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Recovery of Lake Eyre Basin fishes following drought: 2008/09 fish survey report

Dale McNeil & David Schmarr

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EXECUTIVE SUMMARY

The current survey was initiated by the South Australian Arid Lands NRM Board (SAALNRMB) to assess the recovery of native fish populations from drought and identify key management and research requirements for protecting and enhancing these communities. Fish surveys were conducted in December 2008 and May 2009 across the three primary catchments in the South Australian section of the Lake Eyre Basin (LEB); the Neales River (including Peake Creek), the Warburton/Diamantina and Cooper Creek. Monitoring was based on the monitoring strategy outlined under the Lake Eyre Basin Rivers Assessment (LEBRA) program and included sites used for the 2007/08 pilot monitoring under that program.

Pilot monitoring in 2007/08 identified extreme drought conditions across the SA section of the LEB, with many fish species restricted to very few, or single refuge waterholes within each catchment. Following the resumption of small, within channel flows during 2008, some species were able to recolonise the Neales catchment, whilst the majority of fishes continued to be confined to refuge water holes. Re-connectivity did not occur in the Warburton/Diamantina or Cooper Creek catchments and fishes remained confined to refuge waterholes. Some of these refugia contained very harsh water quality levels including salinities above sea-water and possessed accordingly few highly tolerant species. The effect of drought in the LEB therefore, was found to have left native fish populations in very high risk of catchment wide extinctions due to the reliance on very few harsh refuge habitats. If fish were unable to recolonise catchments successfully following subsequent periods of flow, then the SA LEB fish population may require significant and immediate management intervention.

In December 2008, a survey was conducted across the Neales River catchment, but heavy storms prevented access to sites on the Diamantina/Warburton and Cooper Creek. The Neales survey revealed that a second season of hydrological re-connectivity had failed to improve the distribution of native fishes across the catchment. As such, all but two out of seven native species (spangled perch and bony herring) remained at very high risk of drought related, localised extinction.

With further rainfalls in the 2008/09 wet season, both the Neales and Warburton/Diamantina enjoying high levels of flow for extended periods for the first time since the onset of the drought. Subsequent re-sampling in May 2009 revealed that this re-connectivity was adequate for providing re-colonisation for a wide range of species that were previously confined to high risk refuge pools. In the Neales, golden perch and desert rainbow fish and to a lesser degree Lake Eyre hardy head, were able to recolonise upstream into the wider catchment from Algebuckina waterhole, joining bony herring and spangled perch which had re-colonised earlier on smaller flows. In the Warburton/Diamantina, a wide range of species re-colonised in a downstream direction into reaches previously dominated by highly tolerant species such as desert goby and Lake Eyre hardyhead. These also included golden perch, Barcoo and Welch's grunter; Hyrtl's and silver tandan, desert rainbowfish and bony herring.

These surveys have provided important information regarding the ability for LEB fishes to recover from the impacts of drought and provide key insight into their potential sensitivity to future impacts of climate change and/or water resource development in the region. This work has provided the first study of LEB fishes under drought conditions and reveals that large scale changes in fish assemblage structure occur in relation to the highly variable arid-zone climate. This supports previous research suggesting that the arid South Australian Reaches of the Lake Eyre Basin function under a somewhat different ecological framework to those farther upstream in Queensland, where such large scale assemblage shifts are less important in structuring fish community patterns.

This work provides data under the most extreme environmental conditions yet studied in the Basin and is therefore a very valuable indicator of the extremes of natural variability in the system as well as providing an extreme towards which trajectories of river health may be developed based on fish assemblage data. The surveys have also revealed the importance of identifying and carefully managing key drought refuges in the Basin to ensure that native fish are able to survive extreme drying events in the future. This will also ensure that adequate volumes and periods of flow are maintained to allow the successful resilience of fast and slow re-colonisers following the impacts of disturbance. A number of research and management issues are discussed.

INTRODUCTION

In 2005 the Lake Eyre Basin Rivers Assesment (LEBRA) program developed conceptual models that capture the relationship between native fish, hydrological and habitat variables in order to assess native fish as an indicator of the general ecological health of the Basin's waterways, capturing a 'fish –trajectory model' indicative of river health (Table 1). The program also developed a monitoring strategy for evaluating these models and implemented a pilot program to conduct monitoring across the Basin under this framework. This pilot monitoring program was aimed both at testing the conceptual models for fish ecology and for trialling the monitoring framework. The pilot monitoring program was carried out with surveys in Dec 2007 and May 2008 and included 10 South Australian Sites, five in the Neales/Peake catchment, three in the Diamantina/Warburton and one in Cooper Ck. The results of the pilot survey were analysed with respect to the fish trajectory model and monitoring framework.

The results indicated that the monitoring framework was adequate for assessing fish ecology indicators that relate to river health (McNeil *et al.* 2008). It was also discovered; however, that the arid South Australian sections of the Basin did not fit with the fish trajectory conceptual model, developed largely using data from less arid reaches (Queensland sections of LEB rivers) or in much wetter periods (Balcombe & McNeil 2008). The data collected clearly showed that the impact of drought, particularly in the arid western catchments of the Neales River and Peake Creek was higher than previously recorded, with all but one fish species confined to a single refuge waterhole in the Neales catchment. This pattern indicates that the more arid areas of the basin are subject to extreme variation in species richness across the catchments and that critical refugia are essential for fish to survive drought periods compared to more hydrologically reliable reaches in Queensland catchments. Furthermore, the survey revealed that with the resumption of flows during the wet season, there were vast differences in the recolonising potential of different fishes with spangled perch and bony herring showing rapid recolonisation over large spatial scales, whilst all other species remained confined to refuge habitats. This situation means that native fish populations are under extreme risk of local, catchment scale extinction as a result of the current drought and that most species do not possess rapid resilience mechanisms essential for recovery following the resumption of flow.

The current program aims at continuing the monitoring of fish populations across the South Australian section of the Lake Eyre Basin under the framework developed by the LEBRA program. The survey will inform managers on the resilience potential of native fishes following drought and the resumption of flows, both in terms of the success of rapid colonisers that have spread throughout the catchment, and in regard to slower recolonizers that remian confined in high risk refuge habitats. With the resumption of rain and somewhat higher flows during the 2008/09 wet season, the monitoring will also inform management as to the hydrological requirements for slow colonisers, and identify appropriate cues and pathways for effective recolonisation and eleviating the high risk associated with highly confined and isolated refuge populations. The main aims of the current study were to:

1. Assess the status, distribution and ecology of native fish populations following drought.

2. Determine the successful re-establishment of fast colonising species across catchments.

3. Assess the ability for slower recolonisers to re-establish at catchment scales.

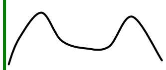
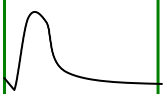
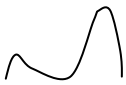
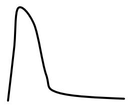
4. Identify the critical flow and connectivity requirements that these species require for recolonising catchments following severe drought.

5. Provide ongoing feedback and re-assessment of the fish trajectory model and monitoring program developed under the LEBRA.

6. Maintain continuity of data collection linking the LEBRA pilot monitoring program to the imminent implementation of long term monitoring under the LEBRA program

7. Identify key knowledge gaps, research and management priorities for improved management of native fishes and aquatic health of Lake Eyre Basin Rivers.

Table 1. Conceptual Model for the response of fish to hydrological regime in LEB waterholes outlined at the LEBRA Fish Trajectory Workshop, Brisbane 2005 (Humphries *et al.* 2005).

	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

METHODS

Sites

The freshwater fish communities of sites in the Neales River and Peake Creek portion of the Lake Eyre Basin (Figures 1) were surveyed in December 2008 and May-June 2009. During the May-June 2009 fieldtrip, sites on the Diamantina/Warburton River and Cooper Creek were also surveyed. The Neales River sites were Algebuckina, Stewart's Waterhole, South Stewart's Waterhole and Hookey's Waterhole (Figure 2). There was one Peake Creek site at the Peake Creek crossing on the Oodnadatta Track (Figure 3). Each of these sites was surveyed previously in December 2007 and May 2008. The Warburton River sites were located on Kalamurina Station at the homestead waterhole and at Stony Crossing. Previous sites on the Diamantina/Warburton were located on the Clifton Hills Station at Ultoomurra Waterhole, Goyder Lagoon and Clifton Hills Outstation. For the May-June 2009 fieldtrip, access to this property was restricted, so additional sites were selected as near to Ultoomurra and Clifton Hills Outstation as possible. The waterhole nearest to Ultoomurra waterhole was on the border between Cowarie and Clifton Hills Stations, however the flow at this point of the river was too high to set fyke nets or sweep a seine net. The waterhole at Clifton Hills Outstation is on the Diamantina River, and when full, runs from there through Pandie Pandie Station almost to the Queensland border, so the waterhole was accessed through Pandie Pandie at the southern border with Clifton Hills, 11 km north of Clifton Hills Outstation. Sites in the Diamantina and Cooper catchments that were sampled in May 2007 were unable to be sampled in December 2008 due to heavy rain and flooding of the Birdsville Track.

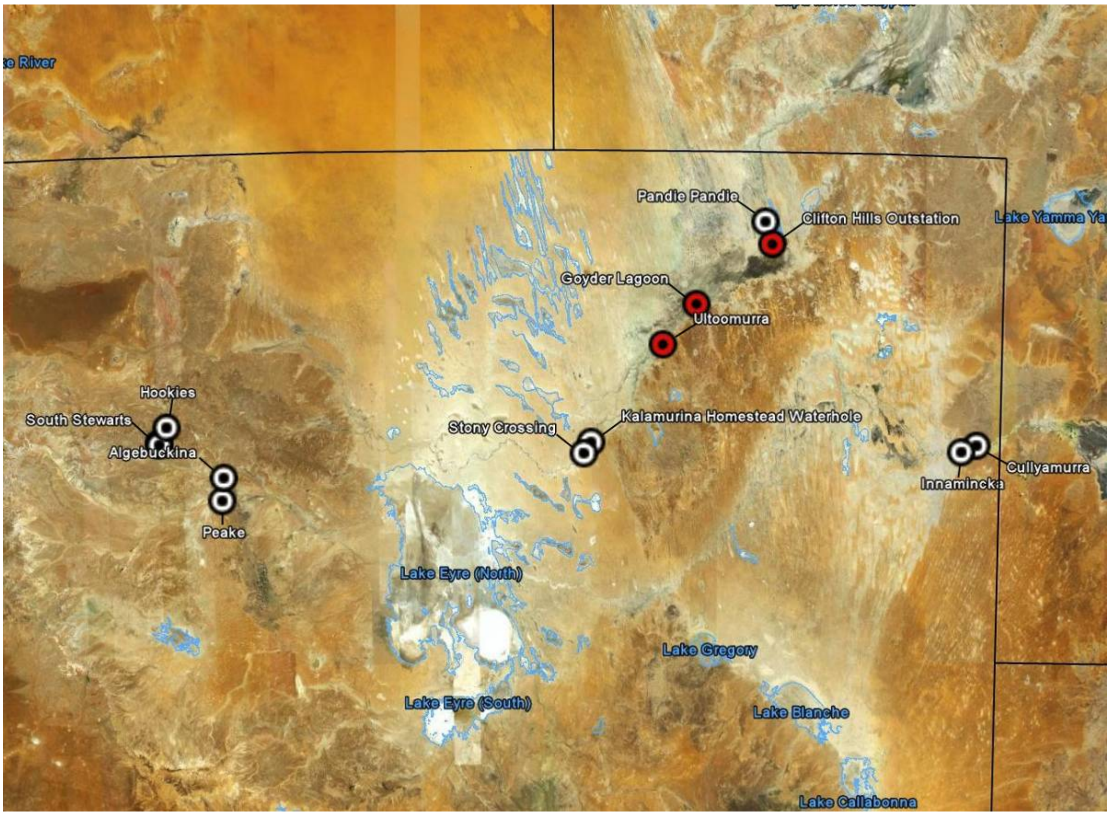


Figure 1. Location of sites in the South Australian portion of the Lake Eyre Basin. Stewart's waterhole is obscured by South Stewart's waterhole. Sites with a red marker are from previous surveys but referred to in text.

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. Three types of fyke nets were used; two single-winged designs [small fykes (3 m leader, 2 m funnel) and large fykes (5 m leader, 3 m funnel)] and a double-wing design (2x 5m leaders, 3 m funnels). All types consisted of 4mm mesh fabric with an inlet arch of 650mm in diameter. These fyke nets have been found to be effective in catching large numbers of both large and small-bodied fish (McNeil *et. al* 2008). All fyke nets were set overnight for approximately fifteen hours.

Where appropriate, a small larval seine net was swept through shallow pools. At Cullyamurra waterhole a 5 inch monofilament gillnet (3 m drop by 10 m length) was deployed for 3 hours and checked hourly. All fish were identified using 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.

During the December 2008 survey, water quality parameters, including temperature, dissolved oxygen, pH and conductivity were measured at each site during each survey using a TPS multistation water quality meter. A standard Secchi disc was used to assess water clarity as a proxy for turbidity. During the May-June 2009 survey, the same parameters were measured using a YSI 6920 water quality sonde. Water quality was measured at the surface and at 0.5 m depth intervals to detect stratification. Observations of the dominant substrate, in-stream macrophytes and riparian vegetation were also recorded at each site.

Data Analyses

The relative abundance of each taxon was calculated for the fish communities captured from each site during each survey. The size distributions of each fish species were also plotted for each site.

The water level at Stewart's Waterhole (Neales River) and Peake Waterhole (Peake Creek) was plotted from January 2007 to the end of December 2008. The flow rates for the Diamantina River at Birdsville and Cooper Creek at Cullyamurra were plotted from January 2007 to June 2009.

To monitor the change in species assemblage over time, the presence/absence of species captured in the December 2008 and May-June 2009 surveys were compared to the two previous surveys in December 2007 and May 2008.

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

Figure 3. Photos of sites at (a) Peake Creek (b) Pandie Pandie, (c and d) Kalamurina homestead waterhole, (e) Stony Crossing, and (f) Cullyamurra waterhole.

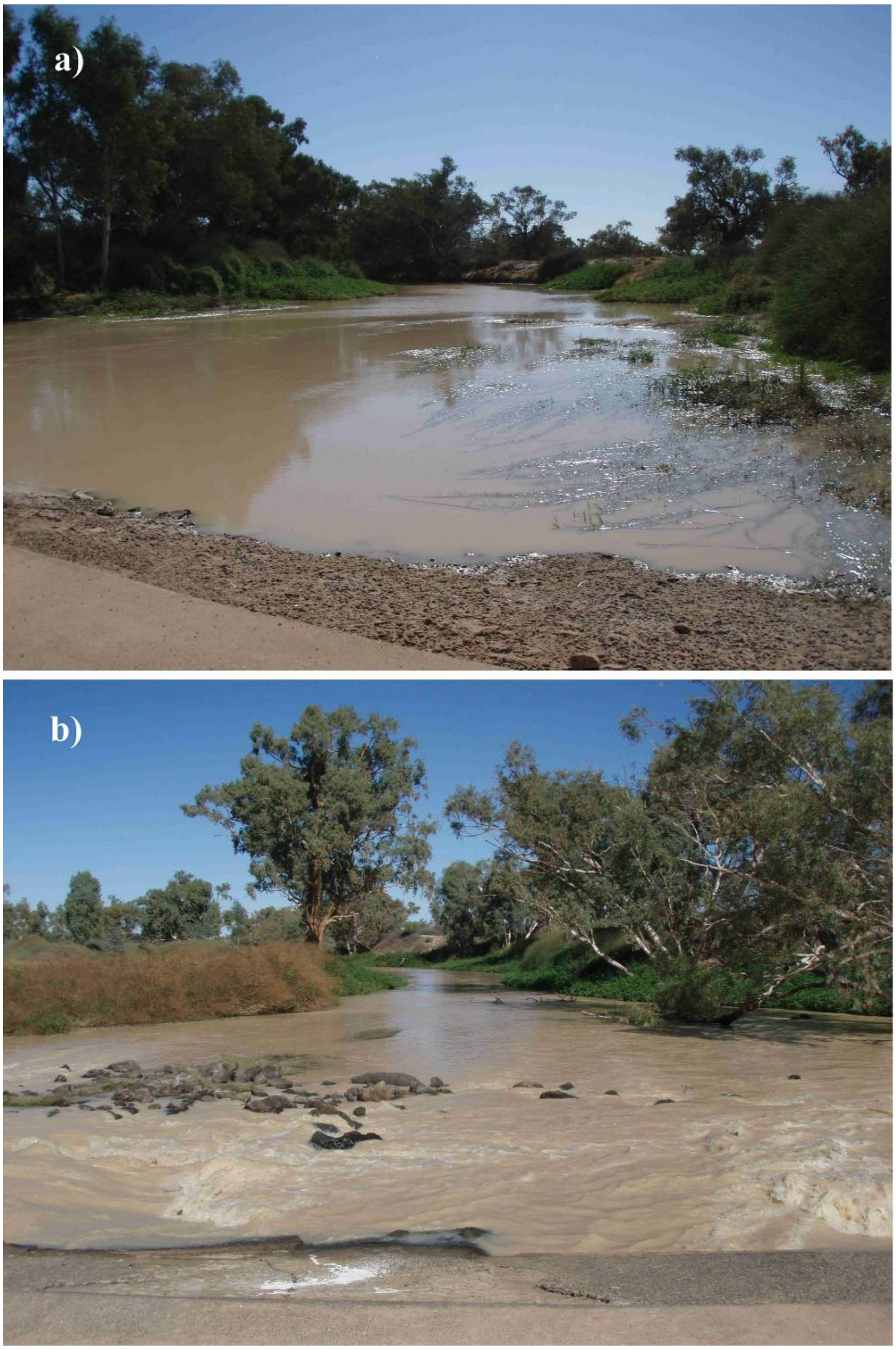


Figure 4. Cooper Ck at Innamincka causeway under moderate-low flow conditions (a) above looking upstream and (b) below looking downstream.

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
Neales River	Algebuckina	Large Reach	December 2008	6x small fykes 3x large fykes 4x double wing fykes
			May 2009	6x small fykes 2x large fykes 4x double wing fykes 7 seine sweeps 4 bait traps
	South Stewart's Waterhole	Large Pool	December 2008	4x small fykes 2x large fykes 2x double wing fykes
			May 2009	4x small fykes 2x large fykes 2x double wing fykes
	Stewart's Waterhole	Large Pool	December 2008	4x small fykes 2x large fykes 2x double wing fykes
			May 2009	4x small fykes 2x large fykes 2x double wing fykes
	Hookey's	Large Pool	December 2008	4x small fykes 3x large fykes 2x double wing fykes
			May 2009	4x small fykes 2x large fykes 2x double wing fykes
Peake Creek	Peake Waterhole	Large Reach	December 2008	3x small fykes 2x large fykes 1x double wing fykes
			May 2009	4x small fykes 2x large fykes 2x double wing fykes
Warburton River	Kalamurina HS Waterhole	Main channel	June 2009	4x small fykes 2x large fykes 4x double wing fykes
	Stony Crossing	Main channel	June 2009	4x small fykes 2x large fykes 4x double wing fykes
Diamantina River	Pandie Pandie	Main channel	June 2009	4x small fykes 2x large fykes 4x double wing fykes
Cooper Creek	Cullyamurra Waterhole	Main channel	June 2009	4x small fykes 2x large fykes 4x double wing fykes Gillnet – 3 hours
	Upstream Innamincka Causeway	Main channel		2x small fykes 1x large fykes 2x double wing fykes
	Downstream Innamincka Causeway	Main channel		2x small fykes 1x large fykes 2x double wing fykes

RESULTS

Overall the 2008/09 surveys collected 48,111 fish representing 15 species from 11 families of fish (Table 3). Of these, only one alien species (Gambusia or mosquitofish) was captured in small numbers in the Neales and Peake. This included 9670 in December 2008 and 38,441 in May 2009. Of these, 42,031 were collected in the Neales catchment, 4007 in the Warburton and Diamantina and 2073 in the Cooper.

