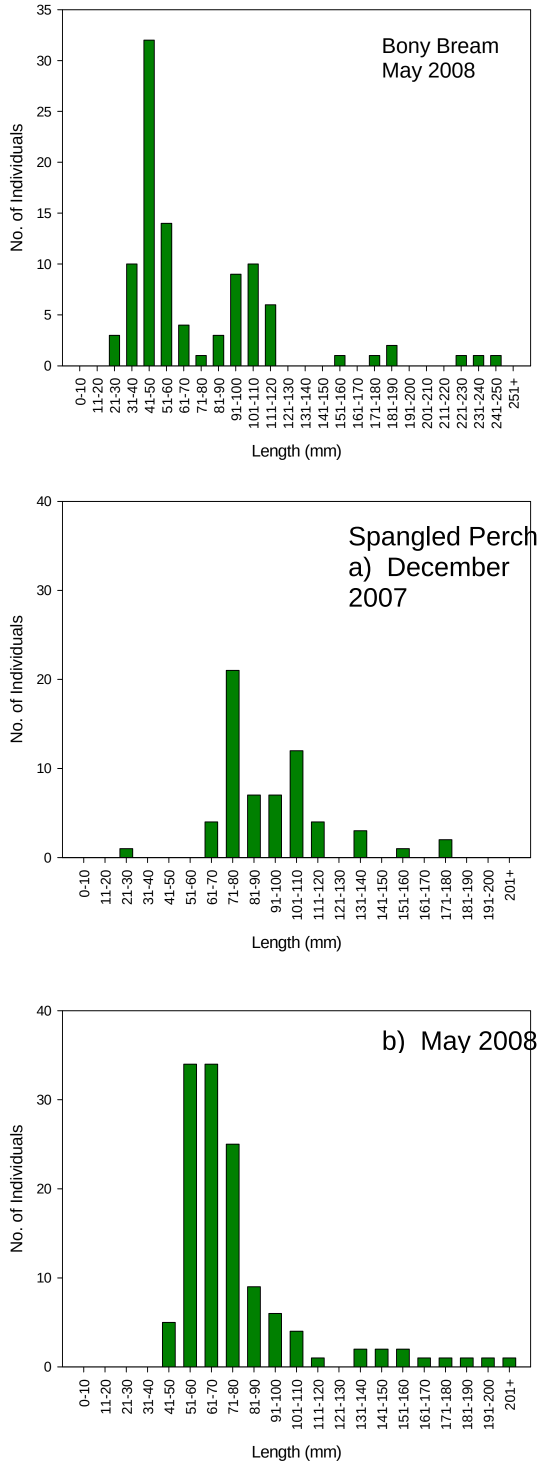
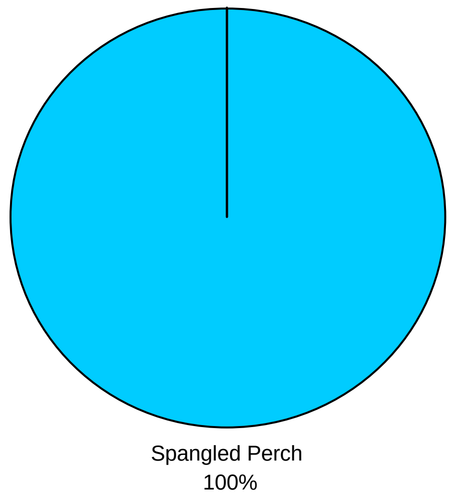


Figure 19. Lengths of fish captured at Hookies Waterhole in December 2007 and May 2008.

a) December 2007



b) May 2008

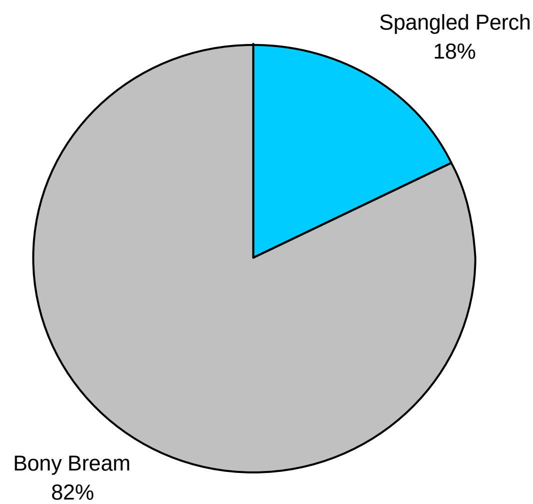


Figure 20. Proportion of each fish taxa (%) captured in Hookies Waterhole in a) December 2007 (total number of fish = 62, catch per fyke net = 10), and b) May 2008 (total number of fish = 724, catch per fyke net = 48).

3.1.8 Stewarts Waterhole (Neales River)

Water Quality & Structural Habitat

The conductivity at Stewarts was the lowest of any of the Neales River sites, whilst the turbidity was relatively high at this site (Table 1). The dissolved oxygen concentration at this site was particularly high in May 2008.

Fish Community

There were no fish captured at Stewarts Waterhole in December 2007, with large numbers of yabbies and other invertebrates caught in the nets (Table 4). In May, however, a small number of Spangled Perch (26 individuals) and Bony Bream (12 individuals) were captured at the site (Figure 22).

Population Structures

Spangled Perch

The Spangled Perch captured at Stewarts Waterhole in May 2008 were predominantly small, but there were also a number of medium-sized individuals of this taxon present (Figure 21). One third of these fish were males in spawning condition (Table 4).

Bony Bream

The Bony Bream captured at Stewarts Waterhole in May 2008 were all medium-sized individuals (Figure 21).

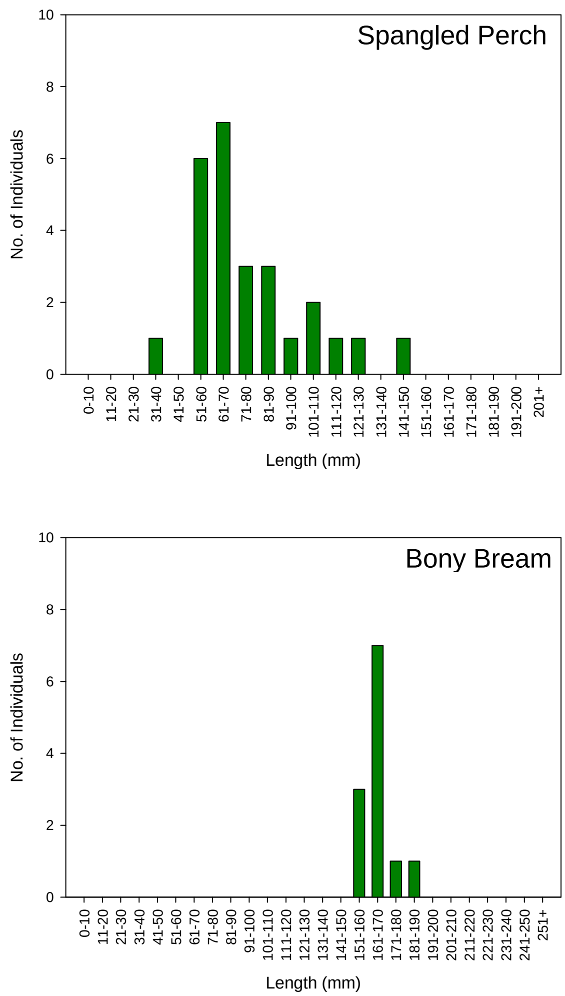


Figure 21. Lengths of fish captured at Stewarts Waterhole in May 2008.

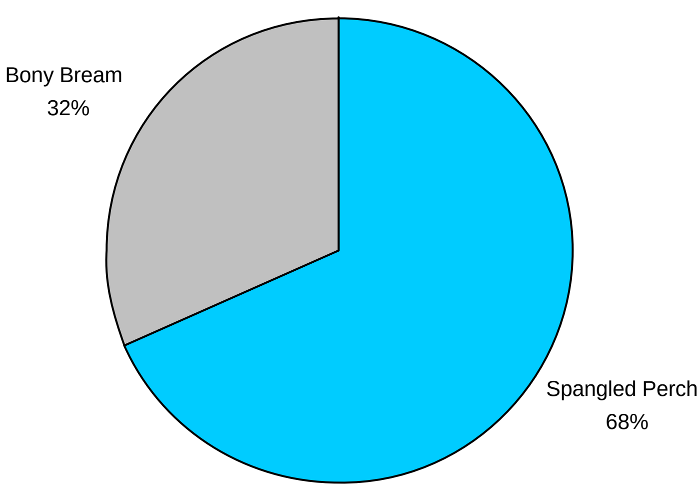


Figure 22. Proportion of each fish taxa (%) captured at Stewarts Waterhole pools in May 2008 (total number of fish = 38, catch per fyke net = 4).

3.1.9 South Stewarts Waterhole (Neales River)

Water Quality & Structural Habitat

The conductivity in the reach at South Stewarts Waterhole was higher than that at Stewarts Waterhole, whilst the turbidity was lower (Table 3). As for Stewarts Waterhole, the concentration of dissolved oxygen was higher in May 2008 than it had been in December 2007.

Fish Community

No fish were captured at South Stewarts Waterhole during the survey conducted in December 2007 (Table 4) despite the site having a reasonable depth of water. Large numbers of yabbies (*Cherax destructor*), and other invertebrates were captured in the absence of fish. In May 2008, two species of fish were present. Of the 46 fish captured at the site (Figure 24), the vast majority were Spangled Perch with only an individual Bony Bream being captured.

Population Structures

Spangled Perch

Most of the Spangled Perch captured from South Stewarts in May 2008 were medium-sized individuals, but there were also some larger individuals (Figure 23). A number of these fish, across a range of sizes, were males in spawning condition (Table 4).

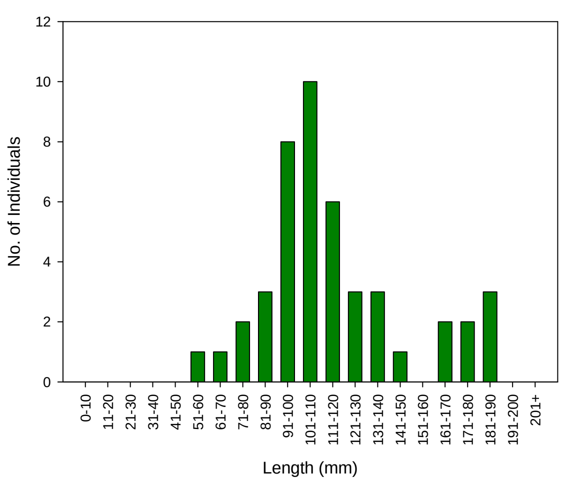


Figure 23. Lengths of Spangled Perch (*Leiopotherapon unicolour*) captured at South Stewarts in May 2008.

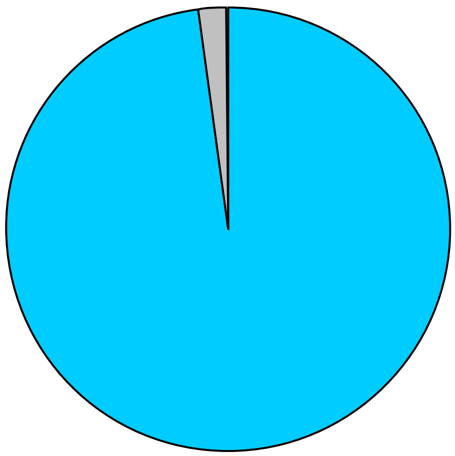


Figure 24. Proportion of each fish taxa (%) captured at South Stewarts pools in May 2008 (total number of fish = 46, catch per fyke net = 9).

3.2 Catchment-scale

3.2.1 Lower Coopers Creek

Hydrology

There were no high flows at Cullyamurra gauging station (Costelloe) in 2005 and 2006, but there was a large flow (>50 000ML/day) in early 2007 (Figure 25) and another large flow in early 2008 (not shown).

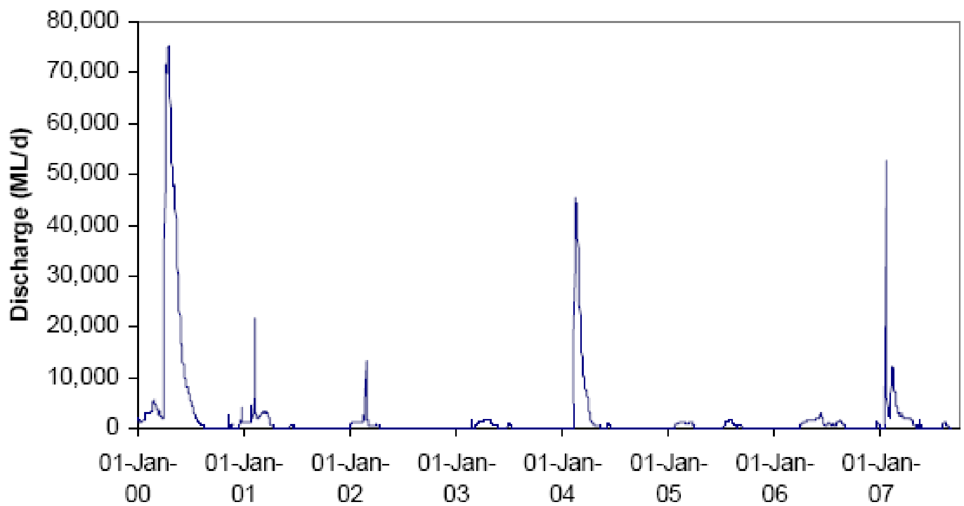


Figure 25. Plots from Costello (2008) showing flow at Cullyamurra gauging station.

Community and Population Structures

The Conceptual Model refers to changes in the structure and condition of fish populations and communities relative to the 'average' flow scenario. The Lower Coopers Creek site at Cullyamurra Waterhole was only surveyed once (May 2008) making comparison between seasons impossible within this catchment. However, comparisons were made between the Lower and Upper Coopers Creek catchment.

