Billabong, Yanco and Colombo Creek Fish Baselining Project 2012-13

Final Report

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Cover Images: Murray crayfish (Yanco Creek), Golden perch (Billabong Creek) and Trout cod (Yanco Creek) collected in this study. Images: C. Sharpe.

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Executive Summary

Fish survey findings

The Billabong, Yanco and Colombo creeks are significant natural resource assets of the Murray and Murrumbidgee catchments and the primary objective of this project was to collect information on the distribution, relative abundance, diversity, and condition of fish communities throughout these systems. In April-June 2013, 40 sites were surveyed, using boat electrofishing along with fyke nets.

In total, 18 293 fish representing 14 species (10 native and 4 exotic) were sampled across the 40 survey sites. Non-native common carp dominated the biomass (63%). Large-bodied native fish included: golden perch and Murray cod and small numbers of silver perch, bony herring and freshwater catfish. There was little evidence for recruitment for any of the large-bodied native fish and there was a high degree of geographical fragmentation among the native fish populations. For example Colombo Creek had few large-bodied native fish and no detectable Murray-Darling rainbowfish.

A new population of trout cod

A major finding of the present study was a new population of the federally endangered trout cod in the upper Yanco Creek, upstream of Tarabah Weir. The presence of trout cod was directly related to the habitat conditions which support these fish, including strong hydrodynamic diversity (fast and slow flowing water) and relatively dense physical habitat (snags).

Managing rivers to support native fish

To enhance these habitats and fish populations we suggest implementation of a managed fish hydrograph to better support the native fish population. The major benefit of a fish hydrograph is that there are explicit fish outcomes using *improved delivery* rather than extra water. The upper Yanco system provides a unique opportunity for Murray CMA and water managers to work together to implement a fish hydrograph to support a previously unrecorded but endangered trout cod population with extension to Murray cod and catfish and importantly for small bodied native fish species. These fish hydrographs could be embedded within the present arrangements for delivery of irrigation water and demonstrate a collaborative ecological solution within a working river.

Small-bodied fish

Small bodied native fish were generally collected at very low abundances and were even absent from some survey sites, particularly in Billabong Creek. The small bodied fish collected during the present project constitute a valuable fish fauna and included many of the ‘common’ species: Murray Darling rainbowfish, Australian smelt, carp gudgeons and un-specked hardyhead. Some of these had patchy distributions, with unspecked hardyhead being common in the Colombo Creek and Murray-Darling rainbowfish only being common in Yanco Creek. Within Jerilderie Lake there is a very strong population of carp gudgeons which were closely associated with dense macrophytes, mainly *Vallisneria* sp.

The absence of carp and redfin, along with the macrophytes, indicates that Jerilderie Lake would be an appropriate habitat for stocking other small bodied fish (e.g. Murray Darling rainbowfish and un-specked hardyhead) and threatened small-bodied fish, such as olive perchlet and southern pygmy perch, which are locally extinct. If a population of these common and threatened species could be established then Jerilderie Lake could be used as a source for further stocking in the region. These recovery recommendations for small-bodied fish could be supported as Jerilderie community participation events.

Carp

Non-native Carp dominated (63%) the fish biomass in the study area, particularly Billabong Creek, with populations showing a structured size range, indicating annual recruitment, with the exception of the Edward River where no young-of-year were detected. Control of carp with integrated techniques is recommended and for Murray CMA the current (2013/14) carp cage trial on the Edward-Wakool system will be important in determining future recommendations for the Billabong/Yanco/Colombo systems.

An integrated fish recovery plan

The Billabong/Yanco/Colombo system has high potential for native fish population recovery, particularly with a new approach that views irrigation as part of sustainable healthy rivers where there is emphasis on the support and input of the local community, irrigators, government and Aboriginal community. The Yanco/Billabong area would not only be an adjunct of main river ecosystems but would become a critical component acting as a key fish spawning zone and habitat refuge.

The major fish recovery actions and an integrated monitoring plan to demonstrate restoration of fish populations are presented within this report but the key recommendations are:

1. Trout cod status investigation and recovery plan for the Yanco Creek.

2. Catfish population status and recovery plan for the Billabong Creek system
3. Implement a native fish hydrograph (e.g. winter base flow and optimised spring spawning flow) to support trout cod and native fish in Yanco Creek and monitor to demonstrate success (e.g. spawning, recruitment).
4. Manage Jerilderie Lake to form a source population for small-bodied native fish.
5. Manage floodplain wetland inundation cycles to enhance native fish recruitment/recovery.
6. Assess the effectiveness of the Tarabah Weir fishway for native fish and as a potential site to remove carp with a carp cage.
7. Reassess the weirs within the system to determine their current and future role and potential for removal.

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1 Introduction

The Billabong, Yanco and Colombo creeks are significant natural resource assets of the Murray and Murrumbidgee catchments. These waterways support important bird, vegetation and native fish communities, including iconic species such as Murray cod, Golden Perch and Freshwater Catfish. Although these important fish species are well known to recreational anglers there is very limited detailed information regarding the structure of the fish community nor the distribution of species throughout the waterway. The lack of formal fish survey information has been recognised as an impediment to future NRM investment and has been highlighted as a key knowledge gap by Murray CMA.

The primary objective of this project was to collect information on the diversity of species and their distribution, the relative abundance of species and their population demographics and to examine the condition of fish populations throughout the Billabong, Yanco and Colombo creek waterways.

Specifically, the aims of the study were to gather baseline information regarding:

- Fish species diversity, distribution and relative abundance;
- The condition of populations, including demographics and biological condition (e.g. length, weight, incidence of disease);
- Habitat attributes within each site and reach including water quality attributes, the diversity and extent of aquatic vegetation, the density and character of woody debris and flow characteristics.
- The diversity and distribution of turtle species

2 Study Area

2.1 Overview

The fish baselining study was centred on the Billabong Creek and its main tributaries Yanco Creek and Colombo Creek. Two off-channel wetlands Mollies Lagoon and Jerilderie Lake were included for survey, as was the Edward River at its confluence with Billabong Creek. At the highest level of distinction, each major creek was defined as a 'waterway'. Jerilderie Lake was also classified as a waterway due to its unique geomorphology and high level of hydrological regulation, which was distinct in relation to the overall study area. Accordingly, there were five waterways investigated (Table 2.1). The second tier of investigation was 'reach'. Reaches were nested within each waterway. Reaches were defined for their management significance including between geographical boundaries and between major weirs (Table 2.1). Finally, survey sites were selected based upon their proximity to weirs, creek junctions and other geographical management units (Table 2.1). Accordingly, a nested survey design of Sites within Reaches within Waterways formed the hierarchy of the study design. In total, 40 sites were selected and surveyed for fish (Table 2.1).

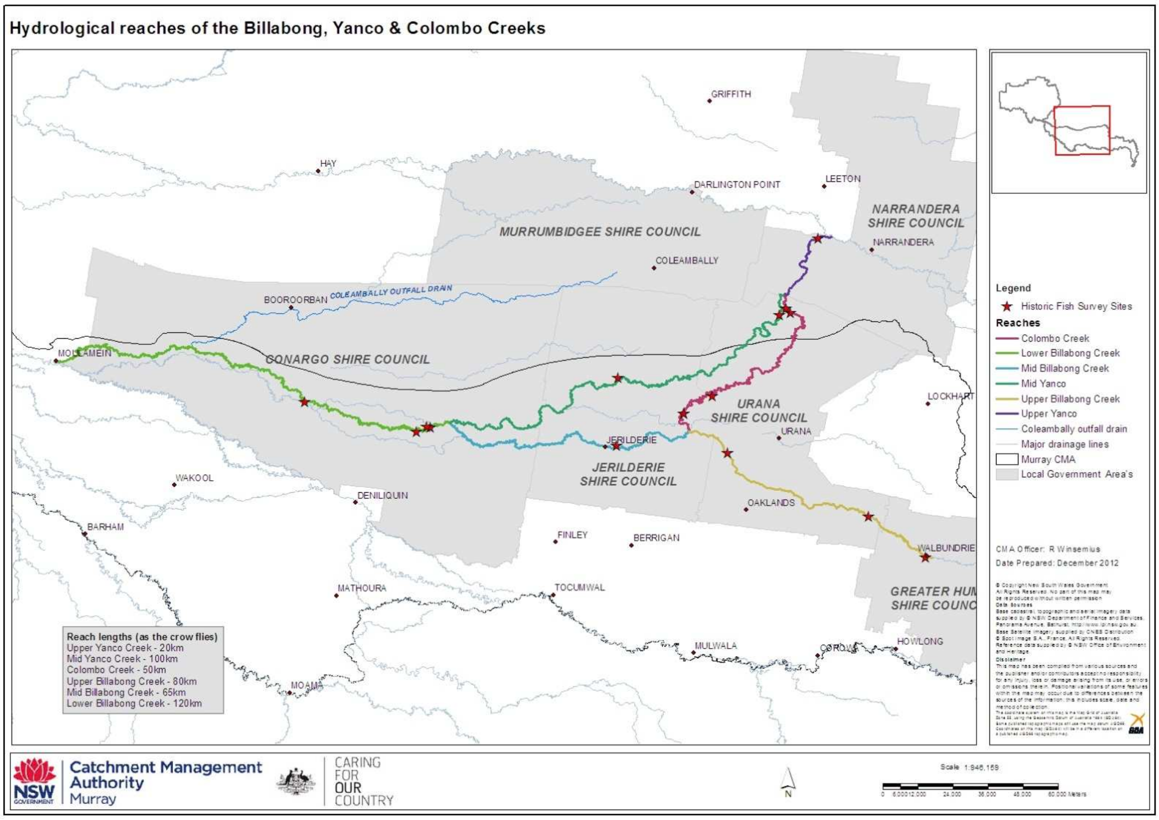

Figure 2.1 Study area showing the main hydrological reaches where fish surveys were undertaken.

Table 2.1 The three tiers of investigation used for the fish baselining study: ‘Waterways’, ‘Reaches’ and individual survey ‘Sites’.

Waterway Reach Site	Waterway Reach Site
Waterway = Billabong Creek (BC)	**Waterway = Colombo Creek (CC)**
Reach 1 = Caroonboon to Wanganella	**Reach 1 = Colombo Creek**
Millabong	Bindiwilla Urana
Wanganella Common	Boonongo
Reach 2 = Conargo to Jerilderie	Boonongo Mud Bank Colombo Creek d/s Upper Sheepwash Weir
Algudgerie TSR	Chesneys Weir d/s
Hartwood TSR	Chesneys Weir u/s
Old Coree	Colombo Creek Eight Mile Weir Pool via Colombo Ski Club
Quiamong d/s Hartwood Weir	**Waterway = Edward River (ER)**
Reach 3 = Jerilderie to Colombo	**Reach 1 = Edward River at Moulamein**
Gammons Jerilderie	Edward River d/s Billabong Creek 1
Innes Bridge TSR	Edward River d/s Billabong Creek 2
The Cape TSR	Edward River u/s Billabong Creek 1
Reach 4 = Moulamein to Windouran	Edward River u/s Billabong Creek 2
Billabong Moulamein Town Bridge	**Waterway = Jerilderie Lake (JL)**
Billamien	**Reach 1 = Jerilderie Lake**
Windouran	Jerilderie Lake
Reach 5 = Wanganella to Conargo	**Waterway = Yanco Creek (TC)**
Booabula u/s Chinamans Weir	**Reach 1 = Molly's Lagoon**
Conargo Town Common	Molly's Lagoon 1
North Run	Molly's Lagoon 2
Reach 6 = Windouran to Caroonboon	**Reach 1 = Yanco Creek d/s Tarabah Weir to Billabong**
Back Nullum	Mundoora Jerilderie
Caroonboon Weir d/s	Wilson Rd Bridge
Murgha Rd bridge	Wononga Jerilderie
	Yathong TSR
	Reach 1 = Yanco Creek u/s Tarabah Weir
	Devlins Bridge Yanco Ck
	Wirrani
	Yarrabee TSR Yanco
	Yanco Creek d/s Molly's Lagoon
	Yanco Creek u/s Molly's Lagoon

3 Survey Methods

3.1 Sampling

Fish surveys were conducted from 23rd April to 14th June 2013. At each site, boat electrofishing as well as small and large fyke nets were deployed to survey the whole fish community. Electrofishing followed SRA protocols with 12 × 90 sec boat electrofishing shots undertaken at each survey site, together with deployment of 10 unbaited concertina bait traps for 2 hrs.

Four large and four small fyke nets (four net pairs per site) were set overnight at each survey site. Nets were set in the afternoon and retrieved the following morning, with set and retrieval time recorded for calculation of catch per unit effort (CPUE) and comparison of relative fish abundance. Large fyke nets were used to increase encounter rates with freshwater catfish and turtles. Small fyke nets were used to increase encounter rates with small-bodied fish species. Examples of boat electrofishing and fyke nets are shown in Figure 3.1.

Figure 3.1 Examples of gear types used in the Baseline Fish survey.

3.2 Species Identification

Fish identifications followed McDowall (1996) and Lintermans (2007). All carp gudgeons were identified to genus level only (i.e. *Hypseleotris* spp.) owing to the current taxonomic uncertainty of the group (Bertozzi et al. 2000; Vilizzi 2013) (Table 3.1). All large-bodied fish species were measured for standard (SL) and total length (TL) (nearest 1.0 mm) and weighed to the nearest 1.0 g. All small-bodied species were counted and released so as to minimise handling stress and mortality rates.

3.3 Flow Guilds

Fish species were grouped into the flow guilds recently identified by Baumgartner et al. (2013). These flow guilds are based on the most recent biological and life history science. It has been recently shown that adaptive flow delivery strategies can be applied to meet the requirements of particular flow guilds, with appropriate flow delivery sequences supporting the maintenance of entire fish communities (Baumgartner et al. 2013). Alignment of local species to the four flow guilds is shown in Table 3.1.

Table 3.1 Fish species recorded across the five waterways under study. Flow guilds: AP = Apex Predators; FDS = Flood-Dependent Specialists; FG = Foraging Generalists; EX = Exotic (first three groups after Baumgartner et al. 2013). YoY Max TL = maximum total length (mm) for Young-of-Year (YoY) of the large-bodied species.

Species name	Common name	Code	Origin	Size	Flow guild	YoY max TL
NATIVE						
Bidyanus bidyanus	Silver perch	Bi	Native	Large-bodied	FDS	117
Craterocephalus stercusmuscarum fulvus	Un-specked hardyhead	Cs	Native	Small-bodied	FG	–
Hypseleotris spp.	Carp gudgeon	Hy	Native	Small-bodied	FG	–
Maccullochella macquariensis	Trout cod	Mm	Native	Large-bodied	AP	115
Maccullochella peelii peelii	Murray cod	Mp	Native	Large-bodied	AP	115
Macquaria ambigua	Golden perch	Ma	Native	Large-bodied	FDS	118
Melanotaenia fluviatilis	Murray-Darling rainbowfish	Mf	Native	Small-bodied	FG	–
Nematalosa erebi	Bony herring	Ne	Native	Large-bodied	FG	93
Retropinna semoni	Australian smelt	Rs	Native	Small-bodied	FG	–
Tandanus tandanus	Freshwater catfish	Tt	Native	Large-bodied	FG	100
EXOTIC						
Carassius auratus	Goldfish	Ca	Exotic	Large-bodied	EX	124
Cyprinus carpio	Common carp	Cc	Exotic	Large-bodied	EX	251
Gambusia holbrooki	Eastern Gambusia	Gh	Exotic	Small-bodied	EX	–
Perca fluviatilis	European perch	Pf	Exotic	Large-bodied	EX	113

3.4 Water Quality

At each site, water quality measurements of pH, electrical conductivity (EC, µS cm^{-1}; standardized to 25 ℃:), dissolved oxygen (DO: mg L^{-1}), turbidity (NTU) and temperature (℃) were taken at a depth of 0.25 m be low the water surface using a Horiba® U52-multiprobe.

3.5 Quantitative Habitat Mapping

At each fish survey site, 13 aquatic habitat attributes were assessed and scored. Habitat attributes are shown in Table 3.2. The habitat assessments were adapted from the established AUSRIVAS Rapid Physical Assessment Protocol and USEPA Habitat Assessment templates. Patterns in fish assemblage structure were later related to habitat attributes to identify which if any habitat features were associated with patterns in fish distribution and abundance.

Table 3.2 Habitat attributes measured as part of the fish baselining study.

Variable	Score					
	1	2	3	4	5	6
1. Channel flow status	Water present as disconnected, isolated pools	Water present as continuous standing pool	Very little water in channel, channel connected	Water fills 25–75% of both banks, deposition bars exposed	Water fills > 75% of both banks, or < 25% of channel exposed	Water reaches base of both banks (bankfull)
2. Flow velocity	No flow	No/Slow flowing weirpool	Slow-moderate flowing pool	Fast flowing	–	–
3. Hydrodynamics	No/slow flow Dominated by one velocity regime, usually No flow shallow	Low flow velocity, low flow diversity	Slow-moderate flowing pool; Low flow velocity, some flow diversity	Pools with runs (aka riffle/run). Moderate-high flow velocity, high flow diversity (Fast and slow flowing areas)	–	–
4. Macrophytes	No submerged or emergent	< 5% cover submerged and or emergent	5–10% cover submerged and or emergent	10–15% cover submerged and or emergent	15–20% cover submerged and or emergent	> 20% cover submerged and or emergent
5. Structural Woody Habitat (Snags) density	Open Water (no snags visible)	< 5% channel cover comprising twigs and branches 1–5cm diameter	5–10% channel cover comprising branches and trees	10–20% cover comprising branches and trees	20–50% cover comprising branches and trees	>50% channel cover comprising branches and trees
6. Structural Woody Habitat (Snags) complexity	Open Water (no snags visible)	< 5% channel cover Twigs and branches 1–5cm diameter	5–10% channel cover composed of a single trunk or limb	5–10% channel cover composed of a trunk or limb with one or two branches	5–10% channel cover composed of one or more trunks with multiple branches	5–10% channel cover comprising complete tree most limbs including the root–ball
7. Riparian zone	Width of RZ <6m, little or no RZ present due to human activities	Width of RZ 6-12m, human activities have impacted the RZ to a high degree	Width of RZ 12-18m, human activities have impacted the RZ only minimally	With of Riparian zone 18-40m, human activities i.e. roads, crops, lawns etc.) present but impact minimal	Width of Riparian zone >40m, human activities do not impact the RZ	Width of RZ <6m, little or no RZ present due to human activities
8. Channel width	Recorded with range finder					

4 Data Analyses

4.1 Size structure

Analyses of population size structure was undertaken by plotting length-frequency distributions for each large-bodied species across (i) the entire study area (all waterways), and (ii) for each waterway.