Neales River

The abundance of all fish species captured in the Neales River is plotted in Figures 5 and 6. Spangled perch and bony herring were the most abundant species in the Neales River in December 2008 and May 2009, while desert rainbowfish appeared in May 2009 and were also highly abundant. An additional five species were only present in Algebuckina waterhole in December 2008, but in May 2009 there were only two species in Algebuckina that couldn't be found upstream: desert goby which weren't captured in any nets, but were observed during seine sweeps, and the introduced mosquitofish. Small numbers of golden perch also made it up to Stewart's and South Stewart's waterholes by May 2009.

The water level measured at South Stewart's (Cramps) waterhole reflects the ephemeral nature of waterholes in the Neales River catchment (Figure 7). The dominant pattern in this system is inundation as a result of summer rains followed by a long drying period over winter, potential desiccation by the end of spring and then inundation the next summer. The depth at which South Stewart's waterhole ceases to flow (marked in red on figure 7) indicates that the Neales River maintained connectivity for a much longer period over the past summer than the previous two summers.

Table 3. Total numbers of fish taxa captured at sites in the South Australian portion of the Lake Eyre Basin in December 2008 (shaded) and May-June 2000. Site codes: Cullyamurra Waterhole (CU), Innamincka Causeway (IC), Pandie Pandie (PP), Kalamurina Homestead (KHS), Stony Crossing (SC), Algebuckina (ALG), Stewart's Waterhole (SW), South Stewart's Waterhole (SS), Hookey's Waterhole (HO) and Peake (PE).

Scientific Name	**Common Name**	**Coopers**		**Diamantina**			**Neales**								**Peake**	
		CU	IC	PP	KHS	SC	HO		SS		SW		ALG		PE	
		Jun-09	Jun-09	Jun-09	Jun-09	Jun-09	Dec-08	May-09	Dec-08	May-09	Dec-08	May-09	Dec-08	May-09	Dec-08	May-09
Ambassis sp.	Glassfish	2	2													
Amniataba percoides	Barred Grunter												5			
Bidyanus welchi	Welch's Grunter	61	20	44	50	122										
Chlamydogobius eremius	Desert Goby				1	1							2		2978	10508
Craterocephalus eyresii	Lake Eyre Hardyhead												30	25	5626	20371
Gambusia holbrooki	Gambusia													16	23	
Hypseleotris spp.	Carp Gudgeon spp.		8													
Leiopotherapon unicolor	Spangled Perch	3	15				37	33	93	12	24	20	5		6	1
Macquaria ambigua	Golden Perch	173	237	80	261	508				1		1	9	4		
Melanotaenia splendida tatei	Eastern Rainbowfish	15			5	2		178		2		39	30	73		
Nematolosa erebi	Bony Bream	4	12	2	20	36	23	120	3	245	34	539	742	173		
Neosiluris hyrtlii	Hyrtl's Tandan	177	538	101	1	3										
Porochilus argenteus	Silver Tandan		8	1081	136	1517										
Retropinna semoni	Australian Smelt	11	770													
Scortum barcoo	Barcoo Grunter	12	5		2	34										
	Native Taxon Richness	**9**	**10**	**5**	**8**	**8**	**2**	**3**	**2**	**4**	**2**	**4**	**7**	**4**	**3**	**3**

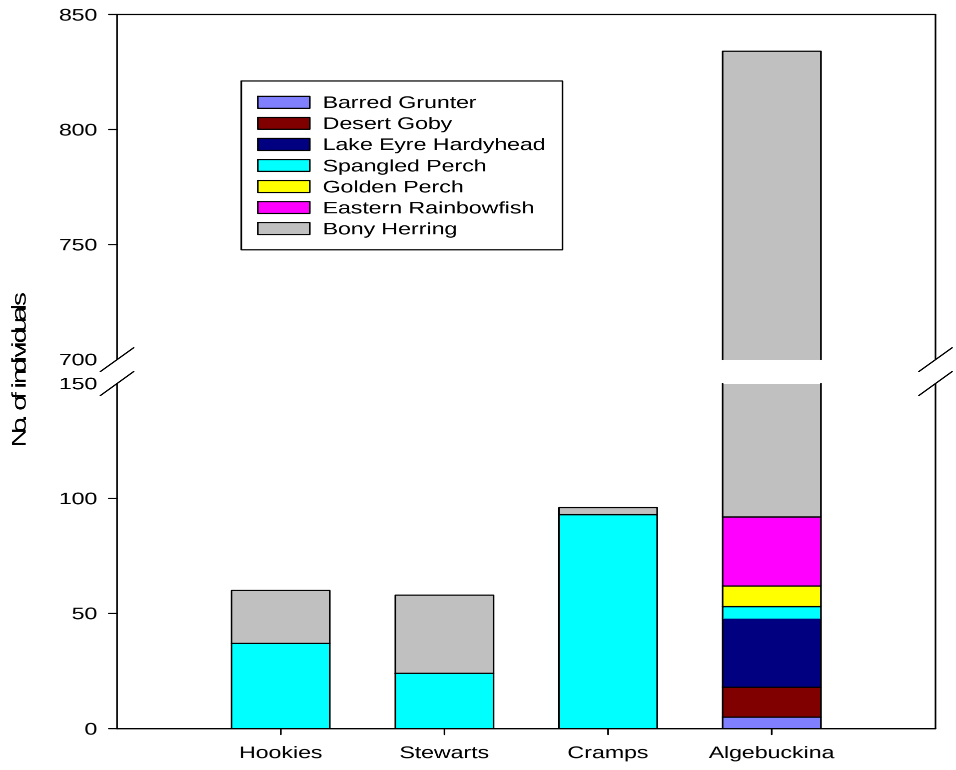


Figure 5. Abundance of fish taxa captured in the Neales River in December 2008.

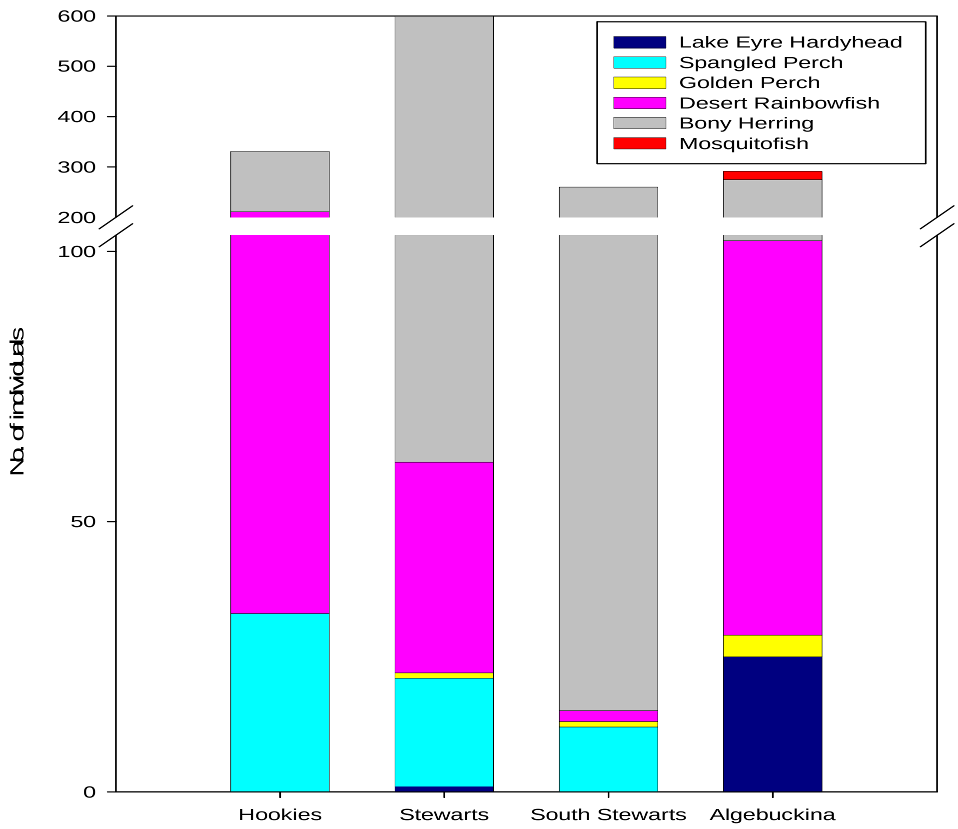


Figure 6. Abundance of fish taxa captured in the Neales River in May 2009.

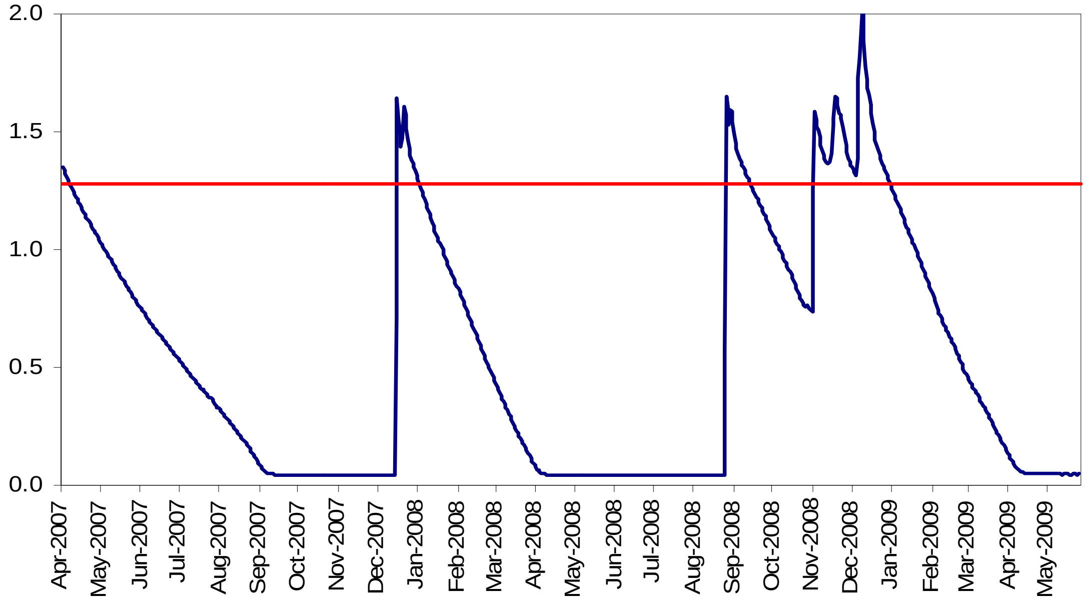


Figure 7. Water level for the Neales River as measured at South Stewart's Waterhole. Red line indicates the cease-to-flow height.

Hookey's Waterhole

Water Quality

Hookey's waterhole was almost full in December 2008 (Figure 7) with warm, highly turbid waters, normal oxygen levels, low salinity and slight stratification largely due to the high turbidity (Appendix 1, Table 1). By May 2009, the water had dropped to only 1.5 m deep, was moderately turbid, low salinity and no stratification (Appendix 1, Table 2).

Fish

Only two species of fish were present at Hookey's waterhole in December 2008: spangled perch and bony herring (Figure 5). The size frequency distribution for spangled perch indicated 3-4 size-classes corresponding to at least the last 3 year-classes (Figure 8). Bony herring had two size-classes most likely corresponding with two year-classes; however the most recent year-class appeared to be absent (Figure 8). Given that bony herring were absent in the first survey in December 2007 it appears that the current year-class had failed to move this far upstream. Older year-classes had either moved upstream previously, or only larger individuals had managed to make it upstream on the most recent flood.

By May 2009, spangled perch have newly recruited fish as well as some older individuals in the population (Figure 9). So too, bony herring appear to have new recruits as well as three other distinct size classes in the population (Figure 9). Desert rainbowfish show a unimodal distribution consistent with their size and reproductive characteristics.

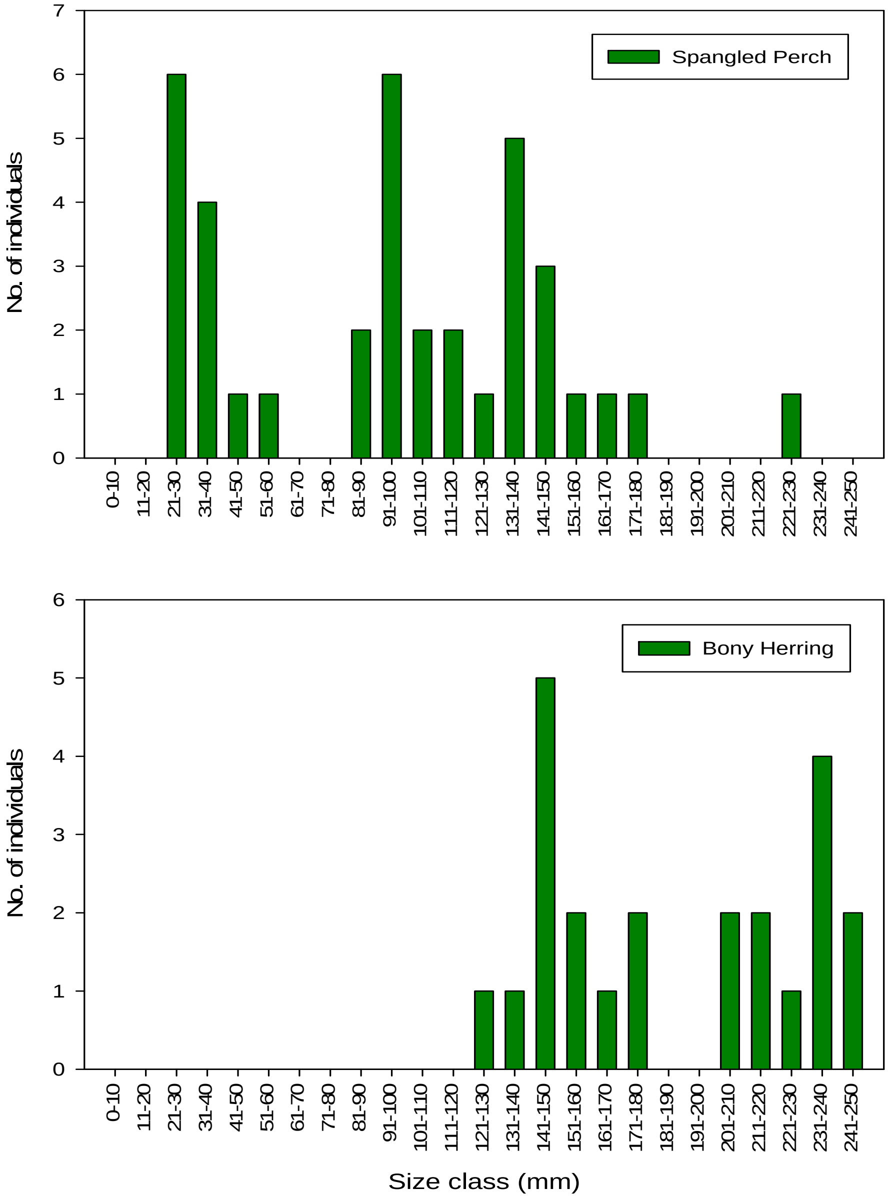


Figure 8. Size frequency distributions of fish captured at Hookey's Waterhole in December 2008.

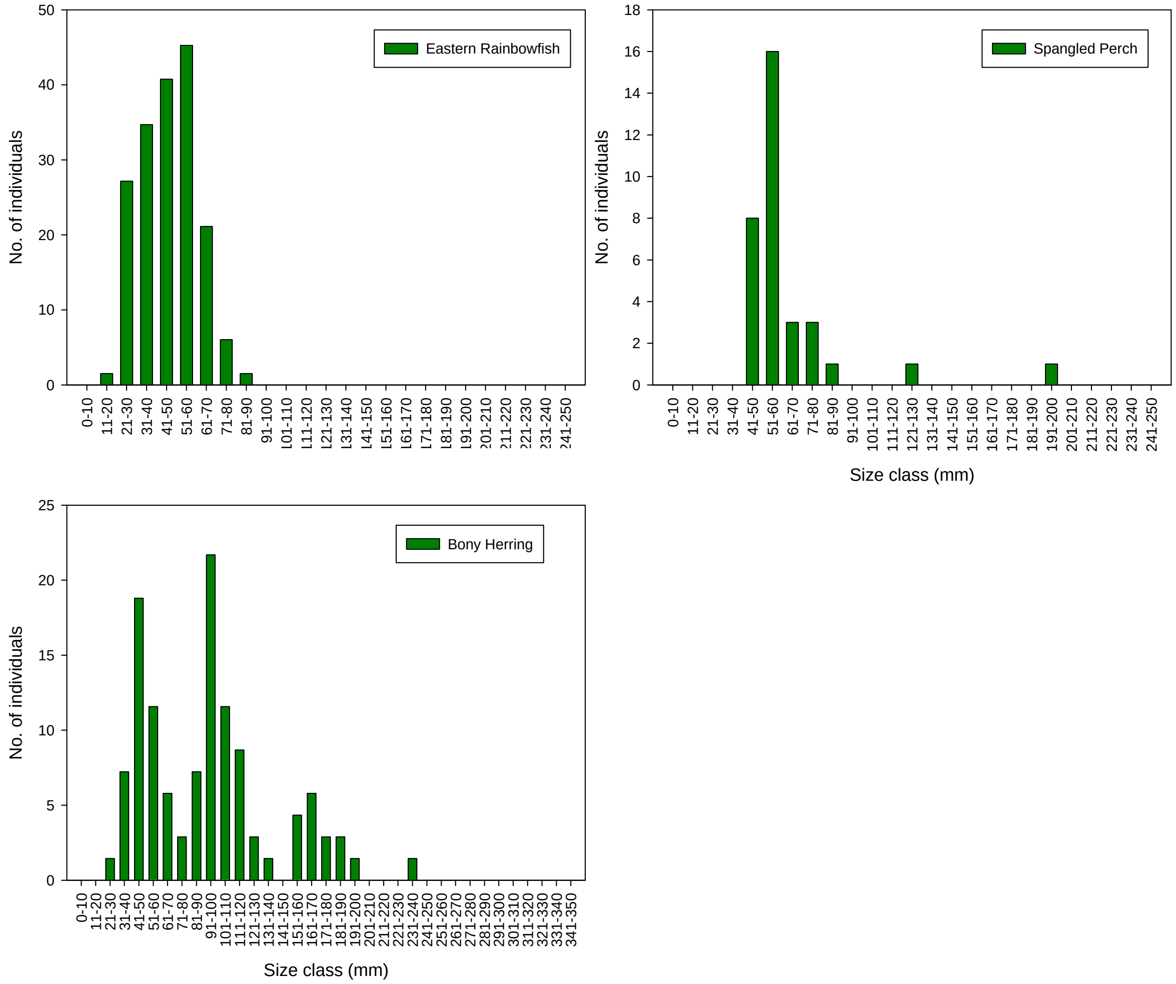


Figure 9. Size frequency distributions of fish captured at Hookey's Waterhole in May 2009. Note that axis scales vary between species.