The species richness of the fish community at Cullyamurra was very high, comprising thirteen species making this the most species rich site sampled in the current study, both in Queensland and South Australia. This site possessed a suite of species identical to the upstream assemblage collected from Coopers Creek in Queensland (Balcombe and Kerezsy, 2008). In addition to the species collected on the western side of Lake Eyre and in the Diamantina, Cullyamurra Waterhole also possessed Silver Tandan, Cooper Catfish, Carp Gudgeon, Glassfish, Australian Smelt and Barcoo Grunter, where the following species Eastern Rainbowfish, Barred Grunter, Desert Goby and Lake Eyre Hardyhead were not sampled Due to the massive size of this waterhole, further surveying is suggested before the presence of some of the more common species that are present in the Cooper Creek catchment, such as Eastern Rainbowfish, can be ruled out at this site.

The species richness and permanence of Cullyamurra Waterhole indicate that this site may be an important fish refuge in the lower Cooper Creek and therefore is important for monitoring the health of aquatic systems in the Lake Eyre Basin.

In contrast to the upper catchment (Balcombe and Kerezsy, 2008), there was no clear evidence of recent recruitment of juveniles into the Hyrtl's Tandan population in the lower catchment (Figure 35.). In the Lower Cooper catchment in May 2008, the population of this taxa, as well as those of Golden Perch (Figure 22), Carp Gudgeons (Figure 29.), Australian Smelt (Figure 30.), Spangled Perch (Figure 31.), Eastern Rainbowfish (Figure 34.), Silver Tandan (Figure 31) and Coopers Creek Catfish (Figure 37.) were all composed of mainly medium-sized individuals. Although there was no evidence of recent recruitment of juveniles into any of these populations, the high abundances of medium-sized fish may have been recruits from January, when high flows occurred (consistent with the Conceptual Model). There were also large fish captured from each of these populations, indicating good survival of fish in the catchment. The introduced Mosquitofish were the only fish taxa captured in the Lower Cooper Creek with a high proportion of small individuals, indicating recent good recruitment of juveniles (Figure 33).

The majority of the Golden Perch (particularly the medium-sized individuals) and Barcoo Grunter (Figure 22 and Figure 33.), as well as a number of Spangled Perch (Figure 31.), Welch's Grunter (Figure 32) and Hyrtl's Tandan (Figure 35.) captured from Coopers Creek in May 2008 had obvious external signs of disease, including both lesions and *Lernea* (Figure 48).

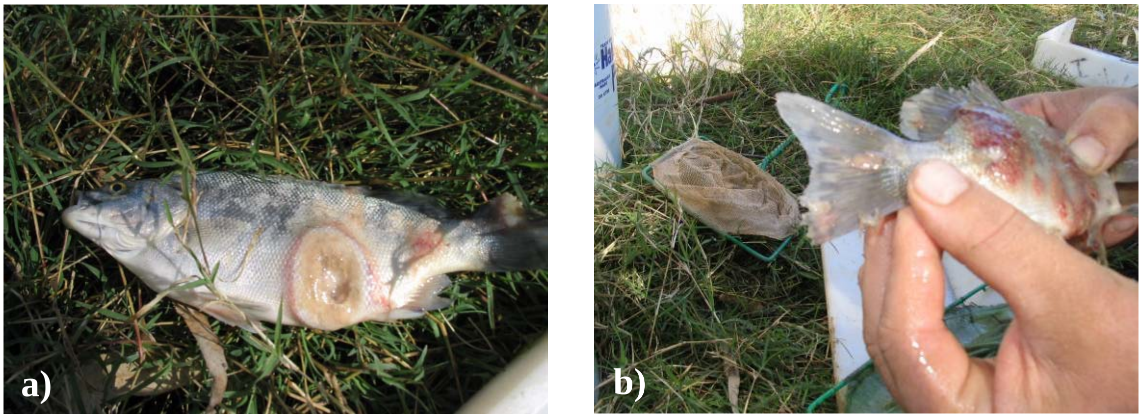


Figure 26. Grunters captured from Cullyamurra Waterhole in May 2008 with (a) severe lesions and (b) *Lernea* infestations.

Trophic Structure

The trophic structure of the fish community in Lower Coopers Creek in May 2008 (Figure 39.) was similar to that of Upper Coopers Creek in March 2008 (Balcombe and Kerezsy, 2008), in that over three quarters of the community were macro-carnivores in both the upper and lower catchment. This high abundance of macro-carnivores in the lower catchment after the large flow is consistent with the expectations from the Conceptual Model. However, the proportion of detritivores was relatively low in the lower catchment. These detritivores were mainly large Bony Bream (Figure 28), and there was no evidence of increased recruitment of these fish after high flows, which contrasts with the predictions of the Conceptual Model.

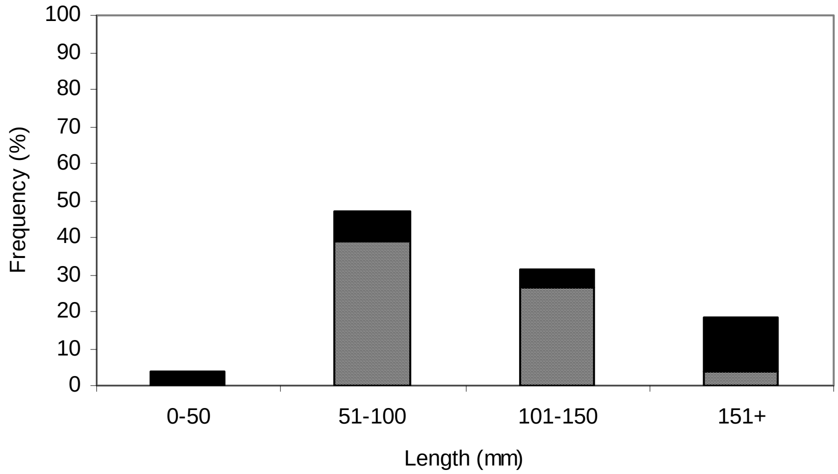


Figure 27. Proportions (%) of Golden Perch (*Macquaria ambigua*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 141). The proportion of diseased fish within each size class is indicated by hatching (n = 97).

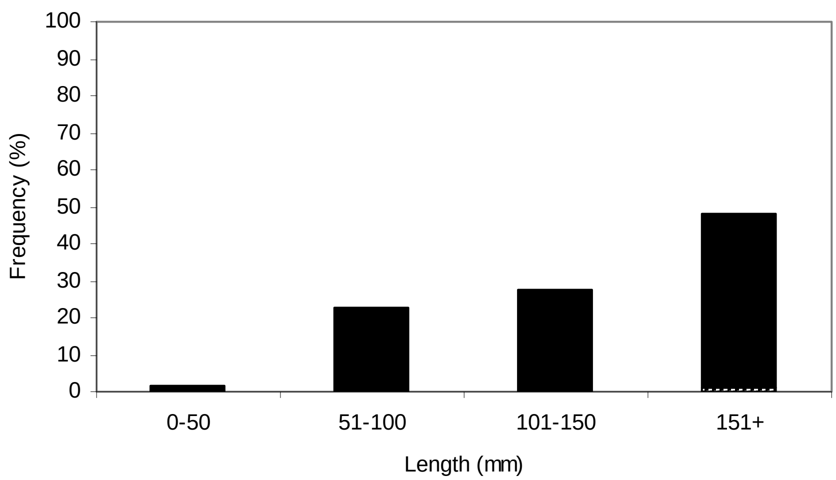


Figure 28. Proportions (%) of Bony Bream (*Nematolosa erebi*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 106). The proportion of diseased fish within each size class is indicated by hatching (n = 1).

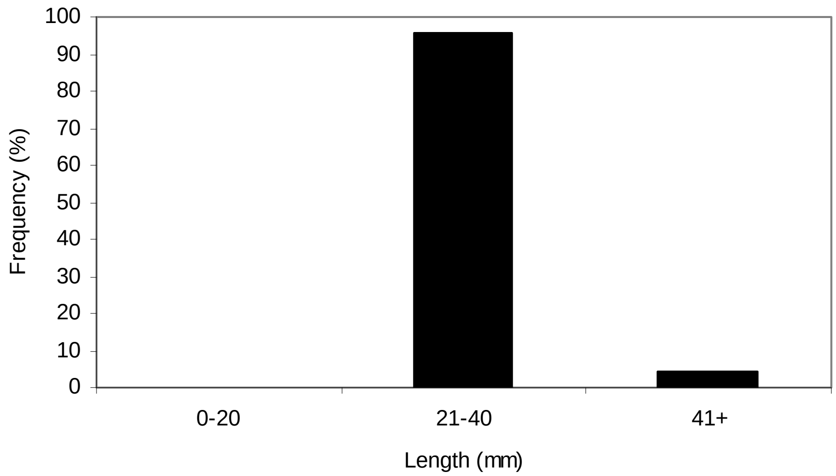


Figure 29. Proportions (%) of Carp Gudgeon species (*Hypseleotris* spp.) from each size class captured in the Coopers Creek catchment in May 2008 (n = 71).

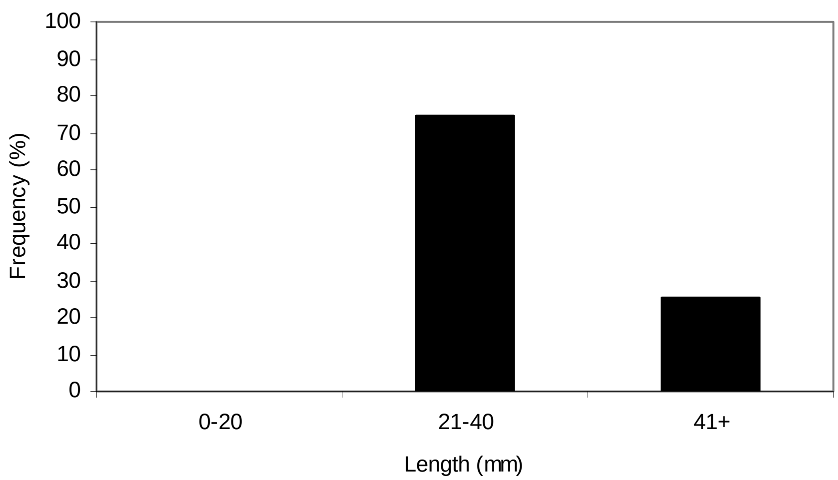


Figure 30. Proportions (%) of Australian Smelt (*Retropinna semoni*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 55).

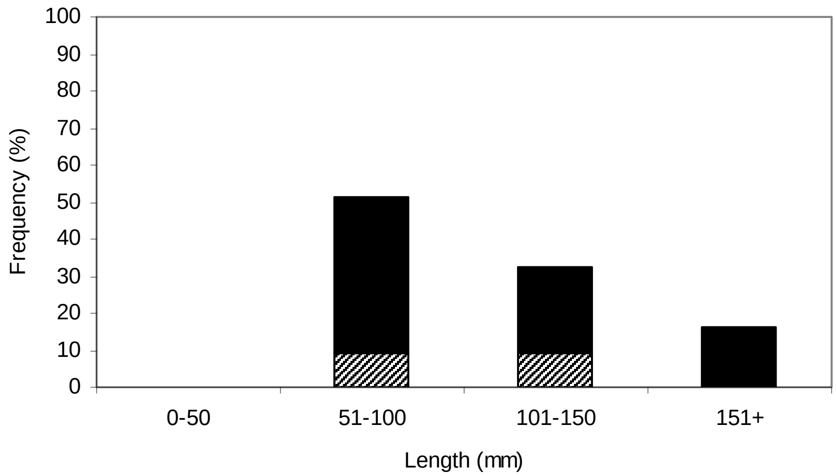


Figure 31. Proportions (%) of Spangled Perch (*Leiopotherapon unicolor*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 43). The proportion of diseased fish within each size class is indicated by hatching (n = 8).

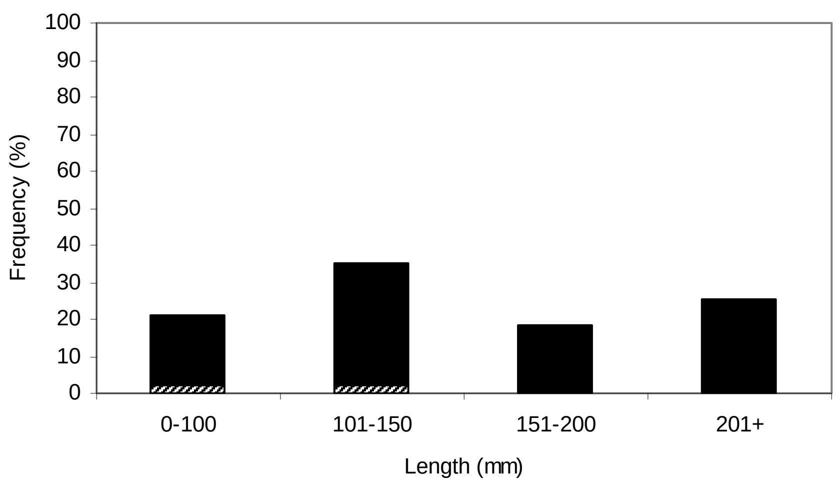


Figure 32. Proportions (%) of Welch's Grunter (*Bidyanus welchi*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 43).