The maximum total length (TL) for the Young-of-Year (YoY) fish of each large-bodied species was determined from the scientific literature and the distribution of values in the corresponding length-frequency histogram was used as an indicator of successful spawning in the most recent breeding season. Recruitment was defined as the survival of a cohort to one year of age or into age 1+ (after first birthday).

4.2 Experimental design

This experimental design utilised 'Waterway' as the main factor and 'Reach' as the nested factor, and with the 'Sites' representing the experimental units. The significant effects for this design are outlined in Table 4.1.

Table 4.1 Interpretation of significant effects for the experimental design applied for sampling fish in the present study.

Source of variation	Interpretation when significant
Waterway	Spatial patterns in fish composition and abundance differ amongst waterways.
Reach	Spatial patterns in fish composition and abundance differ amongst reaches within each waterway.

4.3 Spatial Patterns

Spatial patterns in fish assemblage composition and abundance across waterways and the reaches within were analysed by permutational multivariate analysis of variance (PERMANOVA). Canonical analysis of the principal coordinates (CAP) was used to display these patterns in ordination.

CAP is an ordination of dissimilarity among species abundance data. In this case, fish species and flow guild abundance was compared between waterways (i.e. Billabong, Colombo, Yanco, Jerilderie Lake and Edward River). The ordinations shows the species and flow guilds grouping toward the waterway for which their abundance differed the most in relation to their average abundance across all waterways. The direction and strength of vectors (trend lines) toward a particular grouping indicates a) those species which displayed similar trends (i.e. grouped together), b) the Waterway most responsible for the difference in abundance, and c) positive or negative difference in their abundance. Therefore, for any individual species of flow guild, the difference in their abundance is indicated by the association to any particular waterway. A more technical description of the statistical methods applied is provided separately in Section 9, Statistical Methods,.

4.4 Species/Guild–Environment Relationships

Relationships between species/flow guilds and environmental variables were investigated by between-class Coinertia Analysis (bcaCOIA) (Franquet et al. 1995; Chessel and Thiolouse 2003). This is a multivariate technique similar to ‘indicator species analyses’. In bcaCOIA, two tables of attribute values were compared, namely the scores for environmental variables and the species (or flow guild) abundance tables, with the structure of the sampling design (that is, the waterways surveyed) incorporated. Three plots were then produced, namely: (i) a plot with the scores for the waterways, (ii) a plot with the scores for the species (or flow guilds), and (iii) a plot with the scores for the environmental variables. The location of the waterways, species (or flow guilds) and environmental variables across the plots were then compared with one another and relationships were visually identified. A technical description of this method is provided in Section 9, Statistical Methods.

4.5 Nativeness

Nativeness was calculated as the native/exotic species ratio for each of the sites sampled. Differences were tested between waterways by PERANOVA, which is the univariate equivalent of PERMANOVA. A technical description of this statistical method is provided separately in Section 9 Statistical Methods.

5 Results

5.1 Water Quality and Habitat Attributes

All water quality parameters measured at each reach sampled for fish were within normal ranges (Appendix Table A1). Habitat attributes varied throughout the range identified for each parameter, shown for each site in Appendix Table A2.

5.2 Fish

5.2.1 Assemblage Composition and Abundance

In total, 18 293 fish representing 14 species (10 native and 4 exotic) were sampled across the 40 survey sites (Table 5.1; see also Appendix Table A3). Of these, 299 (1.6% of total) were large-bodied native, 16 627 (90.9%) small-bodied native, 1184 (6.5%) large-bodied exotic and 183 (1.0%) small-bodied exotic (Table 5.1).

Amongst the large-bodied native species Golden Perch and Murray Cod were sampled in the largest numbers, whereas Silver Perch, Trout Cod, Bony Herring and Freshwater Catfish were collected at much lower abundances. Carp Gudgeon was the most abundant small-bodied species and also represented the largest proportion of the overall catch. Australian smelt was the second most abundant small-bodied species, whereas Un-specked Hardyhead and Murray-Darling Rainbowfish were sampled at comparatively lower numbers. Amongst the exotic species, Common Carp was the most abundant, followed by Eastern Gambusia, Goldfish and European Perch, in that order (Table 5.1).

The largest number of fish (mostly Carp Gudgeon) were sampled from Jerilderie Lake, Colombo Creek and Yanco Creek, in that order, and the lowest number from Billabong Creek and Edward River (Table 5.1).

Table 5.1 Total number and percentage of the fish species sampled across the five waterways.

	Billabong Creek		Colombo Creek		Edward River		Jerilderie Lake		Yanco Creek		Total	
Species	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Native												
Large-bodied												
Silver Perch	4	0.44%	1	0.02%	1	0.43%	0	0.00%	0	0.00%	6	0.03%
Golden Perch	109	11.96%	3	0.07%	21	9.01%	10	0.10%	17	0.53%	160	0.87%
Trout Cod	0	0.00%	0	0.00%	0	0.00%	0	0.00%	7	0.22%	7	0.04%
Murray Cod	72	7.90%	1	0.02%	27	11.59%	0	0.00%	13	0.40%	113	0.62%
Bony Herring	0	0.00%	0	0.00%	7	3.00%	0	0.00%	0	0.00%	7	0.04%
Freshwater Catfish	2	0.22%	1	0.02%	1	0.43%	0	0.00%	2	0.06%	6	0.03%
Small-bodied												
Un-specked Hardyhead	2	0.22%	284	6.57%	5	2.15%	0	0.00%	19	0.59%	310	1.69%
Carp Gudgeon	60	6.59%	3398	78.60%	44	18.88%	9370	97.72%	2366	73.09%	15238	83.30%
Murray-Darling Rainbowfish	10	1.10%	3	0.07%	2	0.86%	0	0.00%	210	6.49%	225	1.23%
Australian Smelt	5	0.55%	508	11.75%	53	22.75%	198	2.06%	90	2.78%	854	4.67%
Exotic												
Large-bodied												
Goldfish	20	2.20%	5	0.12%	2	0.86%	2	0.02%	23	0.71%	52	0.28%
Common Carp	564	61.91%	98	2.27%	70	30.04%	0	0.00%	395	12.20%	1127	6.16%
European Perch	0	0.00%	3	0.07%	0	0.00%	0	0.00%	2	0.06%	5	0.03%
Small-bodied												
Eastern Gambusia	63	6.92%	18	0.42%	0	0.00%	9	0.09%	93	2.87%	183	1.00%
	911		**4323**		**233**		**9589**		**3237**		**18293**	

5.2.2 Nativeness

Edward River had the highest level of nativeness relative to all other waterways, and this was due to the presence of all native species with the exception of Trout Cod. Two exotic species were also absent at the Edward River sites - European Perch and Eastern Gambusia (Figure 5.1). Also, nativeness was significantly higher at Billabong Creek and Yanco Creek relative to Colombo Creek. The lowest level of nativeness recorded was in Colombo Creek and this was due to the presence of only Golden Perch amongst the large-bodied species and the absence of Murray-Darling Rainbowfish (which was instead recorded in all other waterways) amongst the small-bodied species, coupled with the presence of each exotic species (PERANOVA results in Appendix Table A4).

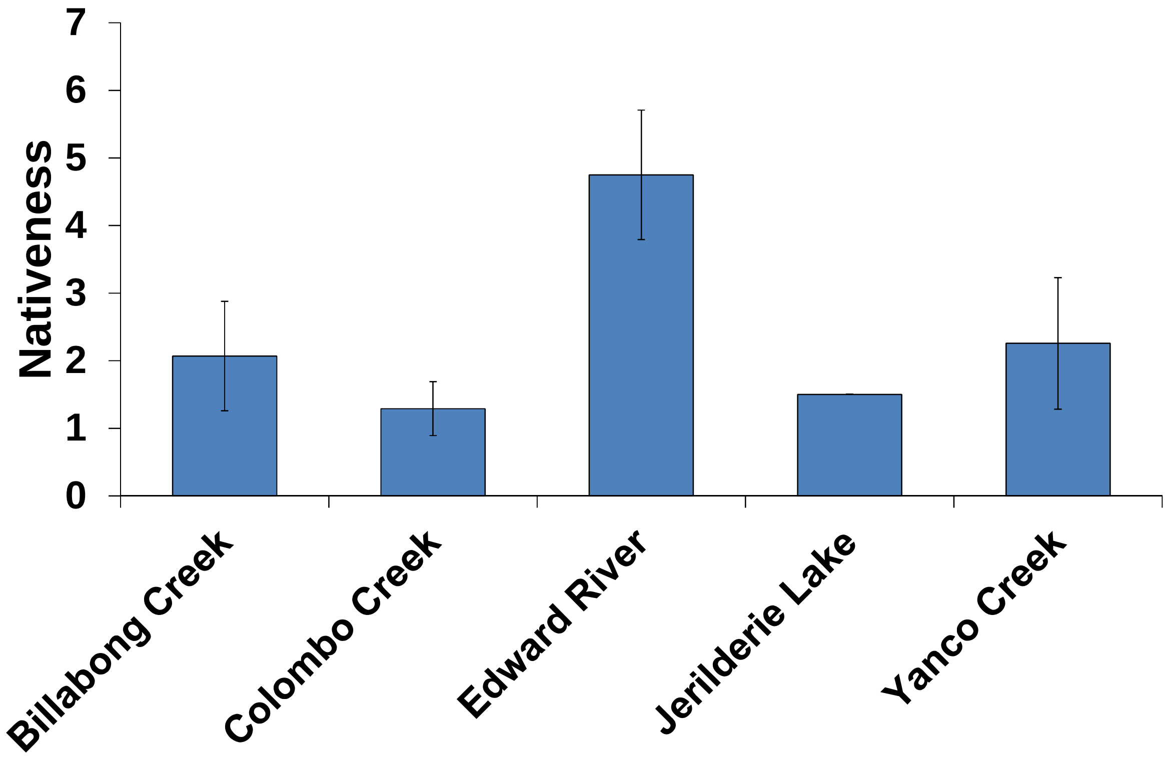

Figure 5.1 Nativeness (native/exotic species ratio) of the fish sampled across the five waterways. PERANOVA results in Appendix Table A4.

5.2.3 Biomass

Common Carp made up by far the largest proportion (63.3%) of the total large-bodied fish biomass, both across the whole study area and in four of the five waterways surveyed (Figure 5.2). Colombo Creek and Yanco Creek were the waterways with the highest carp biomass proportion (89.6% and 86.4%, respectively); whereas, lower and similar levels were recorded at Billabong Creek and Edward River (54.1%, in both cases), but still higher than those for the other species. Second to Common Carp, Murray Cod made up for 24.2% of the biomass at Billabong Creek and 35.2% at Edward River. Golden Perch was third, making up for 20.4% of the biomass at Billabong Creek. Finally, at Jerilderie Lake Golden Perch represented 94.2% of the total biomass, the remaining 5.6% being represented by exotic Goldfish (Figure 5.2).

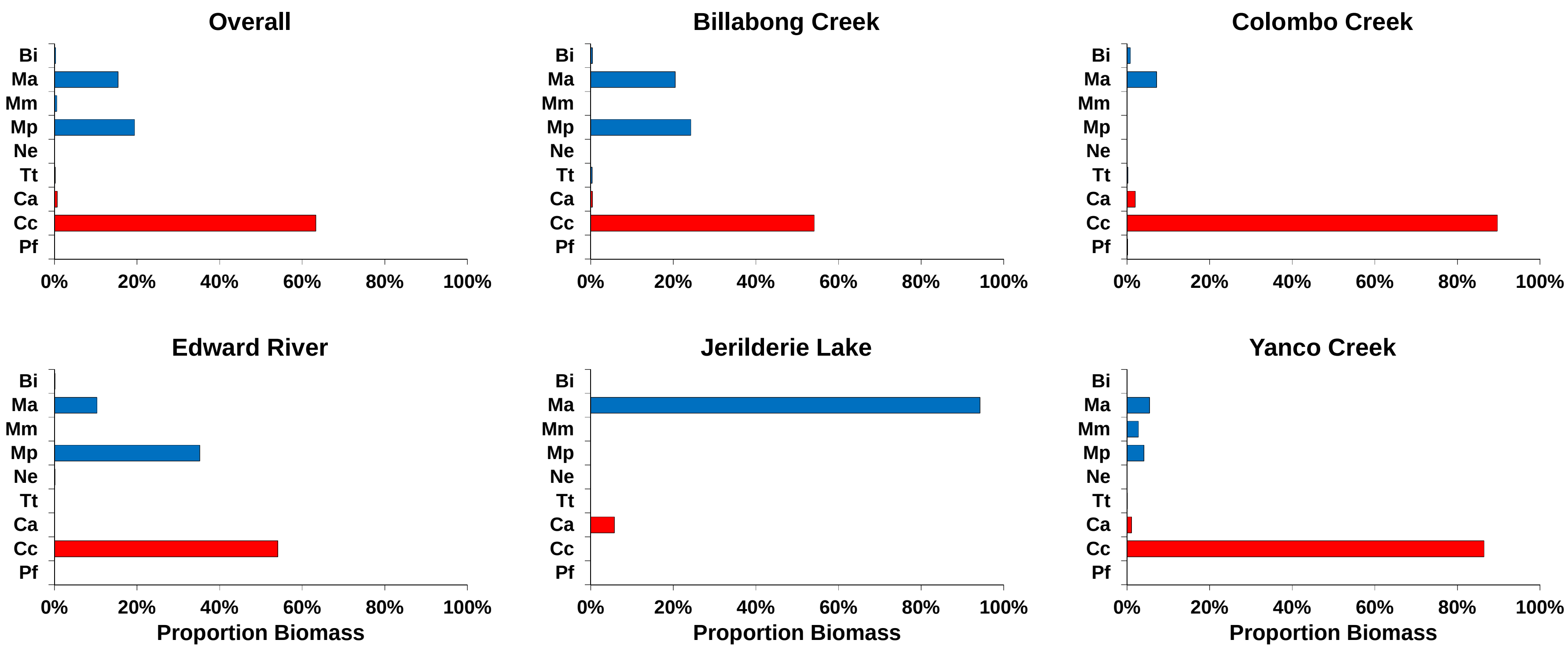

Figure 5.2 Biomass proportion of the fish species sampled across the five waterways. Overall biomass proportion is also reported. Blue bars = native species, red bars exotic species.

5.2.4 Species-specific patterns

Silver Perch – only a few individuals were collected at Billabong Creek, Colombo Creek and Edward River, but not from Jerilderie Lake and Yanco Creek (Table 5.1). Silver perch were more abundant in the Windouran to Caroonboon reach of Billabong Creek (Figure 5.3, top). Of the few individuals caught, none were YoY (<150 mm long) as indicated by the corresponding overall length-frequency distribution (Figure 5.3, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A1.

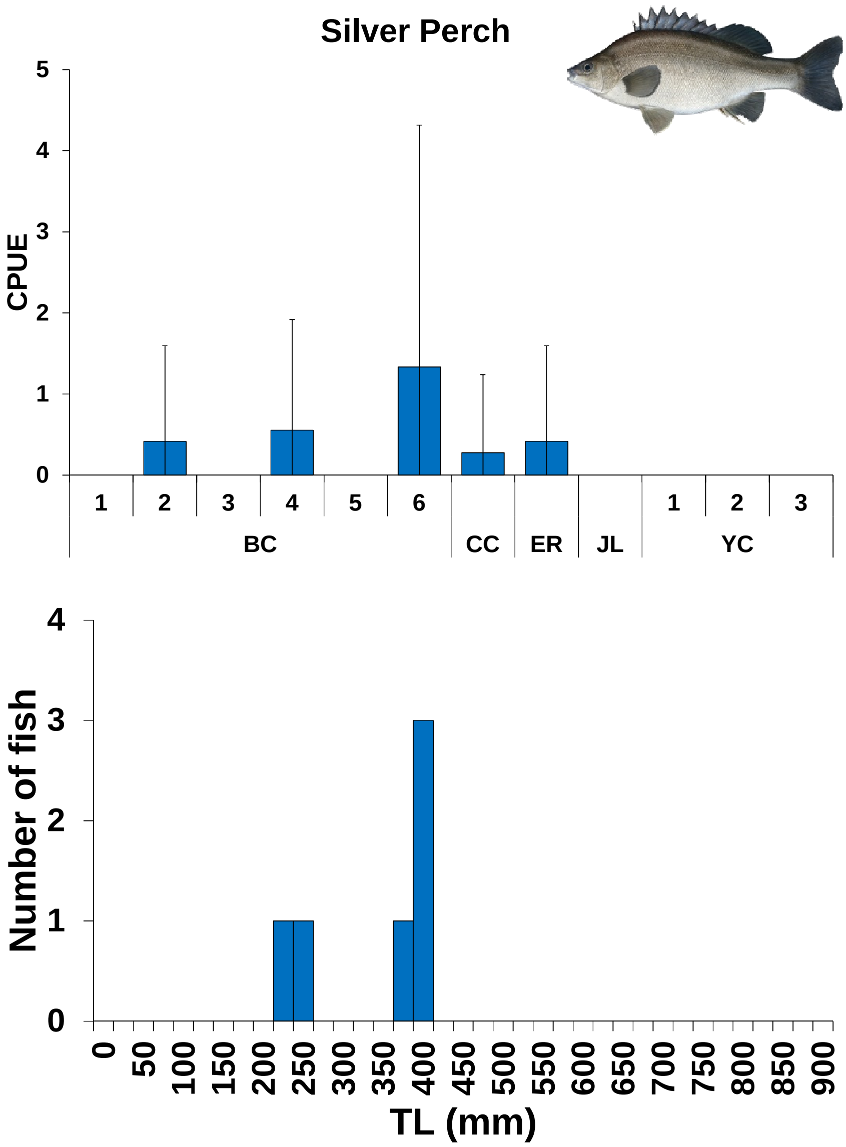

Figure 5.3 Top – CPUE (±SE) abundance (fish h^{-1}) of Silver Perch sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length).