Stewart's Waterhole

Water Quality

Like Hookey's waterhole, Stewart's waterhole was also almost full in December 2008 with warm, highly turbid waters, normal oxygen levels, low salinity and slight stratification largely due to the high turbidity (Appendix 1, Table 1). By May 2009, the water had dropped significantly in depth, was moderately turbid, low salinity and no stratification (Appendix 1, Table 2).

Fish

Only two species of fish were present at Stewart's waterhole in December 2008: spangled perch and bony herring (Figure 5). The size frequency distribution for spangled perch indicated approximately three size-classes probably corresponding to the last three year-classes (Figure 10). Bony herring had three size-classes corresponding to three year-classes (Figure 10). Both bony herring and spangled perch were absent in the first survey in December 2007, so it appears that all year-classes present in Stewart's waterhole had managed to reach this far upstream. In May 2009, spangled perch had only one size class, while bony herring maintained three size classes (Figure 11). Desert rainbowfish showed a unimodal distribution consistent with their size and reproductive characteristics.

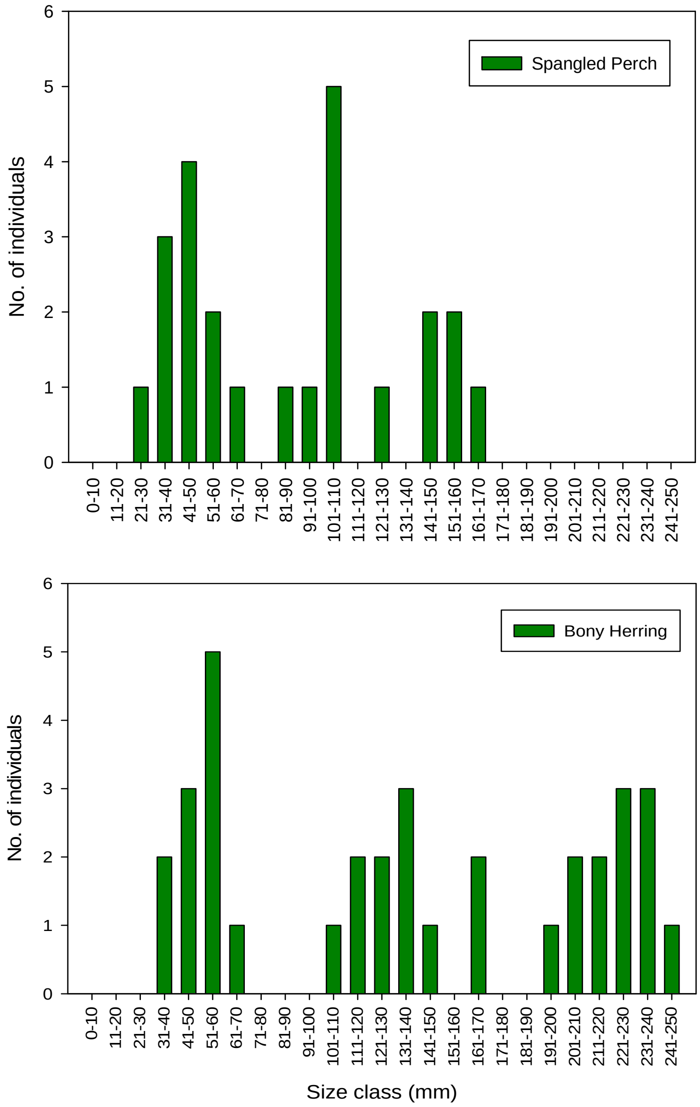


Figure 10. Size frequency distributions of fish captured at Stewart's Waterhole in December 2008. Note that axis scales vary between species.

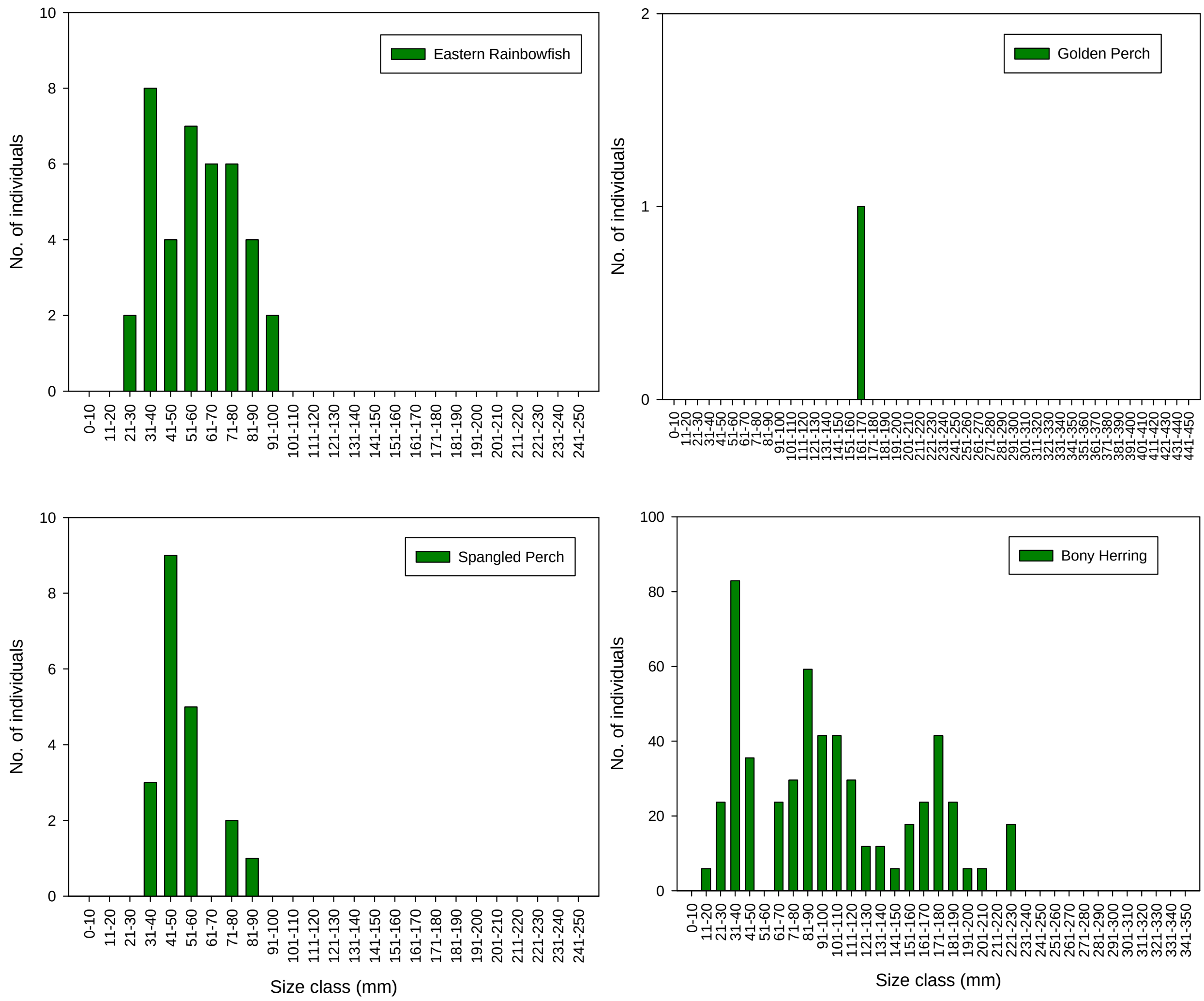


Figure 11. Size frequency distributions of fish captured at Stewart's Waterhole in May 2009. Note that axis scales vary between species.

South Stewart's Waterhole

Water Quality

South Stewart's waterhole was also almost full in December 2008. The waterhole on the main channel was inaccessible due to inundation of the wetland, so a large anabranch that was closer to the access track was sampled instead. This waterhole also had warm, highly turbid water, normal oxygen levels, low salinity and slight stratification largely due to the high turbidity (Appendix 1, Table 1). By May 2009, the waterhole on the main channel was accessible again. It had decreased in depth significantly, had moderate turbidity, normal oxygen levels and no stratification (Appendix 1, Table 2).

Fish

Once again, only spangled perch and bony herring were present at Stewart's waterhole in December 2008 (Figure 5). There were a large number of newly recruited spangled perch at this site with a small number of larger individuals from two other size classes (Figure 12). There was only a few large bony herring at this site (Figure 12), which may be due to the isolated nature of the sample site away from the main channel. By May 2009 there were desert rainbowfish, golden perch and spangled perch all in relatively low abundance, but bony herring were present in high abundance with large numbers of new recruits (Figure 13)(<60 mm TL), which were absent in the sample taken in December 2008.

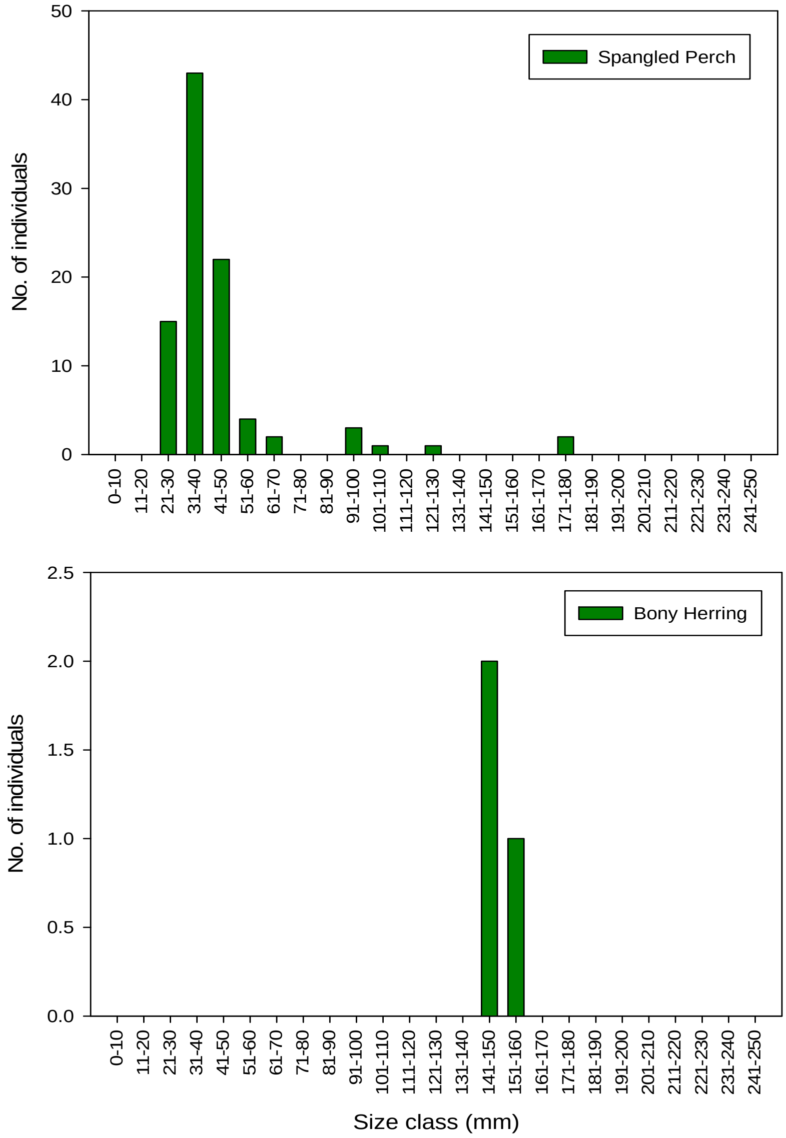


Figure 12. Size frequency distributions of fish captured at South Stewart's in December 2008.

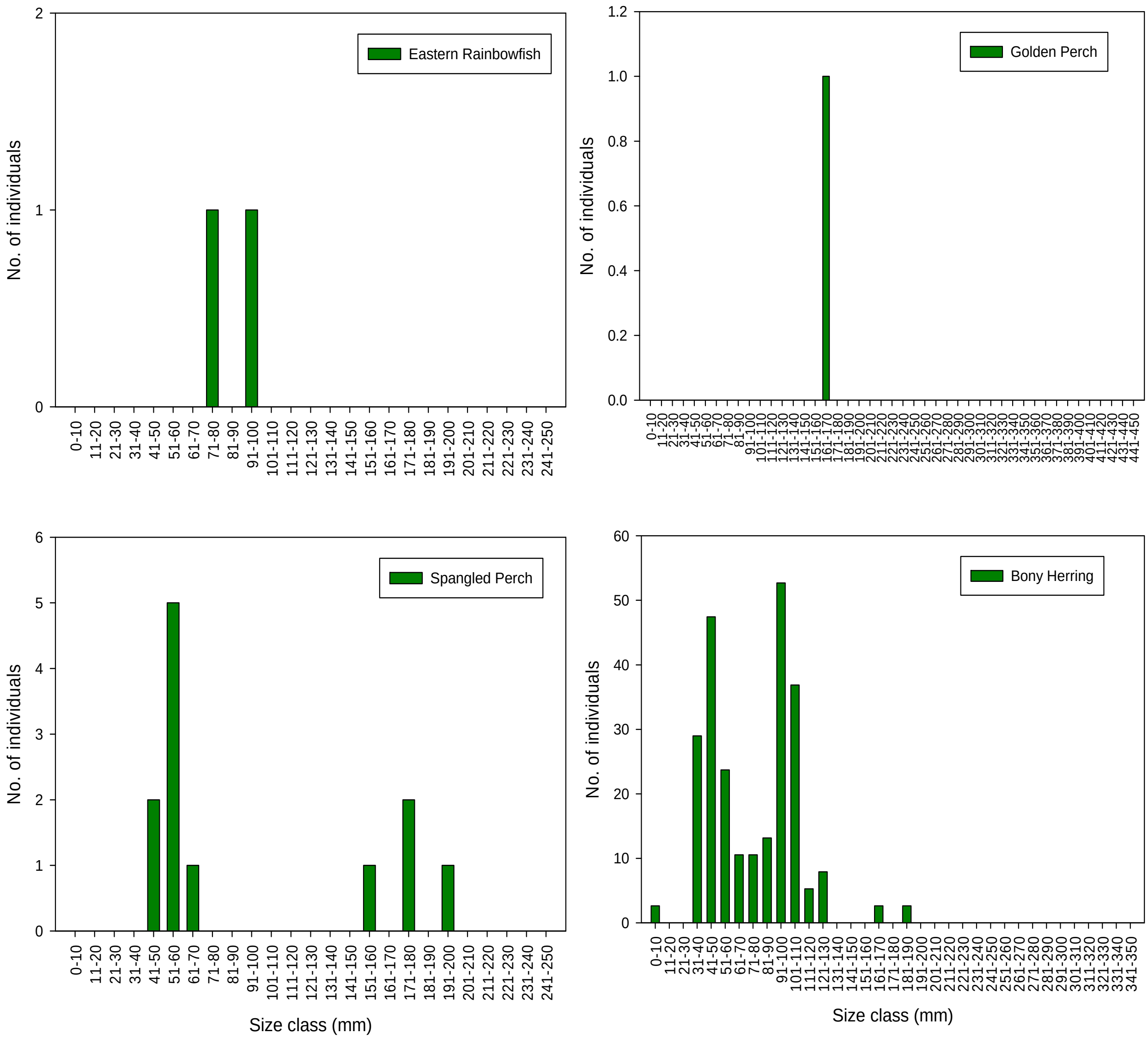


Figure 13. Size frequency distributions of fish captured at South Stewart's in May 2009. Note that axis scales vary between species.

Algebuckina Waterhole

Water Quality & Structural Habitat

Algebuckina waterhole was also almost full in December 2008 with warm, highly turbid waters, normal oxygen levels, low salinity and slight stratification largely due to the high turbidity (Appendix 1, Table 1). In May 2009 it had decreased in depth by over a metre and had normal oxygen, low salinity and no stratification (Appendix 1, Table 2). The shallow rocky pools at the upstream end of the waterhole near the saline spring did have slightly elevated salinity and lower turbidity.

Fish

The following fish were present in Algebuckina waterhole in December 2008: barred grunter, desert goby, Lake Eyre hardyhead, spangled perch, golden perch, eastern rainbowfish and bony herring (Figure 5). Apart from spangled perch, each species displayed a size frequency distribution featuring smaller size-class recent recruits, and in the case of longer lived species, a few larger size classes (Figure 14).

In may 2009 barred grunter and spangled perch were absent, but golden perch, Lake Eyre hardyhead, desert rainbowfish and bony herring were present with much the same size distributions as December 2008 (Figure 14 and 15).

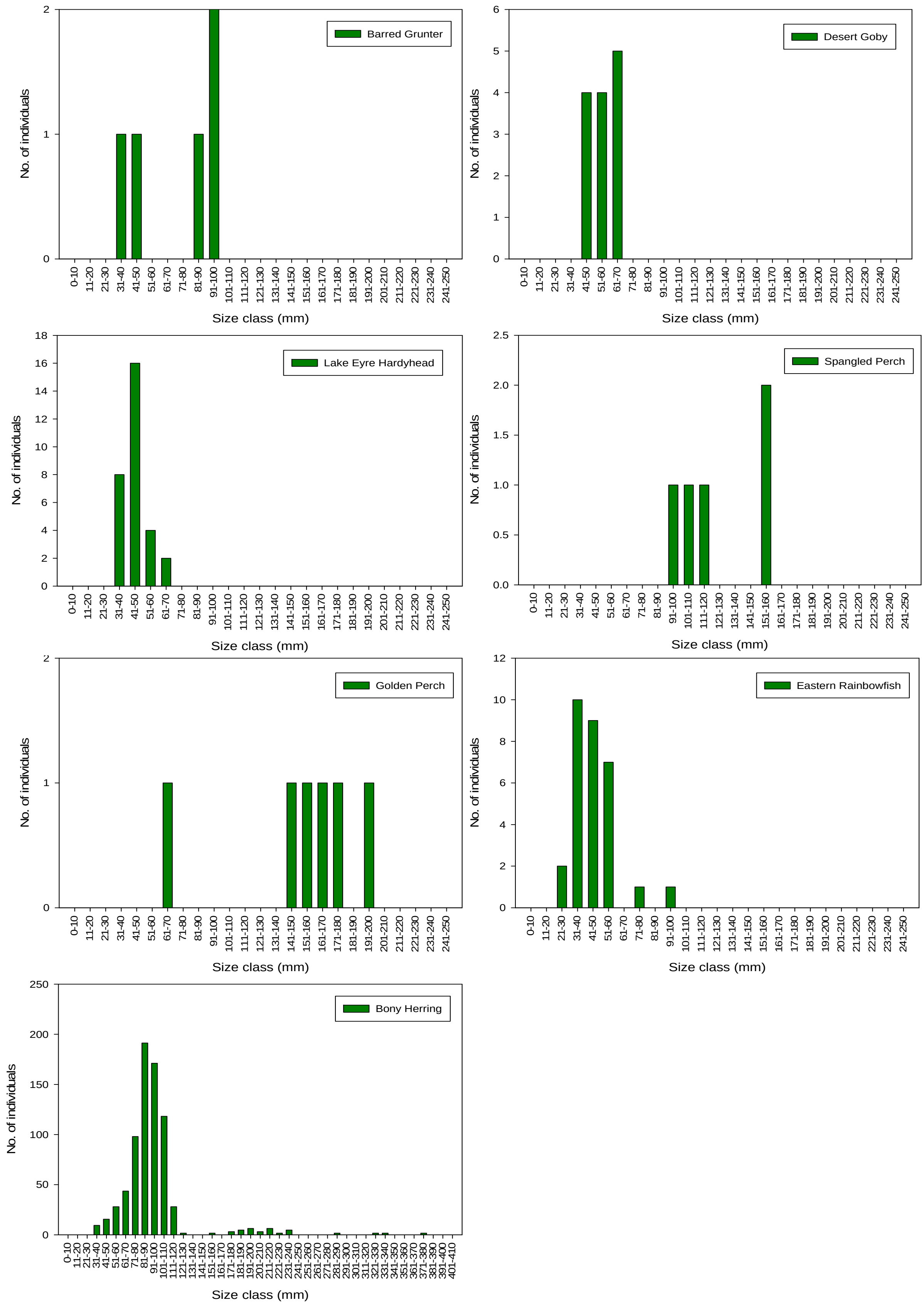


Figure 14. Size frequency distributions of fish captured at Algebuckina Waterhole in December 2008. Note that axis scales vary between species.