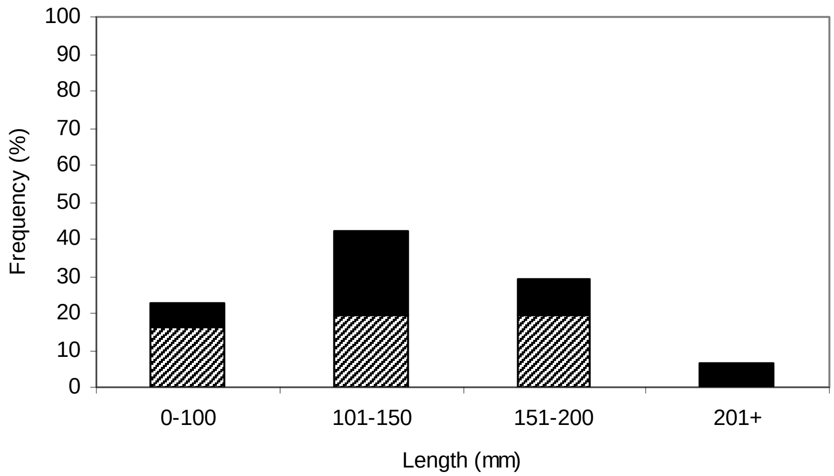


Figure 33. Proportions (%) of Barcoo Grunter (*Scortum barcoo*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 31). The proportion of diseased fish within each size class is indicated by hatching (n = 17).

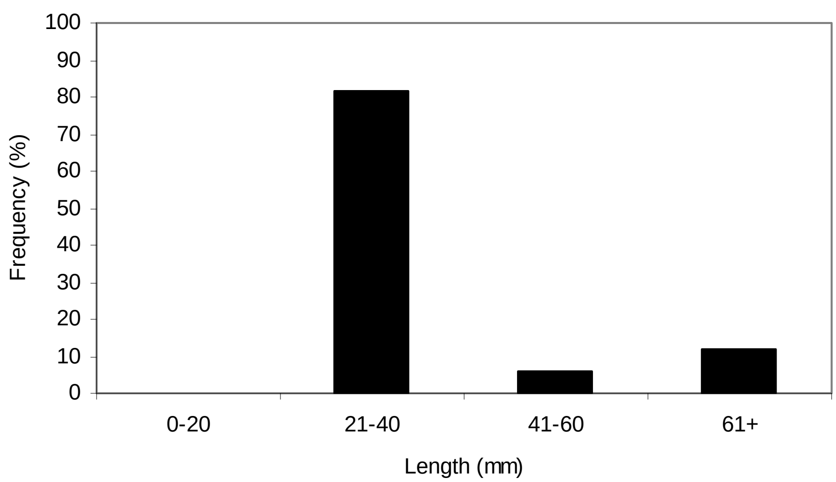


Figure 34. Proportions (%) of Eastern Rainbowfish (*Melanotaenia splendida tatei*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 33).

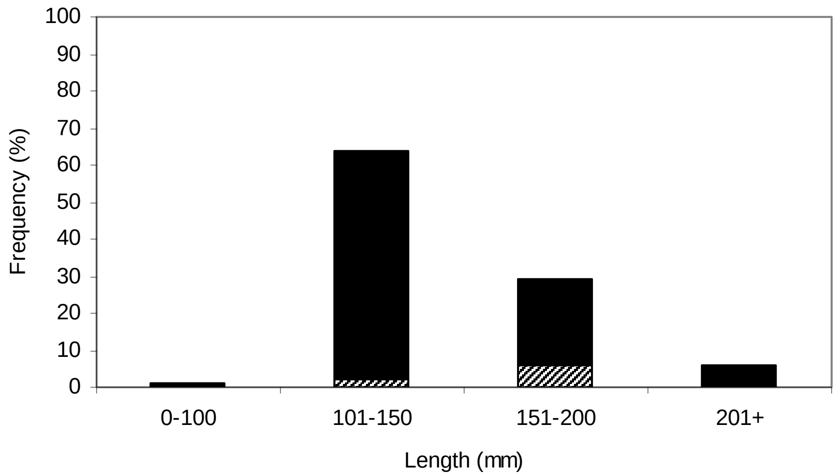


Figure 35. Proportions (%) of Hyrtl's Tandan (*Neosilurus hyrtilii*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 100). The proportion of diseased fish within each size class is indicated by hatching (n = 8).

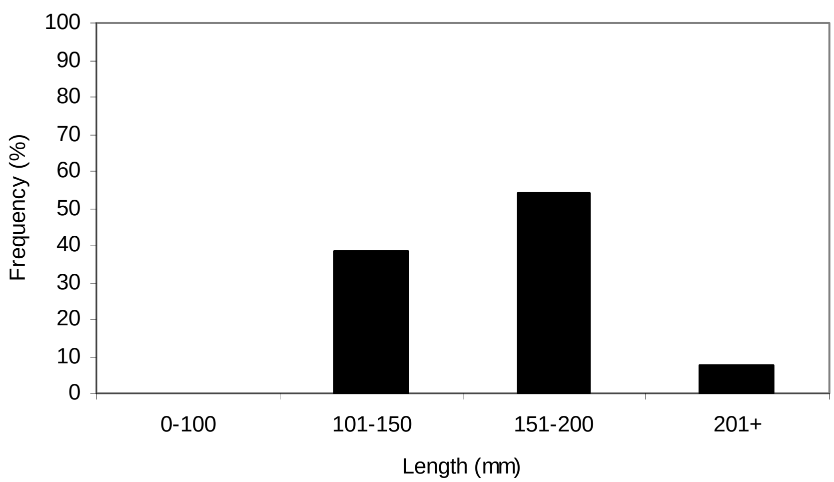


Figure 36. Proportions (%) of Silver Tandan (*Porochilus argenteus*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 13).

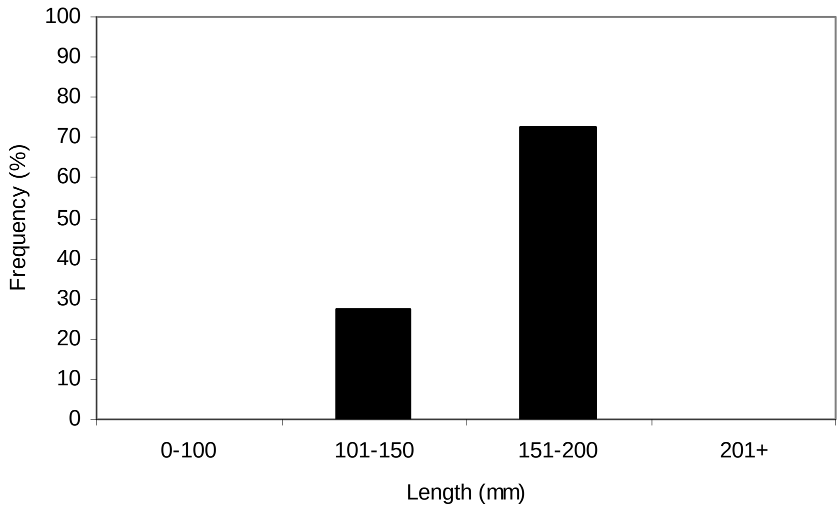


Figure 37. Proportions (%) of Cooper Creek Catfish (*Neosiluroides cooperensis*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 11).

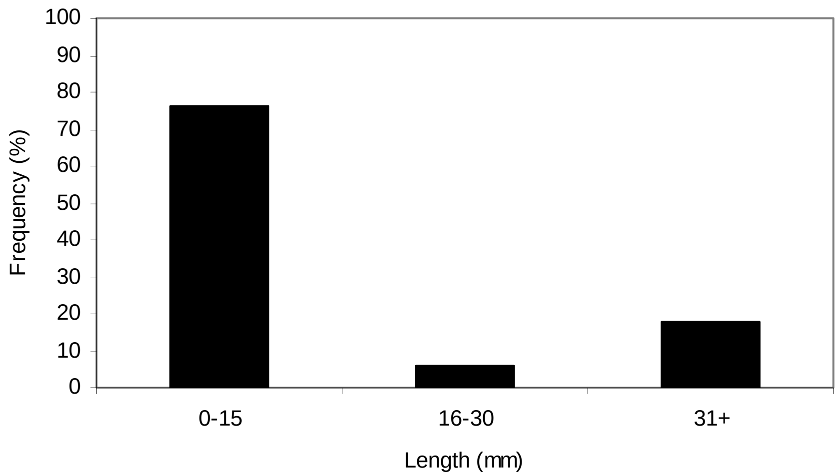


Figure 38. Proportions (%) of Mosquitofish (*Gambusia holbrooki*) from each size class captured in the Coopers Creek catchment in May 2008 (n = 17).

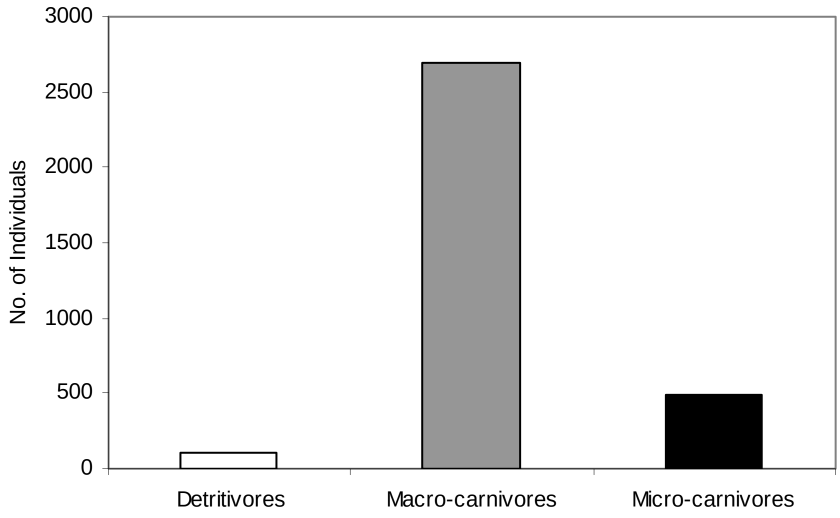


Figure 39. Abundances of fish from each trophic group captured in the Coopers Creek catchment in May 2008 (total n = 3285).

3.2.2 Lower Diamantina River & Warburton Creek

Hydrology

There were very low flows in 2005 and 2006, but a large flow (>20 000ML/day) in early 2007 (Figure 40 from Costelloe 2008, Fig. 9, p.21). There was an average recent flood in the upper catchment prior to the 2008 surveys (not shown). Sites at Clifton Hills and Goyders Lagoon Waterhole had high water levels at the time of the surveys conducted in May 2008, whilst Ultoomurra had dried into a series of small isolated pools.

Community and Population Structures

The diversities of fish communities at Goyder's Lagoon and Clifton Hills were low and dominated by the larger bodied species, Golden Perch, Hyrtl's Tandan and Welch's Grunter (Grunters at Clifton Hills only). Surveying effort at Clifton Hills was high and care was taken to seek out and sample habitats suitable to small-bodied fish including macrophyte beds, backwaters and anabranch creeks. No small-bodied species were found at Clifton Hills, only small individuals of the larger bodied Golden Perch. Without repeat surveys, no comment can be made regarding changes in community and population structures mentioned in the Conceptual Model.

The structure of the Golden Perch population in the Lower Diamantina River in May 2008, was different to that in the Upper Diamantina River in March 2008 (Balcombe and Kerezsy, 2008). In the lower catchment this taxon of fish were mainly large individuals, whereas a high proportion of juveniles were captured during the surveys conducted in the upper catchment in Autumn 2008. Only a small number of Welch's Grunter were captured in the Lower Diamantina, at Clifton Hill, in May 2008, but these fish were also predominantly large individuals (Figure 44.). In contrast to the population structures of these two large fish taxa, there was some evidence of recruitment of juveniles for both the Lake Eyre Hardyhead (Figure 41.) and Hyrtl's Tandan (Figure 43.) populations in the Lower Diamantina River in May 2008.

Species richness was only assessed once at the small pools existing at Warburton Creek, but, as with the small pools in Peake Creek, this site only possessed the most tolerant small-bodied species. These were again the Lake Eyre Hardyhead and Desert Goby, as well as one of the recolonising species, Bony Bream. This site was also surveyed during Aridflo when it also possessed a population of Lake Eyre Hardyheads (Costelloe et al 2004), indicating that these harsh, highly ephemeral pools are still capable of possessing discrete but highly repeatable assemblages of highly tolerant fish communities. The significance of these sites to the overall catchment fish community would rely on their persistence through particularly dry years, again re-emphasising the need for persistent refuge habitats within catchments from which fish can recolonise to less permanent habitats in wetter times. There was no external evidence of disease for any of the fish captured in the Lower Diamantina River.