Golden Perch – were sampled from all five waterways (Table 5.1), but they were more abundant at Billabong Creek and less so at Yanco Creek, Colombo Creek and Jerilderie Lake (Figure 5.4, top). The overall length-frequency distribution across the waterways indicated a well-structured population, but without YoY fish (<150 mm long) (Figure 5.4, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A1.

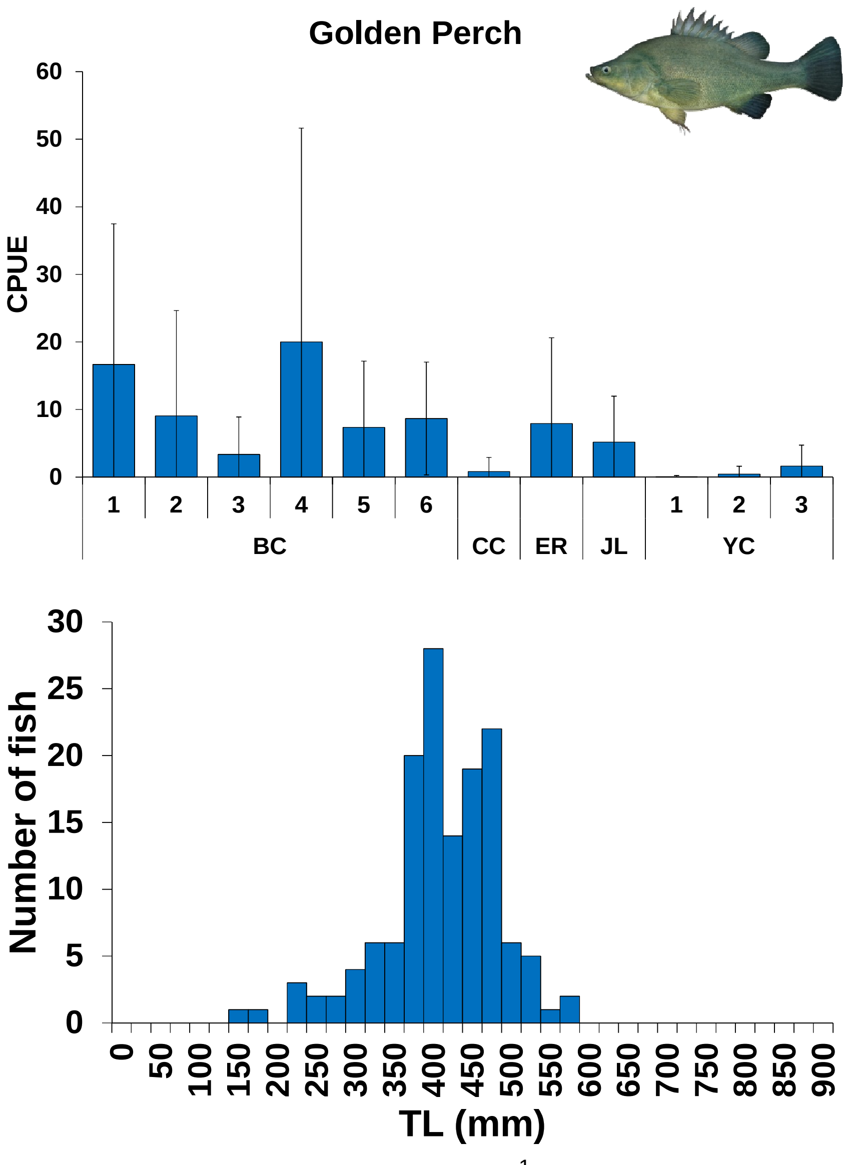

Figure 5.4 Top – CPUE (±SE) abundance (fish h^{-1}) of Golden Perch sampled from five waterway and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length).

Trout Cod –were collected from one reach in Yanco Creek – upstream Tarabah Weir (Figure 5.5, top). The overall length-frequency distribution indicated the presence of only one potential YoY fish (Figure 5.5, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A1.

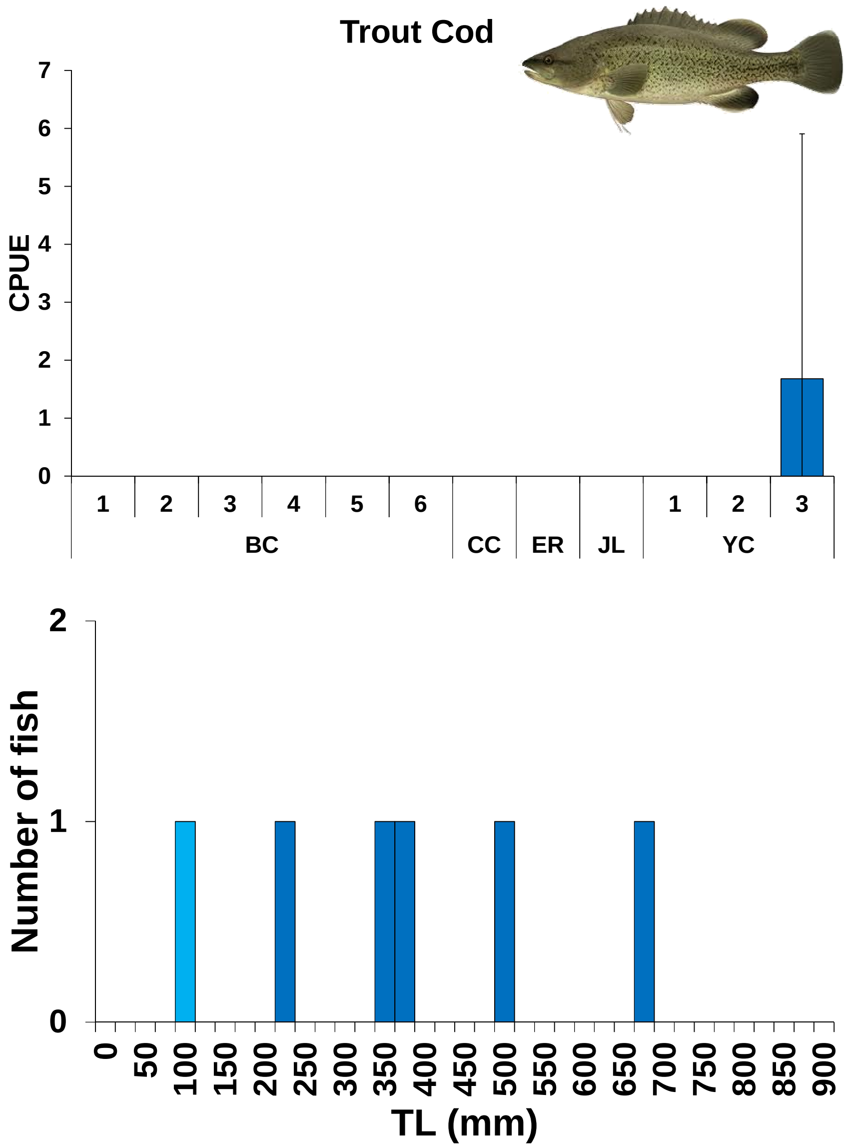

Figure 5.5 Top – CPUE (±SE) abundance (fish h^{-1}) of Trout Cod sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with YoY fish in light blue (see Table 5.1).

Murray Cod –were sampled from all waterways except Jerilderie Lake (Table 5.1) and they were comparatively more abundant at Billabong Creek and Edward River relative to Colombo Creek and Yanco Creek (Figure 5.6, top). The length-frequency distribution indicated a relatively well-structured population, especially in the middle and larger size-classes, and a few YoY individuals (<150 mm long) were also present (Figure 5.6, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A1, indicating the presence of YoY fish at Billabong Creek and Colombo Creek.

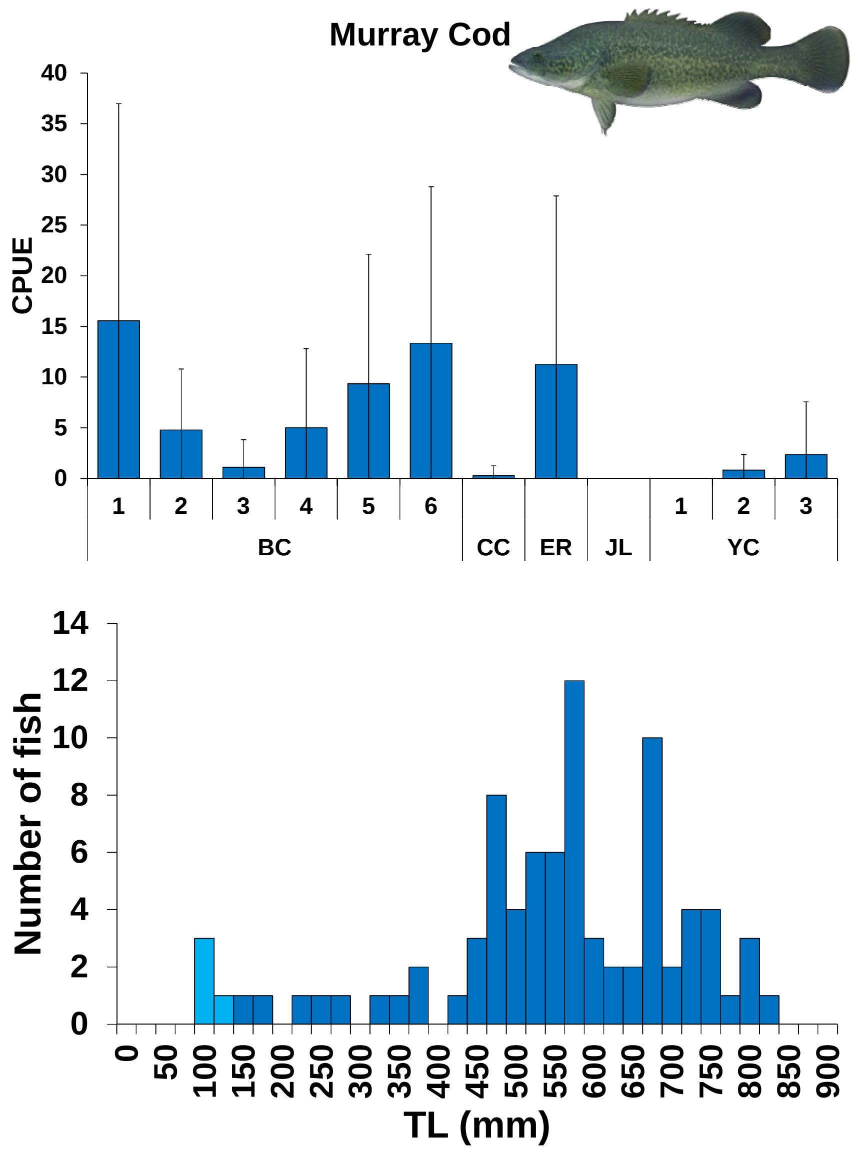

Figure 5.6 Top – CPUE (±SE) abundance (fish h^{-1}) of Murray Cod sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with YoY fish in light blue (see Table 5.1).

Bony Herring – only a few individuals were collected from Edward River (Table 5.1; Figure 5.7, top). The length-frequency distribution indicates the presence of two YoY fish (Figure 5.7, top, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A1.

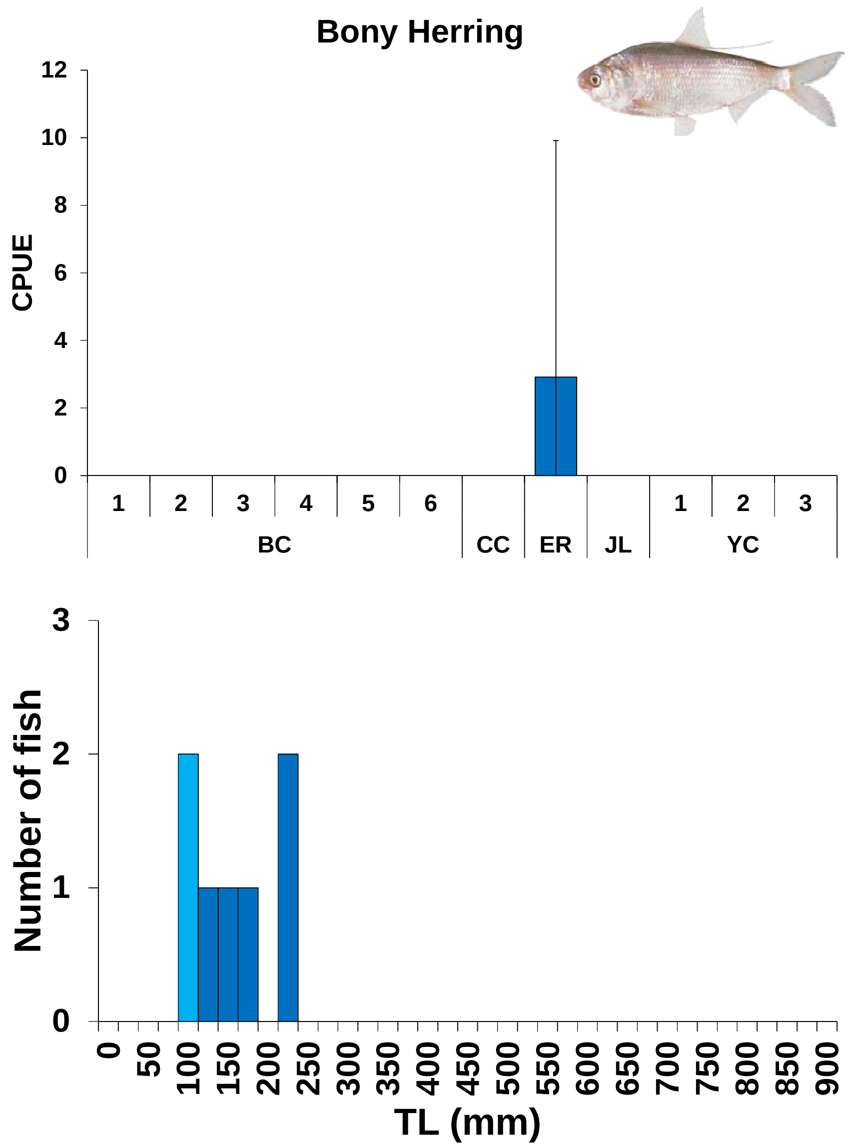

Figure 5.7 Top – CPUE (±SE) abundance (fish h^{-1}) of Bony Herring sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with Young-of-Year fish in light blue (see Table 5.1).

Freshwater Catfish – only a few individuals were collected but these came from all waterways except Jerilderie Lake (Table 5.1) and were comparatively more abundant at Billabong Creek (Figure 5.8, top). The overall length-frequency distribution indicated the presence of one YoY individual (Figure 5.8, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A1, indicating that the YoY fish was sampled at Edward River.

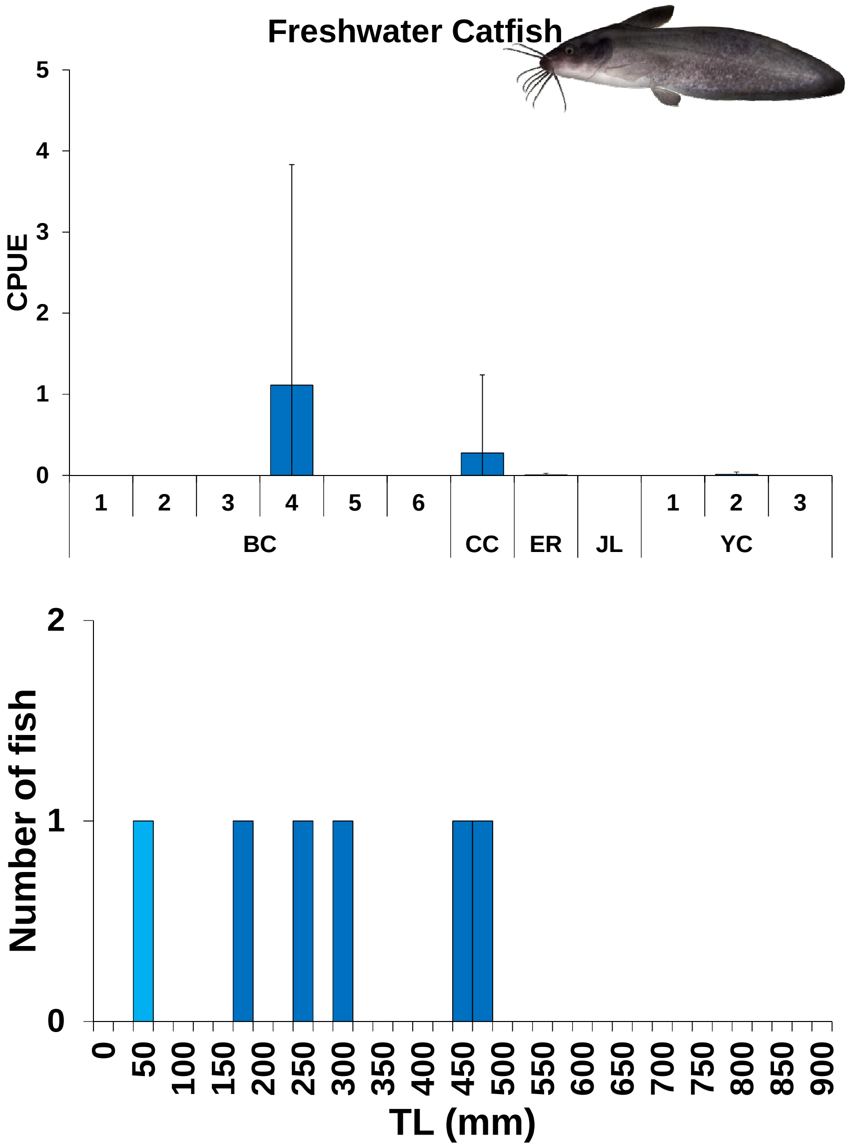

Figure 5.8 Top – CPUE (±SE) abundance (fish h^{-1}) of Freshwater Catfish sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with YoY fish in light blue (see Table 5.1).