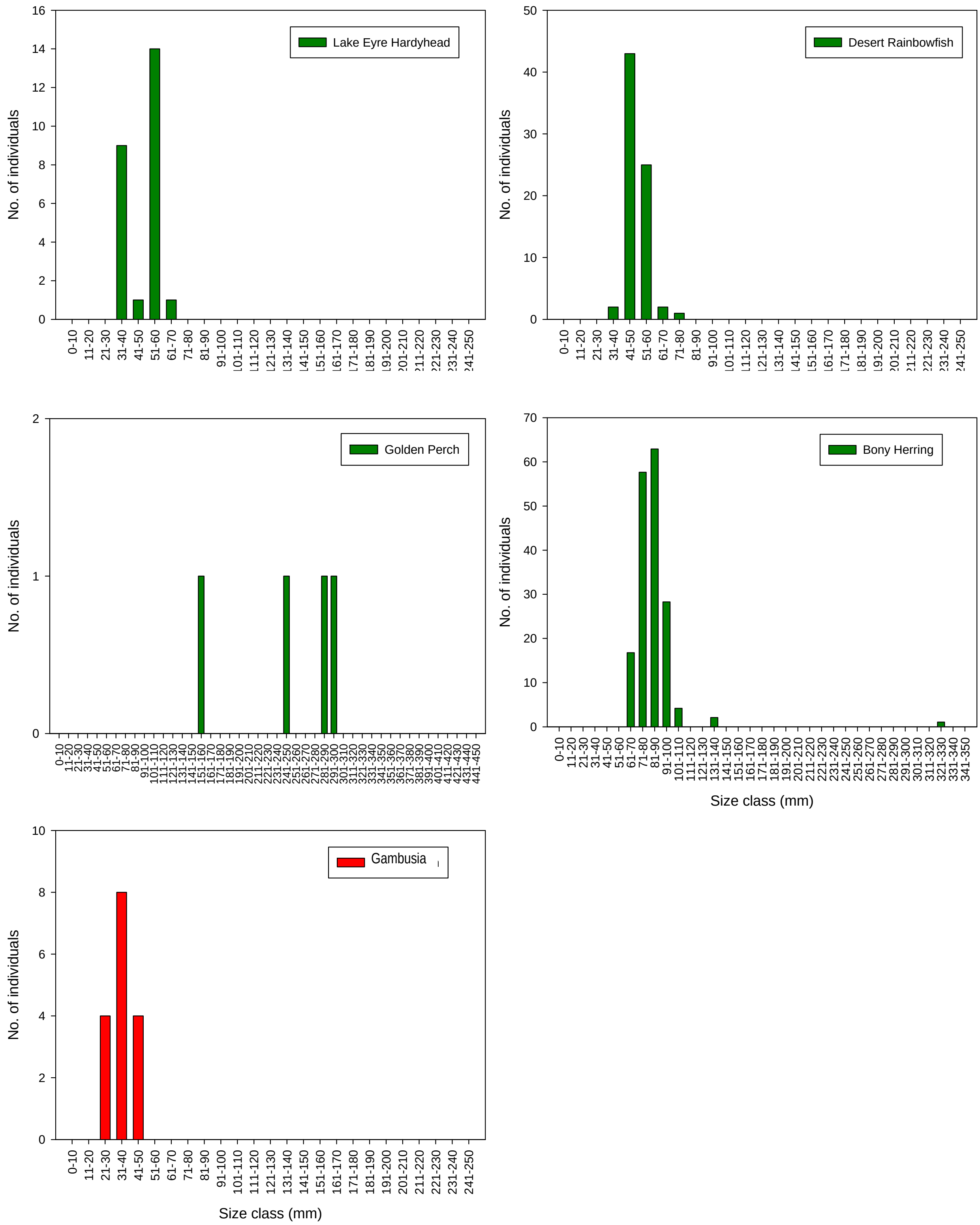


Figure 15. Size frequency distributions of fish captured at Algebuckina Waterhole in May 2009. Note that axis scales vary between species.

Peake Creek

The abundance of all fish species captured in Peake Creek is plotted in Figure 16. Desert goby and Lake Eyre hardyhead were most abundant although small numbers of spangled perch were present in both surveys.

The water level measured at Peake waterhole reflects the highly ephemeral nature of waterholes in the Neales-Peake system (Figure 17). The dominant pattern in this system is inundation as a result of summer rains, followed by rapid drying periods, and a high potential for desiccation. The data for this system were only available up to May 2008. Data after this were projected based on six prior years of water level data and local rainfall records for the entire period. This projection agreed with the water levels observed at Peake Creek during the December 2008 survey.

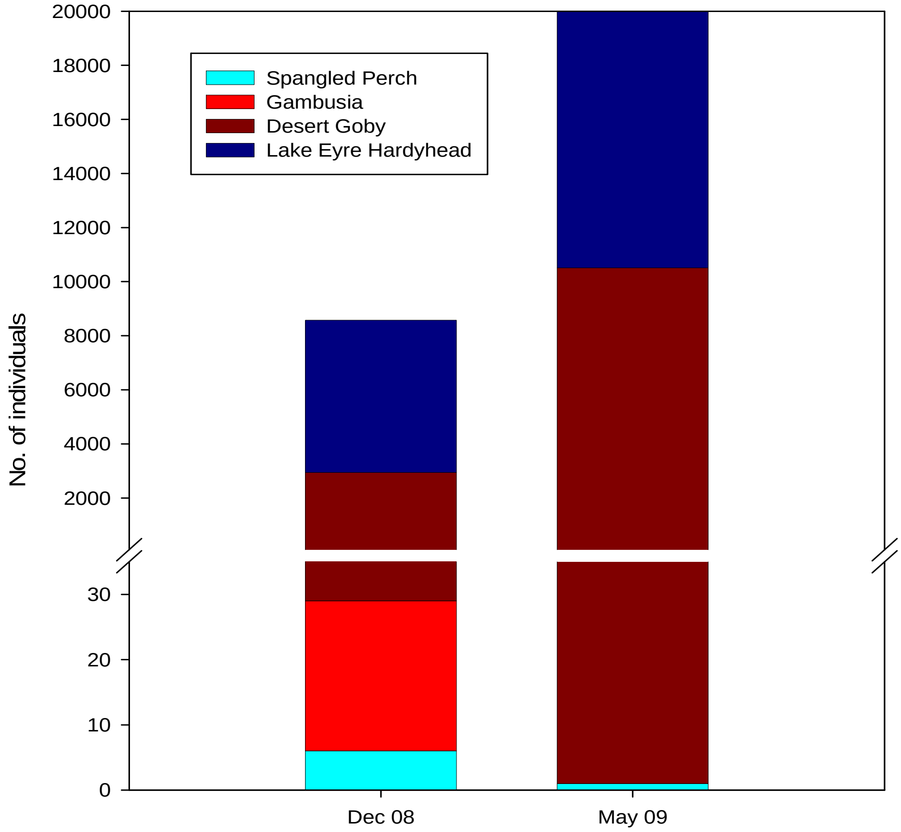


Figure 16. Abundance of fish taxa captured in Peake waterhole in December 2008 and May 2009.

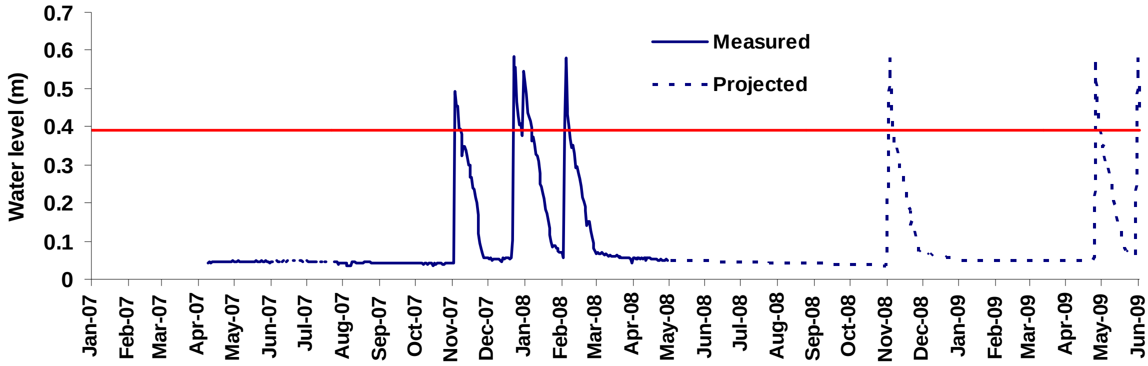


Figure 17. Water level for the Peake Creek measured at Peake Bridge. Data from May 2008 onwards has not been collected. Water level for May 2008 onwards is projected based on local rainfall and past water level response to rainfall. Red line indicates the cease-to-flow height.

Water Quality

Peake waterhole was almost full in December 2008 with warm turbid waters, normal oxygen levels, low salinity and weak stratification (Appendix 1, Table 1). In May 2009 rain on the 30th and 31st had filled the waterhole and Peake Creek was flowing strongly. The water temperature was similar to other sites, and the oxygen levels were normal. The salinity in the top metre of water was slightly saline, but despite the strong flow in the creek, below 1 m depth was extremely hypersaline (Appendix 1, Table 2).

Fish

Desert goby, Lake Eyre hardyhead, spangled perch and gambusia were captured at Peake creek in the December 2008 survey. The size frequency plots indicate almost exclusively unimodal distributions in this waterhole (Figure 18). This is consistent with the highly ephemeral nature of this waterhole and suggests a 'boom and bust' community where small highly saline remnant pools with a few surviving individuals are transformed into large freshwater thriving pools with large numbers of single size-class recruits. Peake creek was the only site where mosquitofish were captured during the December survey.

In May 2009 the size structure of desert gobies was still largely unimodal, but Lake Eyre hardyheads had a distinct bimodal distribution (Figure 19), suggesting recent recruitment in response to good flows in December 2008 and possibly April 2009. Only one large spangled perch was captured in May, suggesting recruitment failure and a decline in adults compared to previous surveys in May 2008.

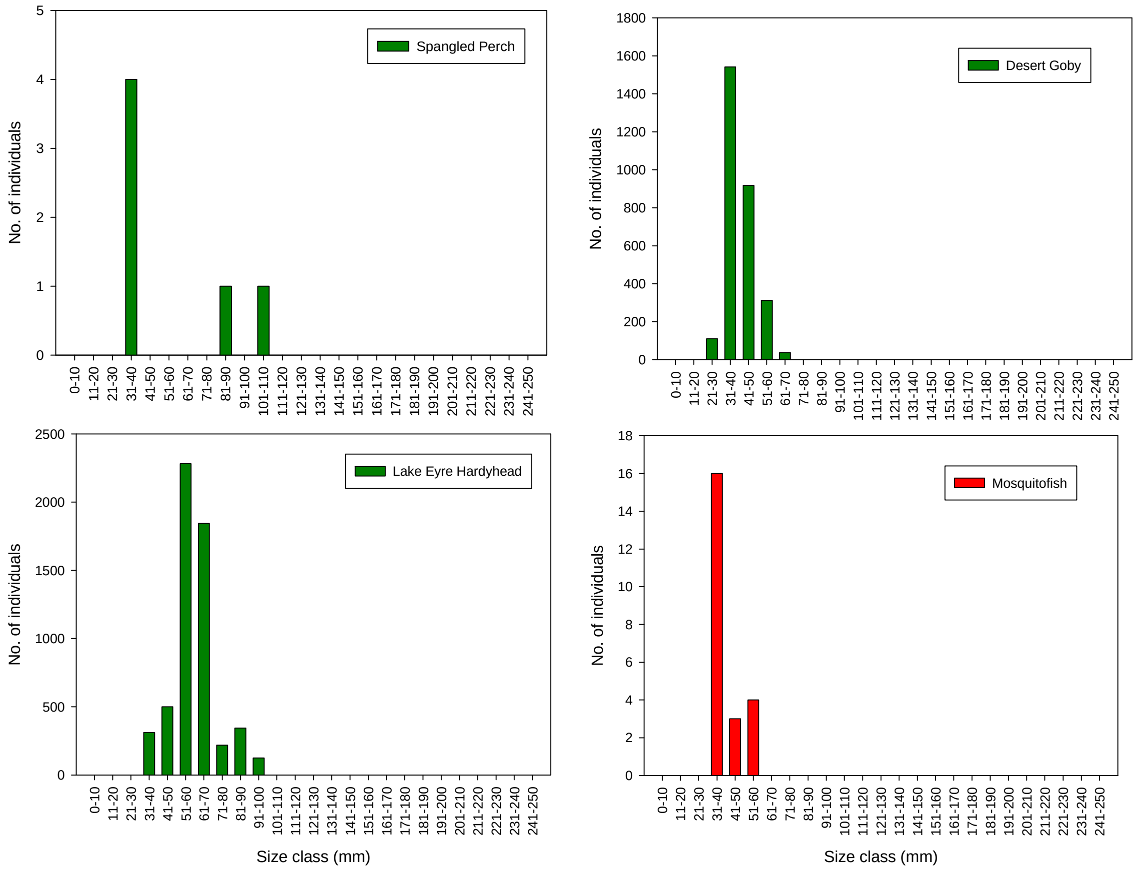


Figure 18. Size frequency distributions of fish captured at Peake Waterhole in December 2008.

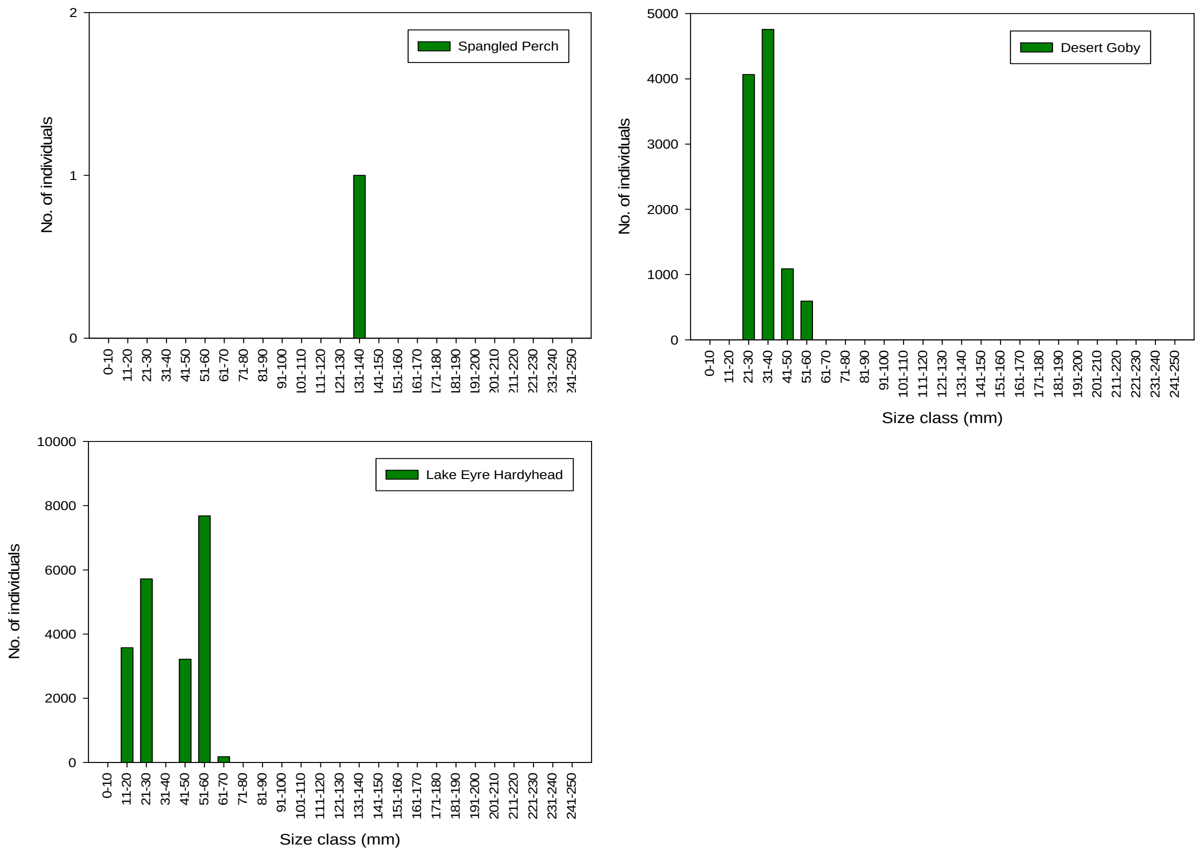


Figure 19. Size frequency distributions of fish captured at Peake Waterhole in May 2009. Note that axis scales vary between species.

The 2008/09 survey was undertaken at the same sites as recent LEBRA sampling during 2007/08 (McNeil *et al*. 2008). In combination, these two data sets provide an overview of the changes in fish assemblage structure as the system recovered from drought following extended desiccation in 2006/07 (Figure 20). In December 2007 there was very low species diversity across most of the catchments. Only spangled perch were found at Hookey's waterhole, whilst Peake waterhole possessed only two species. There were no fish at all in Stewart's and South Stewart's waterholes, which had dried out and refilled before sampling and filled from local rainfall without connecting to refuge habitats. All five have since been recolonised to varying degrees and this progression is shown at the catchment scale in Figure 20. Overall, the ephemeral and stochastic nature of hydrological processes in the Neales-Peake system is reflected in these changes to the fish assemblage between 2006 and 2009.