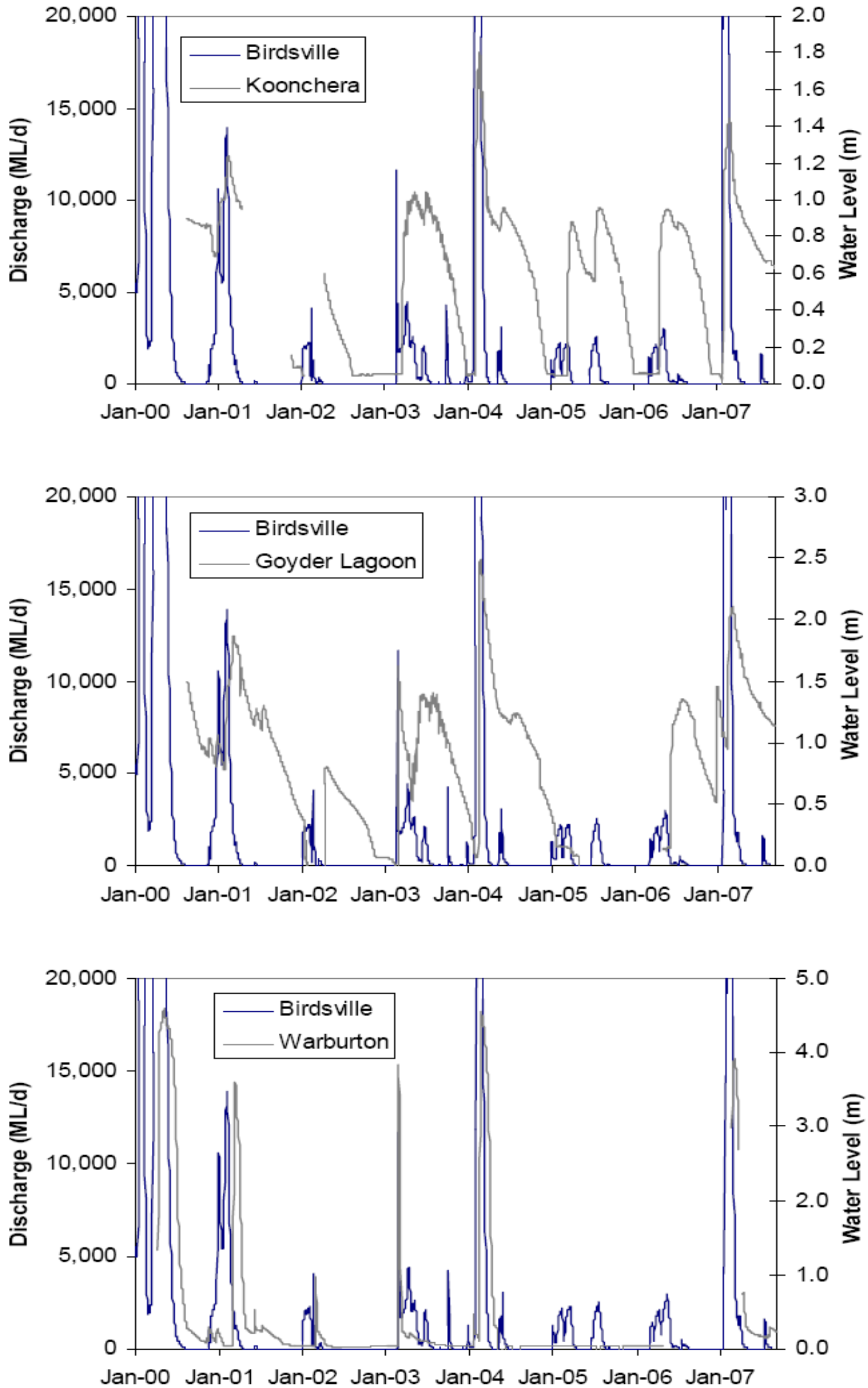


Figure 40. Plots from Costello (2008) showing flow at Birdsville compared to stage height at Koonchera (near Clifton Hills), Goyder Lagoon and Warburton Creek (near Ultoomurra).

Trophic Structure

There were no detritivores captured in the Lower Diamantina River in May 2008, which is consistent with the expectations of the Conceptual Model after a long period of low flow. All the fish captured from the Lower Diamantina were macro-carnivores, whilst in the isolated pools sampled in the Warburton River all the fish were micro-carnivores (except for a lone Bony Bream) (Figure 45. and Figure 46.).

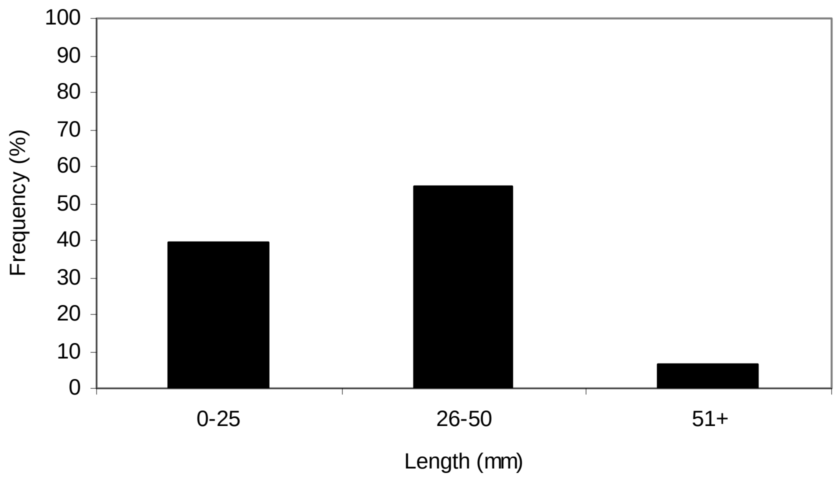


Figure 41. Proportions (%) of Lake Eyre Hardyhead (*Craterocephalus eyresii*) from each size class captured in the Lower Diamantina River catchment in May 2008 (n = 79).

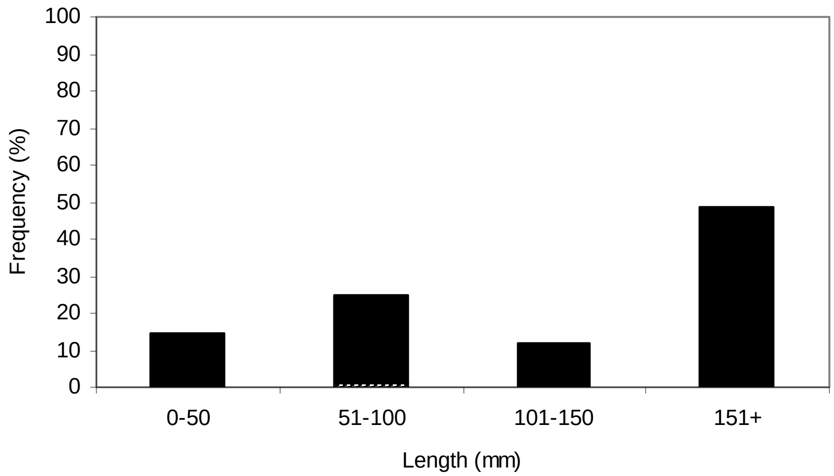


Figure 42. Proportions (%) of Golden Perch (*Macquaria ambigua*) from each size class captured in the Lower Diamantina River catchment in May 2008 (n = 76). The proportion of diseased fish within each size class is indicated by hatching (n = 1).

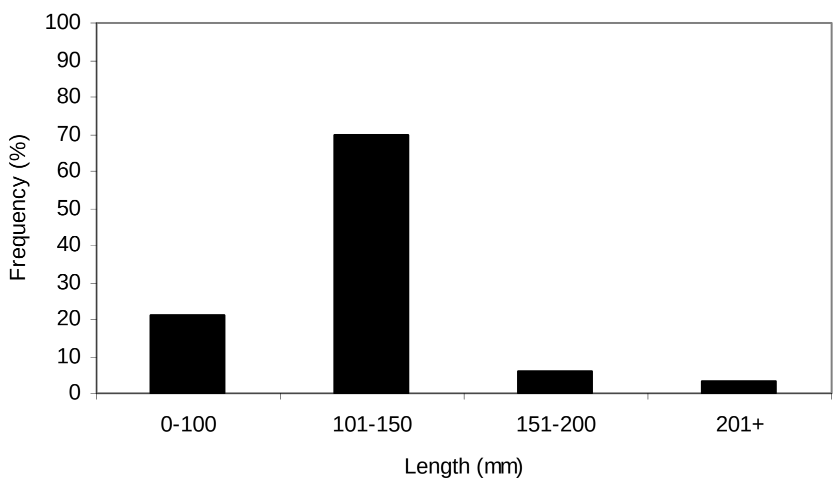


Figure 43. Proportions (%) of Hyrtl's Tandan (*Neosilurus hyrtilii*) from each size class captured in the Lower Diamantina River catchment in May 2008 (n = 66).

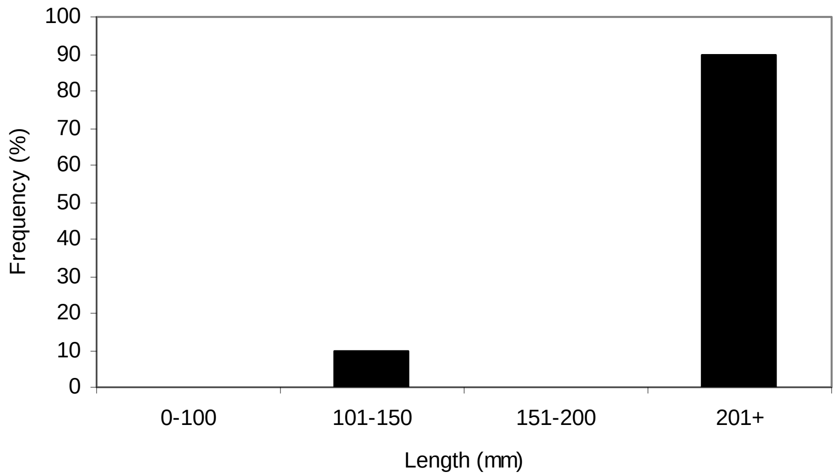


Figure 44. Proportions (%) of Welch's Grunter (*Bidyanus welchi*) from each size class captured in the Lower Diamantina River catchment in May 2008 (n = 10).

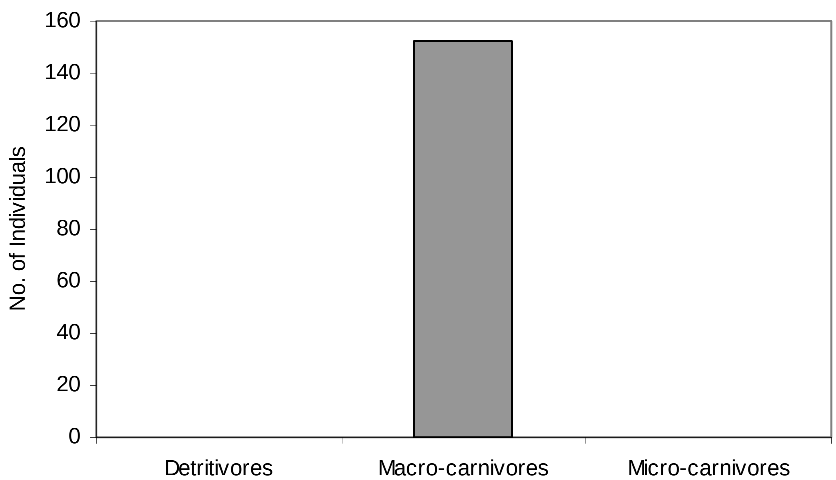


Figure 45. Abundances of fish from each trophic group captured in the Diamantina River catchment in May 2008 (total n = 152).

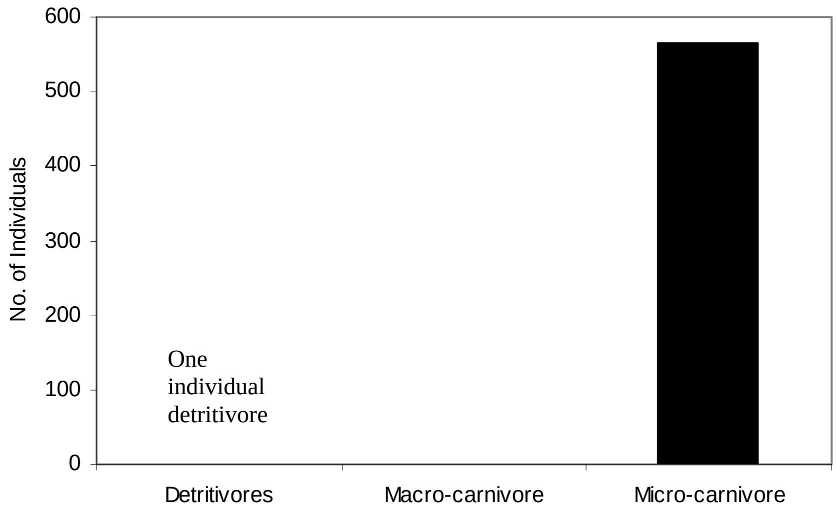


Figure 46. Abundances of fish from each trophic group captured in the Warburton Creek catchment in May 2008 (total n = 567).

3.2.3 Peake Creek

Hydrology

There was no significant flows or flooding prior to the current surveys at Peake Creek (Figure 47). Stage height data from indicates that this creek has been getting progressively drier over recent years.

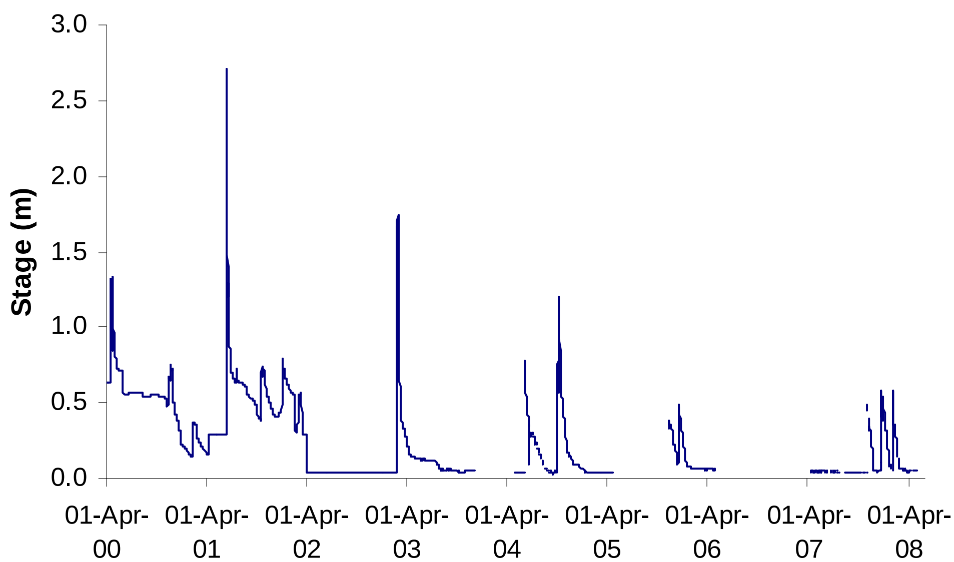


Figure 47. Stage height data for Peake Creek from April 2000 to April 2008**.**

Community and Population Structures

Species richness increased in Peake Creek between December 2007 and May 2008, due to the arrival of Spangled Perch into the resident fish community, formally consisting of Lake Eyre Hardyhead and Desert Goby. Similar to the patterns observed in the adjacent Neales River, Spangled Perch most likely migrated upstream from refuge habitats either in the lower Peake River, or in the Neales River into which it flows.