Un-specked Hardyhead – were sampled in higher abundance at Colombo Creek (Table 5.1), but were also present at Billabong Creek and Yanco Creek, but were absent from Edward River and Jerilderie Lake (Figure 5.9).

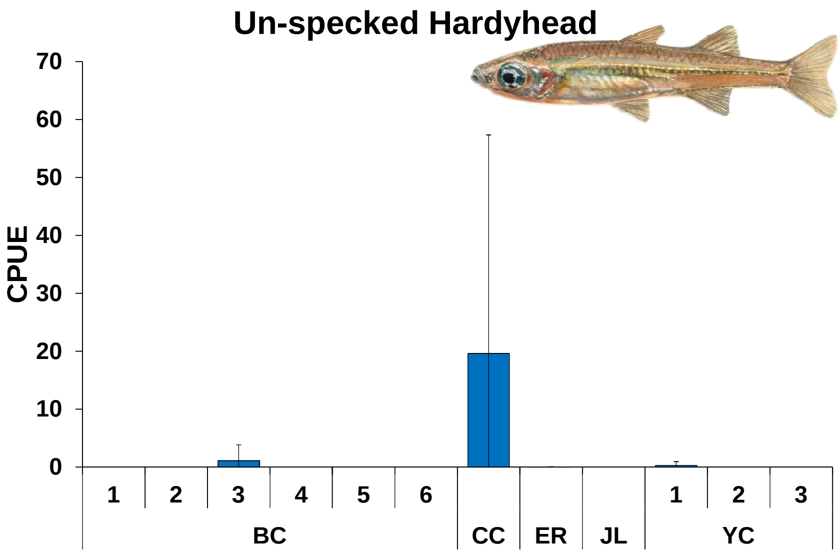

Figure 5.9 CPUE (±SE) abundance (fish h^{-1}) of Un-specked Hardyhead sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1).

Carp Gudgeon – were sampled the highest abundance at Jerilderie Lake (Table 5.1), but were also present in all other waterways, with the lowest numbers recorded at Edward River (Figure 5.10).

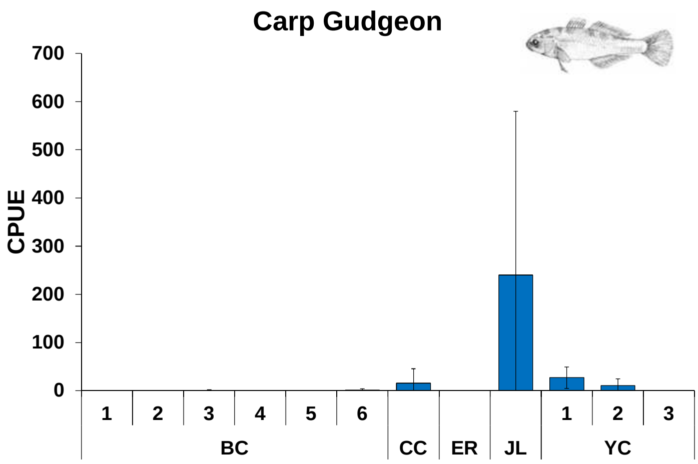

Figure 5.10 CPUE (±SE) abundance (fish h^{-1}) of Carp Gudgeon sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1).

Murray-Darling Rainbowfish – were sampled in higher abundance at Yanco Creek (Table 5.1), but were also collected from all other waterways except Jerilderie Lake (Figure 5.11)

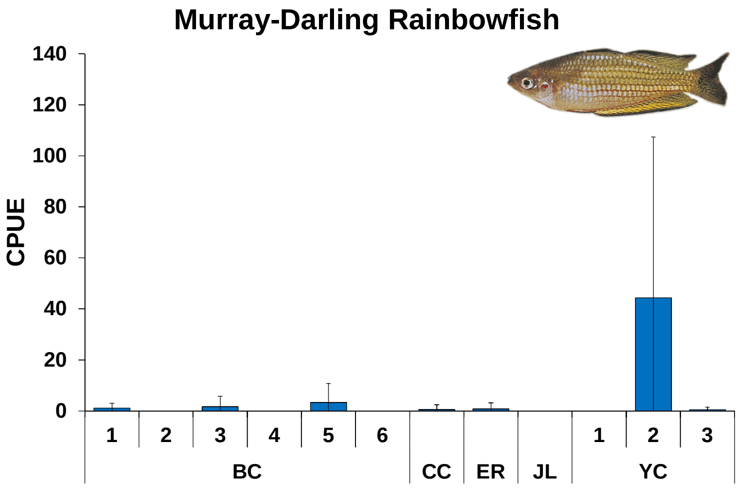

Figure 5.11 CPUE (±SE) abundance (fish h^{-1}) of Murray-Darling Rainbowfish sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1).

Australian Smelt – were sampled in highest abundance at Colombo Creek (Table 5.1), but were also present in all other waterway even though in lower abundance throughout the Billabong Creek reaches (Figure 5.12).

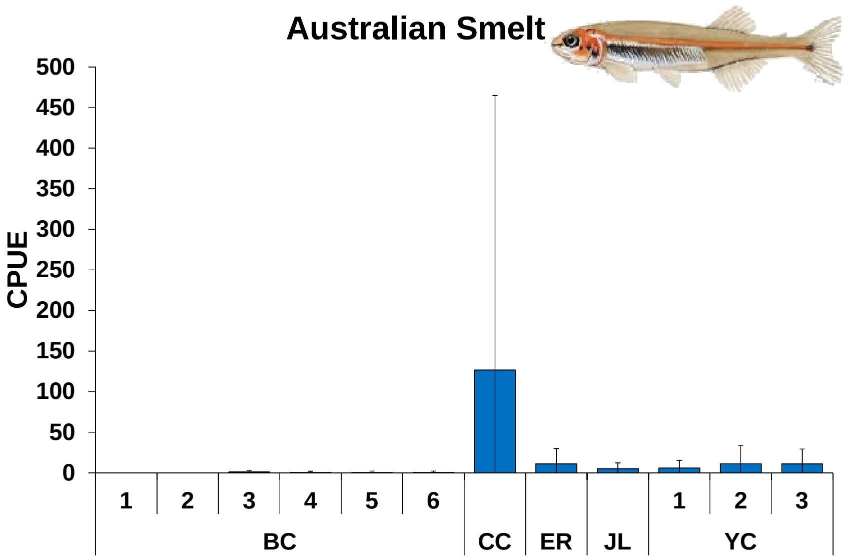

Figure 5.12 CPUE (±SE) abundance (fish h^{-1}) of Australian Smelt sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1).

Goldfish – were sampled in similar abundance across all waterways (Table 5.1; Figure 5.13)

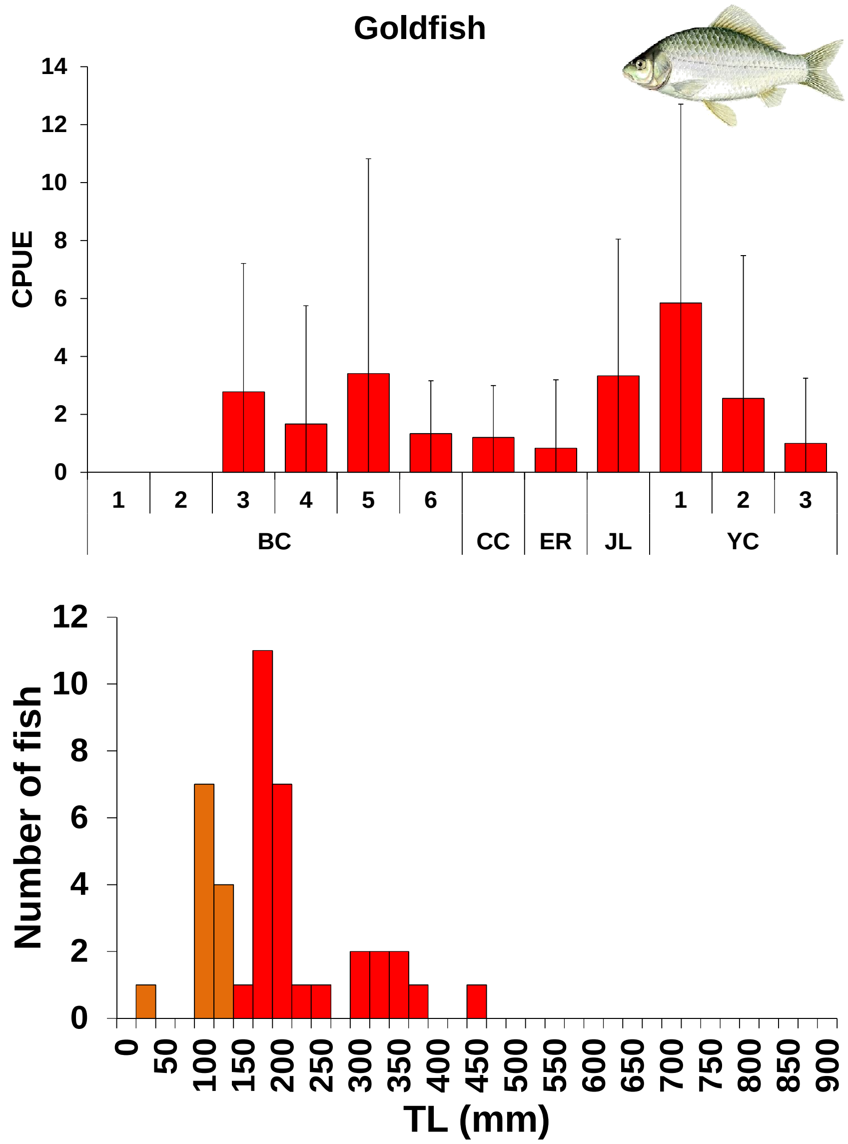

Figure 5.13 Top – CPUE (±SE) abundance (fish h^{-1}) of Goldfish sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with Young-of-Year fish in light orange (see Table 5.1).

Common Carp – were sampled in similar abundance across all waterways except for Jerilderie Lake, where they were not recorded at all (Table 5.1; Figure 5.14, top). The length-frequency distribution indicated a very well-structured population across all size classes, including YoY fish (Figure 5.14, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A2, indicating the presence of YoY individuals in all waterways except Edward River.

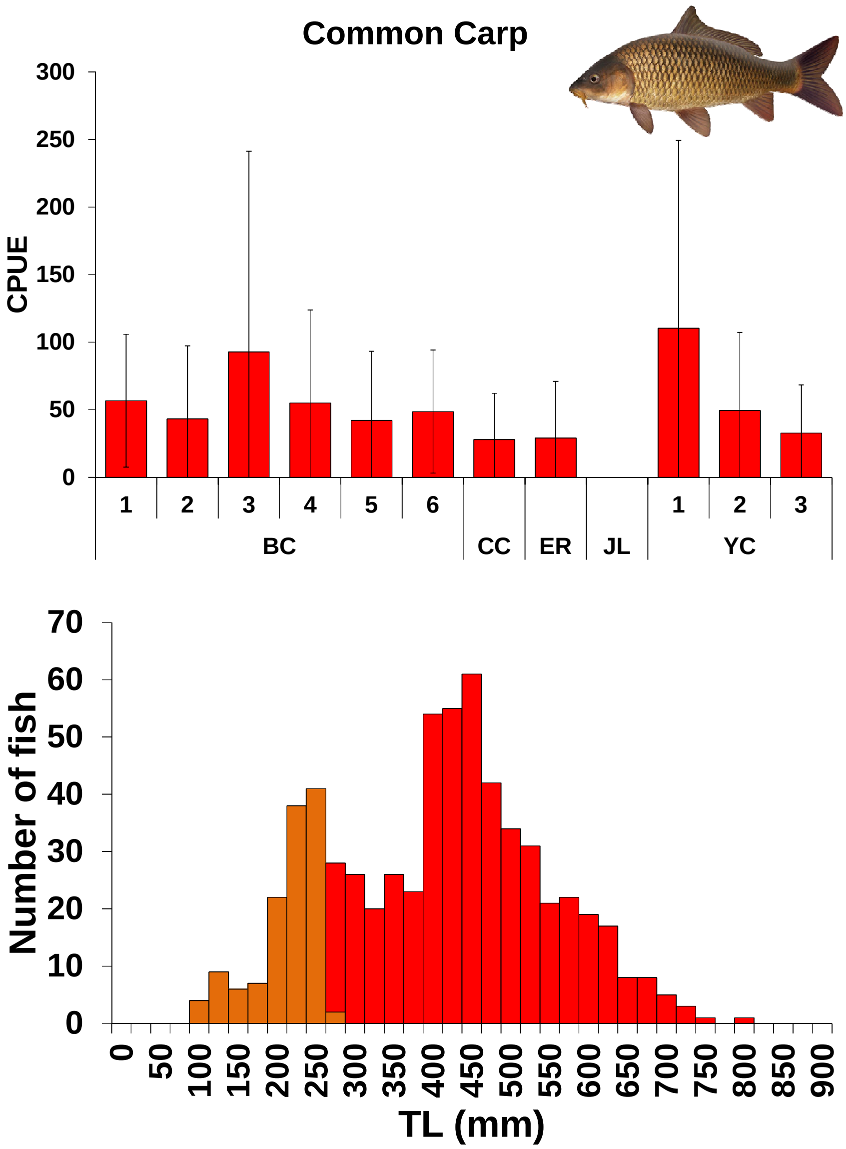

Figure 5.14 Top – CPUE (±SE) abundance (fish h^{-1}) of Common Carp sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with Young-of-Year fish in light orange (see Table 5.1).

European Perch – were sampled from Colombo Creek and Yanco Creek (Table 5.1), but not from the other waterways (Figure 5.15, top). The length-frequency distribution indicated the presence of YoY fish (Figure 5.15, bottom). A breakdown of length-frequencies across the five waterways is provided in Appendix Table A5 and displayed in Appendix Figure A2, indicating the presence of YoY individuals at Molly's Lagoon.

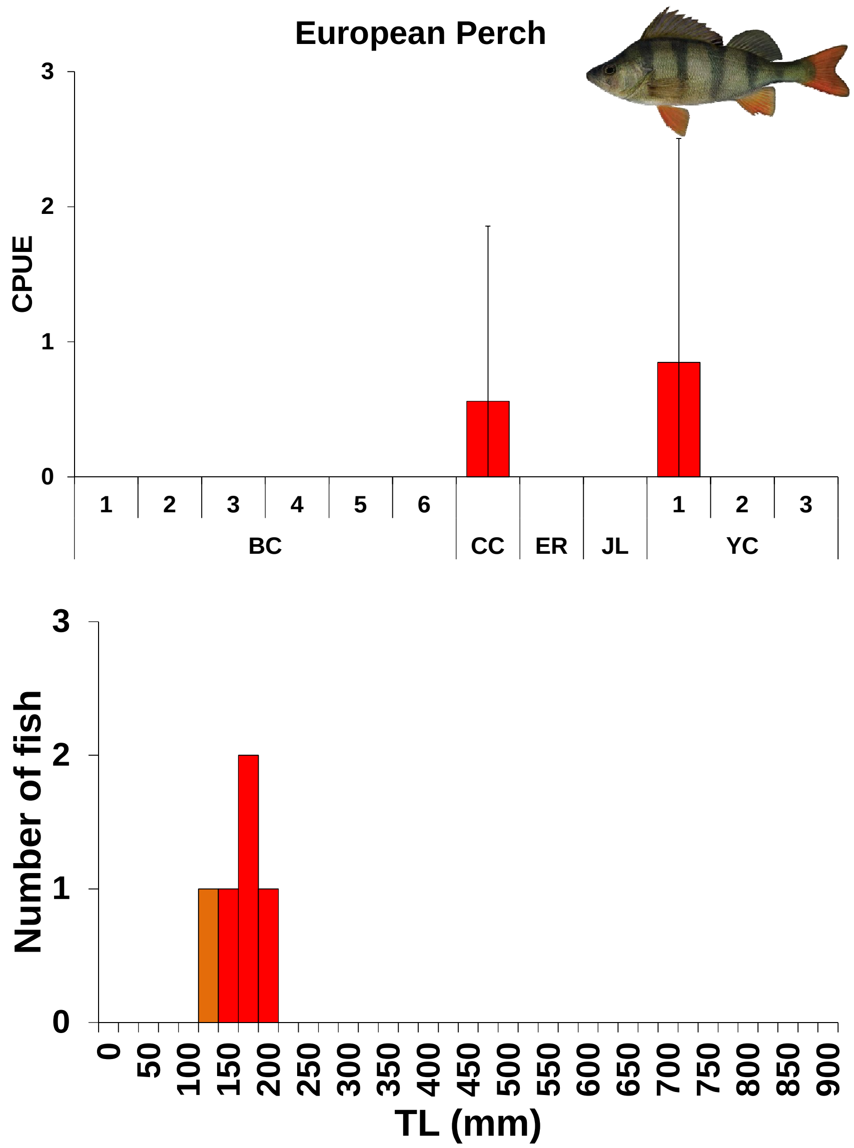

Figure 5.15 Top – CPUE (±SE) abundance (fish h^{-1}) of European Perch sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1). Bottom – Length-frequency distribution (TL = total length), with Young-of-Year fish in light orange (see Table 5.1).

Eastern Gambusia– were sampled from all waterways except Edward River (Table 5.1), and were comparatively more abundant at Yanco Creek and Billabong Creek (Figure 5.16).