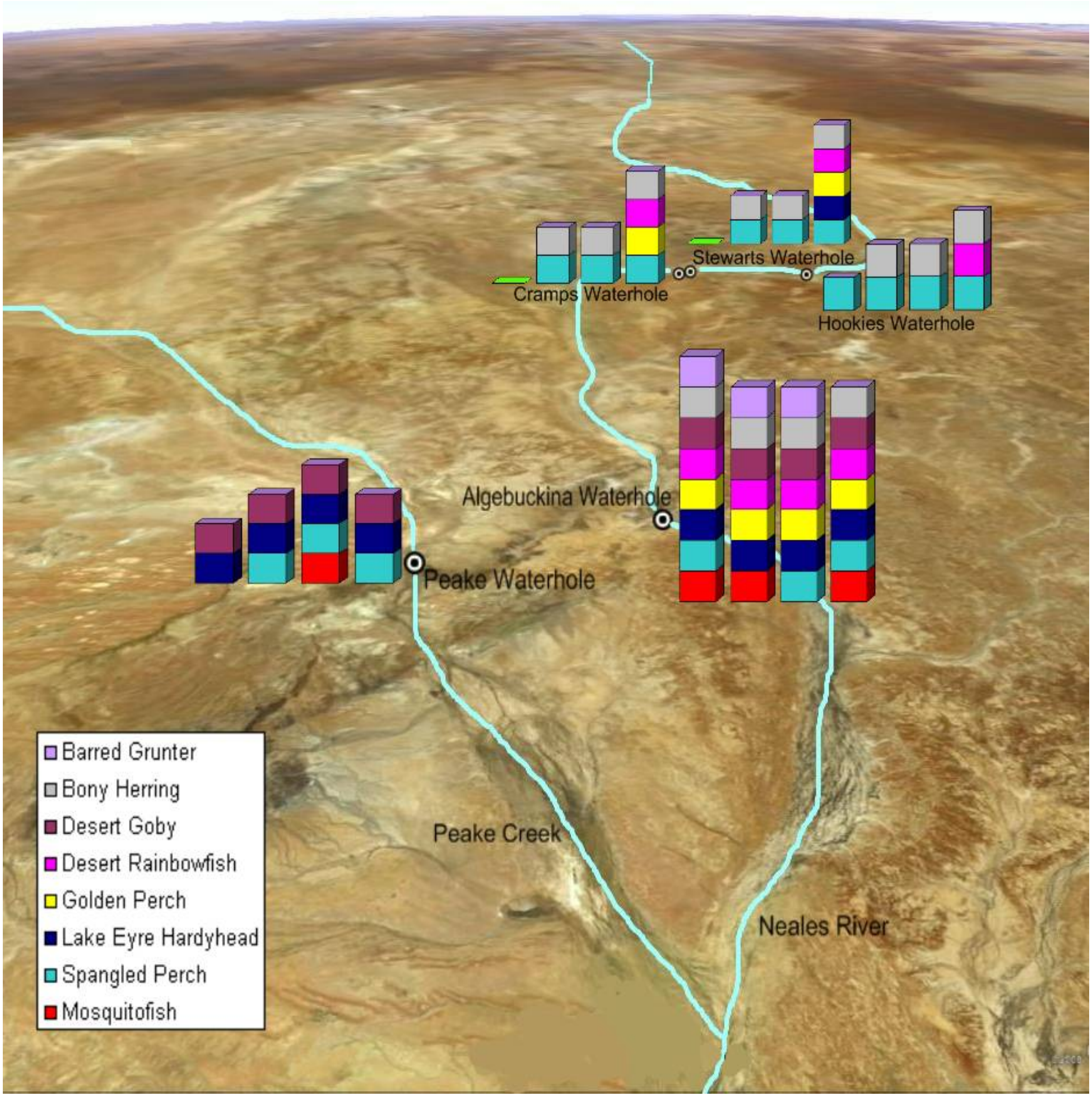


Figure 20. Catchment-scale recovery from drought. Presence/absence of fish species in the four surveys conducted in the Neales-Peake Catchment from December 2007 to May 2009. Species colours correspond to those in the legend. Surveys in order from left to right are December 2007, May 2008, December 2008 and May 2009. Green patches indicate no species present.

Diamantina/Warburton System

The abundance of all fish species captured in the Diamantina River and Warburton River is plotted in Figure 21. Large numbers of golden perch, silver tandan and Welch's grunter were captured at all sites in the Diamantina/Warburton. Hyrtl's tandan were captured in large number at Pandie Pandie Station. Smaller numbers of Barcoo grunter and bony herring were captured at all sites, while desert goby and desert rainbowfish were only captured at sites on Kalamurina Station at the homestead waterhole and stony crossing. Flows along the Diamantina in early 2009 were the highest in several years (Figure 22), peaking at Kalamurina Station at around 8 metres above the level of water encountered during the survey period (Tess McLaren, Kalamurina Station pers. obs.), and also resulting in the partial filling of Lake Eyre. This water presented no problems with finding locations to set nets, but did present problems with keeping nets in place due to the high flow rate.

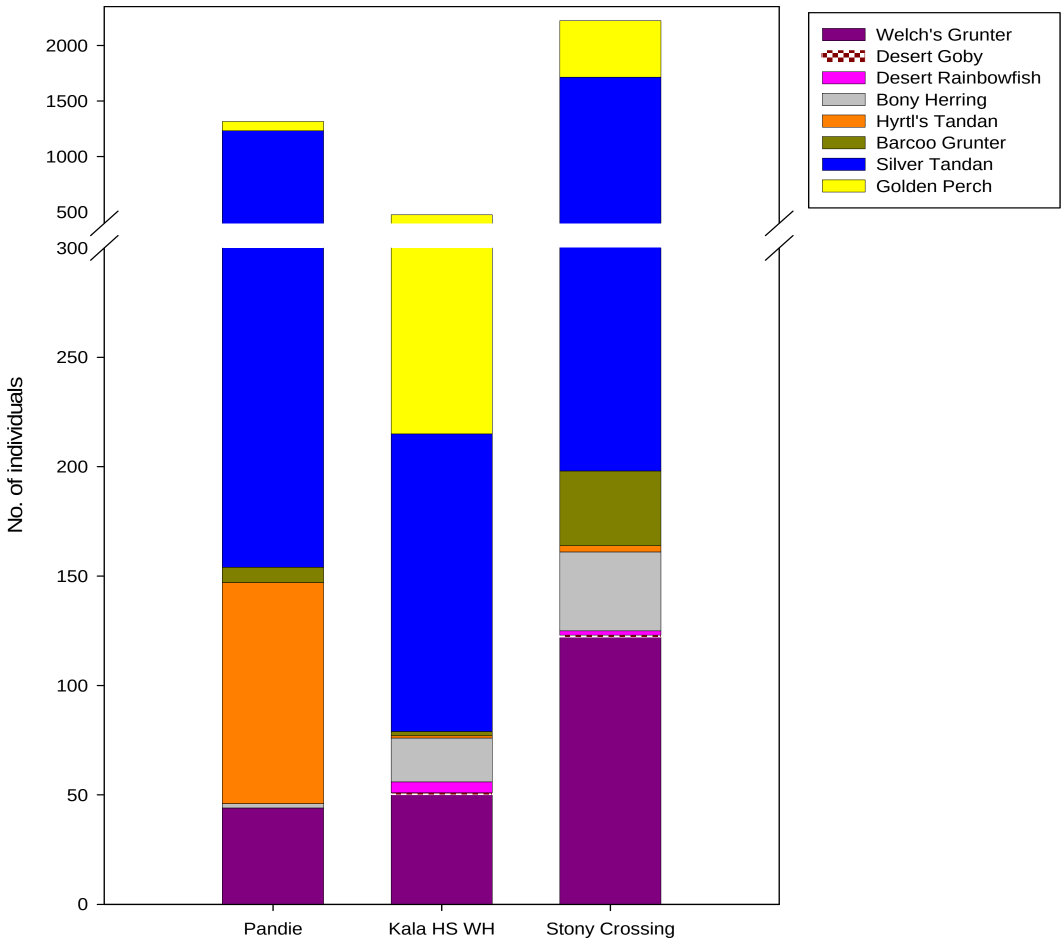


Figure 21. Abundance of fish taxa captured in the Diamantina/Warburton River in June 2009.

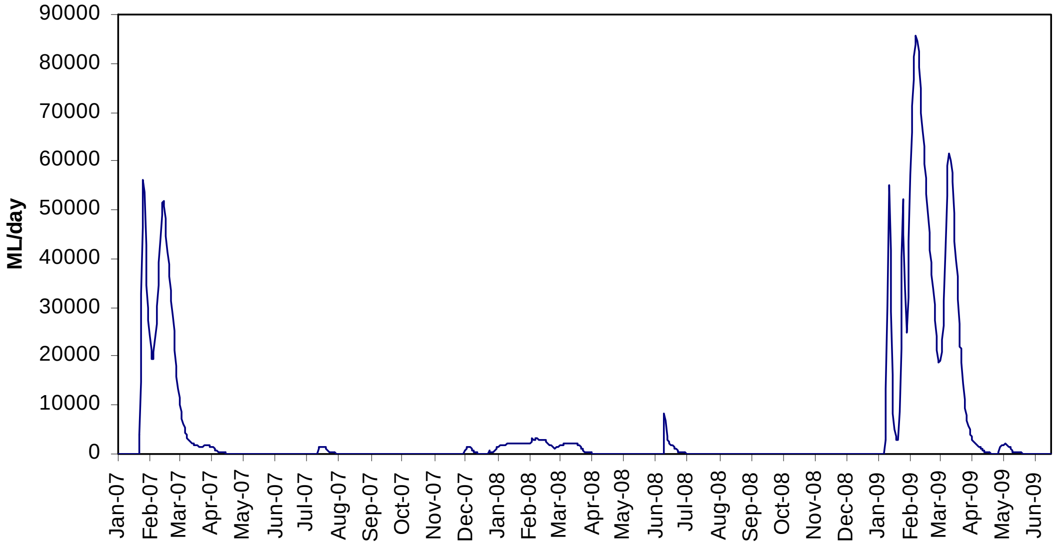


Figure 22. Flow for the Diamantina River as measured at Birdsville.

Pandie Pandie

Water Quality

The water at Pandie Pandie was cool with low salinity, normal oxygen levels and extremely high turbidity (Appendix 1, Table 2).

Fish

Barcoo grunter, Welch's grunter, silver tandan and Hyrtl's tandan all showed roughly unimodal distributions of adult fish, indicating the absence of new recruits for these species (Figure 23). However, golden perch consisted of a very large mode of new recruits, a large mode of roughly one year old fish and only one large adult.

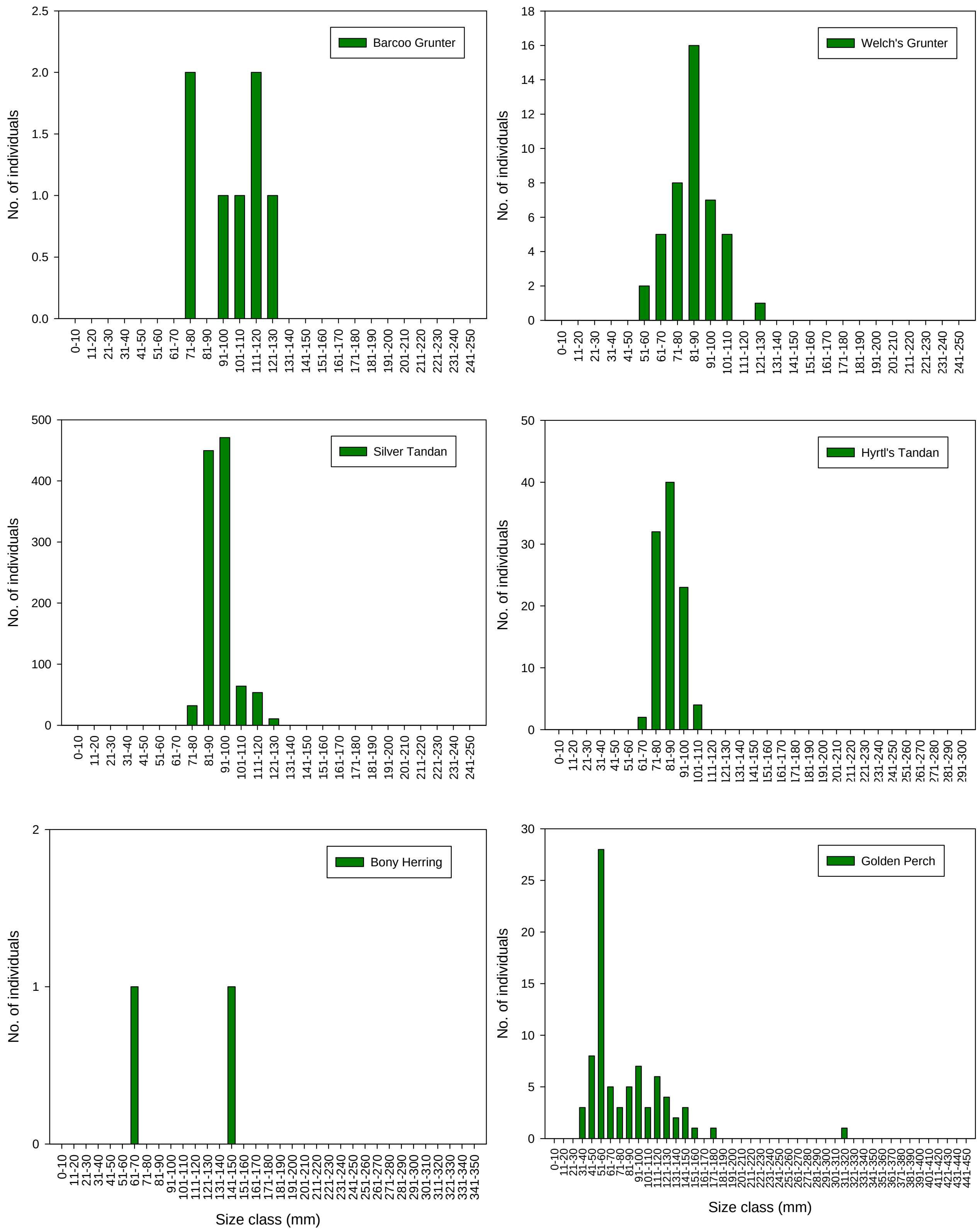


Figure 23. Size frequency distributions of fish captured at Pandie Pandie in June 2009. Note that axis scales vary between species.

Kalamurina

Water Quality

Water quality was measured only at Kalamurina homestead waterhole due to the difficulty in measuring the water at the deepest point at Stony Crossing. The water at Kalamurina was cool with low salinity, normal oxygen levels and extremely high turbidity (Appendix 1, Table 2).

Fish

Owing to time constraints, the size frequency distributions for commonly caught fish (Welch's grunter, silver tandan, and golden perch) were only recorded at the Kalamurina homestead waterhole. Once a sample of over 100 fish had been measured, fish from those species were only counted from then on. The size distribution of these species is the same for both Kalamurina sites. Golden perch showed a large number of new recruits and older juveniles and small number of small adult fish (Figure 24). Welch's grunter and silver tandan showed roughly unimodal distributions of adult fish, indicating the absence of new recruits for these species (Figure 24). Barcoo grunter, Hyrtl's tandan and desert rainbowfish showed similar size distributions at the homestead waterhole and Stony Crossing: namely a unimodal adult size distribution (Figure 24 and 25). Bony herring had different size distributions at each site. At the homestead waterhole there were a larger number of small fish and a few larger fish, while at Stony Crossing there were a larger number of large fish and fewer small fish (Figure 24 and 25).

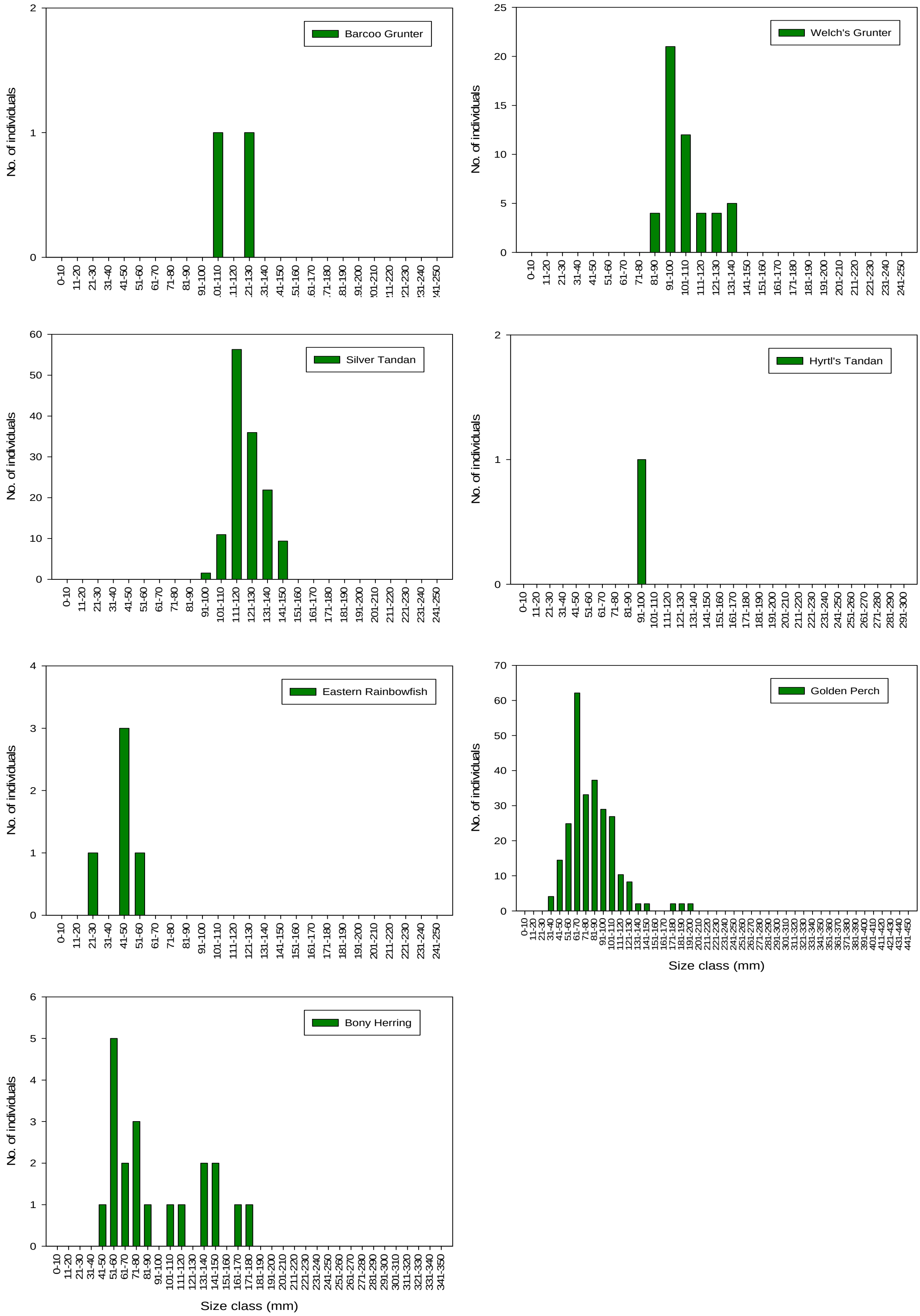


Figure 24. Size frequency distributions of fish captured at Kalamurina Homestead Waterhole in June 2009. Note that axis scales vary between species.