This pattern highlights the variable boom and bust nature of these extreme climate rivers and reveals that the Peake – Neales River system is an excellent study area for understanding the ecological processes and patterns that relate to aquatic systems influenced by Australia's harshest climatic extremes. The fish within these systems all had to tolerate salinities higher than seawater to survive in these refuges and for Spangled Perch, connectivity again lead to recolonisation of the catchment. In Peake Creek we reveal differential characteristics for surviving drought, whereby Lake Eyre Hardyhead and Desert Goby have maintained their populations through tolerance to extreme conditions, whilst Spangled Perch populations contract to less harsh refuge pools. Further monitoring will indicate whether Spangled Perch can also tolerate the extremes of the Peake Creek habitat and persist through the dry season to December 2008.

There was no evidence of recent recruitment of juveniles into any of the populations of fish in Peake Creek (Figures 41-43), consistent with the expectations of the Conceptual Model after a long period of relatively dry conditions (although further monitoring is required to assess *changes* in the structure of fish populations). There were no Spangled Perch captured in Peake Creek in December 2007, but a large number of medium and large fish of this taxa were present in May 2008 (Figure 49.). These fish may have recolonised the reach during the reasonably high flows which occurred between December 2007 and February 2008. Large numbers of both medium- and large-sized Lake Eyre Hardyhead were captured in Peake Creek in May 2008 (Figure 48.), whilst most of the small number of Desert Goby captured at the site during this survey were large individuals (Figure 50.).

None of the fish captured at Peake Creek had any external evidence of disease.

Trophic Structure

The lack of detritivores captured in Peake Creek during both surveys (Figure 51.) is consistent with the expectations of the Conceptual Model after a long period of low flow. Only micro-carnivorous fish taxa were captured in December 2007, but Spangled Perch (macro-carnivores) had also colonised the survey site by May 2008.

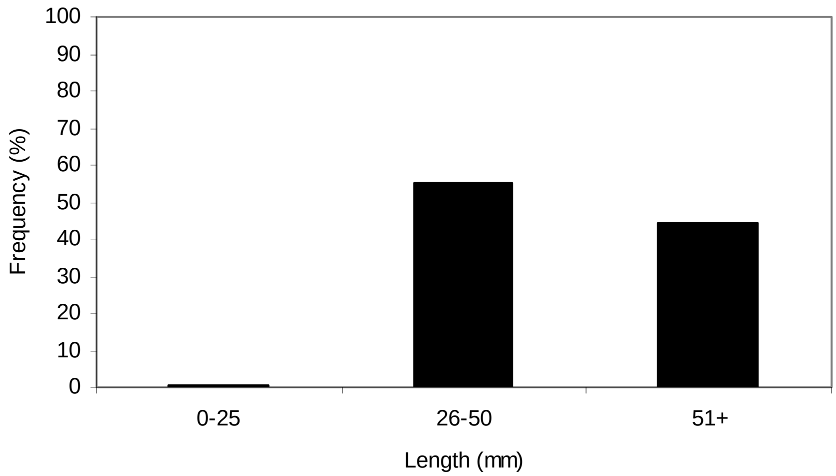


Figure 48. Proportions (%) of Lake Eyre Hardyhead (*Craterocephalus eyresii*) from each size class captured in the Peake Creek catchment in May 2008 (n = 203).

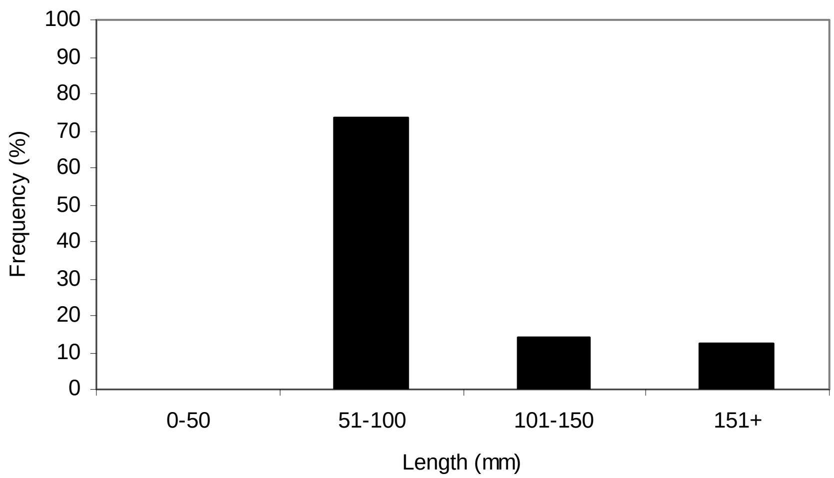


Figure 49. Proportions (%) of Spangled Perch (*Leiopotherapon unicolor*) from each size class captured in the Peake Creek catchment in May 2008 (n = 121).

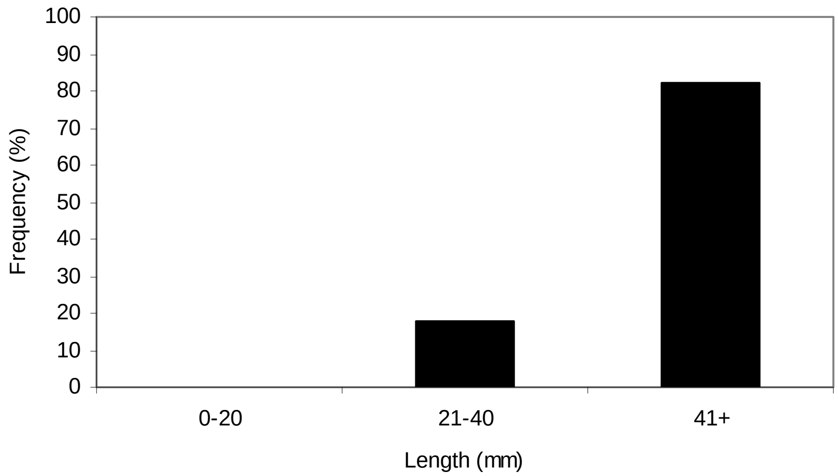


Figure 50. Proportions (%) of Desert Goby (*Chlamydogobius eremius*) from each size class captured in the Peake Creek catchment in May 2008 (n = 17).

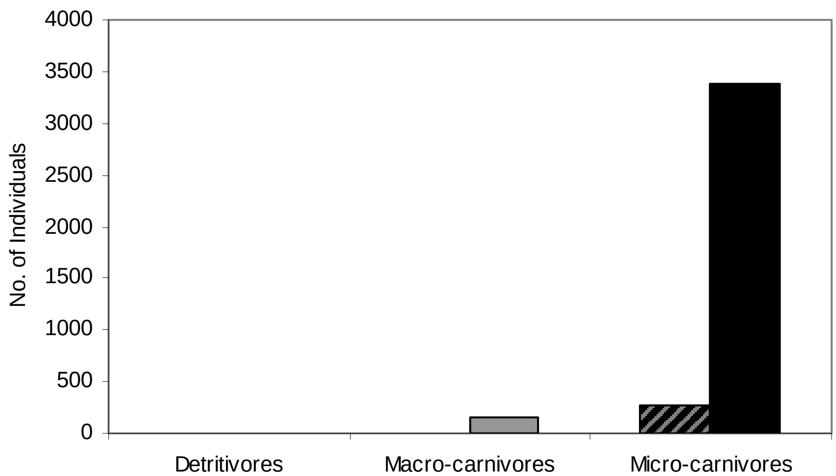


Figure 51. Abundances of fish from each trophic group captured in the Peake Creek catchment in a) December 2007 (hatched bars to the left, total n = 280) and b) May 2008 (solid bars to the right, total n = 3540).

3.2.4 Neales River

Hydrology

There was no significant flows or flooding prior to the current surveys at Neales River (Figure 52). Stage height data indicates that this river has been getting progressively drier over recent years.

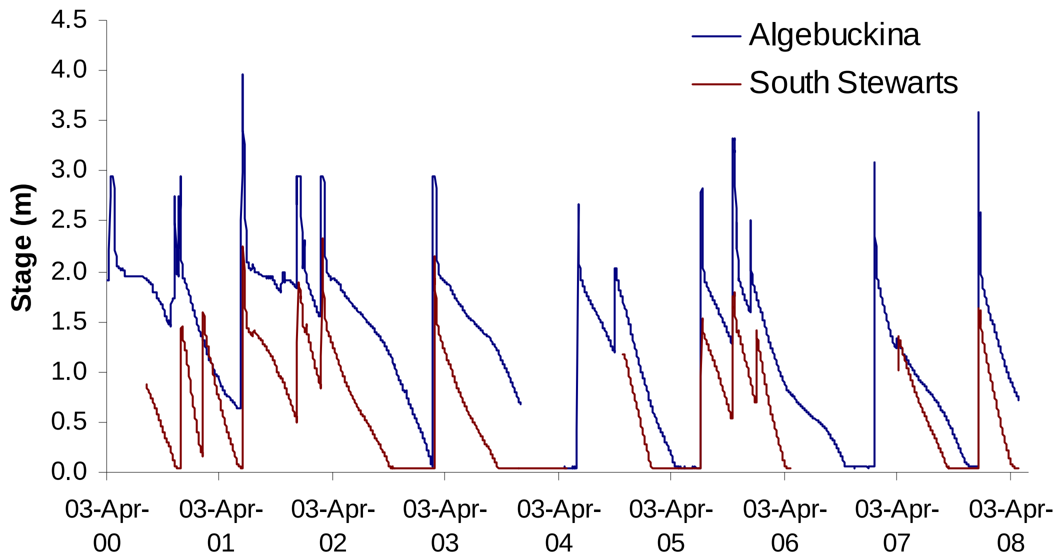


Figure 52. Stage height data for Algebuckina and South Stewarts Waterholes in the Neales River from April 2000 to April 2008**.**

Community and Population Structures

At the catchment scale there was no change in species richness between survey seasons in the Neales River (Table 4). The same eight species were present in both sampling seasons with no species gained or lossed.

At the site scale, however, significant patterns occurred with regard to fish assemblage structure. Most significantly, sites in the mid-catchment (Stewarts, South Stewarts, Mathiesons) supported no fish populations at all in December 2007, suggesting that all pools had dried completely prior to re-inundation at some time prior to the surveys. The collection of large numbers of yabbies indicates a functioning aquatic ecosystem, without fish. Additionally there was only a single species (Spangled Perch) present in Hookies waterhole in December. Over the summer, this predominantly fishless reach was recolonised by two species, Spangled Perch and Bony Bream. Large populations of these species had become re-established in all of these mid-catchment sites by May 2008.

In contrast, Algebuckina waterhole (downstream) possessed all of the species found in the catchment in December, making it the sole refuge habitat for all but one species (Spangled Perch) in the catchment. By May, all species were still present in the waterhole, with the exception of Spangled Perch, which had disappeared from the site.

Only one introduced fish taxa (Mosquitofish, at Algebuckina) was captured in the Neales River, during both surveys (Table 4).

Evidence of increased recruitment of juveniles between the May and December surveys occurred for Eastern Rainbowfish (Figure 55.) and Barred Grunter (Figure 57.), but the estimates of population structure from fish captures was similar between surveys for most taxa. There was evidence of recruitment of juveniles into the Neales River Bony Bream population in both December 2007 and May 2008 (Figure 53.). The Spangled Perch (Figure 54.) and Lake Eyre Hardyhead (Figure 56.) populations in the Neales River were predominantly medium-sized individuals in both December and May. The similarity of population structure between seasons, and the lack of recruitment of juveniles into most populations, may be due to lack of high flows and therefore considered consistent with the expectations of the Conceptual Model.

There was no evidence of external disease for any fish taxa captured in the Neales River during either the December 2007 or May 2008 surveys.

Trophic Structure

Abundances of all trophic groups are expected to decrease in the absence of a recent flood, according to the Conceptual Model. Across the Neale River catchment the abundance of micro-carnivores decreased, whilst the abundance of detritivores (Bony Bream) increased and there was little change in the abundance of macro-carnivores, between the December 2007 and May 2008 surveys (Figure 60.).

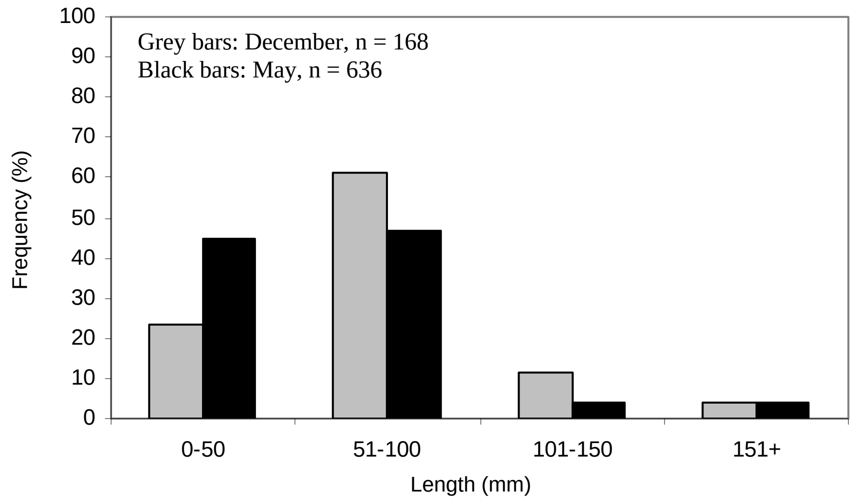


Figure 53. Proportions (%) of Bony Bream (*Nematolosa erebi*) from each size class captured in the Neales River catchment in December 2007 and May 2008.