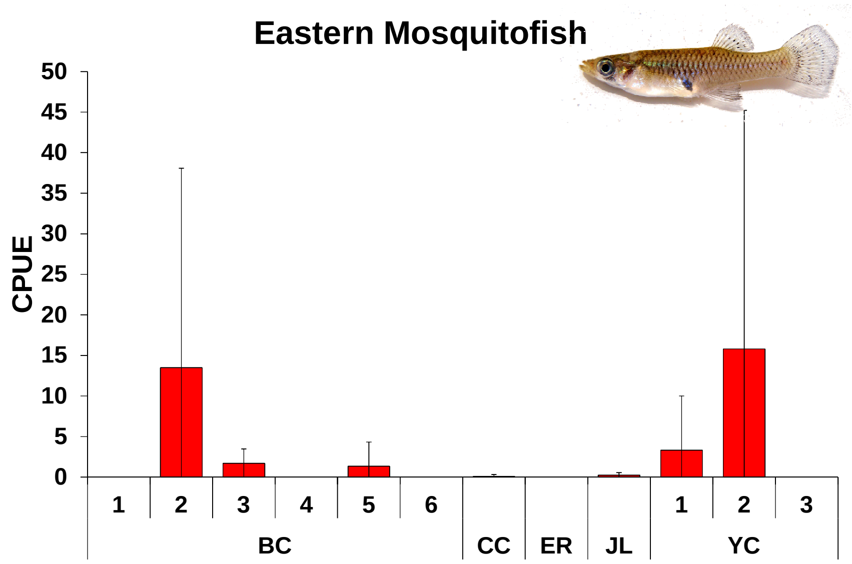

Figure 5.16 CPUE (±SE) abundance (fish h^{-1}) of Eastern gambusia sampled from five waterways and the reaches therein (waterway abbreviations and reach numbers in Table 2.1).

5.2.5 Spatial Patterns

At species level, there were significant differences in assemblage CPUE abundance and composition between Billabong Creek and Colombo Creek, Billabong Creek and Yanco Creek, and between Edward River and Yanco Creek (Figure 5.17, top; PERMANOVA results in Appendix Table A6). Specifically, Golden Perch and Murray Cod were more abundant in Billabong Creek, Un-specked Hardyhead, Australian Smelt and European Perch in Colombo Creek, Carp Gudgeon in Jerilderie Lake, and Murray-Darling Rainbowfish in Yanco Creek.

At the flow guild level, there were significant differences in CPUE abundance and composition between Billabong Creek and Colombo Creek and Billabong Creek and Yanco Creek due to Long-lived Apex Predators (Murray cod and Trout cod), Flood-Dependent Spawners (Golden perch and Silver perch) and exotic species being more abundant in Billabong Creek. Foraging Generalists (e.g. Carp gudgeon, Un-specked hardyhead, Murray-Darling rainbowfish) were most abundant in Colombo Creek, whilst Exotic species were also more abundant in Yanco Creek (Figure 5.17, bottom; PERMANOVA results in Appendix Table A6).

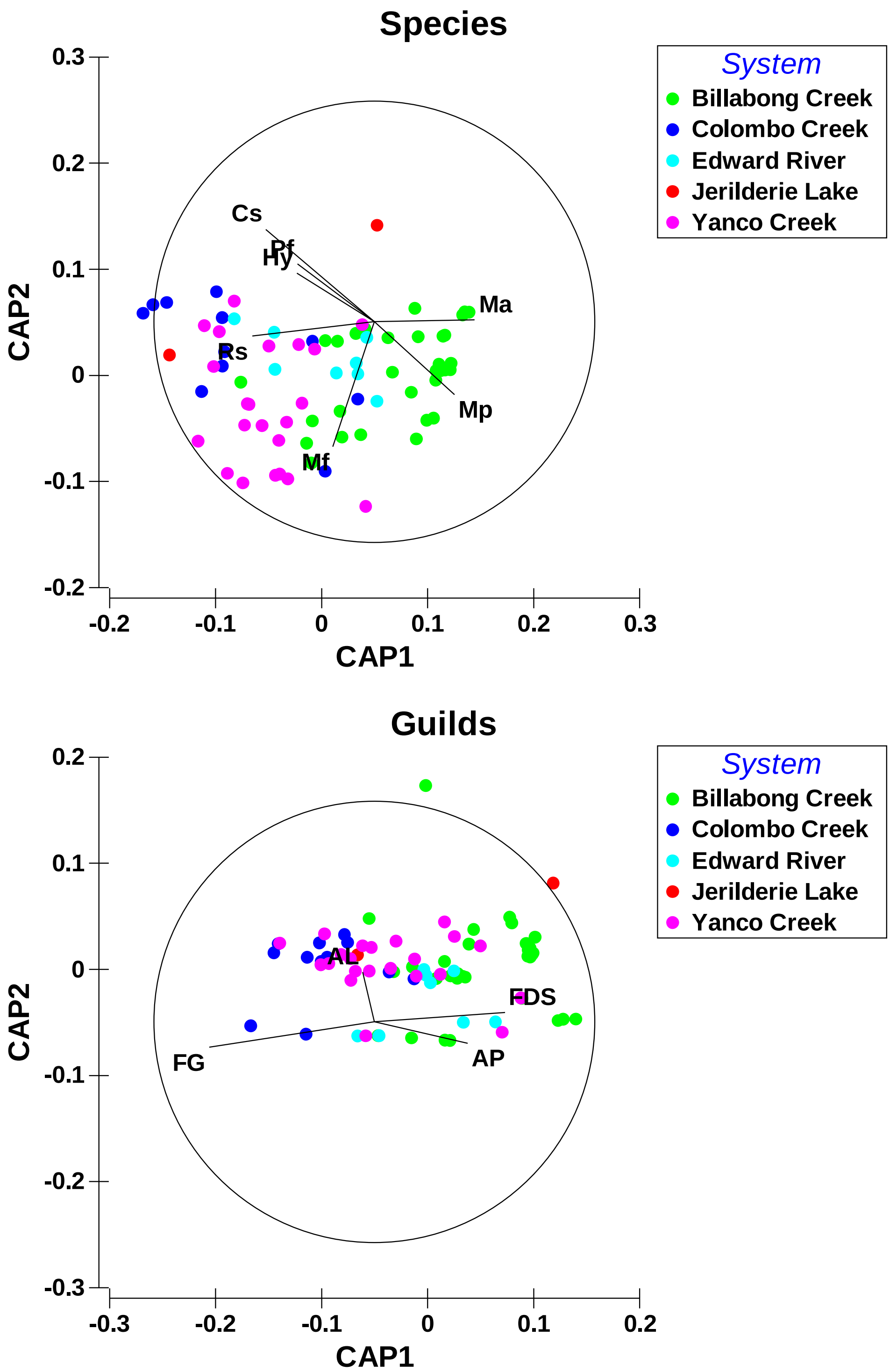

Figure 5.17 CAP ordination plots showing differences in fish species (top) and flow guild (bottom) assemblage composition and abundance amongst the five waterways. Only species with Spearman rank correlation coefficient ρ ≥ |0.4| with the first axis of variation (CAP1) are shown. Species and flow guild codes as in Table 3.1. PERMANOVA results in Appendix Table A6.

5.2.6 Species/Guild–Environment Relationships

The relationship between fish species abundance and environmental attributes showed that Jerilderie Lake and Colombo Creek were different from the other three waterways (i.e. Billabong Creek, Edward River and Yanco Creek) (Figure 5.18, top). Specifically, Jerilderie Lake was characterised by wider channel width, macrophyte density and abundance of Carp Gudgeon and Colombo Creek by higher density of macrophytes and abundance of Australian Smelt.

Snag density and complexity were highest at Yanco Creek, the only site where Trout cod were encountered and where Murray-Darling Rainbowfish was most abundant. Edward River was characterised by faster water velocities than other sits and more complex hydrodynamics in association with higher abundances of Murray cod (Figure 5.18, bottom left and right).

At the flow guild level, foraging generalists were predominant in Colombo Creek, Long-lived Apex Predators (most Murray cod) were more frequently encountered in Edward River, and Exotic species (mainly, Common Carp) were most abundant in Yanco Creek (see above) (Figure 5.19).

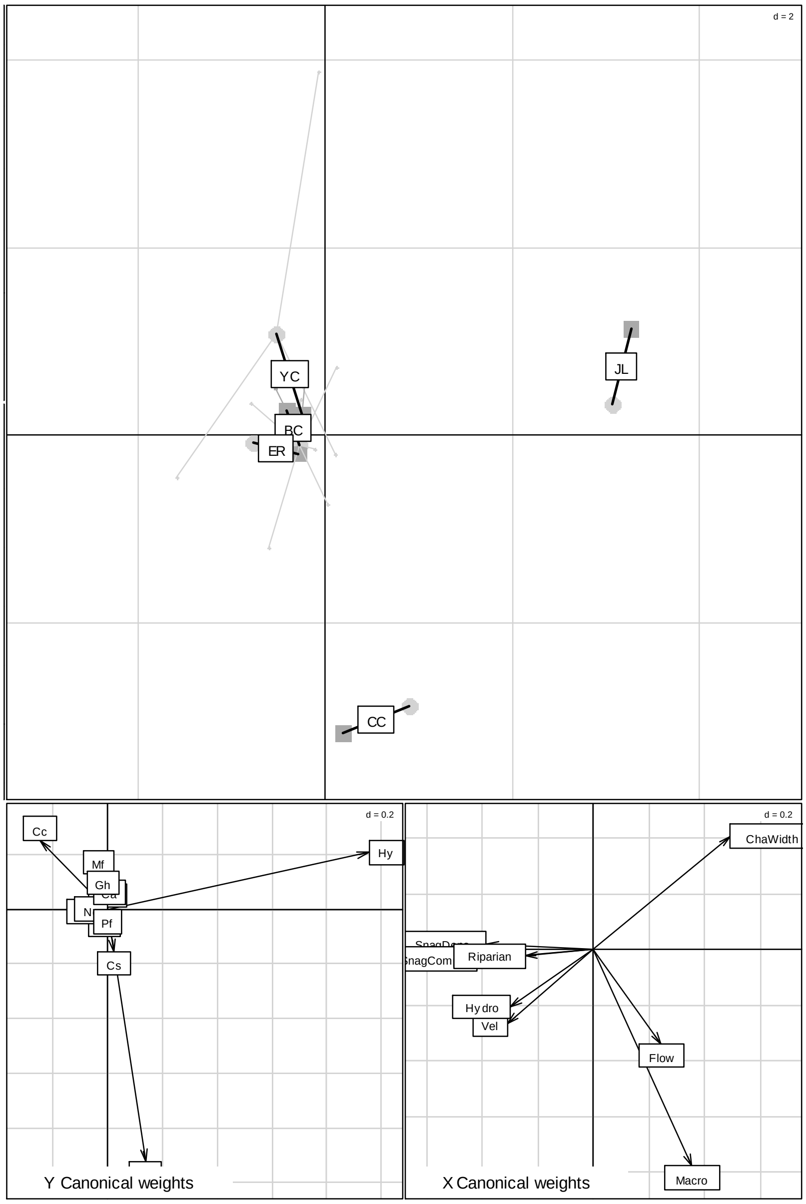

Figure 5.18 Between-class co-inertia analysis (bcaCOIA) results showing differences among waterways (top panel) and their relationships with the fish species (left bottom panel) sampled and environmental variables (right bottom panel) measured therein. Waterway codes as in Table 2.1; species codes as in Table 3.1; environmental variable codes as in Appendix Table A2.

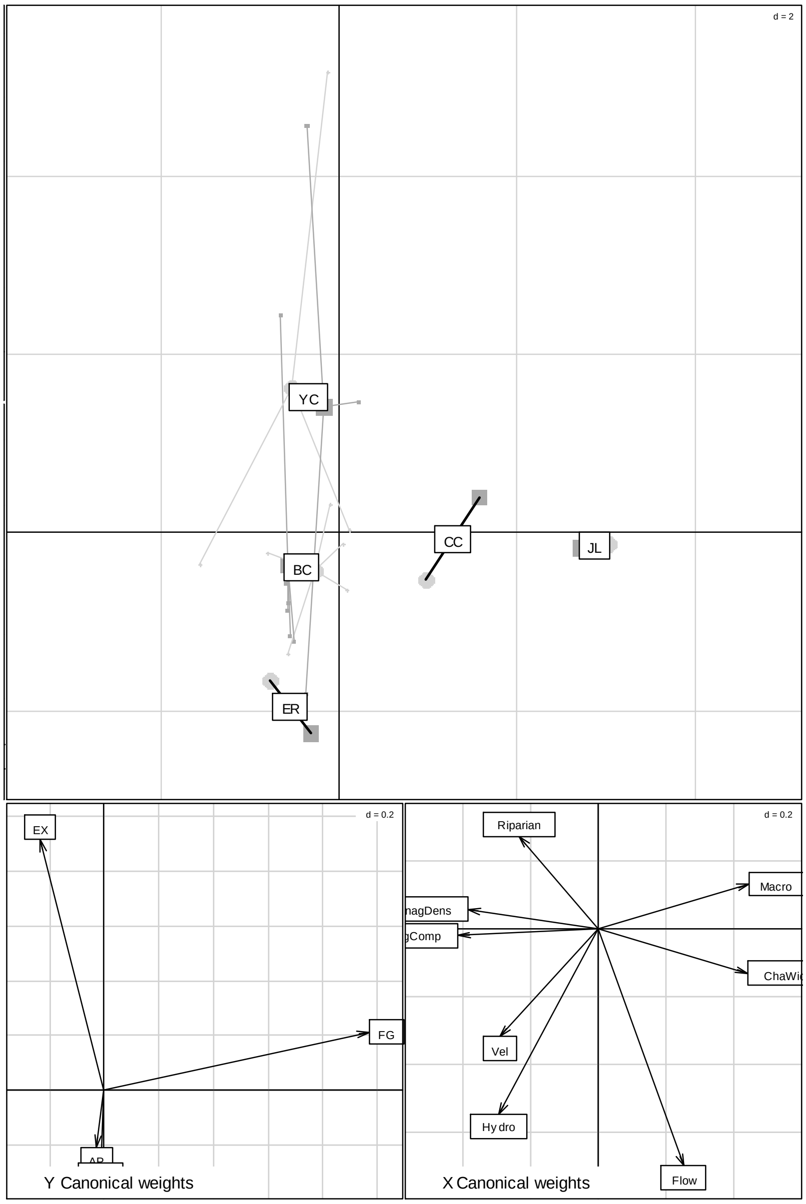

Figure 5.19 Between-class co-inertia analysis (bcaCOIA) results showing differences among waterways (top panel) and their relationships with the fish flow guilds (left bottom panel) sampled and environmental variables (right bottom panel) measured therein. Waterway codes as in Table 2.1; flow guild codes as in Table 3.1; environmental variable codes as in Appendix Table A2.

6 Discussion

6.1 Fish assemblage structure

The primary objective of this study was to determine the diversity, distribution and relative abundance of fish across the Billabong Creek catchment area. This was achieved by sampling 40 sites across a broad geographic region that encompassed Yanco Creek, Colombo Creek, Billabong Creek, Jerilderie Lake and the Edward River. To date this is most comprehensive survey regarding the distribution and structure of fish populations within these waterways. Across all sites, fourteen fish species were collected from ten native and four exotic species. A range of habitat attributes were collected in conjunction with fish surveys at each site and these were used to inform patterns in the occurrence and abundance of fish species.

The main findings of the study are:

- Fish populations across the study area are geographically fragmented. An example of this is for Colombo Creek which had few large-bodied native fish and no detectable Murray-Darling rainbowfish, as compared to the upper Yanco Creek and Edward River which exhibited species that are otherwise unique to the rest of the Billabong Creek system (Trout cod in Yanco Creek, Bony herring in Edward River).
- Freshwater catfish were collected albeit in relatively very low numbers in Billabong Creek, Yanco Creek, Colombo Creek and Edward River, with the capture of post-larvae catfish providing evidence of recent (2013) spawning in Edward River (Figure 6.1).
- A previously unrecorded population of the federally endangered Trout cod was discovered in Yanco Creek, upstream of Tarabah Weir (Figure 6.2). Although only seven trout cod were collected in that reach, those fish represented both sub-adult and adult size classes, from which there is a strong inference of recent recruitment with the population considered to be self-sustaining.
- The occurrence of trout cod was related to particular habitat conditions including strong hydrodynamic diversity (fast and slow flowing water), narrow channel width and complex physical habitat (snags).
- It is recommended that a targeted survey of the trout cod population be undertaken as a management priority to provide information on the actual spatial distribution, population structure and status of the population so that management can be directed to maintaining this very important population.
- Abundances of small bodied native species were overall low relative to comparable anabranch creek systems such as Gunbower Island (Sharpe et al. 2013).
- Small bodied native species were surprisingly absent from some sites in Billabong Creek, despite gear types being deployed to maximise encounter rates (small fyke nets set overnight).

- The lack of aquatic plants at the majority of survey sites in Billabong Creek was associated with low diversity and abundance of small bodied native species.
- The exception was at Jerilderie Lake, where aquatic plants occurred at very high density. This occurred in conjunction with very high abundances of several small bodied native species, in particular the native Carp gudgeons. This positive association was supported statistically.

A unique aspect of the upper Yanco reach is that irrigation flows are diverted down the creek from the Murrumbidgee River every year, and this supports the fish community of this reach. The upper reaches of tributaries often support strong populations of Murray cod, such as Mullaroo Creek, and for Yanco Creek the same logic appears to apply for Trout cod. We suggest that irrigation flows can potentially be used to suit the specific requirements of Trout cod and better support the population (addressed in more detail below).

Amongst the more than thirty weirs that exist throughout the waterways examined in this study, the Tarabah Weir on Yanco Creek is the only weir that permits upstream and downstream fish passage via a fishway. The Tarabah Weir fishway is likely to enable unrestricted movement of fish throughout this important reach. At a catchment scale, the lack of fishways and the present fragmented nature of fish communities (patchy distribution of some species) and populations (various age classes absent from longer lived species) is direct evidence of the urgent need to work with StateWater to prioritise fish passage at the remaining weirs (Alluvium 2012).