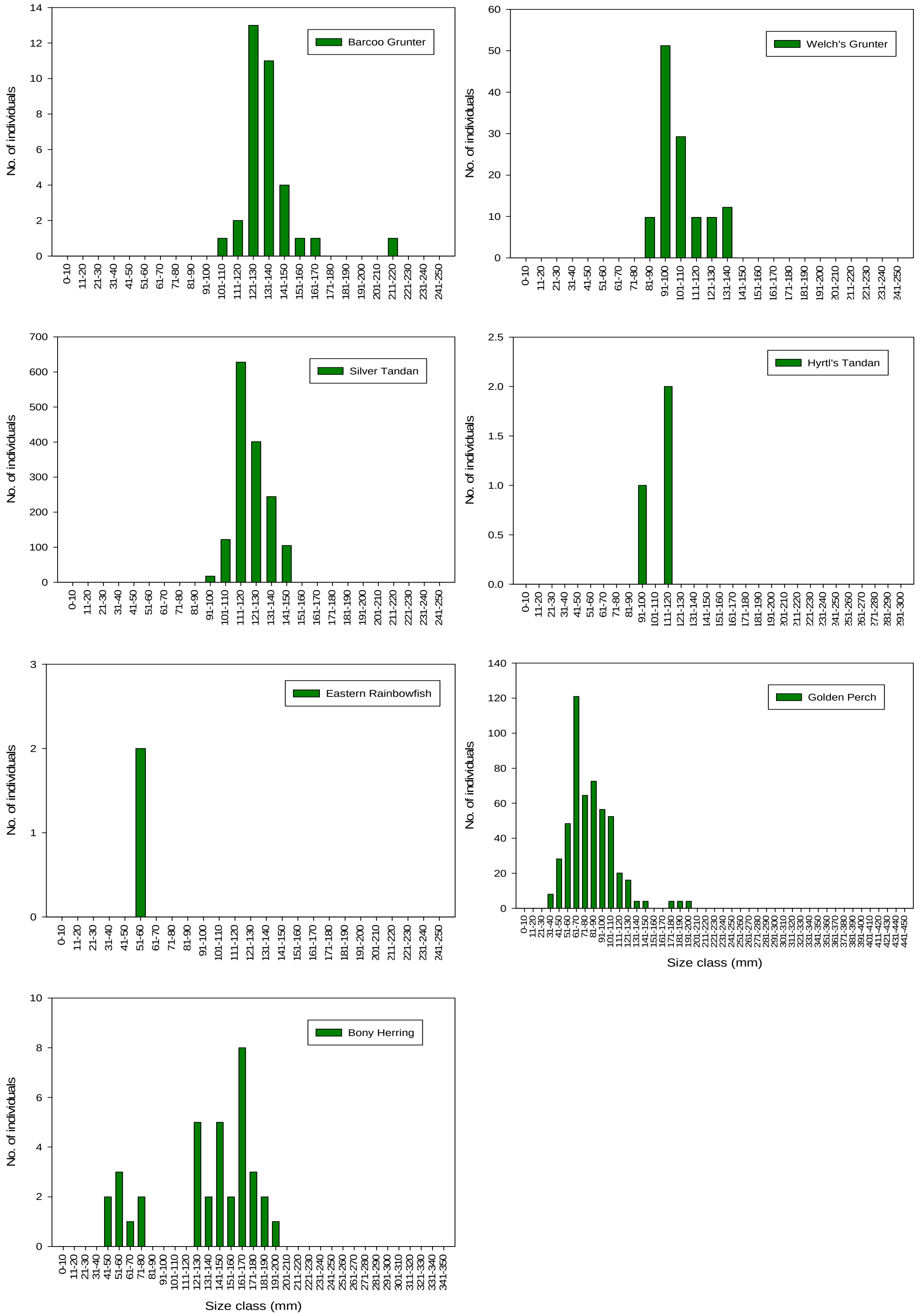


Figure 25. Size frequency distributions of fish captured at Stony Crossing, Kalamurina in June 2009. Note that axis scales vary between species.

Cooper Creek

The abundance of all fish species captured in Cooper Creek is plotted in Figure 26. These sites had the highest diversity encountered in the December 2008 and May-June 2009 surveys. One objective of sampling at Innamincka was to survey the effect of the causeway on the fish assemblage. Results are separated into fish captured above and below the causeway. Also note that Cullyamurra waterhole is located several kilometres upstream from the causeway. Hyrtl's tandan and golden perch were highly abundant at all sites. Spangled perch, bony herring, Barcoo grunter and Welch's grunter were present at lower numbers at all sites. Australian smelt was highly abundant below the causeway but very low at sites above it. Western chanda perch was only present in low numbers at sites above the causeway. Desert rainbowfish were present in moderate numbers only at Cullyamurra. Silver tandan were only present in low numbers at the upstream causeway site. Carp gudgeon were present in low numbers above and below the causeway.

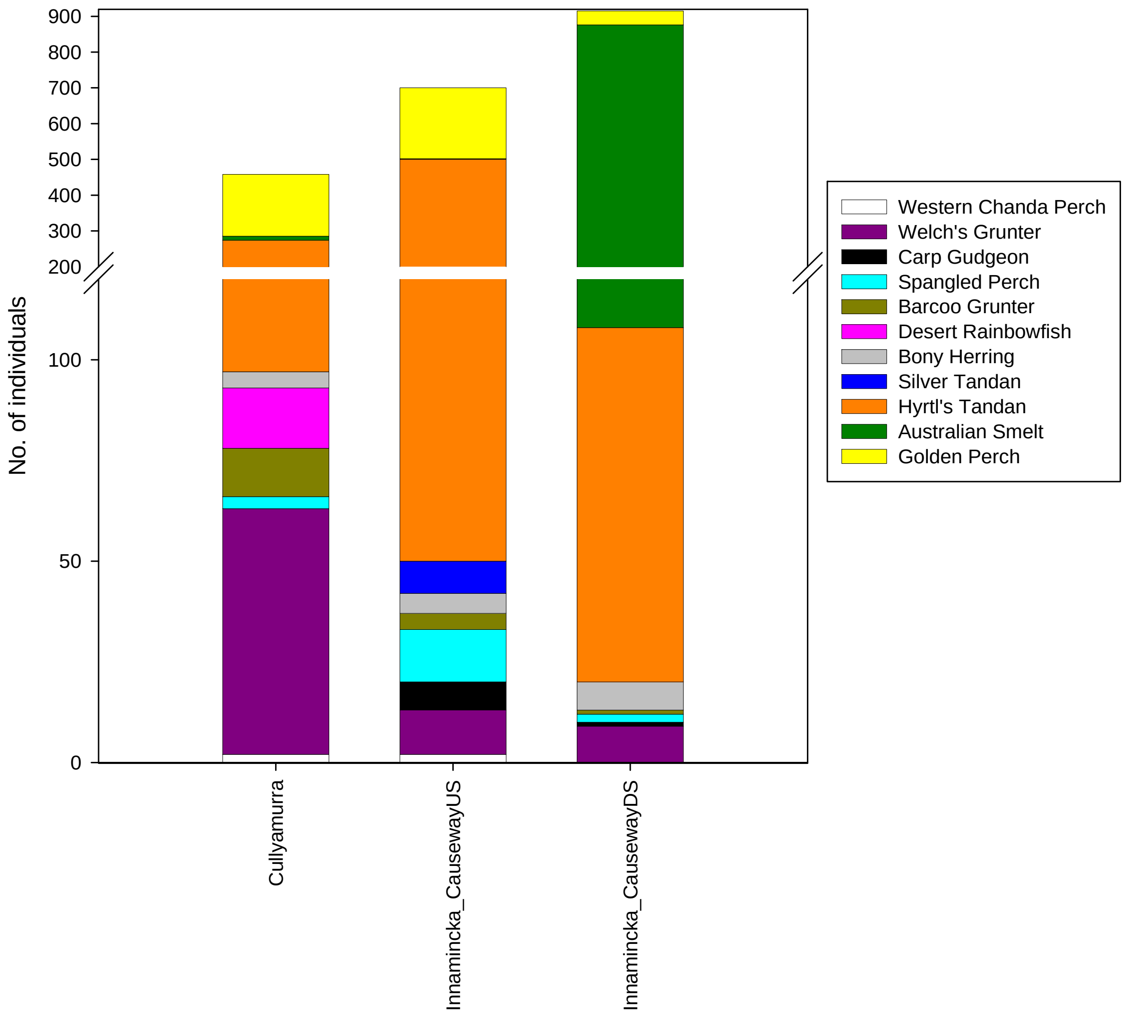


Figure 26. Abundance of fish taxa captured in the Cooper Creek in June 2009.

Cooper Creek had low but consistent flows from January 2009 until the June survey (Figure 27). The water level had only dropped down below the causeway one week before the survey (Darren Wilson, NPWS Ranger, pers. obs.). There had been no major flows down Cooper Creek since June 2008, but the creek only ceased to flow for approximately 5 months between flows (Figure 27).

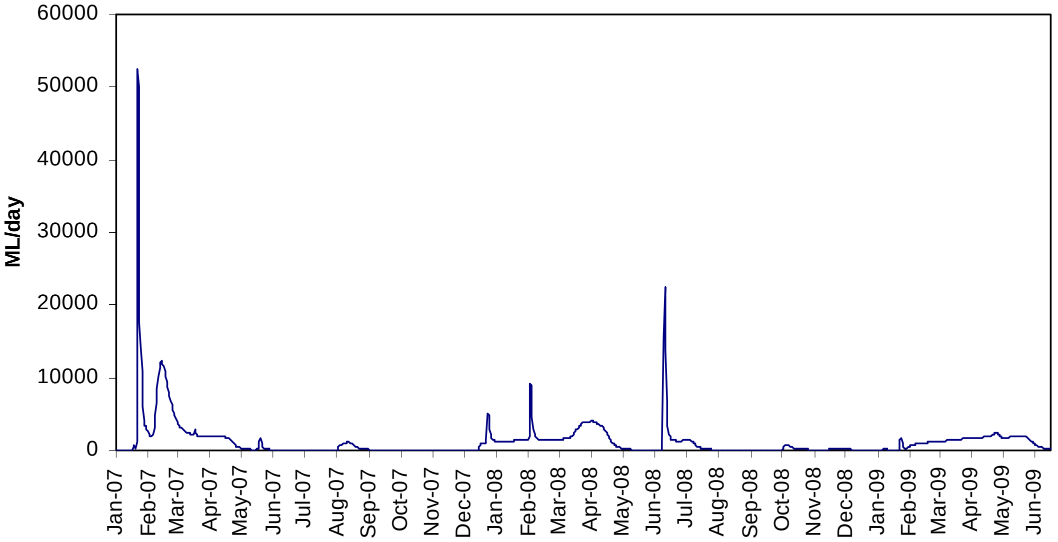


Figure 27. Flow for Cooper Creek as measured at Cullyamurra Waterhole.

Cullyamurra

Water Quality

The water at Cullyamurra waterhole was cool with low salinity, normal oxygen levels and extremely high turbidity. Despite the depth of this waterhole (over 4 m) there was no stratification (Appendix 1, Table 2).

Fish

Desert rainbowfish, Australian smelt, spangled perch and western chanda perch had a unimodal adult size distribution (Figure 28 and 29), while bony herring had single groups of new recruits. The length frequency distribution for Golden perch showed a large number of new recruits and older juveniles and smaller number of small to large adult fish (Figure 29). Barcoo grunter appeared to have a broad cohort of adult fish and one new recruit, while Welch's grunter had a large number of new recruits and a small number of large adults (Figure 28). Hyrtl's tandan possibly displayed 3-4 size classes unlike other locations where there were only 1-2 size classes.

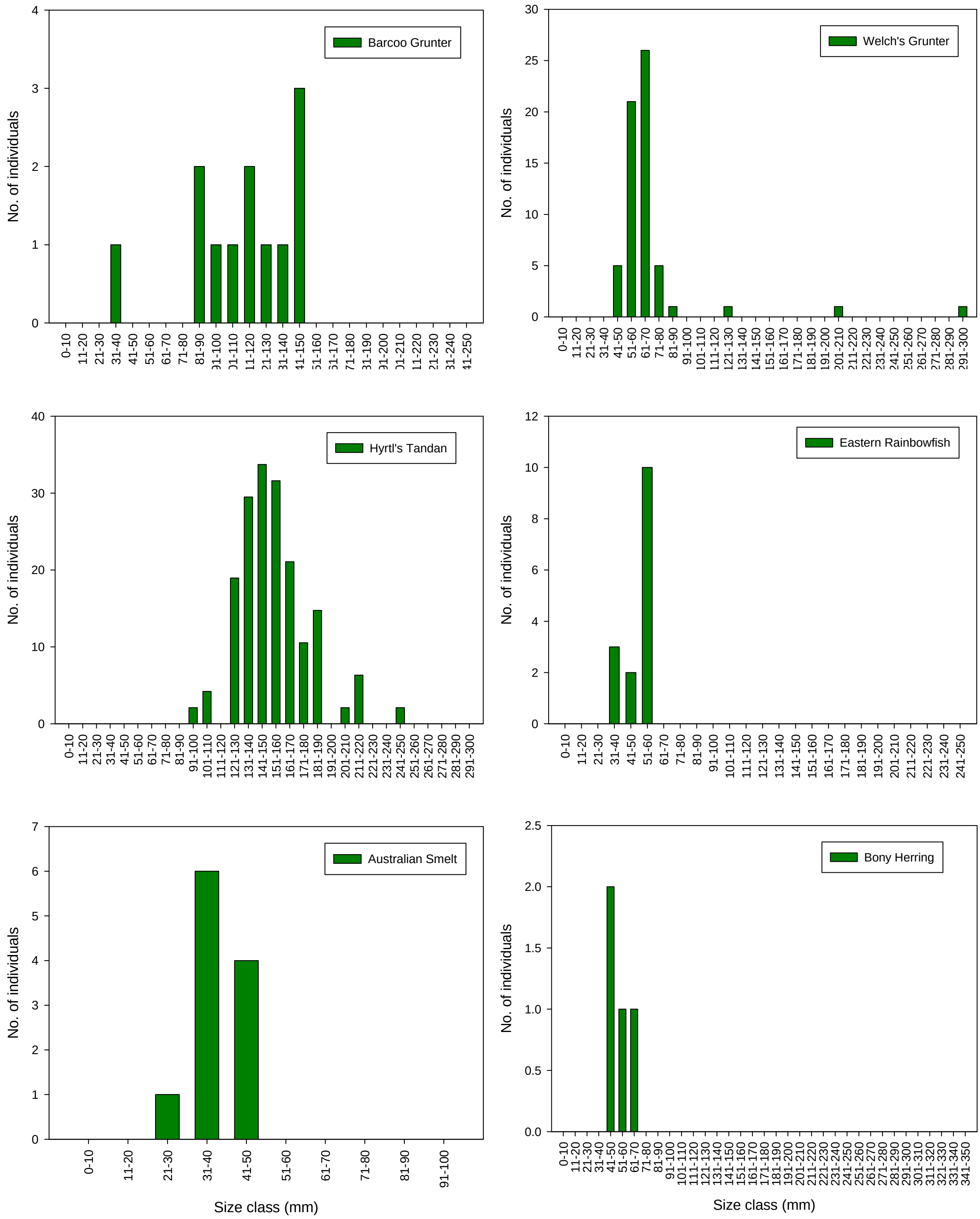


Figure 28. Size frequency distributions of fish captured at Cullyamurra Waterhole in June 2009. Note that axis scales vary between species.

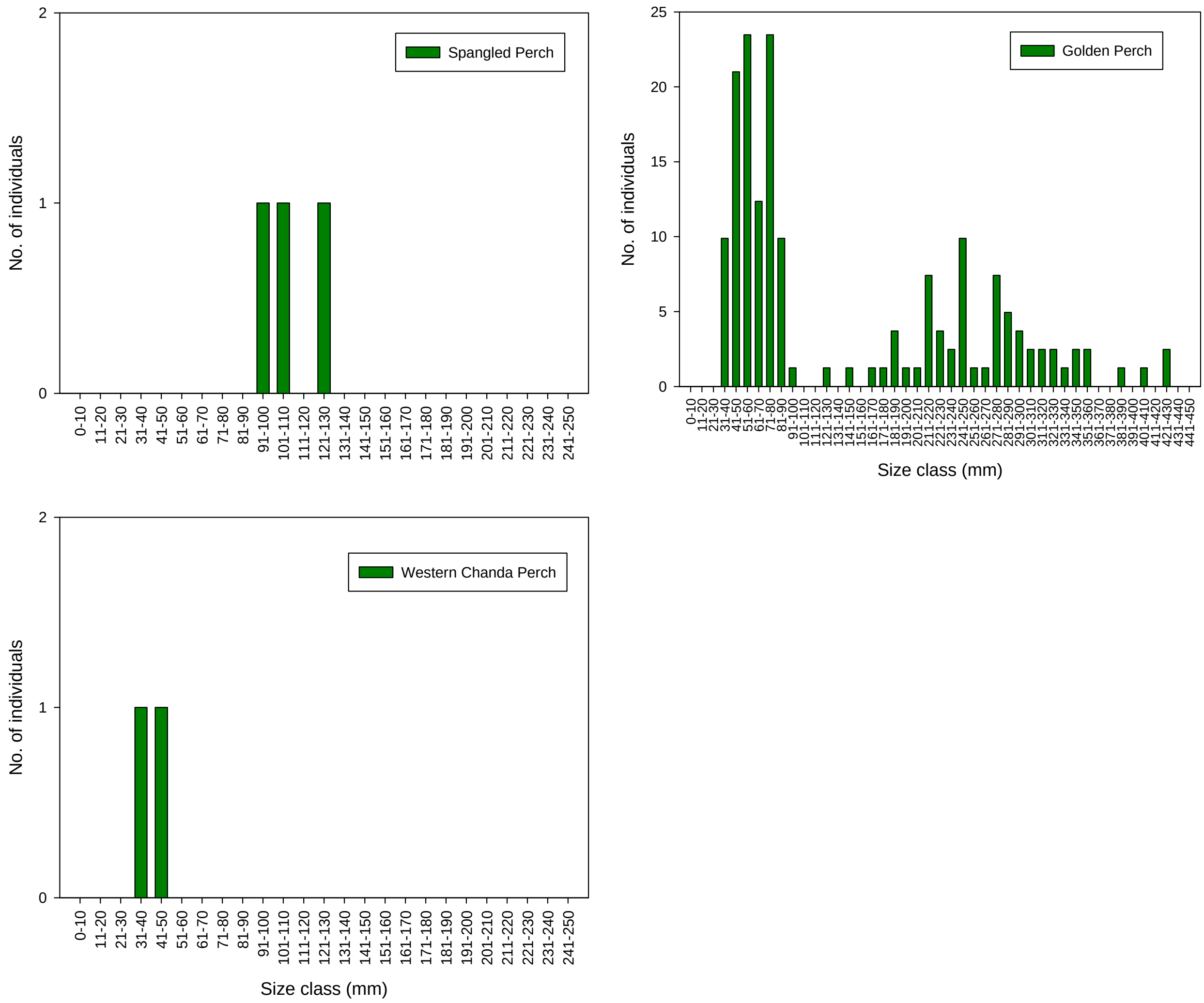


Figure 29. Size frequency distributions of fish captured at Cullyamurra Waterhole in June 2009. Note that axis scales vary between species.