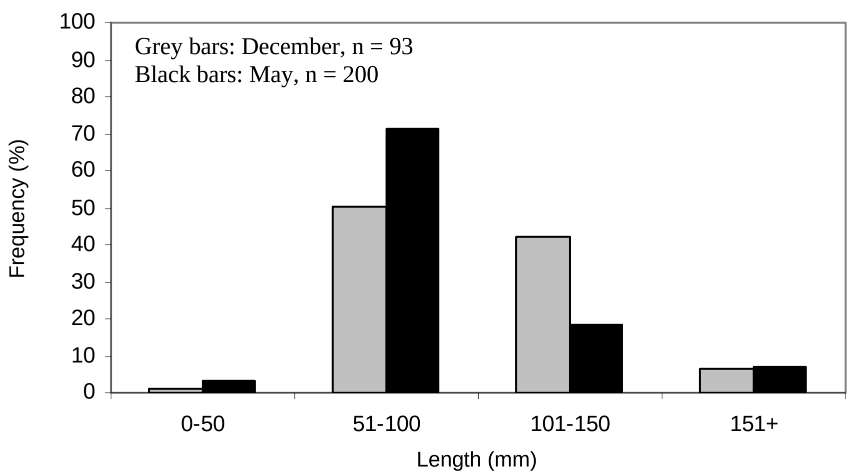


Figure 54. Proportions (%) of Spangled Perch (*Leiopotherapon unicolor*) from each size class captured in the Neales River catchment in December 2007 and May 2008.

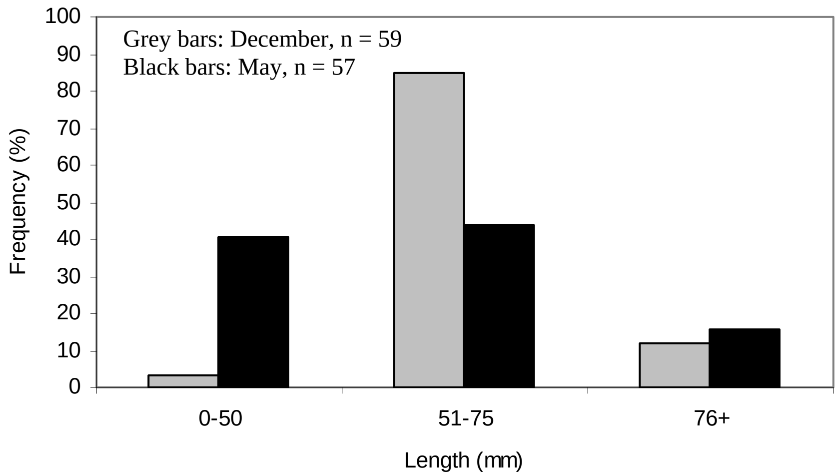


Figure 55. Proportions (%) of Eastern Rainbowfish (*Melanotaenia splendida*) from each size class captured in the Neales River catchment in December 2007 and May 2008.

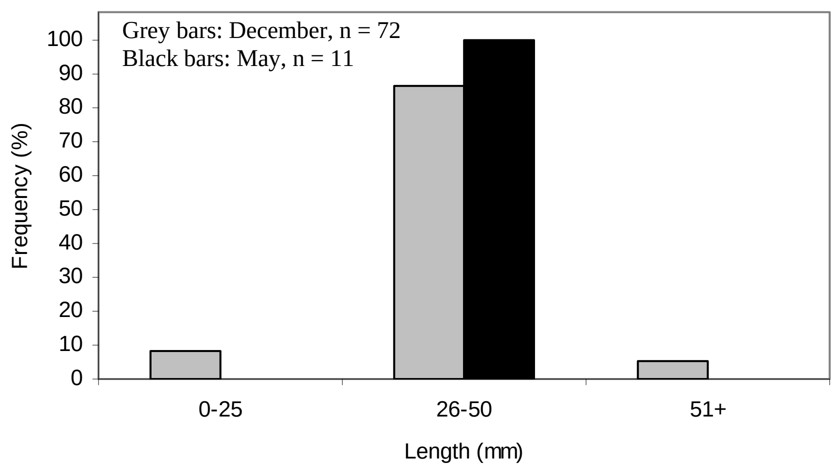


Figure 56. Proportions (%) of Lake Eyre Hardyhead (*Craterocephalus eyresii*) from each size class captured in the Neales River catchment in December 2007 and May 2008.

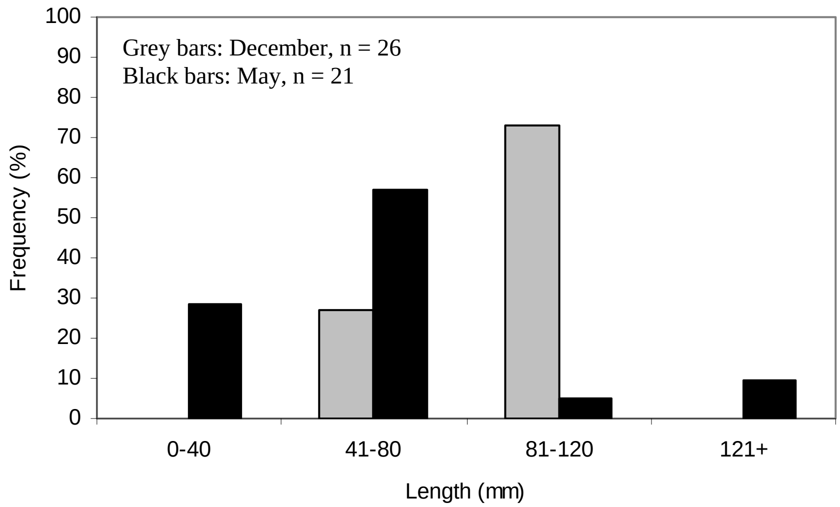


Figure 57. Proportions (%) of Barred Grunter (*Amniataba percoides*) from each size class captured in the Neales River catchment in December 2007 and May 2008.

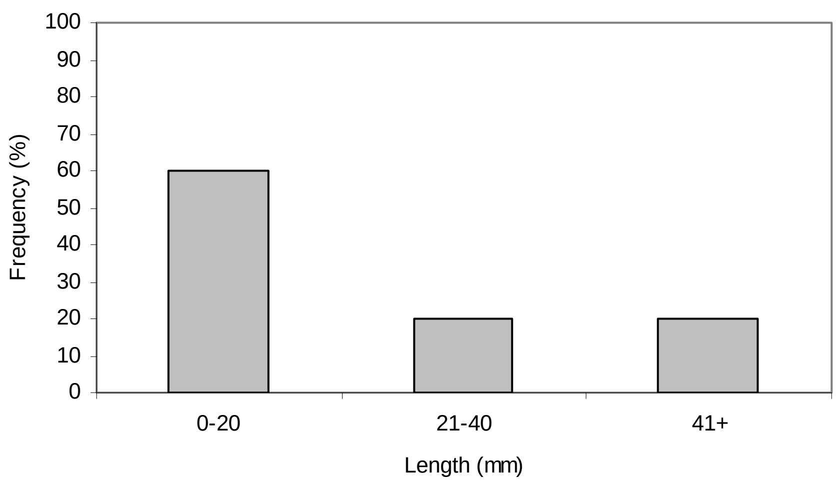


Figure 58. Proportions (%) of Desert Goby (*Chlamydogobius eremius*) from each size class captured in the Neales River catchment in December 2007 (n = 15).

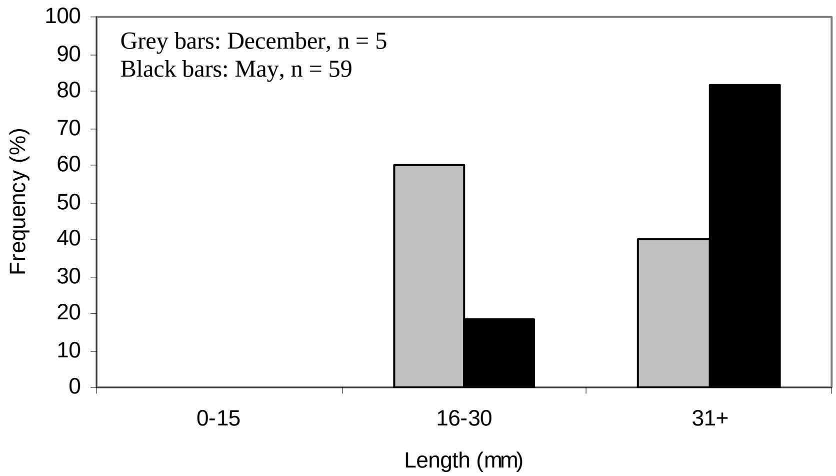


Figure 59. Proportions (%) of Mosquitofish (*Gambusia holbrooki*) from each size class captured in the Neales River catchment in December 2007 and May 2008.

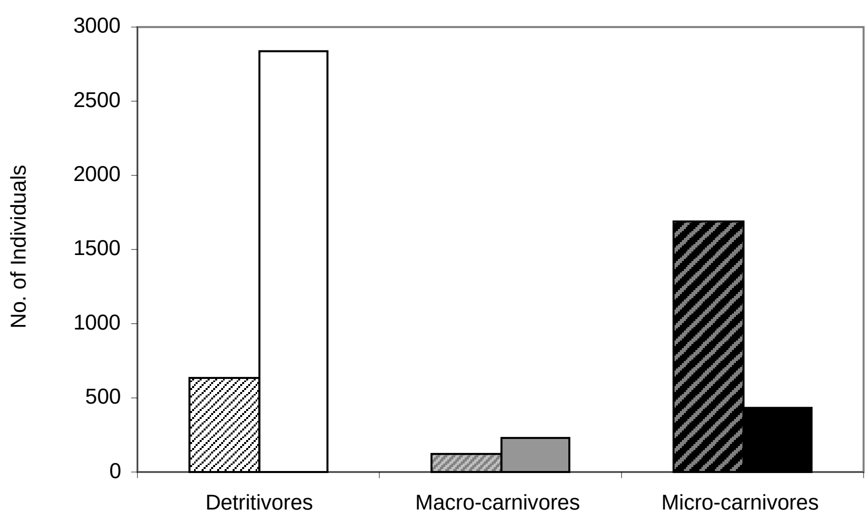


Figure 60. Abundances of fish from each trophic group captured in the Neales River catchment in a) December 2007 (hatched bars to the left, total n = 2441) and b) May 2008 (solid bars to the right, total n = 3501).

Table 3. Water quality parameters, vegetation and predominant substrate at sites in the Diamantina River and Warburton River catchment in May 2008.

Catchment	Site	Temp (°C)		D.O. (ppm)		Cond. (µS)		pH		Turbidity (NTU or Secchi depth mm)		Riparian vegetation cover	In-stream vegetation	Substrate
		Dec	**May**	**Dec**	**May**	**Dec**	**May**	**Dec**	**May**	**Dec (NTU)**	**May (mm)**			
Coopers Creek	Cullyamurra Waterhole		18.5		5.7		275		6.02		na	Intact	Dense *Polygonum* in littoral zone	Muddy w/ some gravel
Diamantina River and Warburton River	Clifton Hills*		17.2		9.0		212		6.13		30	Good	Small patches of *Persicaria*	Muddy
	Goyders Waterhole		8.3		8.7		523		6.87		50	Good	Absent	Clay
	Ultoomurra* (Warburton River)		17.8		13.9		60800		6.43		na	None effective (pools in middle of wide channel)	Absent	Sand
Peake River	Peake Waterhole	27.7	15.8	na	12.6	na	39600	5.2	7.05	600	na	None effective (small pools in middle of a wide channel)	Absent	Mud/Clay
Neales River	Algebuckina	26.0	18.9	8.5	9.7	na	1154	8.50	7.86	7.8	260	Good	Some scattered *Myriophyllum*	Muddy w/ some gravel
	South Stewarts Waterhole	25.0	20.8	7.4	9.4	na	462	7.65	6.84	9.0	240	Good	Some *Myriophyllum*	Clay w/ some gravel
	Stewarts Waterhole	26.4	18.9	7.9	10.4	261	52	8.40	6.54	436	90	Good	Minimal	Gravel w/ some clay
	Mathieson Waterhole	27.8	na	7.63	na	na	na	7.4	na	55.5	na	Good	Absent	Gravel w/ some silt
	Hookies Waterhole	22.9	17.4	3.03	6.53	na	360	6.77	7.14	227.3	50	Good	Absent	Clay w/ some gravel

* Average values calculated from data collected across the reach or amongst pools.

Table 4. Total numbers of fish taxa captured at sites in the South Australian portion of the Lake Eyre Basin in December 2007 (shaded) and May 2008. For each taxon, evidence of captured individuals in spawning condition at the site is indicated by a superscript 'S'.

Scientific Name	**Common Name**	**Coopers**	**Diamantina**			**Neales**									**Peake**	
		CU	CH	GL	ULT	ALG		SS		SW		MW	HO		PE	
		May	May	May	May	Dec	May	Dec	May	Dec	May	Dec	Dec	May	Dec	May
Ambassis sp.	Glassfish	1														
Amniataba percoides	Barred Grunter					28^{S}	21									
Bidyanus welchi	Welch's Grunter	43	10													
Chlamydogobius eremius	Desert Goby				7	224^{S}	56								60	17
Craterocephalus eyresii	Lake Eyre Hardyhead				559	139^{S}	11								220	3361
Gambusia holbrooki	Mosquitofish	17				753	306^{S}									
Hypseleotris spp.	Carp Gudgeon spp.	71														
Leiopotherapon unicolor	Spangled Perch	43				32^{S}			45^{S}		26^{S}		62^{S}	129^{S}		162^{S}
Macquaria ambigua	Golden Perch	171	69	7		5^{S}	10									
Melanotaenia splendida tatei	Eastern Rainbowfish	33				568^{S}	57^{S}									
Nematolosa erebi	Bony Bream	106			1	630	2232		1		12			595		
Neosiluris hyrtlii	Hyrtl's Tandan	2382	60	6												
Neosiluroides cooperensis	Cooper Creek Catfish	11														
Porochilus argenteus	Silver Tandan	13														
Retropinna semoni	Australian Smelt	363														
Scortum barcoo	Barcoo Grunter	31														
	Taxon Richness	13	3	2	3	8	7	0	2	0	2	0	1	2	2	3
Mean number of fish per net		299	10	3*	560*	297	180	0	9	0	4	0	10	48	140*	1170*

Site codes: Cullyamurra Waterhole (CU), Clifton Hills (CH), Goyders Lagoon (GL), Ultoomurra (ALT), Algebuckina (ALG), South Stewarts Waterhole (SS), Stewarts Waterhole (SW), Mathieson Waterhole (MW), Hookies Waterhole(HO) and Peakes (PE).