Historical fish community

The fish species collected in the present study are representative of previous survey data and neighbouring waterways, such as the Murrumbidgee River (Gilligan 2005; Baumgartner 2007; Lintermans 2007; Wassens et al. 2012; SRA 2007) and the Edward-Wakool system (Gilligan et al. 2009; Baumgartner et al. 2013). Notably, several native species are absent from the fish community and these have undergone major range reductions throughout the Murray-Darling river system in the past 50 years, including southern pygmy perch, Murray jollytail, olive perchlet and southern purple spotted gudgeon. Those species cannot be expected to naturally recolonise the waterways examined in the present study because they are locally extinct or very rare in neighbouring source-waters and it is only via restocking that some of these may re-establish populations. For Murray CMA, liaising with NSW DPI to discuss restocking of locally extinct native species is recommended at high priority sites. More detail is provided below for one site examined in the present study that is considered suitable - Jerilderie Lake.

Non-native species

Carp dominated (63%) the fish biomass in the study area, particularly in Billabong Creek, with populations showing a structured size range indicative of strong annual recruitment. The exception was for Edward River, where no young-of-year carp were detected, which suggests limited recruitment in the 2012/13 breeding season. The absence of young carp in the Edward River may simply be a sampling artefact (due to the low number of sites examined relative to other waterways) or may be related to a specially designed native fish hydrograph recently trialled in the Edward-Wakool system (Baumgartner et al. 2013). Control of carp with integrated techniques has also been recently applied in the catchment (Gilligan et al. 2010) and the Williams' carp separation cage is known to be useful at fishways (Conallin et al. 2008). For Murray CMA the current (2013/14) carp separation cage trial on the Edward-Wakool waterway will be important in determining future recommendations to control this invasive pest across the Billabong Creek catchment.

Goldfish, gambusia and redfin were also collected but at low abundances relative to carp and other native species. Those species are common throughout the majority of waterways of the Murray and Murrumbidgee catchments (Gilligan 2005; Baumgartner 2007; Lintermans 2012). One species that was expected but not detected in the present survey was oriental weatherloach. Although weatherloach were only recently recorded in the study area, in 2011, they were not collected in our 2013 survey, indicating that colonisation has been neither expansive nor intensive (Wassens et al. 2012). Eastern gambusia occurred in all waterways except Edward River, and were found at most survey reaches, but at moderately low levels of abundance. Gambusia have the potential to proliferate and then exclude native species, particularly in slow flowing waterways and wetlands (Sharpe et al. 2013). There are few opportunities to control gambusia apart from restoring native fish habitats and flow regimes that favour native fish (Baumgartner 2013; Tonkin et al. 2013; Ho et al. 2013).

6.2 Large-bodied native fish management

Fish recruitment

There was little evidence for recruitment for any of the large-bodied native fish species recorded, with the only exceptions being very small numbers of juvenile sized golden perch in Billabong Creek and a few young of the year sized Trout cod in Yanco Creek. Overall, the size structure of each large bodied fish population indicates a fragmented pattern of recruitment with numerous year-classes being absent, albeit less noticeable for golden perch and Murray cod in Billabong Creek. Small numbers of young-of-year golden perch have previously been collected in Mollies Lagoon (Wassens et al. 2012), the prevalence of which may be enhanced with simple recovery actions (see Table 6.1).

Recent research has provided greater certainty around the conditions that support large bodied fish recruitment, which include implementing a hydrograph designed to facilitate recruitment (with hydrodynamic diversity and a shaped flow peak), restoring fish passage and physical habitat (Baumgartner et al. 2013). The major benefit of a fish hydrograph is that there are explicit fish outcomes using *improved delivery mechanics* rather than extra or less water. We suggest that a partnership between irrigators, Murray CMA and StateWater to restore key flow components to the upper

Yanco and Billabong Creeks to accommodate key life history processes for native fish. Such an approach has been successfully trialled in the Edward-Wakool system NSW (Baumgartner et al. 2013) and at the Gunbower Island TLM Icon Site (Sharpe, Stuart and Mallen-Cooper *in prep*). In the Billabong Creek system this would be highly beneficial for recovery of Trout cod, Murray cod and catfish, with potential extension to golden perch and silver perch.

Yanco Creek Case study

Here we use Yanco Creek as a case-study of regulated flow regimes and ways to optimise flows for native fish *without* large-scale significant changes to the delivery of water for irrigation. Yanco Creek is used here to discuss opportunities but these ideas are equally applicable to Billabong Creek, Colombo Creek and the Edward River.

Yanco Creek present hydrology

Yanco Weir on the Murrumbidgee River near Narrandera diverts water into Yanco Creek to meet downstream irrigation and stock and domestic requirements. Typical maximum flows during spring/summer are about 1,400 ML/day and during autumn/winter flows are reduced to around 70 ML/day. The regulated hydrology includes more water during summer than under natural conditions, where the upper Yanco Creek was once predominantly an ephemeral system with flow only in 1 in 2 years (Wealands et al. 2012).

We do not advocate a return to natural conditions because there are downstream users and also because after many years of regulation the creek geomorphology and hydrodynamics have likely changed; sediment has filled deep holes that were drought refugia in the past and in some reaches flowing dynamics have changed to become weirpools. Restoring a more natural flow regime in these conditions may not necessarily make any ecological improvements. For example, restoring ‘natural’ low flow periods may be harmful to existing fish populations if deep hole refugia are absent, whilst adding flow to a weirpool may be insufficient to create flowing water and hydrodynamic complexity (Mallen-Cooper at al. 2013).

The present hydrology of Yanco Creek is not optimised for fish recovery because there is:

(i) reversed seasonality with high flows in summer and low flows in winter,
(ii) weir pools that lack fast flowing reaches interspersed with slow-flowing reaches,
(iii) much greater daily variation in water height
(iv) high winter weir pool levels but with little passing flow,
(v) reduced end-of-system flow.

Currently there is a particular impact of a non-optimised hydrograph for Trout cod, Murray cod and Catfish, as these are nesting species. Hence, without an appropriate rate of water rise and fall in water levels there can be impacts on key processes such as courtship, nesting site selection, nest abandonment, egg survival and larval survival. For Murray CMA, a key recommendation to support native fish is implementation of a hydrograph that enables key fish life-history stages to be completed, such as flows to enhance trout cod spawning, movement and dispersal. Because it is unclear whether trout cod spawn in Yanco Creek a targeted larval survey is also recommended (see Table 6.1).

Development of a fish hydrograph for upper Yanco Creek

A generic hydrograph, not specifically for Yanco Creek, but an example that can be used as a starting point is shown in Figure 6.1. Firstly, the shape of the hydrograph is based upon providing a late winter rise, which should provide a steady bankfull peak without sharp decreases in level. This will enable trout cod and Murray cod to select nesting sites, undertake courtship and spawn, and for larvae to emerge and drift downstream. Secondly, a winter base-flow should be provided so that small fish are not forced into remnant pools where they are exposed to high mortality result of predation and limited food resources which increase potential for starvation.

In summary, the upper Yanco waterway provides a unique opportunity for Murray CMA, fish scientists, managers and water operators to work together to design and implement a hydrograph to support this previously unrecorded, regionally significant and endangered trout cod population. The hydrograph can be embedded within the present arrangements for delivery of irrigation water and this would demonstrate a collaborative ecological solution within a working river.

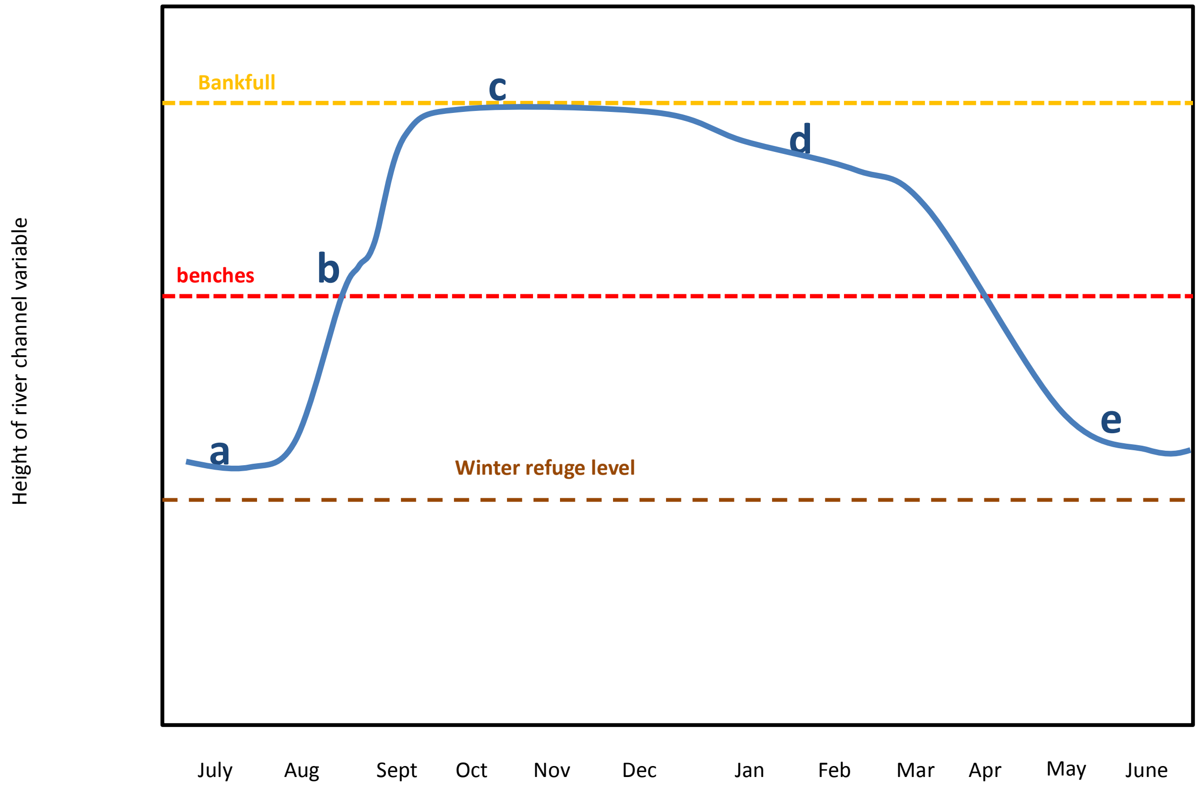

Figure 6.2. A generic hydrograph to support trout cod populations in the upper Yanco Creek. The key components are (a) a higher winter base flow to enable fish survival in deep water, (b) late winter flow ramp up onto benches to stimulate productivity, fish movement and gonad development, (c) bankfull flows during spring and early summer (September to Christmas) to allow courtship, spawning, nesting and larval dispersal, (d) slow ramp down post Christmas back to (e) winter refuge level. This hydrograph proposes *improved water delivery* rather than extra water.

6.3 Small-bodied native fish management

The small bodied fish collected during the present project constitute a valuable fish fauna and included many of the commonly occuring species: Murray Darling rainbowfish, Australian smelt, carp gudgeons and un-specked hardyhead. These species are common but occasionally patchily distributed in regulated rivers and also in floodplain wetlands. For example, unspecked hardyhead were common in Colombo but rare elsewhere, while Murray-Darling rainbowfish were common in Yanco Creek but uncommon at the other sites. These patterns may reflect highly modified waterways, recent blackwater events, limited habitat availability (in particular lack of aquatic plants) or simply the sites that were sampled. Similar to the implementation of a 'large-bodied fish hydrograph' which accommodates key life history processes for targeted guilds of species, a 'small bodied fish hydrograph' can be designed, implemented, monitored and refined to increase spawning and recruitment opportunities and thus the occurrence and resilience of small bodied fish populations. A small bodied fish hydrograph would have different characteristics to a large bodied fish hydrograph. An example of a small bodied fish hydrograph and its ecological components is described in Figure 6.2.

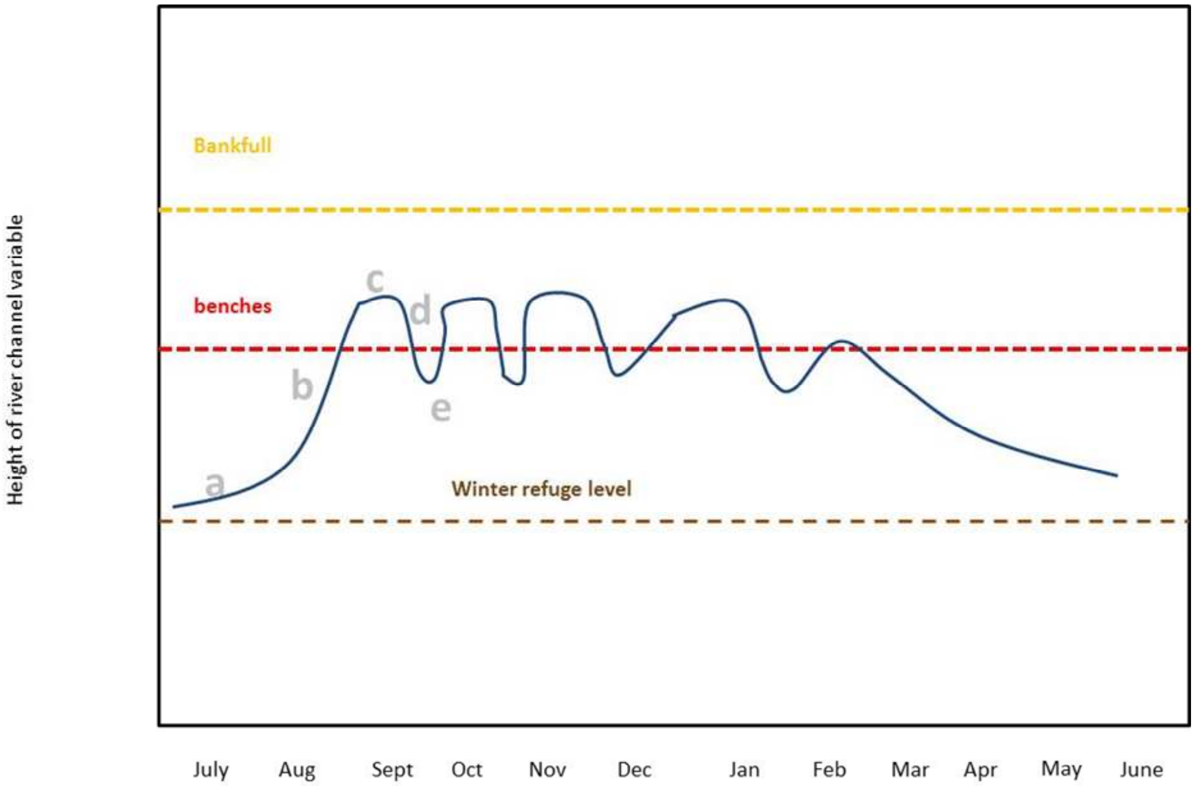

Figure 6.2. A generic hydrograph to support populations of small bodied native fish in the Billabong Creek system. The key components are (a) a higher winter base flow to enable fish survival in deep water, (b) late winter flow ramp up onto benches to stimulate productivity, fish movement and gonad development, (c) bankfull flows during spring and early summer to promote successional processes on benches and to inundate spawning habitats (September to January) to allow courtship, spawning, nesting and larval dispersal, (d) ramp down promote successional processes and larval dispersal and (e) ramp-up to promote second and then multiple spawning sequence. This hydrograph proposes *improved water delivery* rather than extra water

The importance of the floodplain to small-bodied fish

Regular connection of the major creeks with their adjacent floodplain wetlands provides habitat diversity and facilitates the flow of productivity to waterways and their fish communities. One aspect of the ecology of small-bodied fish is that they move from major water courses (e.g. Yanco Creek) laterally into floodplain wetlands to utilise floodplain productivity (Conallin et al. 2011). In the present study we did not sample many wetlands (only Mollies Lagoon and Jerilderie Lake) and hence the fish fauna of many other off stream habitats remains to be determined. Many creeks and wetlands are managed for irrigation rather than fish and have inlet and outlet control structures. We suggest that Murray CMA investigate high value wetlands (e.g. Mollies Lagoon) in terms of restoring wetland hydrographs to optimise outcomes for in particular small bodied native fish. Practically this means regulator operating protocols that enhance native fish movement and recruitment while minimising risks such as stranding or blackwater.

Jerilderie Lake

Within the scope of the present project there was an opportunity to survey some waterways where there was no existing information, including Jerilderie Lake. Jerilderie Lake, managed by local council, dried during the drought and has since been refilled through a small diameter pipe. This explains why few large bodied fish were collected, with only the only large bodied fish collected being golden perch, which were stocked into the lake by NSW DPI. Importantly, carp and redfin have not recolonised the lake.

Within Jerilderie Lake there is a very strong population of carp gudgeons which were closely associated with very dense submerged aquatic plants, mainly *Vallisneria* sp. The absence of carp and redfin, along with the macrophytes, indicates that Jerilderie Lake would be an appropriate habitat for stocking other small bodied fish (e.g. Murray Darling rainbowfish and un-specked hardyhead) and threatened small-bodied fish, such as olive perchlet and southern pygmy perch. If populations of these common occurring and threatened species could be established then it could be used as a source for further stocking throughout the region and ultimately an improvement to the regional fish community. These recovery recommendations for small-bodied fish could be supported as Jerilderie community participation events.

6.4 Why are fish populations degraded?

Native fish populations in the five waterways occurred at relatively low abundances and as fractured populations with some species being locally extinct. The poor numbers are due to three main factors:

- Connectivity
    - Existing weirs prevent fish entering the waterway to recolonise from the Murrumbidgee River, or leaving the waterway to complete spawning migrations and recolonisation of adjoining areas.
    - Loss of fish into irrigation channels.
- Flow
    - Zero and low winter flow provides very poor habitat, especially in Yanco Creek.
    - Little end-of-waterway flow back to the Edward River, so there is no stimulus for fish to enter Billabong Creek.
    - Hydrodynamic diversity (fast and slow-flowing reaches) is reduced by lack of flow in winter and weir pools.
    - Loss of small permanent wetlands (key threatened species habitat).
    - Regular blackwater events in some waterways have also significantly reduced fish populations

- Habitat
    - Snags have been removed or ‘realigned’ in the past.
    - Stream edges are degraded by cattle.