Innamincka Causeway

Water Quality

The water at Cullyamurra waterhole was cool with low salinity, normal oxygen levels and extremely high turbidity. This was a high energy site where a large amount of water flowed through a relatively narrow channel, through culverts and then over a section of rapids, hence there was no stratification (Appendix 1, Table 2).

Fish

There were a number of differences in the abundance and distribution of fish above and below the causeway. Only a handful of Barcoo grunters were captured at the causeway, but the largest fish was captured downstream and the smaller fish upstream (Figure 30). Conversely, Welch's grunter recruits were only captured downstream and adults captured above and below the causeway (Figure 30). There appeared to be no difference between the size distribution above and below the causeway for carp gudgeon (Figure 30) and Australian smelt (Figure 31), although only a few smelt were captured upstream. Upstream of the causeway, Hyrtl's tandan were predominantly small fish while below it they were predominantly large fish (Figure 30). This was a similar case for golden perch, spangled perch and bony herring (Figure 30).

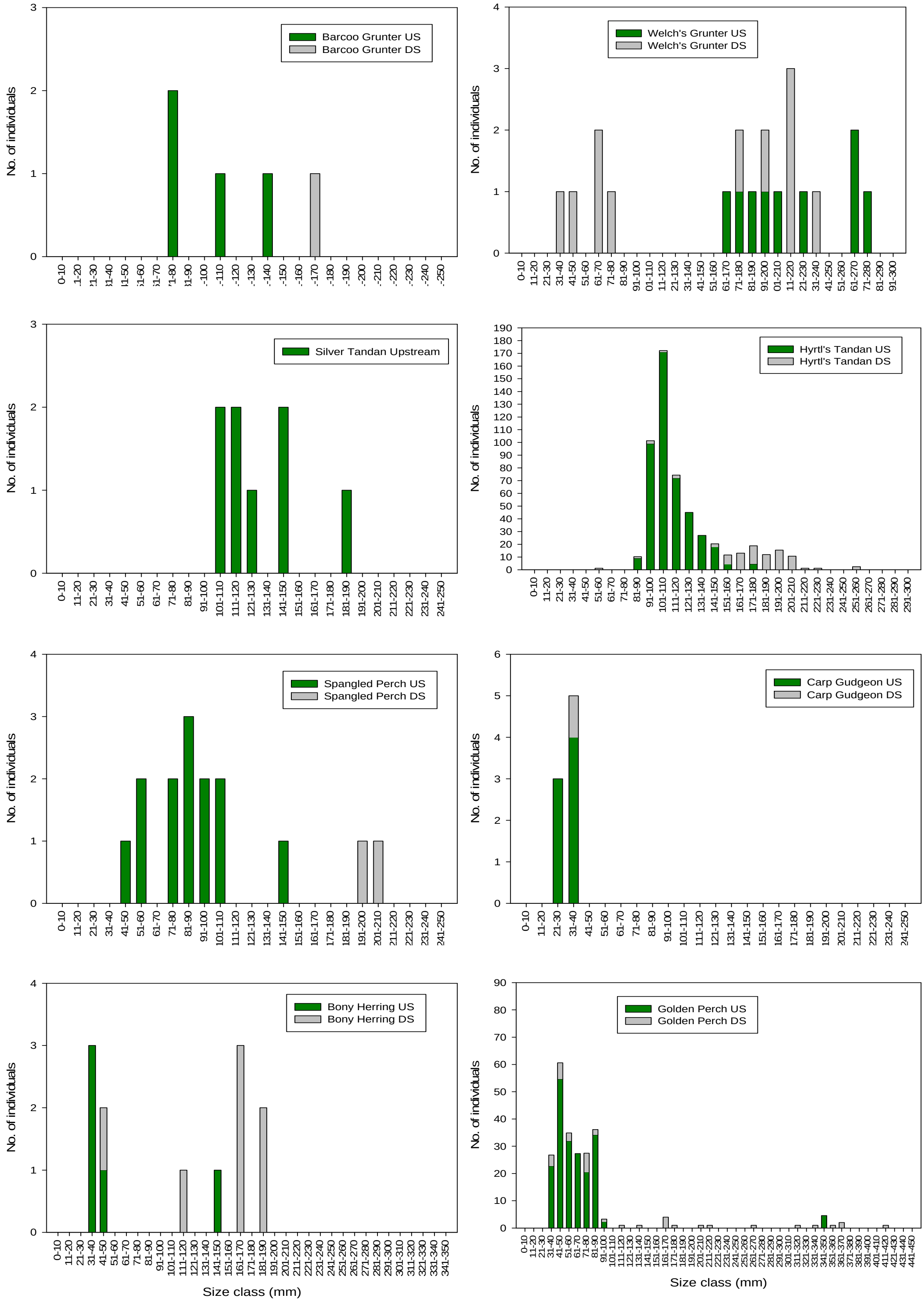


Figure 30. Size frequency distributions of fish captured at Innamincka Causeway in June 2009. Note that axis scales vary between species.

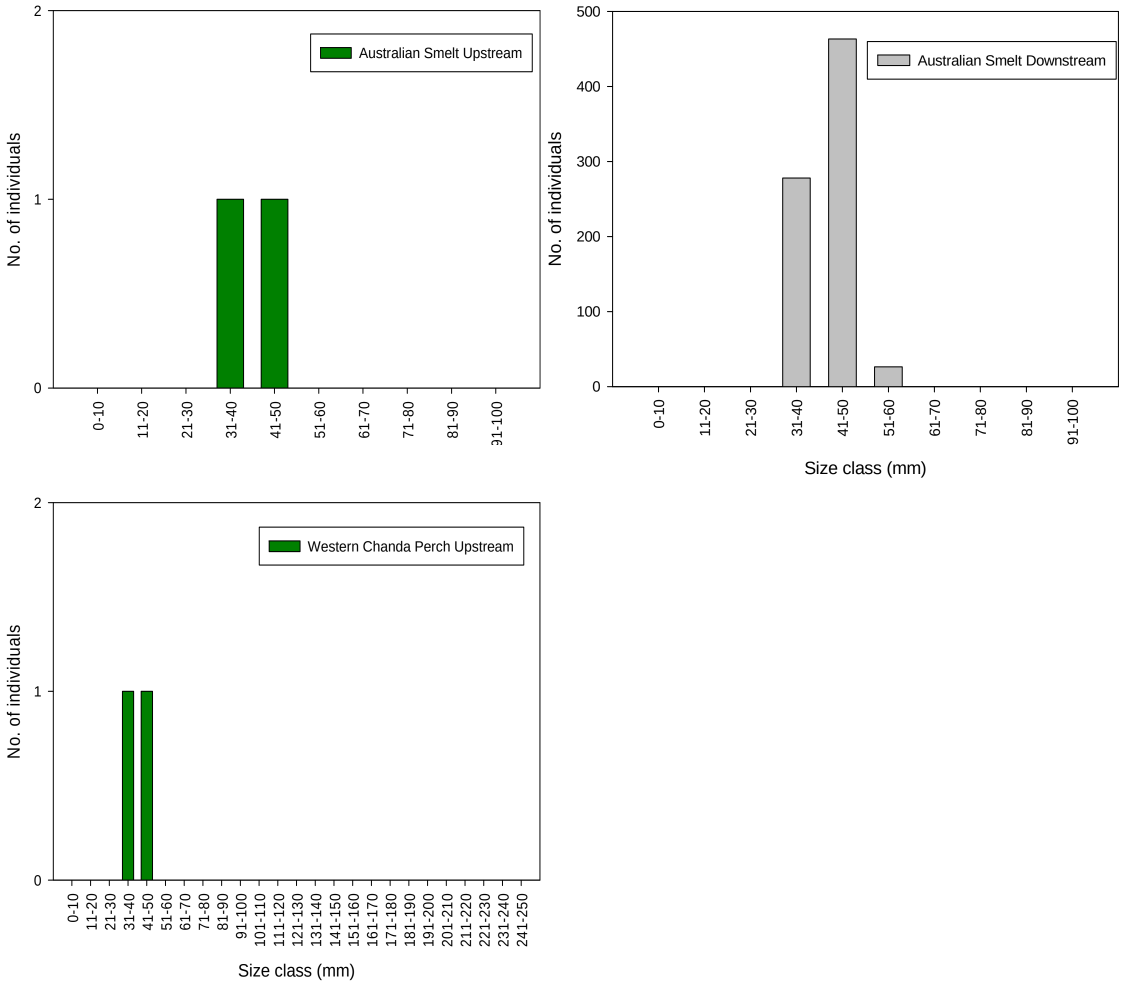


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Figure 31. Size frequency distributions of fish captured at Innamincka Causeway in June 2009. Note that axis scales vary between species.

DISCUSSION

The 2008/09 survey has provided a unique insight into the recovery of native fishes following drought disturbance. The 2008/09 wet season provided the most significant period of hydrological connectivity since the onset of the drought in 2003. Both the Neales and the Diamantina/Warburton catchments had high levels of flow reaching Lake Eyre for the first time since 2003 (Neales) and 2004 (Warburton). Cooper Creek also received higher flows than in previous years, providing connectivity to downstream habitats as far as the Coongie Lakes, but not reaching the lower Cooper or Lake Eyre.

During the drought, the vast majority of freshwater habitats in the SA section of the LEB had dried, resulting in the contraction of most fish species into small refuge habitats (McNeil *et al.* 2008). Some of these refugia provided refuge to a wide range of fish species similar to the 'ARK' type refugia outlined by Robson *et al.* (2008) i.e., the environmental conditions are suitable for the biological and ecological traits of a broad range of species. These included Algebuckina waterhole (Neales), Clifton Hills outstation waterhole (Diamantina) and Cullyamurra waterhole (Cooper). Others such as Peake Ck waterhole (Neales) and Ultoomurra waterhole (Warburton), possessed only a few highly tolerant species, predominantly desert goby and Lake Eyre hardyhead, persisting under very harsh environmental conditions in 'polo club' type refugia (Robson *et al.* 2008) i.e., a small subset of species that persist due to specific biological or ecological traits. In response to the increased connectivity following the 2008/09 wet season, native fishes were provided with the opportunity to escape from their refugia and recolonise areas of those catchments that they had not inhabited since the peak of the drought in 2006.

Neales River Catchment

In the Neales River, lesser volume and durations of connectivity during the 2007/08 wet season had resulted in the expansion of rapidly colonising species; namely bony herring and spangled perch, across the catchment whilst all other species failed to recolonise out of downstream refugia (i.e. Algebuckina waterhole). However, re-connecting flows and longer connectivity in 2008/09 were sufficient to allow gradual recolonisers to expand back across the catchment. In particular, golden perch and desert rainbowfish were able to recolonise all sites within the catchment, whilst Lake Eyre hardyhead had recolonised up to Stewart's waterhole in the mid catchment, but were not found in Hookey's waterhole farther upstream. Slow recolonisers have not yet re-colonised upstream sites following drought (barred grunter, desert goby and the alien gambusia). These results indicate that golden perch, desert rainbowfish and to a lesser extent Lake Eyre hardyhead can be classified into a second group of ‘moderate recolonisers’ that are likely to require somewhat higher levels of flow and connectivity than the ‘rapid recolonisers’ (bony herring and spangled perch) in order to recolonise upstream reaches following drought.

Of great concern is the failure to catch any barred grunters and the observation, but not capture of few desert gobies. There is very little biological information available regarding the barred grunter in the Lake Eyre Basin, and although the species is known to undertake upstream and downstream migrations in other regions (Pusey *et al.* 2004), there is no data on the extent or speed of migration. In Dec 2008, barred grunter was found to have moved upstream from Algebuckina waterhole across the newly constructed causeway. Their failure to reach the mid catchment sites by May 2009 suggest that this species may still be expanding slowly towards Stewart’s waterhole in a similar fashion to the Lake Eyre Basin hardyhead. Further sampling at Stewart’s following the 2009/10 wet season however, will be required to determine if this is the case. If not, the disappearance of the species from Algebuckina, following collection in low numbers in previous seasons, may represent a significant impact of drought on this species suggesting a poor resilience potentially for this species following disturbance. Desert gobies are the most highly resistant of LEB fishes to the impacts of drought and desiccation, but appear to have a low resilience potential. Gobies are likely to take a long time to recolonise upstream catchment areas, but are likely to be the last species remaining under future drying events as observed in Peake Creek following the recent drought (McNeil *et al.* 2008).

Alien Gambusia have shown a perplexing pattern of distribution over the past two years and appeared to be flushed downstream under high flows in December 2008, allowing them to recolonise the slower flowing Peake Creek. Gambusia were again present at Algebuckina by May 2009, suggesting that they were able to recolonise the waterhole under the extended flows later in that wet season. They had also disappeared from Peake waterhole in 2009 after being collected there in Dec 2008. It appears; however, that Gambusia do not exhibit the dominance that they show in the Murray-Darling Basin (MDB), where they dominate the small fish assemblages over much of the Basin (McNeil 2004, Lintermans 2007, Tonkin and MacDonald 2009). The reasons for this remain undetermined but could potentially reflect the extreme variability in flow regime and/or the relatively robust status of native fishes in the LEB compared to the MDB. The data suggests that there may be an opportunity in the future to target small populations of

Gambusia with control activities to further reduce their abundance and distribution in the Basin and to prevent the possible expansion and domination of this pest in the future. The data also suggests that low flow periods are the optimal time to attempt control activities as flow appears to move these populations within areas in the LEB.

In general, Peake waterhole harboured a relatively constant fish fauna, maintaining the three tolerant species (spangled perch, Lake Eyre hardyhead and desert goby) that were at the site in early 2008, although the appearance and subsequent disappearance of gambusia suggests that there has been adequate connectivity to provide exchange with other sites and potentially the Neales channel. Peake provides an excellent example of the exclusive polo-club type refuge (Robson *et al.* 2008) where highly tolerant fishes may persist in very harsh conditions where they are free from the constraints of predation and competition present in more benign habitats where piscivores such as golden perch and competitors such as rainbowfish and barred grunters are able to persist. The very high abundances of desert goby and Lake Eyre hardyhead at Peake suggest that conditions there are ideal for these species. If flow conditions continue to improve in future years, however, predators and competitors may be able to immigrate into this site. The impact of recolonisation by new species into Peake may result in the deterioration of goby and hardyhead populations. This fascinating process can be picked up through continued monitoring at the site and will reveal new information regarding the impact of recolonising species on the permanent residents in these habitats. It is possible that these 'polo-club' refuge species may rely on the presence of smaller and harsh habitats in order to maintain strong and viable population bases across the Basin, which would be heavily impacted by any future attempt to regulate or increase flows in these areas.

The size class data shows that the early recolonisers in the Neales, (spangled perch and bony herring), both show abundant smaller size classes as well as the persistence of larger older fish. The presence of abundant small fish indicates successful spawning and recruitment post recolonisation. This data suggests that these species are likely to be highly resilient to a range of disturbances provided they have migration pathways and appropriate receiving habitats where they are able to take advantage of resources without pressure from predators or competitors. The recent arrival of golden perch and rainbowfish however, may result in changes to the highly abundant and age diverse populations of spangled perch and bony herring in the mid-upper Neales. For the newly arrived colonisers, however, rebuilding viable populations must now be undertaken. Whilst rainbowfish already show signs of recruitment within receiving habitats, golden perch colonists are largely young adults and will require successful spawning and recruitment over coming seasons to rebuild their populations. The overall patterns from the Neales catchment show the sequence and process of successional recolonisation following drought disturbance. The data has shown that the Neales fish community possesses species that are highly resistant to drought impacts, but with poorer resilience (desert goby, Lake Eyre hardyhead) and species with both high resistance and resilience (spangled perch, bony herring). Whilst both groups appear well adapted to drought in the Lake Eyre Basin, those species showing poorer resilience characteristics are likely to be highly impacted by disturbances to which they are not resistant (McNeil *et al.* 2009). Anthropogenic disturbances such as habitat degradation, pollution and the introduction of alien fishes may have a severe impact on these species due to their low capacity for recolonising and recruitment.

Diamantina/Warburton System

Following drought, rainfall in Queensland resulted in flows entering the South Australian Section of the Diamantina inundating the river channel and anabranch systems downstream to at least Goyder's lagoon. This long reach of river was dominated strongly by golden perch and Hyrtl's tandan, with low numbers of Welch's grunter present (McNeil *et al.* 2008). Downstream of Goyder's lagoon, a small number of very shallow isolated waterholes persisted at Ultoomurra where the highly tolerant desert goby and Lake Eyre hardy head existed in high abundance under sea-water level salinities and high temperatures. Under the return of significant flows including some lateral floodplain inundation during the 2008/09 wet season, the fish assemblage of May 2009 was quite different to that of 2007/08. Large abundances of silver tandan and Welch's grunter were caught across all sites, with Barcoo grunter, desert rainbowfish and bony herring added to the golden perch and Hyrtl's tandan found in 2007/08. Desert goby was also present across sites after being confined to Ultoomurra in May 2008. It is believed that this influx of new species represented large scale downstream migration from the upper catchments of the Diamantina moving with Queensland floodwaters downstream into South Australian reaches. This is difficult to determine however, as no detailed survey of refuge habitats has been conducted within the South Australian section of the Basin. Newly obtained information suggests that refuge pools persist as far downstream as Kalamurina which was sampled for the first time during the May 2009 survey and therefore was not surveyed as an isolated refuge habitat. Equally, difficulties accessing Clifton Hills station required that the outstation lagoon sampled in 2007/08 be accessed farther upstream at Pandie Pandie Station and that the Ultoomurra site moved farther downstream to Kalamurina. It is not anticipated that these site changes have impacted the data as fairly consistent catches and fish species were collected throughout the Diamantina/Warburton in May 2009. Future surveys are likely to continue to use these revised sites although the presence of harsh refuge habitats at Ultoomurra should be included in any future work to determine the successional changes that occur in these unique desert refugia.

As Kalamurina is situated only 130 km upstream of the junction of the Warburton and Macumba systems, this survey provides the first opportunity to collect data that may relate to the Macumba. Due to time constraints and the recent flooding of many tracks on Kalamurina Station, it was not possible to reach any refuge waterholes closer to Macumba than Stony Crossing, but this should be investigated in future surveys. The Macumba flows from the Northern Territory northwards of the Neales and is highly ephemeral. Detailed fish surveys have not been conducted in the Macumba, although the current sampling suggests that a wide range of fishes should be able to access its lower reaches. Under situations where both are flowing, the Macumba is likely to be recolonised by the wide range of species collected at Kalamurina and may therefore recover even from periods of total desiccation via this pathway. The presence of refuge habitats and the nature and composition of fish species in the Macumba is unstudied and warrants investigation that might support the protection and management of aquatic ecosystems within this most arid of Australian catchments.