* These values are the mean number of fish captured in each sweep with a seine net at the site. These are not directly comparable to the number of fish captures per fyke net provided for other sites, but are provided as a guide to the relative abundance of fish.

3.3 Basin-scale

To investigate the similarities between sampling sites and whether those similarities were due to the prevailing water quality parameters, we conducted a non-metric multi-dimensional ordination (NMS). The sites were ordinated by the similarities in species presence/absence and the water quality parameters were overlayed over that distribution.

The fish communities in the Lake Eyre basin were mostly distributed by depth and conductivity (salinity) and to a lesser extent dissolved oxygen (DO) and turbidity (Figure 53). Sites that were closer to Lake Eyre had higher salinity unless they were deeper waterholes such as Algebuckina. These higher salinity sites were dominated by Lake Eyre hardyhead and Desert Gobies.

Sites with greater species richness were deeper and had lower salinity. However, the salinity tolerant species occupied the sites with higher salinity. The patterns in species richness largely reflected the permanence/ephemerality of the waterholes. Where there was permanent, good-quality water, there was high species richness; where there was ephemeral waterholes, there was low species richness, and the species that were there were either tolerant to saline conditions (Lake Eyre Hardyheads and Desert Gobies), or they were better equipped to opportunistically occupy previously dry waterholes (Spangled Perch).

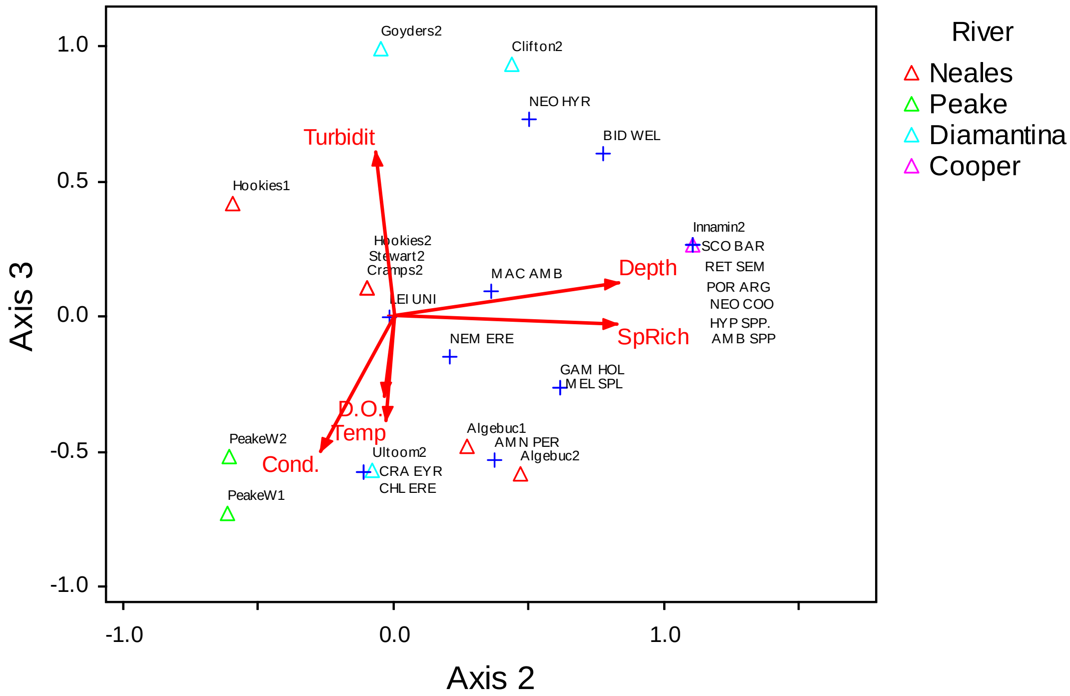


Figure 61. NMS plot displaying the relationship between sites and species presence/absence overlayed by the water quality parameters. AMB SPP = Ambassis sp., AMN PER = Amniataba percoides, BID WEL = Bidyanus welchi, CHL ERE = Chlamydogobius eremius, CRA EYR = Craterocephalus eyresii, GAM HOL = Gambusia holbrooki, HYP SPP = Hypseleotris spp., LEI UNI = Leiopotherapon unicolour, MAC AMB = Macquaria ambigua, MEL SPL = Melanotaenia splendida tatei, NEM ERE = Nematolosa erebi, NEO HYR = Neosiluris hyrtlii, NEO COO = Neosiluroides cooperensis, POR ARG = Porochilus argenteus, RET SEM = Retropinna semoni, SCO BAR = Scortum barcoo.

4 Discussion

There is extreme variability in both the availability of water and the physiochemical environment within reaches of the Lake Eyre Basin. Fish communities naturally expand and contract over seasonal cycles in these highly variable systems (LEBSAP 2008). During the preliminary surveys, new information about the community structure, movement and recruitment of fish populations both within and between each site was obtained. Longer-term studies will provide more information regarding the ecology of different fish taxa and seasonal variations in community structure within sites, against which the Conceptual Model may be tested. Where possible during the present study, the Conceptual Model was tested at the catchment scale and appears to be less suitable for describing the dynamics in the South Australian portion of the Lake Eyre Basin than for the Queensland portion (Balcombe and Kerezsy, 2008).

4.1 Fish Species Richness

Spatial scale is very important when considering patterns of species richness of fish communities in the Lake Eyre Basin, with some sites within catchments clearly acting as very important locations for the maintenance of high diversity, such as Cullyamurra in the Coopers Creek catchment. This site was full of water, had a wide range of habitats, and had the highest fish diversity of any of the sites surveyed during the present study, and was more diverse than any of the arid sites in Queensland (Balcombe and Kerezsy, 2008). Interestingly, the site farthest upstream in the Coopers Creek catchment (Waterloo) had the second highest diversity of any of the South Australian and Queensland sites, whilst the sites in between these two taxon rich sites had slightly lower diversities (Balcombe and Kerezsy, 2008). Cullyamurra was the only site in Coopers Creek where Glassfish and Carp Gudgeons were captured, so may be an important refuge for these taxa, but further monitoring is required to describe the distribution of all fish taxa in the Lake Eyre Basin. Cullyamurra was only surveyed once so no comment can be made on temporal changes in diversity that may be associated with changes in hydrology at this site. Recently, Arthington *et al.* (2005) found that the structure of fish communities in isolated waterholes in the Coopers Creek catchment were related to the extent of floodplain inundation 14 months previously, the interconnectedness of waterholes and the habitat structure within waterholes. As the surface water in pools dropped, habitat loss contributed more to changes in assemblage structure than did water chemistry (Arthington *et al.*, 2005).

The fish community in the Diamantina River was less diverse than that in Coopers Creek. Only the most hardy taxa, Lake Eyre Hardyhead and Desert Goby, as well as a lone Bony Bream, were captured from the small pools at the most downstream site (Ultoomurra). These fish were surviving in pools with minimal surface water and very high salinities, and therefore appear highly resistant to low flows. Considerable time was invested in surveys at Clifton Hills, whereas there was inadequate time for fyke nets to be set at Goyder's Lagoon Waterhole. However, both Golden Perch and Hyrtl's Tandan were captured at both these sites, and Welch's Grunter was the only additional taxon captured at Clifton Hills. The restricted ranges of some taxa (e.g. Coopers Creek Catfish and Barred Grunter) and lower diversity of habitats than available at the Cullyamurra Waterhole would have contributed to lower diversities of fish communities at sites in the Diamantina River. Silver Tandan, Spangled Perch and Rainbowfish were captured in the Queensland reaches of the Diamantina River, but their distribution was patchy, particularly during the surveys conducted in March 2008 (Balcombe and Kerezsy, 2008). The Lower Diamantina catchment was only surveyed in May 2008, and further monitoring would be required to assess the ranges of each fish taxa in this catchment at different times of the year, but the most upstream sites in Queensland appear to be important refuges for a number of native fish taxa.

The results from the western catchments demonstrated a catchment-scale cycle of extinction and partial recolonisation over at least two seasonal cycles across the Neales River catchment. The results are in contrast to the predictions of the Conceptual Model, which dictates no change in species richness related to hydrological variability. This is due to the Conceptual Model's focus on flood related ecology, ignoring the large-scale boom and bust cycles that apparently occur in some portions of the Lake Eyre Basin catchments (Bunn *et al*., 2006). Furthermore, the extinction and recolonisation occurred without the presence of any flooding whatsoever, with pool connectivity providing an opportunity for movement along the river corridor.

Significantly, this pattern only occurred for two species, Bony Bream and Spangled Perch. All other species remained confined to the downstream refuge at Algebuckina between the times of the survey, although Algebuckina may serve as a source of reproduction and recolonisation of upstream sites at other times (in December, six of the eight fish taxa present at Algebuckina were spawning). There is no indication from this short study as to what the requirements are for these 'non-migrating' species to recolonise upstream habitats, except that the small-scale connectivity occurring in 2007/08 was insufficient to either stimulate or facilitate recolonisation. Only continued monitoring, and/or experimental studies, will enable an understanding of the requirements for other species to recolonise from downstream refuges.

4.2 Resistance & Resilience

Evidence of varying survival strategies employed by fish populations across the Lake Eyre Basin is a very significant finding in regard to the resistance and resilience of arid river fish populations to the extremes of drought. Some populations (e.g. Bony Bream and Spangled Perch) appear to be sustained by recolonisation, whilst others (e.g. Lake Eyre Hardyhead and Desert Goby) are able to tolerate extremely harsh abiotic conditions in isolated pools, even with a number of individuals in spawning condition in these small pools. Desert Goby can tolerate water temperatures of 40°C, dissolved oxygen concentrations as low as 0.8mg/L and salinities up to 60ppt (Glover, 1982), whilst Lake Eyre Hardyhead have the highest and widest salinity tolerance of any Australian fish (0-110ppt, Glover and Sim, 1978). Unmack (1994) suggested that, as there is no permanent water throughout the lower reaches of rivers entering Lake Eyre, which is the range of Lake Eyre Hardyhead, these fish appear to persist by 'leap-frogging' between semi-permanent waterholes. This indicates that single refuge habitats, as well as connectivity to allow movement, are crucial in the maintenance of fish biodiversity at the catchment scale. Furthermore, the flow patterns required for recolonisation following drought are different across species with Bony Bream and Spangled Perch moving at long distances under within-channel flows. There is also anecdotal evidence that Spangled Perch are able to survive through low flows by aestivating in mud, but this has not been proven (Llewellyn, 1973). This suggests that these species are particularly resilient to drought impacts following resumption of flows. All other species require something different, and will potentially recolonise only during larger flood events. For these species, recolonisation after drought may be a much slower process requiring the resumption of more significant or particular types of flows.

In terms of the overall health of the Lake Eyre Basin fish community, this pattern suggests that the majority of species may be highly susceptible to any development or change that can impact the persistence and quality of refuge habitats, not just for the duration of the cease to flow period, but for a potentially extended time whilst they await the resumption of some larger flows to enable their recolonisation of other sites in the catchment. For Spangled Perch, this now relates also to pools farther up the catchment as all fish moved out of the refuge habitat at Algebuckina and must now recolonise this site from upstream.

If the appropriate requirements for resistance and resilience within a system are being met (i.e. in a healthy catchment) then the catchment-scale species assemblage should not change from year to year, even though individual species' populations may expand and contract between reaches. Further information about these expansions and contractions can only be elucidated through regular long-term monitoring.

As a result, not only is the present Conceptual Model not equipped to account for fish sustainability in these highly variable catchments within the Lake Eyre Basin, but the historical focus on flood related ecological patterns needs to be refined to take into account the expansion and contraction of fish from refuge habitats. As an indicator of potential impacts from climate change or water resource development, the role of refuge habitats and the requirements of fish species to tolerate the conditions therein and recolonise successfully from these will be a key aspect in how these disturbances might impact the health of the Lake Eyre Basin fish community. In terms of a trajectory of change, the less variable upstream habitats such as those presently in the Queensland section of this study, may move towards the patterns recorded for the Neales (and Warburton) catchments if flows become more variable in the future. By using monitoring data from both upstream Queensland sites and the highly variable South Australian sites, we may be able to develop a trajectory of change from the more stable *status-quo* upstream toward the harsher conditions downstream where species presence–absence is clearly dictated by climatic and hydrological variability.

4.3 Population Structure

There was much variability in the structure of fish populations, even within the same site and time of year. Across each of the catchments there was some evidence of recruitment of juveniles that were possibly associated with spawning during higher flows over summer, consistent with the expectations from the Conceptual Model. However, this was species-specific and only occurred in the catchments with the most permanent water, i.e. both the upper (Balcombe and Kerezsy, 2008) and lower Coopers catchment, the upper Diamantina (Balcombe and Kerezsy, 2008), and to a lesser extent the lower Diamantina, but not in the drier Peake Creek and Neales River catchments. Migration was also an obvious source of recruitment into the fish communities of certain sites, particularly those in the drier catchments, and as mentioned above these migrations may also be driven by higher flows. Although the population structure of fish populations in the Neales River didn't change much between survey seasons at the catchment scale, a number of waterholes that had no fish in December 2007 had been recolonised by May 2008.

To gain a greater insight into the population structures of fish communities in the Lake Eyre Basin there is scope to use otolith aging techniques which have the potential to provide detailed information on the age structure, growth rates and times of spawning of different fish populations and the addition of these studies to future surveys should be given serious consideration. Given the logistical issues preventing more regular surveys of the isolated sites across the Lake Eyre Basin, the use of otoliths should prove cost effective, as a large amount of information can be obtained by collecting a sample of fish during each trip.