All of these impacts can be readily addressed by proven techniques such as fishways, providing suitable flows, and habitat rehabilitation. Importantly, because these waterways are anabranches, the key opportunity is that any additional flow used for fish is returned to the waterway. Hence, recovery recommendations do not depend on large water allocations and can be integrated into the existing water delivery schedule.

6.5 Fish recovery in working rivers

Other regulated anabranches (e.g. Mullaroo Creek in north western Victoria, Gunbower Creek in Victoria mid-Murray River near Barham) have revealed that the streams and associated habitats that are used to deliver irrigation water have, in fact, immense potential to support thriving populations of native fish and become a functioning part of the broader river ecosystem (Mallen-Cooper et al. 2013). The Yanco/Billabong area would not only be an adjunct of main river ecosystems but it would become a critical component. The streams and wetlands would act as refuges during droughts and during ‘blackwater’ events in the main river that kill high numbers of fish.

The Billabong/Yanco waterways have high potential for fish population recovery, particularly with a new approach that views irrigation as part of sustainable healthy rivers where there is emphasis on the support and input of the local community, irrigators, government and the Aboriginal community. In this way, fish population recovery will have common goals with stakeholders as an essential part of river restoration. This philosophy differs from the more traditional approach of returning waterways to as close to natural conditions as possible as more can be achieved by realising the potential of irrigation flows (Baumgartner et al. 2013; Mallen-Cooper et al. 2013, Sharpe, Stuart and Mallen-Cooper *in prep*).

Yanco Creek provides greater ecological value regionally as a permanent flowing-water habitats connected to the Murrumbidgee River and its adjacent wetlands, which provide an integrated mosaic of habitat diversity. With habitat rehabilitation these streams would become spawning and nursery areas for native fish, as well as migration pathways. Hence, for these streams, flow, connectivity and habitat become key actions.

7 Recommendations

The primary objective of this project was to collect information on the distribution, relative abundance, diversity, and condition of fish communities throughout the Billabong, Yanco and Colombo creek waterways to aid management decisions by Murray CMA. These data now provide a comparative baseline for future studies.

The main fish recovery recommendations from this report are summarised in Table 6.1, which also includes an integrated monitoring plan to demonstrate restoration of fish populations. The major recommendations and monitoring requirements are:

1. Trout cod status investigation and recovery plan for the Yanco Creek.
2. Catfish population status and recovery plan for the Billabong Yanco and Colombo Creek system
3. Implement a native fish hydrograph (e.g. winter base flow and optimised spring spawning flow) to support trout cod and native fish in Yanco Creek and monitor to demonstrate success (e.g. spawning, recruitment).
4. Manage Jerilderie Lake to form a source population for small-bodied native fish.
5. Manage floodplain wetland inundation cycles to enhance native fish recruitment/recovery.
6. Assess the effectiveness of the Tarabah Weir fishway for native fish and as a potential site to remove carp with a carp cage.
7. Reassess the weirs within the system to determine their current and future role and potential for removal.

Table 6.1. Priority fish Recovery Recommendations for consideration by Murray CMA.

River waterway	Recovery recommendation	Priority	Monitoring requirements/measure of success	Monitoring action (timing/method)
Billabong, Yanco and Colombo	Prioritise weirs and barriers for removal or fish passage	VERY HIGH	Native fish population response to improved fish passage	Scope this project
Yanco Creek	Winter base flow to support trout cod	VERY HIGH	Specific survey to determine trout cod abundance/population structure	Habitat assessment (WINTER: depth, snags) Trout cod demography, electrofishing survey (WINTER)
Yanco Creek	Implement native fish recovery hydrograph	VERY HIGH	Native fish diversity and recruitment Demonstrate enhanced trout cod spawning/recruitment after improved flow/habitat management Regional trout cod population enhanced	Eggs and larvae survey timed to coincide with flow event to determine broad spawning patterns: spawning in Yanco Creek and/or Murrumbidgee River (SPRING: targeted larvae survey) Trout cod demography, electrofishing survey (SPRING) Strong age class response from target species (AUTUMN: fish sampling/ageing)
Jerilderie Lake	Stock with small-bodied fish (e.g. rainbowfish, hardyhead, southern pygmy perch) to provide baseline population to recover regional populations	VERY HIGH	Recruitment/establishment of a source population of small-bodied fish and threatened species	Monitor small bodied fish recovery (SPRING: survey every 2 years) Monitor to ensure carp and redfin are absent
Yanco Creek	Fish passage	VERY HIGH	Determine the effectiveness of the fishway for passing native fish and carp. Assess potential for construction of a carp cage	Fishway trapping and/or acoustic movement study and/or micro chip study.
Billabong, Yanco and Colombo Creeks	Recover catfish populations	VERY HIGH	Design and implement hydrograph to enhance catfish spawning and recruitment opportunities.	Determine spatial distribution of adults in system particularly Colombo Creek near Upper Sheepwash Weir Long-term monitoring to detect recruitment
Yanco Creek	Re-snagging upper reach to support trout cod	HIGH	Trout cod abundance	Map present snag density (WINTER) Prioritise areas for re-snagging
Mollies Lagoon	Enhanced connectivity/inundation regime to optimise fish recruitment	HIGH	Golden perch and native fish recruitment, passage, nil stranding Develop regulator operations protocol and optimise inundation patterns	One-off survey to provide recovery data and actions (SUMMER)
Floodplain lakes	Provide fish access to and from wetlands	HIGH	Conduct a baseline fish survey of high priority wetlands Develop wetland regulator operating protocols to enhance fish passage, fish recruitment and reduce risks of blackwater and fish stranding	Fish recruitment in floodplain lakes (annual sampling, ageing)

8 References

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9 Statistical Methods

9.1.1 Spatial Patterns

Multivariate patterns in fish assemblage composition and abundance (CPUE) across waterways and reaches within waterways were analysed by permutational multivariate analysis of variance (PERMANOVA) separately on the species and flow guilds.

Two data matrices were produced: 77 × 14 (samples × species) and 77 × 4 (samples × flow guilds), with the samples represented by the combinations of Waterway × Reach(Waterway) × Site. The statistical analyses were based on the completely randomised hierarchical design described above, with a different number of reaches nested within each waterway (hence, unbalanced design: Milliken and Johnson, 2008). Waterway (five levels: Billabong Creek, Colombo Creek, Edward River, Molly's Lagoon, Yanco Creek) was the main factor, Reach (seven levels for Billabong Creek, one for Colombo Creek, One for Edward River, one for Molly's Lagoon, two for Yanco Creek) the nested (within-waterway) factor, and Sites the experimental units (nested within each reach). Both factors Waterway and Reach(Waterway) were fixed, Site was random.

CPUE abundance data were first √√-transformed (because of abundance values spanning across three orders of magnitude) and a Bray-Curtis dissimilarity measure then applied to the resulting resemblance matrices. Statistically significant effects were followed by *a posteriori* pairwise comparisons ($\alpha = 0.05$).

Canonical (discriminant) analysis of the principal coordinates (CAP) ordination (Anderson and Willis 2003) was used in support to PERMANOVA to display patterns in fish community composition and abundance across macrohabitats. Choice of the number of CAP axes was automatic and identification of the species responsible for the patterns was based on an absolute value of the Spearman rank correlation coefficient $|\rho| \geq 0.4$, which represented a good compromise between retention of the most important species responsible for the patterns and clarity in visual interpretation of the ordination plots. Whereas, all flow guilds were retained due to their limited number.

All multivariate statistical analyses were carried out in PERMANOVA+ for PRIMER v6 (Anderson et al. 2008), with 9999 permutations of the residuals under a reduced model.

9.1.2 Species/Guild–Environment Relationships

Relationships between species/flow guilds and environmental variables were investigated by between-class Coinertia Analysis (bcaCOIA) (Franquet et al. 1995;

Chessel and Thiolouse 2003). This is a multivariate technique similar to ‘more conventional’ redundancy analysis and canonical correspondence analysis but more flexible and free from some of the contraints with the latter. Analyses were carried out in R x64 v3.0.1 (R Development Core Team 2008.

9.1.3 Nativeness

Differences in nativeness (native/exotic species ratio) across the five waterways under study were tested by permutational univariate analysis of variance (PERANOVA). The 39 × 1 (samples × nativeness) data vector, with the samples represented by the sites sampled within reaches and within waterways, was first normalised and a Euclidean dissimilarity measure applied. A one-factor design was used to test for differences between the four macrohabitats with a posteriori pair-wise comparisons at $\alpha = 0.05$. Statistical analysis was carried out in PERMANOVA+ for PRIMER v6 (Anderson et al. 2008), with 9999 permutations of the raw data.

9.2 References

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10 Appendices

Appendix Table A1 Water quality parameter values measured across the five waterways under study.

Waterway Reach Site	pH	EC (µS cm^{-1})	DO (mg L^{-1})	Turbidity (NTU)	Temperature (°C)
Billabong Creek					
Caroonboon to Wanganella					
Millabong	7.68	151	7.65	120	12.5
Wanganella Common	7.74	144	7.04	159	13.6
Conargo to Jerilderie					
Algudgerie TSR	7.95	141	7.99	106	15.9
Hartwood TSR	7.72	128	6.94	115	15.3
Old Coree	7.61	131	7.08	115	15.2
Quiamong d/s Hartwood Weir	7.72	128	6.98	114	16.0
Jerilderie to Colombo					
Gammons Jerilderie	7.91	155	8.13	89	16.4
Innes Bridge TSR	7.98	208	8.58	95	17.2
The Cape TSR	8.93	155	7.86	104	25.6
Moulamein to Windouran					
Billabong Moulamein Town Bridge	7.59	149	7.28	101	11.7
Billamien	7.90	144	7.94	245	13.6
Windouran	7.81	131	7.68	124	13.7
Wanganella to Conargo					
Booabula u/s Chinamans Weir	7.63	149	6.61	116	14.0
Conargo Town Common	7.72	135	7.25	54	13.9
North Run	7.79	146	7.83	57	13.7
Windouran to Caroonboon					
Back Nullum	7.88	138	8.17	189	13.9
Caroonboon Weir d/s	7.91	146	8.17	105	13.5
Murgha Rd bridge	7.78	135	7.41	239	12.8
Colombo Creek					
Colombo Creek					

Bindiwilla Urana	7.69	141	7.29	42	16.1
Boonongo	7.84	111	7.71	94	16.2
Boonongo Mud Bank Colombo Creek d/s Upper Sheepwash Weir	7.17	130	4.18	10	12.0
Chesneys Weir d/s	7.83	131	8.14	34	17.0
Chesneys Weir u/s	7.86	124	7.54	32	16.7
Colombo Creek Eight Mile Weir Pool via Colombo Ski Club	7.70	132	7.74	14	12.3
Edward River					
Edward River at Moulamein					
Edward River d/s Billabong Creek 2A	7.84	97	7.85	122	12.9
Edward River ds Moulamien	7.66	75	7.93	81	11.8
Edward River u/s 1A	7.65	60	7.62	69	12.7
Edward River u/s Moulamien 2	7.84	72	7.89	77	12.1
Jerilderie Lake					
Jerilderie Lake					
Jerilderie Town Lake	8.02	413	7.63	45	12.5
Yanco Creek					
Molly's Lagoon					
Molly's Lagoon 1	7.33	132	6.13	112	11.1
Molly's Lagoon 2	7.56	132	6.19	143	12.0
Yanco Creek d/s Tarabah Weir to Billabong					
Mundoora Jerilderie	7.87	163	7.81	71	16.3
Wilson Rd Bridge	7.82	135	7.90	52	14.4
Wononga Jerilderie	7.74	132	6.86	36	14.7
Yathong TSR	7.88	110	7.91	101	17.3
Yanco Creek u/s Tarabah Weir					
Devlins Bridge Yanco Ck	7.75	136	8.51	29	12.6
Wirrani	7.90	137	8.21	38	12.4
Yanco Creek d/s Molly's Lagoon	7.86	124	8.08	55	12.3
Yanco Creek u/s Molly's Lagoon	7.75	186	7.40	133	11.8
Yarrabee TSR Yanco	7.75	186	7.40	133	11.8

Appendix Table A2 Environmental variable values measured at the site level across the reaches within waterways sampled for fish. Flow = Channel flow status; Vel = Flow velocity; Hydro = Hydrodynamics; Macro = M; SnagDens = Structural woody habitat (snags) density; SnagComp = Structural woody habitat (snags) complexity; Riparian = Riparian zone; ChaWidth = Channel width.

Waterway Reach Site	Flow	Vel	Hydro	Macro	SnagDens	SnagComp	Riparian	ChaWidth
Billabong Creek								
Caroonboon to Wanganella								
Millabong	5	4	4	1	4	5	4	32
Wanganella Common	5	2	2	1	3	3	2	30
Conargo to Jerilderie								
Algudgerie TSR	5	2	3	2	2	3	5	36
Hartwood TSR	5	2	2	2	3	5	4	32
Old Coree	5	3	3	1	5	6	4	32
Quiamong d/s Hartwood Weir	5	3	3	1	3	4	4	36
Jerilderie to Colombo								
Gammons Jerilderie	5	4	4	1	5	6	2	32
Innes Bridge TSR	4	4	4	1	5	6	4	32
The Cape TSR	5	3	3	3	3	5	2	26
Moulamein to Windouran								
Billabong Moulamein Town Bridge	4	3	3	1	2	3	1	21
Billamien	5	3	2	1	2	4	2	26
Windouran	4	4	4	1	5	6	5	20
Wanganella to Conargo								
Booabula u/s Chinamans Weir	5	2	2	2	2	3	3	38
Conargo Town Common	5	3	3	2	4	5	3	30
North Run	4	4	4	1	5	6	4	22
Windouran to Caroonboon								
Back Nullum	4	4	4	1	5	6	3	19
Caroonboon Weir d/s	4	4	4	1	5	6	5	26
Murgha Rd bridge	5	2	2	1	3	5	3	29
Colombo Creek								
Colombo Creek								
Bindiwilla Urana	5	4	4	3	4	5	2	32
Boonongo	5	3	3	2	4	4	3	38
Boonongo Mud Bank Colombo Creek d/s Upper Sheepwash Weir	6	1	1	4	2	2	3	49
Chesneys Weir d/s	5	4	4	2	2	3	3	24

Waterway / Reach / Site	Flow	Vel	Hydro	Macro	SagDens	SnagComp	Riparian	ChaWidth
Chesneys Weir u/s	6	2	2	2	2	4	2	43
Colombo Creek Eight Mile Weir Pool via Colombo Ski Club	6	2	1	5	2	3	4	46
Edward River								
Edward River at Moulamein								
Edward River d/s Billabong Creek 2A	5	3	4	1	4	6	3	26
Edward River ds Moulamien	5	4	4	1	5	6	3	43
Edward River u/s 1A	5	3	4	1	4	5	3	28
Edward River u/s Moulamien 2	4	4	4	1	3	6	3	29
Jerilderie Lake								
Jerilderie Lake								
Jerilderie Town Lake	6	1	1	3	1	1	2	109
Yanco Creek								
Molly's Lagoon								
Molly's Lagoon 1	2	1	1	1	3	5	4	29
Molly's Lagoon 2	2	1	1	1	3	5	4	39
Yanco Creek d/s Tarabah Weir to Billabong								
Mundoora Jerilderie	4	2	1	2	2	3	2	47
Wilson Rd Bridge	4	4	4	1	5	6	2	21
Wononga Jerilderie	4	2	1	2	2	3	2	40
Yathong TSR	5	4	4	2	5	6	3	26
Yanco Creek u/s Tarabah Weir								
Devlins Bridge Yanco Ck	4	4	4	1	5	6	4	12
Wirrani	4	4	4	1	5	6	4	11
Yarrabee TSR Yanco	4	4	4	1	4	6	4	11
Yanco Creek d/s Molly's Lagoon	4	4	4	1	6	6	4	19
Yanco Creek u/s Molly's Lagoon	4	4	4	1	6	6	4	11

Appendix Table A3 Raw abundance of the fish species sampled across the five waterways under study.