The analysis of size class data indicates that for all species concerned, immigrating fishes were dominated by smaller size classes and most likely represents large numbers of rapidly growing, recently spawned and recruited individuals (Costelloe *et al.* 2004). Low numbers of larger individuals of golden perch, Barcoo grunter and bony herring were caught indicating the presence of multiple age classes, but the Diamantina/Warburton catch was predominantly large numbers of young of year juveniles. This supports the close linkage between river flows and recruitment in the Lake Eyre Basin (Costelloe *et al.* 2004) with recruitment most likely originating in mid-upper catchment areas but extending far downstream, most likely into Lake Eyre itself. The movement of fishes into Lake Eyre during filling has not been well studied, although it is known that large numbers of fishes are found in the lake after filling. The actual patterns of dispersal, habitat use, and ecology of fish within Lake Eyre has not been quantified although large numbers of bony herring and Lake Eyre hardyhead have turned up in huge fish kills during lake drying. An important aspect of native fish use in Lake Eyre is the potential for native fishes to enter the lake, utilising its rich resources and return safely into permanent reaches. A key question to consider is whether fish entry into Lake Eyre is a one way—

dead end or are filling events utilised by native fish to improve recruitment to lower reaches during wetter periods?

A secondary aspect of critical importance revolves around the ability of fish to use Lake Eyre as a migration pathway into other tributary catchments. This is particularly important in preventing catchment scale extinctions of species. For instance, the loss of Algebuckina waterhole during drought may result in the loss of most species of fish from the Neales catchment. The only natural recolonisation pathway would be from other catchments during the filling of Lake Eyre. Some species such as Hyrtl's tandan have been found in the Neales in the past but not recently. It may be that these species are able to occasionally recolonise the Neales during rare filling events but are unable to persist within the catchment for the long term. With large numbers of silver tandans and Welch's grunters currently moving down the Warburton into Lake Eyre, the opportunity may exist for these species to cross the Lake and colonise western catchments such as the Neales.

The recent filling event at Lake Eyre provides a unique opportunity to address this possibility and inform future risk and management scenarios. It is suggested that tracking of immigrant fish populations moving into the lake be undertaken to reveal the possible end-points (or sinks) for these migrating fish. This data could also be developed in conjunction with genetic information to classify the past and present genetic connectivity or isolation across Lake Eyre fish populations. The presence of distinct genetic units without interconnecting pathways greatly changes the conservation status and potential risks and consequence of population extinctions. Recent applications of otolith microchemistry may also be utilised to determine the source and sink populations of Lake Eyre Basin fishes and to identify important spawning and recruitment 'hot-spots' that may warrant increased levels of conservation prioritisation and protection (MacDonald *et al.* 2009). A detailed study of refuge (source) and receiving (sink) habitats and the relationship between their fish assemblages and hydrological connectivity is highly recommended to comprehensively address the catchment scale ecology of LEB fishes. Whilst relevant across all catchments, such a study is perhaps best targeted to a smaller catchment such as the Neales where this research can feasibly be conducted at the necessary catchment scale.

Cooper Creek

Cullyamurra waterhole near Innamincka is a very large and critical refuge habitat for the lower Cooper Creek providing a source population for a wide range of LEB fishes from which they may recolonise the lower catchment during inundation. Accordingly, a wide range of LEB species were captured there in May 2009. With the exception of Cooper Creek catfish and gambusia, these were the same species caught during the 2007/08 survey. Whilst silver tandan and carp gudgeon were not caught within Cullyamurra, their presence nearby above the Innamincka causeway suggests they are likely to be present within Cullyamurra, which due to its immense size is difficult to survey comprehensively in a short time. This diversity re-emphasises the importance of this site as a refuge waterhole of immense importance to the sustainability of native fish in the South Australian section of Cooper Creek.

The Innamincka causeway site, only a few kilometres downstream was surveyed for the first time in May 2009 following reports that the causeway was providing a barrier to upstream fish migration and that large numbers of large fish, particularly golden perch, were becoming stranded and being captured *en masse* by recreational fishermen (Henry Mancini, SAAALNRMB, Dave Grant, PIRSA Fisheries, pers. com.). The data confirms that the causeway is potentially a significant barrier to native fish. Fish were sampled equally above and below the causeway, with the data showing that large adult specimens of spangled perch, golden perch, bony herring, Hyrtl's tandan, and Barcoo grunter were all restricted to below the causeway, with smaller individuals captured predominantly above the fishway. This data suggests that for these species, the causeway may be excluding the upstream passage of large adult fish. If passage over the causeway is not possible, then these fish cannot gain access to the important refuge at Cullyamurra, just upstream of the causeway. If large adult fish with strong fecundity and spawning capabilities cannot return or move into Cullyamurra, then the causeway may be reducing the potential health and long term viability of populations in Cullyamurra.

The opposite was true for Welch's grunter for which large numbers of small juveniles were caught below the causeway and larger fish predominantly present above. This suggests that the smaller Welch's grunter may be unable to ascend the barrier with strong negative consequences for recruitment of this species at Cullyamurra from downstream spawning grounds. Similarly, small bodied smelt appear to be unable to transcend the causeway with over 700 individuals caught just below the barrier, compared to catches of 2 and 11 above the causeway and at Cullyamurra. The actual impact of the barrier will require more detailed study in line with fish passage projects carried out elsewhere in the MDB (Stuart *et al.* 2008), however the current data suggests that under some conditions, the causeway may be a significant barrier preventing the movement of several native species of fish into the Cullyamurra refuge. Given that many of these species have recreational fishing importance, the recreational values of the Cullyamurra Reserve may also be impacted.

The level of disease in some species at Cullyamurra was exceptionally high in May 2008, with up to 90% of golden perch existing in a heavily diseased state. Disease was also exceptionally common for Barcoo grunter with very low levels of infection for Hyrtl's tandan and spangled perch (McNeil *et al.* 2008). In May 2009, however, disease rates were exceptionally low whilst high abundances of those species affected were caught in good condition. The nature of bacterial infection in the LEB fishes is largely unknown and further research is recommended to address the nature and dynamics of these infections as well as their impact on fish dynamics.

Conclusions

Overall, the 2008/09 survey provided a unique and valuable insight into response and recovery of LEB fishes following drought disturbance. The data from the Neales and Warburton/Diamantina catchments provide details of upstream and downstream emigrational responses of fish to the resumption of flows. These results indicate that downstream migration is undertaken by a wide range of species, largely juveniles, during flow events even without significant flooding. Upstream migration responses are highly variable across species, with distinct groups of rapid, moderate and slow recolonisers identified through this research.

These results are consistent with the highly variable hydrological nature of the Basin's waterways (Puckridge *et al.* 1998 & 2000, Costello 2007 & 2008, Humphries *et al.* 2007). More importantly, it supports the claim that the arid South Australian section of the Basin is extreme even for the LEB with highly dynamic patterns in species assemblage structure varying with catchment scale patterns in hydrological drought and connectivity (Balcombe & McNeil 2008, McNeil *et al.* 2008). The period of recovery from the peak of drought in 2006 through increasingly milder seasons and increasing flow levels, has provided a unique opportunity to capture these processes. The survey has also re-established the importance that a small number of critical refuge habitats play in protecting fish through dry periods and providing a source population for the recolonisation of catchments following the easing of drought disturbance (Robson *et al.* 2008, McNeil *et al.* 2009).

The survey has also highlighted the potential for migrational barriers to prevent movement into and out of key refuge habitats. In particular, the study found that the Innamincka causeway is likely to be preventing some fish from gaining access to the Cullyamurra waterhole, with potentially heavy impacts on the recruitment and population structure of the fish community at that site. The study has also highlighted the importance and value of collecting continual and long term data sets in understanding the complex and variable nature of riverine ecosystems in the Lake Eyre Basin. Data collected under the current twice yearly monitoring structure using sites across each catchment provides excellent detail of the relationship between seasonal hydrology, habitat inundation and the ecology of Lake Eyre Basin fishes. Finally, the survey has established a very low abundance and impact of alien invasive fishes in the South Australian LEB. Great care must be taken to prevent the introduction of new invasive species and/or the expansion of existing aliens across the Basin.

Recommendations for Research and Management

The close linkages between hydrological and fish population dynamics and the lack of significant levels of anthropogenic disturbance, mean that the ecology of fish in the LEB is intricately linked to the climatic and riverine process that make up the Lake Eyre Basin Rivers ecosystem. The continuous monitoring of fish populations across the Lake Eyre Basin therefore provides a strong indication of the ongoing ecological condition and health of aquatic ecosystems in the Lake Eyre Basin (Humphries *et al.* 2005). The strongest recommendation both for research and management is therefore that the fish monitoring program be continued in an ongoing manner so as to provide an indication of the ecological condition of the Basins waterways. If possible this should be combined with lobbying of the LEBRA group to support ongoing monitoring of fish at these sites.

A number of specific recommendations and suggestions for future research and management of freshwater fish in the Lake Eyre Basin are provided:

1. A targeted assessment of the impact of the Innamincka causeway on fish passage, followed by the design and construction of an appropriate rock ramp fishway that allows passage of small fish such as Australian smelt and juvenile Welch's grunter as well as large adult golden perch and other large bodied species.

2. A catchment scale assessment of linkages between hydrological variability, river flows and the spatial dynamics of fish assemblages. Such a study is required to

fully understand the way in which drought; flooding and intermediate flow regimes interact to determine the ecology and distribution of native fish. This should be targeted towards a smaller catchment such as the Neales.

3. A study of the utilisation of Lake Eyre by fish including a study of the movement of fish into, within and out of Lake Eyre is recommended using well developed fish tracking technologies such as acoustic telemetry and otolith microchemistry. The focus of the study should be the fate of fish moving into Lake Eyre and address key questions such as:

    a. Can they return to their nursery catchments after utilising lake resources?

    b. Can fish move through the lake to colonise new catchments?

    c. Could alien species potentially pass through the lake to infest new catchments?

    d. How important are fish in providing a flow of carbon, nutrients and energy into the Lake Eyre ecosystem?

    e. Are there commercial opportunities to utilise fish in the lake that won't impact on ecosystem processes?

4. An assessment of introduced fish species in the LEB including the determination of status for past introductions, the development of control approaches for existing pest populations and response planning for potential future introductions. This should be run in conjunction with PIRSA fisheries bio-security unit.

5. The development of community education and liaison programs to increase the level of knowledge and management capability within the community, both in terms of protecting native fish and aquatic habitats and in preventing the future introduction of alien fishes.

6. The exploration of indigenous cultural heritage, stories and anthropological data, to give further insight into the past abundance and distribution of LEB fish species. The use of otoliths from middens may provide important historical insight into species distributions and hydrological conditions.

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APPENDIX 1

Table 1. Water quality data collected in the Neales/Peake system in December 2008.

Date	Time	Site	Depth	D.O. (ppm)	Cond. (µS)	pH	Temp (°C)	Secchi depth (mm)
1/12/08	15:00	Stewart's	0	5	116.2	7.96	33	25
1/12/08	15:00	Stewart's	0.5	4.4	110.3	7.4	27.9	
1/12/08	15:00	Stewart's	1	4.2	106	7.7	26.1	
1/12/08	15:00	Stewart's	1.5	4.1	109.2	8.3	24.6	
1/12/08	15:00	Stewart's	2	2.9	111.9	7.4	24.2	
2/12/08	9:30	Stewart's	0	5.8	118.8	7.7	27.3	
2/12/08	9:30	Stewart's	0.5	5	115.4	7.3	25.4	
2/12/08	9:30	Stewart's	1	3.6	114.7	7.2	24.6	
2/12/08	9:30	Stewart's	1.5	2.6	116.5	6.9	23.8	
2/12/08	9:30	Stewart's	2	0.3	115.7	5.9	22.8	
2/12/08	16:00	Hookey's	0	4.37	93	7.3	32.9	25
2/12/08	16:00	Hookey's	0.5	3.49	111.2	7.1	27.5	
2/12/08	16:00	Hookey's	1	3.38	107.7	6.63	24.5	
2/12/08	16:00	Hookey's	1.5	2.09	107.8	6.6	23.5	
2/12/08	16:00	Hookey's	2	0.25	107	6.4	22.6	
2/12/08	16:00	Hookey's	2.5	0.01	110.6	6.8	21.8	
3/12/08	9:30	Hookey's	0	3.65	76.1	6.4	24.3	
3/12/08	9:30	Hookey's	0.5	3.45	107	6.4	23.6	
3/12/08	9:30	Hookey's	1	3.32	108.3	6.3	23.2	
3/12/08	9:30	Hookey's	1.5	3.43	108.5	6.3	22.6	
3/12/08	9:30	Hookey's	2	0.27	105.4	6	22	
3/12/08	9:30	Hookey's	2.5	0.01	111.5	6	21.1	
3/12/08	15:00	Algebuckina	0	7.2	288	7	27.5	30
3/12/08	15:00	Algebuckina	0.5	7.2	289	7	27	
3/12/08	15:00	Algebuckina	1	7.3	291	6.7	26.8	
3/12/08	15:00	Algebuckina	1.5	7.2	294	6.8	26.7	
3/12/08	15:00	Algebuckina	2	7.1	294	6.8	26.7	
3/12/08	15:00	Algebuckina	2.5	6.2	295	6.8	26.5	
3/12/08	15:00	Algebuckina	3	5.9	295	6.8	26.5	
4/12/08	11:00	Algebuckina	0	6.5	329	7.3	25.7	
4/12/08	11:00	Algebuckina	0.5	6.2	340	7.2	25	
4/12/08	11:00	Algebuckina	1	6.3	338	7.2	24.6	
4/12/08	11:00	Algebuckina	1.5	6.6	347	6.8	24	
4/12/08	17:00	Peake	0	8.5	1301	7.8	28.3	50
4/12/08	17:00	Peake	0.5	8.3	1343	7.8	27.6	
4/12/08	17:00	Peake	1	6.3	1350	7.7	26.9	

Table 2. Water quality data collected in the Neales/Peake, Diamantina/Warburton and Cooper Creek in May/June 2009.

DateTime	Location	Depth m	Temp C	Cond. mS/cm	pH	NitrateN mg/L	Turbidity+ NTU	ODO Conc mg/L
30/05/2009 9:23	South Stewart's	0.0	14.23	0.283	7.73	21.17	30.1	7.87
30/05/2009 9:25	South Stewart's	0.5	14.24	0.283	7.68	25.43	30.3	7.18
30/05/2009 9:25	South Stewart's	1.0	14.23	0.283	7.68	29.14	31	7.06
30/05/2009 9:26	South Stewart's	1.5	14.22	0.283	7.68	28.25	34.8	6.97
30/05/2009 11:31	Stewart's	0.0	14.62	0.671	8.56	51.76	37.2	8.17
30/05/2009 11:33	Stewart's	0.5	14.61	0.674	8.55	52.65	37.7	7.95
30/05/2009 11:34	Stewart's	1.0	14.57	0.674	8.53	51.39	40.4	7.63
30/05/2009 14:22	Hookey's	0.0	14.11	0.283	8.14	19.83	40.3	9.02
30/05/2009 14:23	Hookey's	0.5	14.18	0.282	8.09	27.47	43.1	8.75
30/05/2009 14:24	Hookey's	1.0	14.19	0.282	8.06	27.69	54.5	8.63
1/06/2009 11:25	Algebuckina	0.0	14.45	0.839	8.58	50.81	20.5	9.87
1/06/2009 11:26	Algebuckina	0.5	14.32	0.839	8.58	52.86	21	9.78
1/06/2009 11:27	Algebuckina	1.0	14.13	0.835	8.53	58.21	22.3	9.42
1/06/2009 11:29	Algebuckina	1.5	14.07	0.834	8.5	59.57	25.6	9.34
1/06/2009 11:39	Algebuckina2	0.0	13.04	2.396	8.76	168.8	5.9	11.46
1/06/2009 11:42	Algebuckina2	0.5	15.43	4.733	8.67	287.3	17.6	20.93
1/06/2009 15:55	Peake	0.0	14.46	12.234	7.48	1143	17.6	10.05
1/06/2009 15:56	Peake	0.5	14.47	12.344	7.45	1130	17.7	10.07
1/06/2009 15:57	Peake	1.0	14.66	86.093	7.92	4945	15.5	6.8
1/06/2009 15:58	Peake	1.5	16.04	147.79	7.7	4213	394.9	4.24
3/06/2009 11:36	Kalamurina	0.0	14.06	0.879	8.05	147.9	671.7	9.94
3/06/2009 11:36	Kalamurina	0.5	14.05	0.879	8.05	143.6	682.6	9.92
3/06/2009 11:37	Kalamurina	1.0	14.05	0.88	8.05	142.4	666.2	9.91
3/06/2009 11:37	Kalamurina	1.5	14.05	0.88	8.05	140.8	662.7	9.9
3/06/2009 11:38	Kalamurina	2.0	14.05	0.879	8.05	139.7	671.6	9.89
3/06/2009 11:40	Kalamurina	2.5	14.06	0.879	8.06	142	679.6	9.88
3/06/2009 11:40	Kalamurina	3.0	14.06	0.877	8.06	140.8	898.1	9.87
6/06/2009 6:52	Pandie	0.0	14.67	0.154	7.89	294	918.1	9.1
6/06/2009 6:53	Pandie	0.5	14.69	0.152	7.74	281.6	908.6	8.68
6/06/2009 6:53	Pandie	1.0	14.69	0.152	7.66	270.5	910.2	8.45
6/06/2009 6:54	Pandie	1.5	14.69	0.152	7.62	245.6	909.7	8.32
6/06/2009 6:55	Pandie	2.0	14.68	0.152	7.59	241.1	916.5	8.25
6/06/2009 6:55	Pandie	2.5	14.68	0.152	7.56	238.6	913.8	8.2
6/06/2009 6:56	Pandie	3.0	14.68	0.153	7.54	237.3	915.6	8.17
7/06/2009 11:40	Innamincka	0.0	14.98	0.146	7.69	219.4	484.3	9.29
7/06/2009 11:41	Innamincka	0.5	14.86	0.146	7.62	189.5	489.5	8.86
7/06/2009 11:41	Innamincka	1.0	14.84	0.146	7.59	174.5	484.8	8.68
7/06/2009 11:42	Innamincka	1.5	14.86	0.146	7.58	167.1	470.9	8.57
7/06/2009 11:43	Innamincka	2.0	14.85	0.146	7.58	153	474.8	8.52
7/06/2009 11:44	Innamincka	2.5	14.85	0.146	7.58	155.4	475.2	8.51
7/06/2009 15:57	Cullyamurra	0.0	15.07	0.146	7.52	111.4	532.6	8.04
7/06/2009 15:58	Cullyamurra	0.5	15.06	0.146	7.49	113.5	470.7	7.93
7/06/2009 15:58	Cullyamurra	1.0	15.02	0.146	7.49	113.5	489.3	7.86
7/06/2009 15:59	Cullyamurra	1.5	14.94	0.146	7.48	116.1	449.9	7.78
7/06/2009 15:59	Cullyamurra	2.0	14.91	0.146	7.47	114.8	483.2	7.73
7/06/2009 15:59	Cullyamurra	2.5	14.91	0.146	7.46	115.6	503.6	7.7
7/06/2009 16:00	Cullyamurra	3.0	14.89	0.146	7.45	114.9	500.7	7.65
7/06/2009 16:00	Cullyamurra	3.5	14.89	0.146	7.45	119.8	517.6	7.61
7/06/2009 16:01	Cullyamurra	4.0	14.89	0.146	7.44	119.3	626.6	7.6