4.4 Trophic Structure

The trophic structure varied greatly among different catchments and even between upper and lower ends of the same catchment (comparing data from South Australia to that from Queensland, see Balcombe and Kerezsy, 2008). There may be large shifts from systems with all three trophic guilds present in large waterholes, to systems dominated by hardy micro-carnivores with decreasing surface water. Taxa have also been demonstrated to shift diet with changes in flow in arid rivers (Balcombe *et al*., 2005). These may be opportunistic shifts to the most abundant food source or ontogenetic shifts, both of which require further study before their importance can be assessed. A number of the sites surveyed in December 2007 also had no fish, and yabbies and beetles occupied the highest trophic levels in these systems. Given the high degree of variability in the trophic structures of the different sites, and even within those sites which were surveyed during both December and May, much more investigation is required to determine: how changes in hydrology and other abiotic variables influence the trophic structure of these systems; the most typical trophic structure expected in these systems at different times of the year; and, thresholds at which there are changes in the trophic structures of these systems. There was only some agreement between the predictions of the Conceptual Model relating to the association of trophic structure to flow and the patterns observed in the South Australian portion of the Lake Eyre Basin. Further surveys, covering a wider range of the flow scenarios outlined in the Conceptual Model, would be required to evaluate the relationship between flows and changes in trophic structure (which may also be driven by seasonal changes in temperature and insolation).

4.5 Fish Biomass

This was not measured under the pilot survey design as the extra time and effort for storing and weighing fish was unavailable. Measurement of biomass would add value to the assessment of ecological function, but it is time-consuming and requires extra processing of fish during hot conditions. With the large numbers of fish captured, the stress caused to fish and large amount of extra effort required may not justify its inclusion in future monitoring programs.

4.6 Alien Taxa

Only a single alien species, Mosquitofish, was collected in the South Australian portion of the Lake Eyre Basin. This species was present in high abundance in Algebuckina Waterhole in the Neales River and Cullyamurra in the Cooper Creek. Both of these habitats serve as the most permanent and important refuge pools for fish in the lower reaches of their catchments. It appears that these pools also serve as a refuge for Mosquitofish and this species is not well adapted to the more variable environment of the less permanent sites. Efforts to control these fish would best be directed towards major refuges during periods of low flow.

Control of this widespread species would be difficult and potentially impossible given their tolerance of a broad range of abiotic conditions and widespread integration into the Australian fish fauna (Wager and Unmack, 2000). There are indications from the current survey that this species is not as dominant in the Lake Eyre Basin as it is across the Murray-Darling Basin (Lintermans, 2007). The data from the present study support the Conceptual Model of no change in the abundance of alien species under the present 'no flood' conditions.

4.7 Disease

Whilst a very small degree of disease was detected in the Diamantina (a small Golden Perch from an anabranch creek possessed severe lesions) the majority of disease impact was found at Cullyamurra, in the Cooper Creek, where most Golden Perch and Barcoo Grunter suffered severe lesions and ulcerations (Figure 26, 62). Parasitism by *Lernaea* was also evident and there were some examples of infection radiating from *Lernaea* attachment sites (Figure 26). It has been claimed that *Lernaea* is a parasite introduced into the Murray-Darling Basin by introduced European Perch (*Perca fluviatilis*) and Carp (*Cyprinus carpio*) and transmitted to native fish (Lintermans, 2007). The presence of the parasite in the Lake Eyre Basin, where neither of these fish is present, raises questions about the origin and spread of this parasite. It is possible that it has spread through Murray Cod, Goldfish or Mosquitofish introduced from the Murray-Darling system, but this issue requires detailed study before any explanation can be developed.

The Conceptual Model suggests that this degree of disease should relate to the degree of disturbance stemming from the previous flood, however, the very low levels of flooding in the Cullyamurra region does not support this. Potentially, disease outbreak is unrelated to flood magnitude and will be best explained by other factors. There were no obvious external stressors acting directly at the Cullyamurra Waterhole, which had a largely intact riparian zone, a range of aquatic habitats and large volume of surface water, although this site is near Innamincka, and is a popular site for tourists/recreational fishers which may act as vectors for the introduction of disease. However, it is not known how the process of disease works and this is an area for dedicated study by disease specialists such as the SARDI fish diseases group. It is clear that the outbreak of disease is highly species specific, for example impacting Barcoo Grunter far more than Welch's Grunter.

There was no evidence of external disease for any fish taxa captured in the Neales River or Peake Creek during either the December 2007 or May 2008 surveys. As no flood occurred in this system, the pattern is consistent with the Conceptual Model under the low degree of disturbance emanating from moderate in-channel flows occurring in 2007/08.

Figure 62. (a) Grunters and (b) juvenile Golden Perch with external signs of disease. These fish were captured at Cullyamurra, in the Coopers Creek catchment.

4.8 Survey Methodology and Monitoring Framework.

Surveys were conducted to ensure that the highest amount of fish diversity was captured at each site, within constraints of time limits. Whilst for common species the degree of surveying effort was more than sufficient, a high level of survey coverage is essential for determining the presence of rare species. A good example of this is the capture of only a single Glassfish amongst 3200 fish at Cullyamurra Waterhole. Although the effort of detangling and counting huge numbers of Hyrtl's Tandan was taxing with such a large number of nets, the detection of a new species was very important when considering the biodiversity value of the site and in identifying target species for management actions.

There was an identified need to standardise surveying effort across sites and seasons, however this has to be balanced against the need to detect rare species and to cover maximal habitat niches. This is a direct trade-off between quantifiable assessments of fish abundances and maximising the chances of capturing all fish taxa present at each site. This is specifically an issue in very large waterbodies such as Clifton Hills, Goyders Lagoon and where very low species richness may be, to some degree, an artefact of the surveying effort not covering the microhabitats where other species may have been present within the site. Clearly this was not as big an issue where fish densities were higher, at Cullyamurra, although it raises questions about the recorded 'absence' of species such as Rainbowfish which may in fact have been present in other reaches of the waterhole.

This is an issue common to the majority of netting surveys conducted in freshwater systems in Australia and we take this opportunity to flag the need for experimental investigations into fish surveying efficiency, surveying area and limitations of surveying gear types. Recent investigations under the Murray darling Basin Commission's Sustainable Rivers Audit (MDBC 2004) have not gone far enough in developing comparable standardised approaches to assessing fish assemblage and abundance in a way to allow directly quantifiable comparisons. The final monitoring framework should include surveying protocols that can maximise both species detection and provide comparable abundance data with a realistic degree of effort. It is also suggested that the final monitoring framework should include an appropriate timeframe for surveying larger habitats to ensure that all sites are given an adequate level of survey effort, also keeping in mind the requirement for additional time in the field for travelling long distances between isolated sites. Sweeps with a seine net were useful for surveying small pools, but more taxa were captured in fyke nets than in sweeps with a seine net at sites where both techniques were employed and seines nets are not adequate for surveying large waterbodies.

The vastness and extreme variability of arid rivers necessitates broad spatial coverage and long-term studies to understand how these systems function. The ability to judge the Conceptual Model is hindered by the lack of long-term datasets for comparison of the dynamics of fish communities in response to a wide range of flows. The collation and analyses of data from AridFlo, Dryland Refugia and Wet/Dry projects would be very valuable, and could be used to guide future surveys. Besides information about the how the structure of fish communities changes in relation to flows, other major knowledge gaps include, but are certainly not limited to, information about the genetics and distribution of keynote taxa, taxonomy and conservation status of fish in the basin, tolerances of different taxa to physicochemical parameters, implications of increased abundances of alien taxa, impacts of grazing/trampling by livestock and terrestrial alien taxa, and impacts of tourism/recreational fishing and mining.

The waterbodies in the Lake Eyre Basin are generally considered to be in good ecological condition, and are amongst the last unaltered dryland river systems in the world (LEBSAP 2008; Unmack, 1994). This region should be carefully managed and monitored to ensure that this good condition is maintained into the future. Water resource development is currently a minor threat to the integrity of the Lake Eyre Basin fish communities, but may act to change flow regimes, reduce floodplain habitats and alter the dynamics of refuge waterholes if not carefully managed in the future (Bunn *et al.*, 2006).

4.9 Connecting with Communities and Landholders

Future monitoring effort should also take into account strong levels of local support encountered at some sites, especially around population centres such as Innamincka. At this site, rangers from the SA Department of Environment and Heritage and locals showed a strong interest in the project and have been pro-active in providing information and photographic evidence for flow and fish community patterns as well documenting and providing evidence for multi-species upstream migrations during flow events. They have also expressed an interest in assisting with the ongoing monitoring program. Additionally, all sites were located on private leaseholds or aboriginal community lands and these landholders need to feel a strong affinity and connection to the project. This highlights the benefit of connecting with regional communities, agencies and landholders to the monitoring program and consolidating these relationships. The most recent surveying trip was planned to coincide with a trip by hydrologists, from SA DWLBC and Melbourne University, who were calibrating gauges across the Lake Eyre sites. These researchers helped to find those sites along the lower Diamantina River, in addition to providing hydrological data. The maintenance of gauges is on-going (Costelloe, 2007; 2008), so site-specific hydrological data will be available for future surveys.

4.10 Summary: Testing FTMs and monitoring fish for river health

In general, the South Australian Pilot Monitoring survey revealed that the arid reaches of the Neales/Peake, Lower Diamantina/Warburton and Lower Cooper catchments were far more variable ecologically than the more stable upper reaches of the Basin in Queensland. This variability related to climate and hydrology and was expressed in the population structure of waterholes in these reaches. In general, three types of habitats were found:

1: Permanent deep refuge waterholes: These possessed higher species richness (relating to habitat diversity), more large bodied species and fewer micro carnivores (where habitat availability was low). The two principal refugia were Algebuckina (Neales) and Cullyamurra (Cooper) and possibly Clifton Hills outstation although this requires more exhaustive sampling). These habitats act more like the upstream Queensland pools but are incredibly important, as they are the most downstream refugia for the entire fish assemblage. These habitats fit the FTM best and biomass, species richness, recruitment, presence of disease and abundance are most important as indicators in these habitats.

2: Ephemeral Large Pools: These pools possessed fewer species but often-larger bodied fish such as spangled perch and bony herring (Neales) or Golden perch and Hyrtl's Tandan (Warburton). These habitats are important for native fish but due to their transient nature they will go through periods of local extinction, low species diversity (migratory species) and during wetter periods serve as important habitats for a wide range of species (this must be verified by monitoring in wetter periods but is suggested by the ARIDFLO data). Impacts on hydrology (such as water abstraction or climatic drying) are likely to impact these sites heavily. If these transient habitats are continuously moving between no fish and low fish diversity, then populations will come under increasing pressure, especially for slow-recolonising species (almost all small bodied fish) that may require either large floods or successive in stream flows to recolonise following local extinction. Alternatively, a decline in the number or regularity of years in which these habitats serve as high diversity habitats will also signal a decrease in catchment scale population health and may threaten total catchment wide extinction for some species. These transient habitats are difficult to relate to the FTM due to their incredible variability but make up the majority of fish habitats in the arid section of the LEB. Species richness, presence/abundance of micro-carnivores, recruitment are likely to be the most important FTM indicators in these habitats.

3: Small saline refugia: These are shallow pools, often at the downstream extreme of regular flow (Peake, Ultoomurra). They possess few highly tolerant species, commonly hardyhead and desert gobies, but may intermittently possess transient tolerant species such as spangled perch or bony herring. These pools were almost always as salty as sea-water, yet they represent a saline refuge where hardyhead and gobies can largely escape the predation pressure present in permanent refugia. Although in harsh climatic periods such as 06/07/08, these pools may become saltier than sea-water and may be reduced to only a single species, they still possess the highest abundances of these tolerant species and serve as key refugia from which they can recolonise catchments upon resumption of flows. These habitats fit poorly into the FTM and abundance/biomass, abundance of alien species and recruitment are likely to be the best FTM indicators for these pools. The persistence and recolonisation of these habitats through time are likely to be the best indicators of river health for these habitats. Although these pools may dry up completely, they should be present and inhabited most years. Species richness should not regularly be lower than two.

Overall, efforts to find generalisable indicators for the FTM are thwarted by the high climatic and hydrological variability, patchiness and dynamic nature of fish assemblage structure and species distribution. This does not however, oppose the validity of using the FTM, rather the project has highlighted the need to create more detailed, species and potentially site (or at least regional/catchment) specific FTMs that can be combined to inform the overall river health trajectory using monitoring data outputs.

The monitoring strategy developed in the FTM workshop (Humphries et al. 2007) and trailed over 07/08 is an affective approach in collecting good quality long-term data on the ecological health of LEB rivers. It is suggested that significant resources be directed towards this monitoring program to ensure that it captures a wide range of sites over a wide range of catchments/reaches. Without good coverage, the monitoring program risks missing key impacts to river health before they become irreversible. The arid catchments and reaches of the LEB are especially useful as indicators of declines in river health as they form the harsh edge of the LEB ecosystem where climate and flow are variable and intermittent and pressures on aquatic biota are highest. Basin wide impacts will become evident at these sites before they are likely to be detectable upstream. As such, the monitoring outputs from these sites will serve as a comparative target for a trajectory of decline in river health. As demonstrated through multivariate techniques, more stable and species rich refuge pools (Type 1 above) may begin to produce data more similar to type 2 or 3 habitats and movement along this trajectory will represent a decline in the integrity and health of these systems. This trajectory may also be useful to detect decline in condition of Queensland sites but this will require more comprehensive assessment.

It is suggested that comprehensive monitoring be initiated as soon as possible during the present drought (in the SA section) to capture the harshest extremes of natural climatic variability and ensure we can capture the widest range of data from within the natural climatic range. Furthermore it is suggested that monitoring programs be linked where possible to biological, ecological and hydrological research projects to maximise the value of monitoring outputs and to improve and develop species FTMs into the future.

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Figure 63. Two of the authors out in the field, DGM on the left with a Bony Bream and DJR on the right with a Golden Perch.