Waterway / Reach / Site	Silver Perch	Golden Perch	Trout Cod	Murray Cod	Bony Herring	Freshwater Catfish	Un-specked Hardyhead	Carp Gudgeon	Murray-Darling Rainbowfish	Australian Smelt	Goldfish	Common Carp	European Perch	Eastern Gambusia
Billabong Creek														
Caroonboon to Wanganella														
Millabong	0	3	0	12	0	0	0	0	0	0	0	25	0	0
Wanganella Common	0	12	0	2	0	0	0	1	1	0	0	26	0	0
Conargo to Jerilderie														
Algudgerie TSR	1	4	0	4	0	0	0	10	0	0	0	41	0	21
Hartwood TSR	0	3	0	1	0	0	0	2	0	0	0	15	0	18
Old Coree	0	13	0	2	0	0	0	2	0	0	0	28	0	0
Quiamong d/s Hartwood Weir	0	3	0	4	0	0	0	2	0	0	0	15	0	16
Jerilderie to Colombo														
Gammons Jerilderie	0	3	0	0	0	0	2	2	3	1	3	115	0	2
Innes Bridge TSR	0	0	0	2	0	0	0	14	0	1	0	25	0	1
The Cape TSR	0	5	0	0	0	0	0	8	0	0	2	28	0	3
Moulamein to Windouran														
Billabong Moulamein Town Bridge	1	3	0	1	0	0	0	6	0	1	3	36	0	0
Billamien	0	9	0	2	0	0	0	1	0	0	0	47	0	0
Windouran	0	24	0	7	0	2	0	0	0	0	0	16	0	0
Wanganella to Conargo														
Booabula u/s Chinamans Weir	0	4	0	2	0	0	0	9	1	0	10	17	0	2
Conargo Town Common	0	8	0	4	0	0	0	1	5	1	0	36	0	0
North Run	0	1	0	9	0	0	0	0	0	0	0	20	0	0

Waterway Reach Site	Silver Perch	Golden Perch	Trout Cod	Murray Cod	Bony Herring	Freshwater Catfish	Un-specked Hardyhead	Carp Gudgeon	Murray-Darling Rainbowfish	Australian Smelt	Goldfish	Common Carp	European Perch	Eastern Gambusia
Windouran to Caroonboon														
Back Nullum	0	5	0	6	0	0	0	0	0	0	0	24	0	0
Caroonboon Weir d/s	2	3	0	11	0	0	0	0	0	1	1	21	0	0
Murgha Rd bridge	0	6	0	3	0	0	0	2	0	0	1	29	0	0
	4	**109**	**0**	**72**	**0**	**2**	**2**	**60**	**10**	**5**	**20**	**564**	**0**	**63**
Colombo Creek														
Colombo Creek														
Bindiwilla Urana	1	2	0	1	0	0	0	30	1	90	1	21	0	2
Boonongo	0	0	0	0	0	0	0	27	0	33	1	16	0	0
Boonongo Mud Bank Colombo Creek d/s Upper Sheepwash Weir	0	0	0	0	0	1	0	545	0	0	0	6	1	0
Chesneys Weir d/s	0	1	0	0	0	0	106	1125	2	350	1	19	1	16
Chesneys Weir u/s	0	0	0	0	0	0	40	79	0	4	1	27	1	0
Colombo Creek Eight Mile Weir Pool via Colombo Ski Club	0	0	0	0	0	0	138	1592	0	31	1	9	0	0
	1	**3**	**0**	**1**	**0**	**1**	**284**	**3398**	**3**	**508**	**5**	**98**	**3**	**18**
Edward River														
Edward River at Moulamein														
Edward River d/s Billabong Creek 2A	1	11	0	14	0	0	0	21	0	13	0	35	0	0
Edward River ds Moulamien	0	3	0	2	0	0	0	11	0	15	0	7	0	0
Edward River u/s 1A	0	2	0	7	6	1	1	6	2	4	2	19	0	0
Edward River u/s Moulamien 2	0	5	0	4	1	0	4	6	0	21	0	9	0	0
	1	**21**	**0**	**27**	**7**	**1**	**5**	**44**	**2**	**53**	**2**	**70**	**0**	**0**

Waterway Reach Site	Silver Perch	Golden Perch	Trout Cod	Murray Cod	Bony Herring	Freshwater Catfish	Un-specked Hardyhead	Carp Gudgeon	Murray-Darling Rainbowfish	Australian Smelt	Goldfish	Common Carp	European Perch	Eastern Gambusia
Jerilderie Lake														
Jerilderie Lake														
Jerilderie Town Lake	0	10	0	0	0	0	0	9370	0	198	2	0	0	9
	0	**10**	**0**	**0**	**0**	**0**	**0**	**9370**	**0**	**198**	**2**	**0**	**0**	**9**
Yanco Creek														
Molly's Lagoon														
Molly's Lagoon 1	0	5	0	0	0	0	19	604	0	6	3	97	0	4
Molly's Lagoon 2	0	0	0	0	0	0	0	902	0	1	5	58	2	0
Yanco Creek d/s Tarabah Weir to Billabong														
Mundoora Jerilderie	0	2	0	0	0	1	0	683	59	10	5	40	0	42
Wilson Rd Bridge	0	1	0	1	0	0	0	77	43	1	6	27	0	13
Wononga Jerilderie	0	0	0	0	0	1	0	82	23	0	0	39	0	34
Yathong TSR	0	3	0	1	0	0	0	16	54	19	1	49	0	0
Yanco Creek u/s Tarabah Weir														
Devlins Bridge Yanco Ck	0	1	4	1	0	0	0	2	5	32	2	18	0	0
Wirrani	0	0	1	1	0	0	0	0	0	4	0	26	0	0
Yanco Creek d/s Molly's Lagoon	0	3	1	7	0	0	0	0	26	2	1	20	0	0
Yanco Creek u/s Molly's Lagoon	0	1	0	1	0	0	0	0	0	3	0	7	0	0
Yarrabee TSR Yanco	0	1	1	1	0	0	0	0	0	12	0	14	0	0
	0	**17**	**7**	**13**	**0**	**2**	**19**	**2366**	**210**	**90**	**23**	**395**	**2**	**93**
	6	***160***	***7***	***113***	***7***	***6***	***310***	***15 238***	***225***	***854***	***52***	***1127***	***5***	***183***

Appendix Table A4 PERANOVA differences in nativeness (native/exotic species ratio) across the five waterways under study. *A posteriori* pair-wise comparisons are given for the significant effects (α= 0.05, in bold type). $F^{\#}$= permutational *F* value; *t* = *t*-test value; P^{MC} = Monte-Carlo permutational probability value (suitable for small sample sizes). Reach code as in Table 2.1. See also Figure 5.1.

Source	df	MS	$F^{\#}/t$	P^{MC}
Waterway	4	5.45	11.43	**<0.001**
BC v CC			2.23	**0.040**
BC v ER			5.78	**<0.001**
BC v JL			0.68	0.505
BC v YC			0.56	0.579
CC v ER			8.04	**<0.001**
CC v JL			0.48	0.651
CC v YC			2.30	**0.033**
ER v JL			3.04	**0.053***
ER v YC			4.40	**<0.001**
JL v YC			0.74	0.471
Residual	34	0.48		

* Marked as statistically significant for heuristic purposes (that is, at α = 0.10) because of the low power of the tests due to small sample sizes.

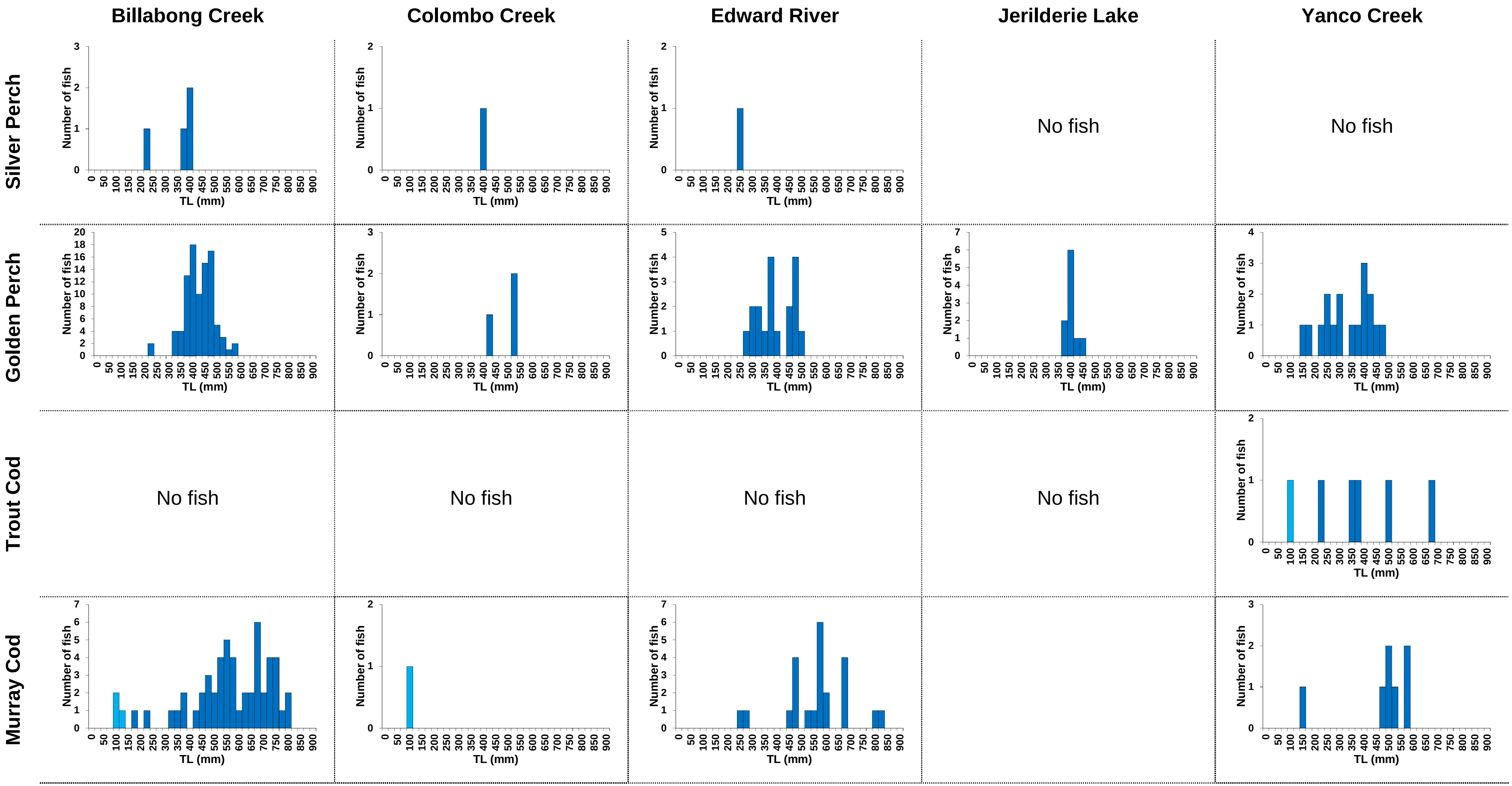
Appendix Table A5 Summary statistics for total length (TL, mm) of the large-bodied fish species broken down across the five waterways. See also Appendix Figure A1 and Appendix Figure A2.

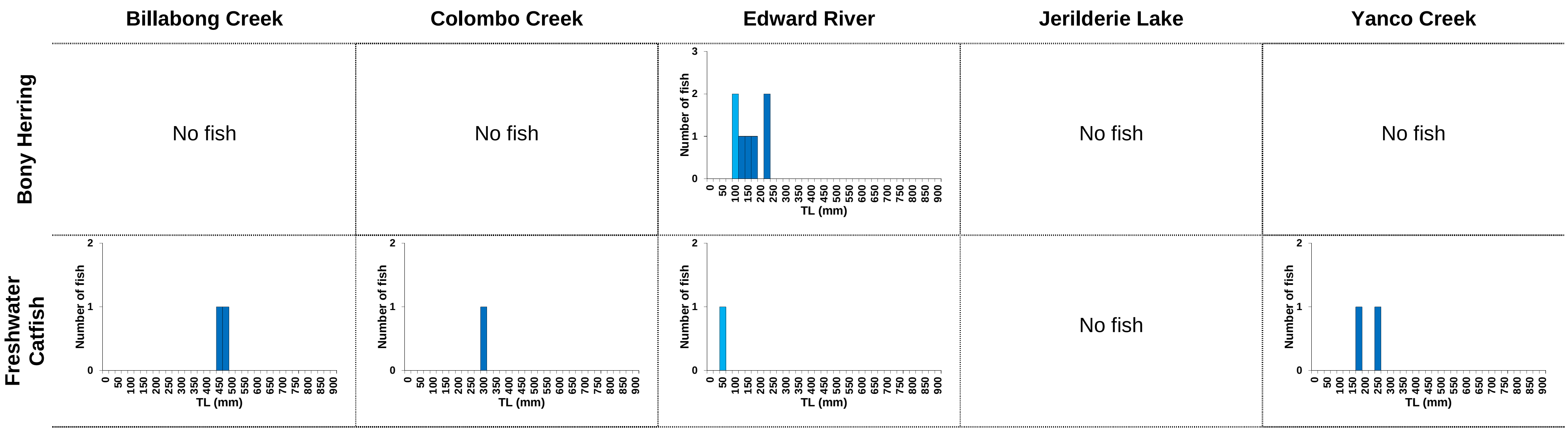
Species	*n*	Mean	SE	Min	Max
Billabong Creek					
Native					
Silver Perch	4	342	40.6	222	394
Golden Perch	94	414	6.3	217	572
Murray Cod	54	542	24.2	77	800
Freshwater Catfish	2	458	8.0	450	466
Exotic					
Goldfish	15	180	20.6	81	322
Common Carp	300	387	8.2	111	747
Colombo Creek					
Native					
Silver Perch	1	387	–	387	387
Golden Perch	3	487	31.0	425	521
Murray Cod	1	97	–	97	97
Freshwater Catfish	1	289	–	289	289
Exotic					
Goldfish	4	244	88.4	84	449
Common Carp	56	467	14.2	127	713
European Perch	3	161	15.1	139	190
Edward River					
Native					
Silver Perch	1	243		243	243
Golden Perch	18	382	16.5	265	489
Murray Cod	23	550	27.7	247	805
Bony Herring	7	144	20.9	78	217
Freshwater Catfish	1	35	–	35	35
Exotic					
Goldfish	2	183	8.5	174	191
Common Carp	42	538	15.6	357	785
Jerilderie Lake					
Native					
Golden Perch	10	387	6.3	355	427
Exotic					
Goldfish	2	208	125.0	83	333
Yanco Creek					
Native					
Golden Perch	17	320	24.2	147	460
Trout Cod	6	357	83.2	83	653
Murray Cod	7	456	55.5	135	562
Freshwater Catfish	2	209	37.0	172	246
Exotic					
Goldfish	18	167	17.6	16	357
Common Carp	234	361	7.6	81	699
European perch	2	134	26.5	107	160

Appendix Table A6 PERMANOVA differences in fish species and flow guild assemblage composition and CPUE abundance (number of fish h^{-1}) across the five waterways (codes as in Table 2.1). *A posteriori* pair-wise comparisons are given for the significant effects (α= 0.05, in bold type). $F^{\#}$= permutational *F* value; *t* = *t*-test value; $P^{\#}$= permutational probability value.

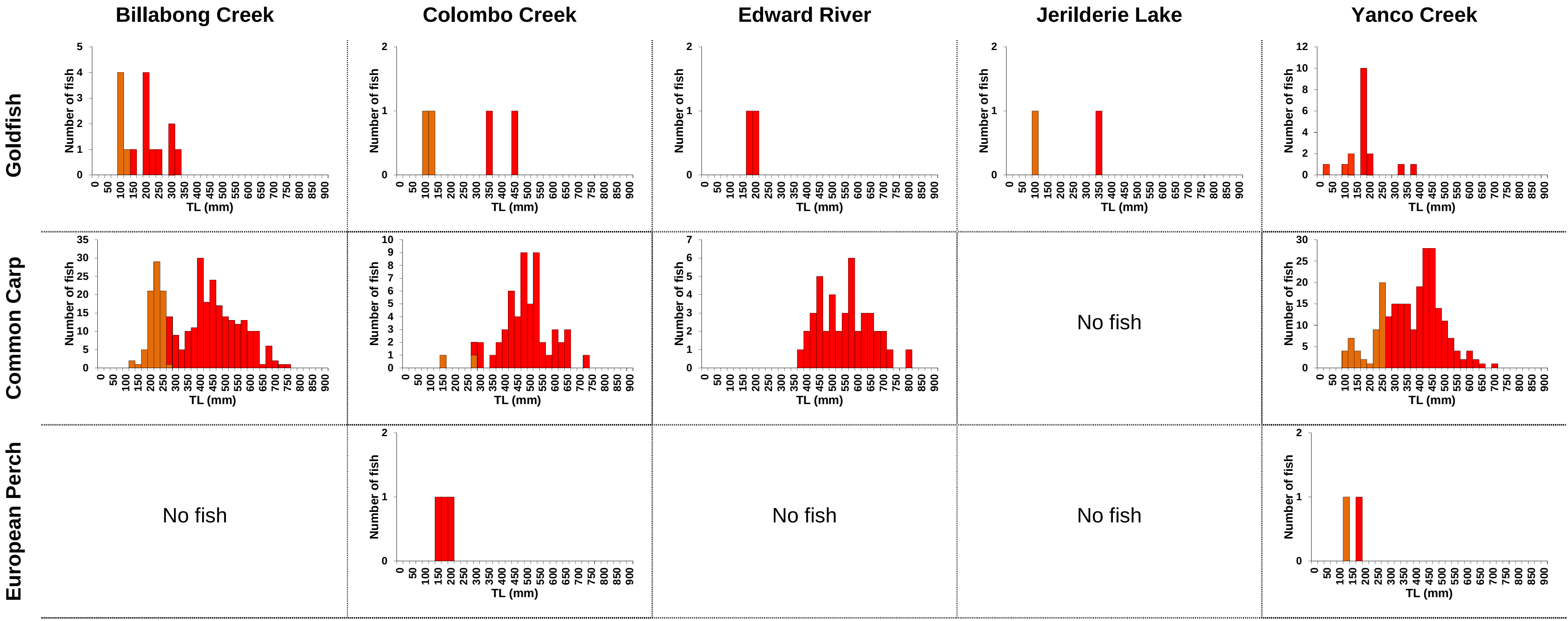
Source	df	MS	$F^{\#}/t$	$P^{\#}$
Species				
Waterway	4	6624.1	2.62	**<0.001**
BC v CC			2.22	**0.004**
BC v ER			1.26	0.179
BC v JL			1.15	0.281
BC v YC			2.12	**0.003**
CC v ER			1.33	0.155
CC v JL			1.16	0.359
CC v YC			1.20	0.186
ER v JL			1.04	0.492
ER v YC			1.54	**0.044**
JL v YC			1.29	0.155
Reach(Waterway)	7	3231.5	1.28	0.156
Residual	65	2523.7		
Guilds				
Waterway	4	5614.5	3.29	**<0.001**
BC v CC			2.76	**0.001**
BC v ER			1.29	0.180
BC v JL			0.98	0.479
BC v YC			2.20	**0.005**
CC v ER			1.73	0.064
CC v JL			1.70	0.065
CC v YC			1.19	0.229
ER v JL			1.26	0.316
ER v YC			1.49	0.100
JL v YC			1.26	0.212
Reach(Waterway)	7	1588.3	0.93	0.535
Residual	65	1707.4		

Appendix Figures (see description in Figure heading below)





Appendix Figure A1 Length-frequency distributions (TL = total length) for the large-bodied native fish species sampled across five catchment waterways. YoY in light blue. Summary statistics in Appendix Table A5.



Appendix Figure A2 Length-frequency distributions (TL = total length) for the large-bodied exotic fish species sampled in five catchment waterways. Young-of-year in orange. Summary statistics in Appendix Table A5.